An EMC Framework for South Africa

by

Francois A Venter

Thesis presented in fulfilment of the requirements for the degree of MSc Ing (Elektronies) at the University of Stellenbosch

March 2003

Supervisor: Prof. H.C. Reader

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

FA Venter

Abstract

This thesis pursues the establishment of a new Electromagnetic Compatibility (EMC) framework for South Africa. The aim of this framework is to ensure that the user is protected from sub-standard products as well as to ensure that products such as medical devices operate safely within the electromagnetic environment.

The thesis presents a basic introduction into EMC and then overviews current worldwide legislation. After this information is studied a new framework is proposed for South Africa. This framework covers all areas of industry and the standards with which one has to comply as well as the procedure for demonstrating the compliance of the product.

In order to establish the basis whereby smaller manufacturers can show compliance by means of in-house testing, a method for establishing measurement accuracy is also presented. In conclusion some standard measurements and an overview of some alternative measurement techniques are presented.

Opsomming

Hierdie tesis ondersoek en stel 'n nuwe Elektromagnetiese Versoenbaarheids (EMV) raamwerk voor vir Suid Africa. Die doel van die raamwerk is om 'n eenvormige stelsel daar te stel waarteen produkte getoets kan word om die publiek teen onder standaard produkte te beskerm. In sekere gevalle help die raamwerk ook om te verseker dat produkte soos mediese toerusting veilig werk in die Elektromagnetiese omgewing.

Die tesis lê 'n basiese inleiding oor EMV voor en gee 'n opsomming van huidige wêreldwye wetgewing as inleiding tot 'n raamwerk vir Suid Afrika. Nadat die inligting bestudeer is, word 'n nuwe raamwerk vir Suid Afrika voorgestel. Die raamwerk dek die hele elektroniese industrie, spesifiseer die toepaslike standaarde en voorsien die metodes hoe voldoenning aan die vereistes bewys moet word.

Die tesis verskaf ook riglyne hoe kleiner vervaardigers kan bewys dat hulle voldoen aan die vereistes, deur in-huis toetsing. Tesame met 'n oorsig oor basiese meet tegnieke en alternatiewe tegnieke word 'n metode daar gestel vir sulke vervaardigers om hul metings se akuraatheid te bewys.

Acknowledgements

- Prof Howard Reader (University of Stellenbosch) : For making it possible for me to complete the degree, despite me being in Pretoria and him being in Stellenbosch. All his support and advice is also appreciated.
- Johan Pieters, John Wood (Alcatel Altech Telecoms) : Firstly for giving me the opportunity to enroll for the degree and for the financial support that accompanies such a commitment. Secondly for their continued support, the use of company facilities and the opportunity to work on this thesis during work hours.
- Carol Gibson (Alcatel Altech Telecoms) : For the time that she spent, without reward, checking the grammar and spelling in this document.
- Suzan van der Meulen (Omnigo) : For the time that she spent, without reward, checking the grammar and spelling in this document.
- Hans Joubert (ITC Services) : For the use, at no cost, of the Open Area Test Site at the ITC's premises in Pretoria.
- Thank you to the examining panel for their constructive remarks that led to the completion of the thesis.

Table of contents

Chapter 1 - Introduction

1.1 Introduction

As the 21st century dawns one notices that most developed countries in the world have legislation in place specifying some EMC requirements for products sold and used in the country. The legislation of the electromagnetic spectrum has become necessary due to the increasing number of electrical products that are being manufactured. A drastic decrease in the size of components, products and level of control signals over the last few years, coupled with a drastic increase in product complexity, make products potentially more vulnerable to EMC problems [1]. An increase in the operating frequency of products has also increased the likely emission frequency range. For these reasons it has become important to investigate stricter control of the EMC performance of products. There is however one pitfall that one must guard against and that is to ensure that one does not over regulate EMC. It is therefore important to ensure that the right type of legislation is implemented and that this legislation is in line with legislation in other countries and trade partners. It is also not beneficial to have legislation that restricts trade. A proposal for discussion, of new legislation is presented is chapter 6. This proposal is presented in terms of an EMC framework, covering, in addition to the legislative issues, implementation (chapter 6), testing/compliance (chapters 3, 4 and 5) and industry/public awareness (chapter 6) considerations.

The process of legislating the amount of electromagnetic energy that may be emitted by electrical products in certain frequency bands, called emissions, started in 1952 in South Africa[2]. At the time the South African Post Office, under the signature of the Postmaster General, published the first act in the Government Gazette often referred to as the Radio Regulations Act - Hereafter referred to as The Act. Between this date and 1996 The Act was amended a number of times. Unfortunately these amendments have not been sufficient if one compares South Africa's current legislation with other developed country's. The first few versions of The Act specified limits for the allowable emissions without specifying any test methods. These early versions of The Act also did not cater for different types of products and their special considerations and was therefore not always very easy to use. After South Africa took up its rightful place in the international community after the 1994 elections some of these problems were solved in that the new versions of international standards were used for test method references. All of the initial problems have however not been solved and it is therefore necessary to update South Africa's legislation again to bring it in line with world trends.

Another country or region's legislation cannot just be copied, as South Africa has unique requirements in terms of its population, economy, testing capabilities, environmental effects and equipment used in the country. One may therefore need to adjust some requirements to make them fit in with the South African environment.

This thesis was published in March 2003 and it should therefore be noted that references to standards and authorities can only be considered accurate up to this date.

1.2 International, regional standards and Standards Bodies

Any person that is confronted with the task of finding a technical standard in a standards library or on the Internet, realises quickly that hundreds of these standards exist in the world. The question is therefore often asked: "How do I decide which standards to use or where to look?". In the following chapters of this thesis, reference will be made to a number of standards bodies and series of standards and even to some specific standards. It is therefore necessary to consider who these bodies are.

It is firstly important to know that there are mainly three groups of standards bodies, namely International, Regional and Local. Examples of these are given in figure 1. In the first row, examples of three international standards bodies can be seen: ISO (International Organisation for Standardisation), IEC (International Electrotechnical Commission) [3] and ITU (International Telecommunication Union).Beneath these bodies one finds the regional standards bodies such as

CENELEC (European Committee for Electrotechnical Standardisation) and ETSI (European Telecommunications Standards Institute). These two bodies are responsible for standardisation within the European union. The latter being responsible specifically for Telecommunication standards in the European union.

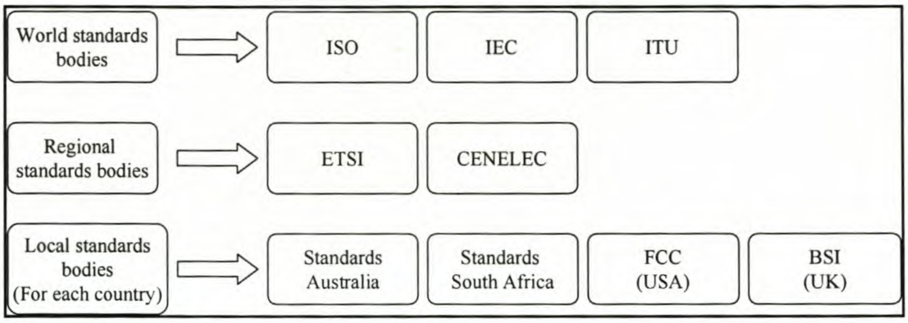

Figure 1: World standards bodies

The last level of standards bodies are national standards bodies such as Standards Australia, Standards South Africa (previously SABS), FCC (Federal Communication Commission) in the USA and British Standardisation Institute. These local bodies are responsible for national standards in their respective countries. Each of the bodies mentioned above have their own internal structure of technical and sub-committees responsible for writing and maintaining standards.

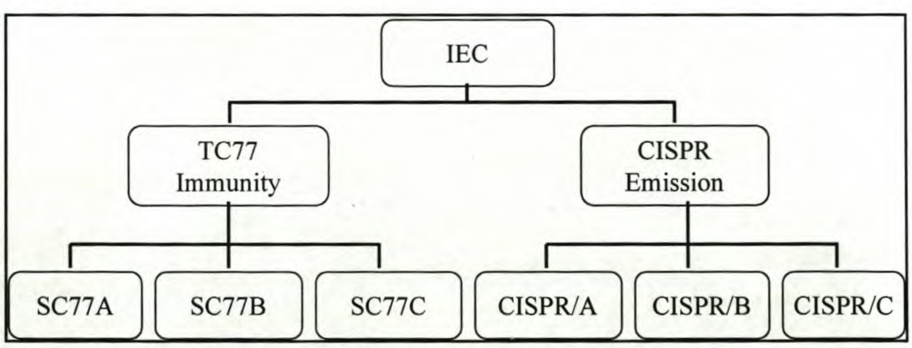

Figure 2: Examples of IEC Technical & sub-committees

Figure 2 gives examples of some of the technical committees of the IEC pertinent to this thesis . In the IEC, two EMC related technical committees exist, namely TC 77 and CISPR (International Special Committee on Radio Interference). As can be seen from figure 2 each of these committees have sub-committees under them looking into specific areas such as SC77A which is tasked with low frequency phenomena and CISPR SC/A which is tasked with Radio-interference Measurements and Statistical Methods. Within the IEC, TC 77 is responsible for the existence of the IEC 61000-series of standards and CISPR for the CISPR-series of standards. The IEC 61000-series of standards contains mainly immunity requirements such as lightning surges and electrostatic discharges, where the CISPR-series of standards contains mainly Electromagnetic Interference requirements (EMI).

By co-operation between national standards bodies such as the Standards South Africa and International bodies such as the IEC, international standards are being written and maintained. Later in this thesis we will consider some of these standards in more detail.

1.3 General EMC Background

Before legislation can be considered Electromagnetic Compatibility (EMC) should be explained. EMC is firstly, in most cases, a term used to group a number of Electromagnetic phenomena with which a product has to comply. Different EMC phenomena that can be encountered will now be discussed. Possible sources and possible weak points of some equipment for these phenomena will also be considered.

In ensuring that a product meets EMC requirements one needs to comply with requirements that can be divided into two basic categories, i.e. Emissions and Susceptibility. Emission, in this case, can be described as unwanted electromagnetic energy that is transmitted from a product to a victim. The energy can be transmitted in one of three ways, namely: radiated (loosely referred to as coupling through the air), conducted (along a signal or power cable) or some combination of the two. Although radiated emission can be generated from any electrical source, it is known that the most common sources are oscillators, switching circuits and high current tracks or wires. Conducted emission can also originate from any source. The most common source is switching circuits such as switching power supplies. Requirements also exist for conducted emission resulting from the harmonics of the power frequency.

In general, susceptibility can be described as the inverse of emission. When testing for susceptibility, an attempt is made to verify whether the equipment can withstand the likely emissions from other sources. Common susceptibility sources that are tested for are lightning surges, transients pulses, mains voltage interruptions, radiated and conducted electromagnetic fields as well as electrostatic discharges. When the requirements for an environment and product are defined, one must consider the likely sources and recipients of emission in close proximity of the equipment in question as well as the likely susceptibility levels of this equipment. Therefore if equipment operates close to or on the same supply network as circuits where high current, power frequency switching occurs then one may need to consider mains harmonic interference testing.

Solving EMC problems is unfortunately not done by looking up the applicable phenomena in a table and implementing certain quick measures. One can predict the likely sources of emission or areas of susceptibility in most cases. It does however often happen that unexpected additional sources exist. It has however been proven [8] many times that most EMC problems can be avoided by applying some good basic design rules. References [1], [6], [7] and [8] are four of a number of publications that elaborate on this subject. The question can now rightly be asked: "When do we need to consider the EMC requirements of a system?".

1.4 EMC Management plans

Many companies have realised by now that testing products for EMC can be very time consuming and expensive. One must therefore ensure that one makes optimal use of the money available for testing. Most products that fail catastrophically do so because no or little consideration was given to good EMC practice during the design and/or construction of the product. Since electromagnetic radiation cannot be seen, people may not realise how serious the problems can be. It is therefore necessary to create a general awareness of EMC in a company. This fact is underlined in [1]. Once this foundation has been laid one can more easily implement changes to ensure EMC compliance.

It is important to introduce a management system for EMC since uncontrolled changes for EMC can prove unnecessary and very costly to the price of the product.

Changes must also be introduced at the correct stage of the product development cycle. For instance one must introduce PCB layout changes as early in the development cycle as possible, where shielding changes and filtering, provided provision has been made for them, can be introduced at a later stage. It has been shown in [1], [4] and [5] that the designer has more measures available when the product is being designed compared to when it is in production. For instance if the oscillator is noisy then he might have to change to a different oscillator that might not be pin compatible or he might have to add filtering, both options necessitating a PCB change. As may be envisaged, this can be fatal for the future success of a product that is already in production. To make these changes during the design phase would be trivial and cost virtually nothing compared to the expensive nature of the other option. Figure 3 gives a graphical representation of these facts.

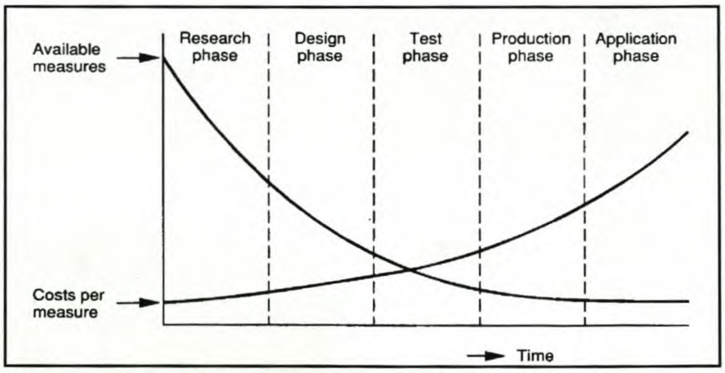

Figure 3: EMC measures & cost vs. time

As can be seen in [4] EMC consideration must be included in every stage of the product`s development cycle. There are considerations such as the environment within which the product has to operate ~~in~~, that must be included in the feasibility stage. In the design phase for instance more attention to decoupling, filtering and segregation of circuits has to be considered. This philosophy can be applied to all of the other phases of the project[4].

1.5 Overview of thesis

The thesis consist of seven chapters. This chapter gives an introduction to EMC, EMC management plans and the history of legislation in the country. Chapter two presents an overview of worldwide EMC legislation including South Africa`s current legislation. Chapters three and four presents two ways of introducing an EMC management plan and the consequences of not considering EMC management, by means of three case studies. Chapter five provides some measurements made. Chapter six contains the proposal of a new EMC framework for South Africa, inclusive of certification, special requirements for certain products and related quality issues. The testing issues in chapter 5 and the case studies in chapters 3 and 4 are important in the context of the framework as it shows how companies, especially small ones, can minimize their testing costs, by ensuring that the product comply by the time that it is submitted for testing. The thesis concludes with an overall summary in Chapter 7. Appendix A is supplementary to the text of the thesis as it contains additional photographs of measurements.

1.6 References

[1] Tim Williams, "EMC for Product Designers - Meeting the European EMC Directive", Second Edition, ISBN: 0750624663, Newnes publishing, Great Britain, 1996.

[2] "Telecommunications Act of 1996", State Press, Pretoria, South Africa, Act 103, Government Gazette No 17581 of 15 November 1996

[3] Georges Goldberg and Hans Teichmann, "Electromagnetic Compatibility. The role and contribution of IEC Standards", First Edition, IEC, Geneva, Switzerland, 1999

[4] JB Maree "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", Chapter 3, pp. 3-1 - 3-14, University of Stellenbosch, December 1998

[5] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[6] K Armstrong, "Design Techniques for EMC", Hyperlink: http://www.emc-journal.co.uk, December 2000

[7] M O'Hara, "EMC at component level", First edition, pp. 118 - 160, ISBN: 0750633557, Newnes, Great Britain, 1998

Chapter 2 - Establishing the need for a new EMC framework

2.1 Introduction

Before any suggestions can be made as to new EMC legislation for South Africa one needs to understand what is currently in place in the country and where these laws can be improved. It is also necessary to consider other countries and world trends when deciding on new legislation as one would not want to restrict trade due to unnecessary or incorrect legislation. For these reasons the legislation of a number of regions and countries in the world will be investigated.

2.2 Overview of current South African legislation

In 1952 the South African Post Office, under the signature of the Postmaster General, published the first EMC control legislation as an act in the Government Gazette often referred to as the Radio Regulations Act. Although this act was amended a number of times between 1952 and 1996 the main focus of the law remained unchanged. In 1996 a new Telecommunications Act[1] was published establishing the South African Telecommunication Regulatory Authority. In paragraph 95 of this act SATRA was tasked with the enforcement of the Radio Regulations Act of 1952 (Act No. 3 of 1952). On 5 May 2000 SATRA was dissolved and the Independent Communications Authority of South Africa (ICASA) was formed by the promulgation of a new Telecommunications Act[2]. After all these changes the basis of the technical EMC requirements are still the same as those published in 1952.

As one can see from [3] and the other references listed in paragraph 1of [3] the Radio Regulations Act only specifies limits for different classes of equipment. The classes of equipment includes but is not limited to "portable tools incorporating electric motors...", "gas discharge lamps, neon signs and filament lamps" and "television and radio receivers". One of the problems with the way in which this legislation has been written is that it does not cater for new technology that has been developed since the law was promulgated. The question could therefore be asked: "What class would be appropriate for an electric fence controller or a multimedia personal computer with a built in television/radio receiver?" The answer is that the law provides no guidance in such a case. Tables 2.1 and 2.2 give extracts from the limits specified by [3].

Table 2.1 - Requirements for Household and similar appliances

Class	**Notes**	**Frequency Range**	**Interference signal voltage at mains terminals (dB/uV)**	**Radiated power, dB relative to 1pW (dB/pW)**
(a) (iii)	[1] The limit increases linearly with frequency from the lower specified value at the low frequency to the higher specified value at the high frequency.	150 to 500 kHz	66 to 56 + $20\text{Log}_{10}C$[1]	-
		0.5 to 5 MHz	56 + $20\text{Log}_{10}C$[1]	-
		5to 30 MHz	60 + $20\text{Log}_{10}C$[1]	-
		0.03 to 1GHz	-	45 to 55 + $20\text{Log}_{10}C$[1]

where $C = \frac{30}{f * N}$, f is a factor obtained from Table 3 of [3] and N is the click rate

(for N > 30 or for continuous interference N = 30 and for N < 0.2, C = 25 000).

Table 2.2 - Requirements for Information technology equipment (ITE) (Class A)

Class	**Notes**	**Frequency Range**	**Interference voltage at mains terminals (dB/uV)**	**Radiated interference field (dB/uV)**
(g) (i)	[1] The first value is the limit when measured with a Quasi-peak detector and the second when measured with an Average detector.	150 to 500kHz	79/66[1]	
		500 kHz to 30 MHz	73/60[1]	
		30 to 230 MHz	-	30
		230 MHz to 1GHz	-	37

Table 2.3 - Requirements for Information technology equipment (ITE) (Class B)

Class	Notes	Frequency Range	Interference voltage at mains terminals (dB/uV)	Radiated interference field (dB/uV)
(g) (ii)	[1]The first value is the limit when measured with a Quasi-peak detector and the second when measured with an Average detector. [2] The limit increases linearly with frequency from the lower specified value at the low frequency to the higher specified value at the high frequency.	150 to 500 kHz	(66-56)/(56-46)[1,2]	
		500 kHz to 5 MHz	56/46[1]	
		5 MHz to 30 MHz	60/50[1]	
		30 MHz to 230 MHz	-	30
		230 MHz to 1GHz	-	37

Another common problem that occurs due to legislation that contains specific requirements and methods is that it always seems to be lagging behind world trends. The reason for this is that legislation generally takes a long time to pass all the parliamentary structures before it becomes a law. It has also happened quite often in the past that this kind of legislation is considered of less importance to other legislation in the country. By the time it is promulgated into law one may already need to amend it again due to other world trends. The current legislation of South Africa has a third major problem in that no methods are specified. This becomes a big problem in cases where disputes need to be resolved between different test laboratories, between the legislator and owner of a product or between users.

2.3 Overview of worldwide trends in EMC legislation

2.3.1 Australasia

As discussed in detail in [4] the first EMC regulations introduced by the Australian Communications Authority (ACA), and which became mandatory on 1 January 1997, were requirements that demanded compliance with Australian standards, based on international (CISPR) EMI standards. According to [4] the ACA experienced some problems with the definitions given in standards such as CISPR 22 for Class A and Class B environments in the first year of the implementation of this legislation. They therefore amended the legislation on 11 November 1998 to mandate the applicability of standards without reference to a particular environment. With this amendment they ensured that if a product falls within the scope of one of the compulsory standards and is not specifically excluded from the framework then it has to comply. This change made the practical implementation of the legislation easier. In terms of implementation dates for the legislation the ACA issued the legislation in such a manner that products placed on the market before 1 January 1997 had until 1 January 1999 to comply. Since products placed on the market after that date had to comply immediately one saw the date of 1 January 1999 as the final implementation date for all products[5]. It should therefore be noted that until this day Australia has only legislation in place that regulates the emission from equipment. No immunity regulations are as yet in place.

The Australian standards that have been promulgated in the above-mentioned legislation are based on the CISPR-series of international standards. It should however be noted that they are not exactly the same. National deviation from the CISPR standards are therefore used. For example one will find that AS/NZA 2064.1/2 is the emission standard for Industrial, scientific and medical equipment based on CISPR 11.

2.3.2 Far East - Taiwan, Korea, People's republic of China

In Taiwan R.O.C (Republic of China) a BMSI (Bureau for Standards Metrology and Inspection) approval mark is required to show compliance with EMC and safety requirements. Testing for this purpose can be done at any BMSI accredited laboratory. Such laboratories can be found in Taiwan, the United States or in Europe[6]. It should also be remembered that countries like Taiwan have a 120V supply network and would therefore require that products be tested at 120V and not at a nominal supply of 230V.

From 1991 until 1 July 2000 Korea used a Korean standard for EMI requirements [7]. Thereafter their standards were aligned to international standards [7],[8]. Originally testing could only be done at a government laboratory but recently this changed and now testing can be done at any RRL (Korean government department that accredits laboratories) accredited laboratory. From 1 January 2000 immunity requirement based on the IEC 1000 immunity standard series has also become compulsory.

The People's Republic of China presents one of the largest emerging markets of the 21st century as it opens up to industrial development. It does seem that the bureaucracy of the Chinese State Government and interference from provincial authorities makes the approval process tedious [9]. By 1 January 2000 all ITE products had to be certified for EMC. The resulting CCIB (China Inport & Export Inspection Bureau) mark includes a small "S & E" to indicate both safety and EMC approval [10].

2.3.3 Russian Federation

In the Russian Federation Gosstandart is the Federal Administration for Standardization, equivalent to the NIST in the USA and South African National Accreditation Service (SANAS) and the National Metrology Laboratory (NML) in South Africa. Rostest, located in Moscow, is one of the few Russian centres accredited by Gosstandart for EMC certification of products. The Russian mark to demonstrate safety and EMC compliance is GOST-R. In general, it seems that the Russian product certification system is not very well defined. When asking certification experts what the Russian requirements entail they produce a variety of different results. There are, however, two things that came out of everybody's views and that is that it can be very expensive and tedious if you do not know what you are doing. A lot of bureaucratic red tape is involved.

It was not possible for the writer to confirm whether certification of products is mandatory, i.e. GOST-R mark. What was however clear was that the certification will consist of an inspection of existing Compliance Documentation including ISO 9000 certification, EMC test data, safety test data, environmental test data along with other inspections of calibration equipment and methods. To accomplish this a trip for Gosstandart and Department of Communication officials to the factory is necessary. In this described process no actual testing is done. It should however be clear that this can be a tedious and very expensive exercise (US$ 44,000[11]).

2.3.4 Americas

A number of countries in South America are currently in the process of establishing safety and EMC legislation. A number of them have however implemented legislation that will now be reviewed.

In Argentina EMC and safety approval is required for electrical equipment. This approval is managed through the CNC (Comision Nacional de Comunicaciones). During the approval of products safety, EMC and in some cases functional compliance will be evaluated. The standards being used are national and national testing is of course also mandatory. These standards are, however, mainly based on international standards like IEC European and CISPR standards. Argentina introduced regulation 92/98 on August 18th, 1998 which requires the safety compliance [12]. This regulation is being introduced gradually from the above mentioned date up to April 2002 when it will be completely implemented [13]. EMC compliance is however, seemingly only required for products such as telecommunication equipment.

Although Brazil has some EMC legislation in terms of compliance criteria and test methods published in Government Gazette's for RF transmitters no formal EMC framework exists [14]. It is also clear that a lot of emphasis is being placed on acceptance of results from elsewhere. When testing has been done elsewhere an engineer with CREA registration must state that the equipment is what the importer/manufacturer say that it is, when it is put in the market. Wider EMC requirements are being introduced at the moment. For other South American countries like Argentina, Mexico, Peru, Ecuador, Uruguay and Venezuela approval is required to connect telecommunication equipment to the PSTN, and in some cases safety approval is required. No EMC approval is required. For most other Latin American countries, foreign certificates are accepted or no approval requirements exist.

In the USA, EMC legislation is initiated and policed by the Federal Communications Commission under title 47 of the Code of Federal Regulations [15]. Part 15 contains the limits for intentional and unintentional radiators. A most important point is that emission from domestic appliances (excluding microwave ovens) is not regulated. The only time when restrictions due to emission will be applicable to these devices is when it can be shown that the equipment generates harmful interference. Requirements for digital devices are also contained in part 15. Digital devices include, amongst others things, information technology equipment and certain industrial, scientific and medical equipment. Under certain conditions the limits of standards such as CISPR 22 will be accepted. Testing is however required above 1GHz.

In the last few years the FCC rules have changed significantly. From a system where type approval was the norm they moved to a system where a declaration of conformity can be used or the product can be tested either by the manufacturer or a third party laboratory. The routes available for a specific product are still dictated by the FCC. Where third party testing is done, it can be done at a laboratory outside the USA. In the past testing was in most cases only done in the USA.

2.3.5 Europe

The European Union (EU) started in the late1980's to develop a self declaration system generally referred to as the CE Mark (Taken from the French, translated: European Conformity). From 1 January 1997 the application of the CE mark has become compulsory for all products sold in the EU [16]. In Europe a manufacturer has two choices namely, complete self declaration and testing at a third party laboratory. For some products the route to be followed is prescribed by the legislation, but in most cases any one of the routes can be followed. In the complete self declaration case a manufacturer tests the product himself and issues a declaration of conformity based on a technical construction file containing the proof that the product complies. In the second case the product is submitted to a third party laboratory that performs the tests and issues the declaration on behalf of the manufacturer.

Although the system seems to work very well, numerous complaints [17] are in circulation, of products that bear the mark but do not comply. This seems to be mainly because the CE Directive requires compliance with the "essential requirements" of the directive and not full compliance with the limits and methods of the standards. In the writer's opinion this is probably the weak point of the CE Mark. This method of writing legislation makes the application easier for manufacturers, but it makes the policing more difficult. The fact that the policing of the CE Mark directive seems to be effective and that the directive allows for corrective action in a case where the essential requirements are met, but interference with other systems do still exist, seems to make amends for the "deficiency".

Countries like Hungary, Estonia, Latvia and Lithuania, accept CE mark declarations of conformity and test results to European standards notwithstanding the fact that they are not officially part of the European union.

2.3.6 Other

Although very severe safety regulations are in place in Saudi Arabia no specific EMC regulations are in place [18]. India has EMC and safety legislation in place that are based on international standards, such as CISPR 22 for Information Technology Equipment [19]. Standardisation Activities in India is controlled by the Bureau of Indian Standards.

2.4 References

[1] "Telecommunications Act", Department of Communication, Government Gazette 17581, Act No. 10 of 15 November 1996

[2] "Telecommunications Act", Department of Communication, Government Gazette 21154, Act No. 13 of 5 May 2000

[3] "Amendment of the Radio Regulations", Department of Posts and Telecommunications, Government Gazette No. 10158, Act No. R 587 of 27 March 1986

[4] "Australian EMC Regulation and Routes to Compliance", Chris Zombolas, Compliance Engineering, 1999

[5] "Australian EMC Overview", http://www.ets-tele-com/tics/global/au/au_cert_emc.htm, 19 September 2000

[6] EMAIL correspondence, Ted Eckert, American Power Conversion Corporation, 14 January 2000.

[7] "Korea aligns itself with international standards", John Whaley, YS Kwon, Young Kim, Approval Magazine, pp. 10,11, January/February 2000, ISSN: 1359 1991

[8] EMAIL correspondence, Sang-Man Kim, Samsung Electro-Mechanics Co., Ltd., 21 July 2000.

[9] "Conflict of authorities makes Chinese approval difficult", John Whaley, Approval Magazine, pp. 10,11, January/February 1999, ISSN: 1359 1991

[10] EMAIL correspondence, George Alspaugh, Lexmark International Inc., 14 October 1999

[11] EMAIL correspondence, Chris Maxwell,GN Nettest, 15 March 2000

[12] "Argentina Compliance Services page", http://www.nccrc.com/textfiles/argentina.htm, 26 October 2000

[13] "Argentinian certification overview", http://www.ul.com/argentina/overview.htm, 9 October 2000

[14] EMAIL correspondence, Sérgio Rocha Loures, Siemens Ltda., 10 February 2000

[15] "Approval routes for EMC compliance", http://www.approval.co.uk/emcusa.htm, 27 October 2000

[16] "Concise guide to the EMC Directive", http://www.approval.co.uk/emcinfo1.htm, 27 October 2000

[17] "The EMC Directive - Necessary interpretation", http://www.emc-journal.co.uk/current/000807.html, 31 October 2000

[18] "Extra requirements in Saudi regime", Nigel Harvey, Approval Magazine, pp16 -17, Mar/April 1999, ISSN: 1359 1991.

[19] EMAIL correspondence, KevinNewland, 1 May 2000

Chapter 3 - Case study: A complete EMC Management plan

3.1 Introduction

The case study presented in this chapter shows how a full EMC management plan should be implemented on a large project. Consideration is given in chapter 4 to a more compact version of this plan. The main point that must, however, be realized when reading chapters 3 and 4 is the potential value of an EMC management plan. In the writers' opinion the value of such an EMC management plan is still greatly underestimated by the industry in general [5]. Although these case studies are hypothetical, the technical aspects as well as the problems and solutions described in them are based on real life experiences. The reader must also realize that the implementation of an EMC management plan and the solution to an EMC problem will in practice not always be as easy as it may seem from the case studies presented.

3.2 Case study - Implementing a full EMC management plan

Eugene, a new appointee, at Telecom Inc., has been given the task to find a way to properly manage the design of a large new system that Telecom Inc. wants to develop. The appointed project manager, Lisa, motivated his appointment at the company since she felt that they needed somebody who has some project management experience as well as some EMC design experience. She could have managed the project, but felt that she needed some help to find a way of stopping EMC problems from delaying the completion of the project, as it did in the past. The required system consists of a hundred line telephone line monitoring module and RF transmission module for the recorded data.

3.3 Finding a solution

Eugene therefore sets out on this project, knowing that his career will be made if he can find a solution that works. He has the chance to save the company thousands of rands and a lot of embarrassment. This was very clear to him from the extracts of their general project review meeting minutes, showed to him by Lisa:

Project 176539: **Project start date** : 1999-04-17

Delivery due: 1999-11-01

Actual delivery : None

Notes: Client cancelled order on 2000-01-16, due to late delivery of product. Product experienced severe emission problems during pre- and full-compliance EMC testing

Project 176543: **Project start date :** 1999-12-01

Delivery due: 2000-04-11

Actual delivery : 2000-06-01

Notes: Delivery late due to emission and surge failures during EMC compliance testing.

Project 176546: **Project start date :** 2000-01-02

Delivery due: 2000-08-01

Actual delivery : 2000-11-06

Notes: Delivery late due to emission failures during compliance testing. An extra design cycle had to be undertaken to solve the problems.

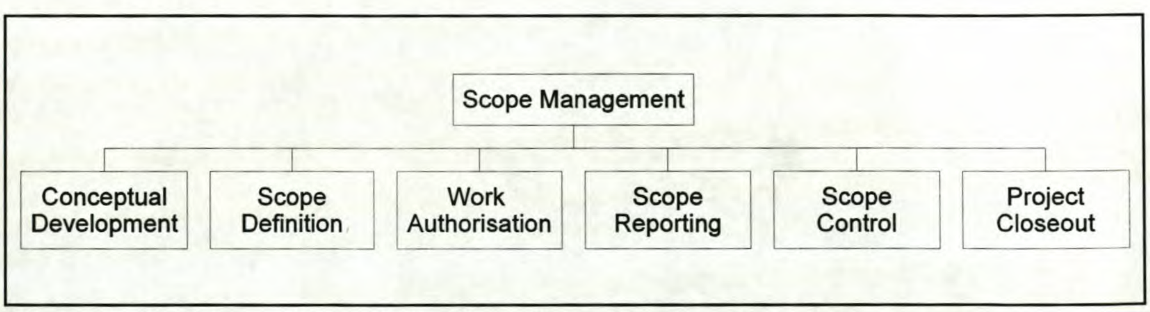

Figure 1: PMI Body of knowledge ([1] Chapter3, Figure 1 pp. 45)

For Eugene the first order of business is to investigate the design cycle stages that their projects go through. After he had a look at the last ten projects he concludes that they follow, almost to the letter, the guidelines of the Project Management Institute (PMI) body of knowledge [1] that he learned about during his Project management Diploma course - copied in figure 1. Following on these overlying principles, one could say that each project plan has to have the following stages:

- ★ Feasibility study & Conceptual design, Feasibility review*
- ★ Detailed design, Design review*
- ★ Model build, Compliance testing, Project review**
- ★ Project closeout*

* Project milestone where the project stages, since the last milestone, is reviewed and where approval is given to proceed to the next stage.
** A project milestone as described in *. Additionally, however, a decision is made regarding the necessity of another design cycle or whether the project can be allowed to proceed to the next stage.

Since the project stages used and the management of these stages seems to be in order he deduces that a lack of project management is not the problem. A quick overview of some EMC test reports shows him that the laboratories being used for EMC testing are also acceptable. Since all of the EMC problems have been solved in the projects that he reviewed he must conclude that the problem can not lay in the EMC measures that are being used. The problem must therefore be that these measures are only introduced during compliance testing or during a redesign cycle. The next week Eugene spends most of his time studying literature that he obtained from the university library.

After paging through a pile of material he decides that most of what he needs he can find in the material that lay in front of him. It contains all the information he requires to draw up a proposal. He decides to call his proposal an EMC management plan. His proposal hi given in table 1.

Table 1: Proposals for the essential elements of an EMC management plan

No	Proposal	Justification
1	Create a general awareness of EMC in the company[2], [4].	If designers, sales representatives and managers are not aware of the implications of EMC non-compliance and generally what EMC is, then they will not grasp the reasons for the rest of the proposal.
2	Consider the implications of EMC on the larger system and not just on the individual components [2], [4].	If a product consists of more than one component, one will have to realise that interconnections or a combination of components may cause problems
3	Review EMC performance and measures during every project review meeting[2].	Since a good project management foundation exists within the company one can easily add a check during the review meetings where the EMC performance and measures are considered. By doing this the collective input of the design team can be obtained regarding the measures. Everybody will also stay informed regarding the measures being used. This will ensure that the general EMC knowledge will improve and that everything possible is being done to obtain effective EMC solutions.

No	Proposal	Justification
4	Consider EMC performance from the start of the project [2], [3], [4], [Chapter 1 (Figure 3)]	It is possible to introduce virtually every measure in the feasibility stage of a project, where one does not want to make design changes during the latter stages. It is also cheaper to introduce, for example, a filter in the initial design, than at the end, because the PCB layout would probably have to be changed.
5	Distribute the effort of incorporating measures for EMC compliance over the complete development cycle[2], [3], [4].	This process is called concurrent engineering [3] and places the bulk of the effort at the start of the design cycle with a gradual decrease in effort through the cycle. This will ensure that as many problems as possible are solved early in the early design cycle.
6	Introduce an EMC control plan [2]	An EMC control plan is a plan that is drawn up, preferably during the feasibility study, that summarises the EMC phenomena that have to be considered, and ways how the perceived problems can be prevented. This plan should also form the basis of the EMC design rules for the person doing the circuit layout. Such a control plan can be a determining factor regarding the feasibility of the project within the parameters specified.

No	Proposal	Justification
7	Introduce an EMC test plan [2], [4]	An EMC test plan must be introduced to define the EMC requirements that have to be met, as well as the points in the development cycle where compliance will be measured. This test plan must be drawn up during the feasibility study. It is also an indicator of the feasibility of the project within the parameters specified.
8	Appoint an EMC coordinator [2], [4].	An EMC co-ordinator is required to ensure that the correct measures are introduced and that the control plan and test plan requirements are being met.

The last phase of Eugene`s project has now arrived. Since he obtained approval from Lisa and the rest of the management team to try and implement this EMC management plan, he now has to find some practical way of implementing his ideas.

3.4 Testing the proposal on a project

As Eugene starts to implement the plan he realises that the feasibility study of the project has virtually been completed, by John, with whom the idea for the product originated. After some discussion he convinces John to allow him a week to draw up control and test plans based on the written requirement specification that they obtained from marketing. He will then table these plans with the feasibility report next week. After a week of work he came up with the following plans.

Table 2: Eugene`s EMC control plan[2]

No	Definition of risks
1	Switching noise from power supply
2	Harmonic noise from reference clock
3	Supply noise from fast switching circuits
4	Cable routing and noise from the inter-module cables and unshielded I/O lines
5	General radiated emission
6	Lightning protection

No	Suggested design practices
1	Use a supply filter with a 3dB cut-off frequency 20 times higher than the switching frequency. The filter should be placed as close as possible to the entry point of the power supply.
2	Keep reference clock tracks as short as possible and frequency as low as possible. Use the slowest (rise time) clock possible. Keep all other tracks as far away as possible form the clock. Do not route tracks underneath reference clock.
3	Decouple every power entry of each IC with a 100nF ceramic capacitor. Additionally, use a non-electrolytic capacitor of approximately 1uF as a tank capacitor on the supplies of components drawing in excess of 5mA.
4	Use chip filters and shielded cables on the inputs and outputs of interconnecting circuits. Use filtered connectors where unshielded I/O lines enter and exist the equipment.

5	All PCB`s should be at least four layers with two layers being power layers. Give preference, when routing busses, in terms of the shortest route, to least significant bits. Keep tracks as far away from the edges of the board as possible and place a guard track around the edge of all layers, that is connected to earth. Provide a reliable chassis connection between components and for the system as a whole. During this stage care should be taken to minimize ground loops on the PCB.
6	Place lightning protection devices for primary protection as close as possible to I/O connectors of the system. Secondary protection should follow the primary protection. On interconnecting lines provision should be made for secondary protection. Interconnecting lines should be kept away from I/O connectors and cable/connector shields should be connected to chassis.

Table 3: Eugene`s EMC test plan

No	Test description	Complete after which project stage
1	Conducted emission CISPR 22B, ETS 300 386-1	Model build
2	Radiated emission CISPR 22B, ETS 300 386-1	Model build
3	Lightning and transient surge protection ETS 300 386, ITU K.20	Pre-release
4	Conducted emission CISPR 22B, ETS 300 386-1	Post release
5	Radiated emission CISPR 22B, ETS 300 386-1	Post release
6	Lightning and transient surge protection ETS 300 386, ITU K.20	Post release

Since Eugene`s EMC management plan was accepted by management he was also considered to be the EMC coordinator. As the project progresses he carefully monitors the implementation of the EMC measures in his EMC control plan. During the weekly progress meetings opportunities arise to make slight modifications and additions to the plan, which he does. Since everything seems to be moving ahead speedily and without any significant problems he notices a change in the attitude of the rest of the design team members towards him. He almost senses a general acceptance of his ideas. This he realises was the fruit of his hard work during the past months. What he does however know is that he has the opportunity in the next few days to either cast this new found trust of his co-workers in concrete or to wipe it out completely. In the next two to three days he will perform the pre-compliance testing after the complete system model has been built.

As he starts testing the next day he realises that he might just succeed as the initial results looked very promising. There is only one hump at approximately 2MHz that fails marginally. The rest of the peaks are well below the limit. He should be able to find the origin of this one problem fairly easily, he thinks. That was until the radiated emission scan reached 915MHz, the IF frequency of the RF transmitter, where a massive peak was visible. As he counted the divisions on the graph - three and a half in total, which represent 35dB over the limit - he knows that he is in trouble. Although he knows that nobody could have anticipated all the possible problems, he still feels dejected. In conclusion he informs the rest of the team that he will investigate the problem and try to give them a solution by the next day.

Eugene has just made himself some coffee, hoping that it might wake him up. He worked until 7pm last night, without success, when he went home just to lie awake the whole night trying to find out what the problem was. As he places his coffee on the desk he looks at the RF circuit lying on the table. The RF circuit was enclosed in its own metal box for shielding purposes. As he picks the box up he notices a grey substance on the corner opposite from the earth wire connection. "That`s it," he yells!! "I've got it". He looks at his watch, which reads 7:15am. He has an hour and forty-five minutes to prove that the problem can be solved. He sets out by covering the top, bottom and both sides of the RF box in masking tape. What he realised, is that the rails of rack where the system components like the RF circuit, are housed in, are metal. Placing an earthed metal enclosure on a metal rail might cause a ground loop with earth connection on the box, that can act as an antenna for the IF frequency of the RF circuit. The masking tape should isolate the enclosure from the slides and thereby breaking the loop. The only earth connection would then be the earth wire at the back of the box. As he runs the test again he sips his coffee. He is staring at the screen like somebody who is watching a gripping movie. At 910MHz he stops breathing, or so it feels to him. As the scan reaches 920MHz he knows that he found the solution: Plastic rails instead of metal ones.

An hour later he describes the events of the morning and the solution to the rest of the development team. He concludes that there was probably a resonant loop present on the box between the intentional earth at the back and the front corner that was scraping into the metal rail. Happy that he found a solution to the main problem he asks the team for permission to search for the source of the emissions at 2MHz. He states that he suspects that it is a power supply problem which he should be able to fix in a day or two. After some resistance from a few people it was agreed that he would have three days, until Friday, to come up with a solution, while they complete the outstanding documentation.

Full of confidence he sets out to find the one remaining problem. By four o'clock he starts to notice an improvement in the level of the frequencies around 2MHz. By the time the clock on the laboratory wall reaches going home time, he knows what the solution to the problem is. For the last thirty minutes Lisa has been watching over Eugene`s shoulder with a smile on her face as he soldered and de-soldered capacitors on the board. As the last scan passes the 5MHz point she realises that Eugene has suppressed the peaks at 2MHz to 5dB under the limit. Reluctantly she asks him what he did. Full of confidence Eugene explains that he replaced the line to chassis capacitors on the input of the power supply filter with polypropylene capacitors.

He continues to explain that somebody showed him some graphs the other day of ceramic capacitors that had resonant peaks frequencies in the 1-5MHz band. That was probably the case with their supply of ceramic chip capacitors as well.

3.5 The closing out meeting

A month later - three days after the successful completion of the compliance EMC tests he sits in the closing out meeting. As he looks at the pad in front of him he realises that somebody is talking to him. He must have been day dreaming. He looks up from the pad just in time to realise that Lisa has asked him for the second time whether he had any comments about the project. Now fully awake he states that he is satisfied with the project outcome. He also states that he was surprised by the failure at 915MHz. He thought at that stage that those kind of problems should not occur as they have taken every measure possible to ensure EMC compliance. What he did learn, he states, is that one must be prepared for some problems at the testing phase, as one can easily miss something during the design. In conclusion he expresses the wish that all of the problems that they have in future, at the testing phase, be as easy to solve as the ones they had with this project. At 11:15am, on Friday the 15th of June 2001, a content project team leaves the meeting room for a pub lunch, feeling satisfied with the work of the last five months.

3.6 References

[1] Rory Burke, "Project Management. Planning and Control", Chapter 1, Management Press, Cape Town, Second Edition, 1995, ISBN: 0-6230-16250-3

[2] Tim Williams, "EMC for product designers - Meeting the European EMC Directive", Chapter 8, Newnes, Oxford, Second edition, 1996, ISBN: 0-7505-2466-3

[3] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[4] JB Maree, "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", Chapter 3, pp. 3-1 - 3-14, University of Stellenbosch, December 1998

[5] JB Maree, "External Examiners' observation", January 2003

Chapter 4 - Case studies: Implementation of a partial EMC management plan versus no EMC management plan

4.1 Introduction

The first case study in this chapter is presented to show what can happen to a product development cycle if a good EMC management plan is not in place or if such a plan is not followed. From these problems, valuable lessons can be learnt, which can be implemented in future projects.

The second case study shows how a partial EMC management plan can be introduced. Plans like these will typically be used on projects which do not warrant the expense or effort of a full EMC management plan but cannot afford to run into the kind of problems described in 4.2.

4.2 Case study 1 : No EMC management plan

This case study was drawn up from a real situation. However, for obvious reasons of confidentiality, product specific information is withheld and names have been changed. In order to maintain the required confidentiality level only phenomena will be discussed instead of specific practical implementation data. What went wrong in the development cycle of "The Widget" will now be investigated.

4.2.1 The product request and design

Frank le Roux, a Chief engineer at Widget and Gadget Inc. is looking perplexed as he walks down the passage to the office of some of the engineers that report to him. In his hand he holds an A4 sheet of paper containing the notes he wrote during a meeting with John Bagger, the Marketing Manager. He has been asked to develop a product for delivery in ten weeks time based upon these notes. As he tells his engineers about the request he knows that they will probably struggle to meet the deadline. After considering the already heavy workload of his engineers he assigns the project to Pieter Fourie, a young engineer. Since this is his first project as project leader, Pieter gladly accepts the task.

Trying to piece the puzzle of this product together Pieter starts by drawing up a project plan. He knows that he cannot spend too much time on "luxuries" like the project plan, because he needs to do the design. As he speaks to Karl, a Senior Sales Engineer, he finds out that some of the technical specifications supplied, came from what the marketing team were told about the competition`s product. Whether this information was accurate he would never know as neither a set of their features nor a sample of their product could be obtained. Following these discussions Pieter did the design. Another problem that Pieter faces is that he keeps on getting new information from Karl. The effect of these changes in requirements is that he has to re-do the design a number of times.

As Pieter is still young and inexperienced, and since he has wasted some time in re-designing the product he moves forward rapidly with the design. He does this without considering the implications of EMC requirements on the product. After he receives the completed PCB layout from the drawing office he is asked to show it to the EMC specialist in the division, Pedro da Silva. Pedro briefly looks at the layout and concludes that certain modifications have to be made, otherwise the product, appropriately named The Widget, would fail to meet the EMI requirements. His concerns are listed in table 1.

Table 1: Pedro`s concerns regarding the design

No	Concern	Reason for the concern
1	Tracks from the input/output (I/O) connector pass too close to the mains filtering	Coupling to the primary side of the supply filters may occur
2	The enclosure seams are not electrically well joined	The screening effect of the enclosure might not be good enough to ensure that the circuit passes

3	The I/O connectors are unfiltered	Unshielded lines connected to the outside of the I/O connectors will radiate any noise inside the system that is coupled to the connectors
4	The board is not wide enough to separate effectively sensitive circuits from each other.	Coupling between circuits will occur because circuits cannot effectively be separated. This might increase the amount of emission

Since Pedro was given little time to evaluate this design, he realised that he might have overlooked some critical aspects, and that the measures that one can introduce at the current stage of the project might be limited, due to time constrains. Frank and Pieter decided at this stage that most of Pedro`s suggestions should not be implemented as this would delay the project even further, and would drastically increase the cost of the product.

4.2.2 Testing and Re-designing the Widget

Two weeks later Pedro was asked by Pieter to test the Widget for EMI. The end result was that the Widget failed radiated emission by a substantial margin. Although Pedro expected this to happen, he was also surprised to see the margin by which it failed. It is now time for Pedro to spend a bit of time testing and experimenting with changes to the design. After a week of changing component values, cutting tracks and re-routing them, shielding connectors and building boxes he came up with the list of problems in table 2, that caused the Widget to fail.

Table 2: Causes of emission failure of the Widget

No	Causes of failure	Reasons for causing failure
1	Signal tracks were routed under the crystal	These tracks picked up the crystal harmonics and transported them over the board causing emission to be radiated from them. They also, through crosstalk, coupled to the power supply tracks causing the frequencies to be radiated from the power supply cord. The power supply filter was optimised to work up to 2MHz and subsequently not at these high frequencies.
2	Decoupling capacitors were too far from IC`s	As the IC`s switch, they draw a current pulse from the supply that has a fast rise time. The high frequency spectrum generated by this pulse is not effectively decoupled due to the placement of the decoupling capacitors.
3	Power supply filters were incorrectly placed	Signal lines were routed close to both sides of the power filter. This allowed noise on these tracks to be coupled onto the "clean" filtered tracks, which in turn radiated the noise to the outside world through the supply cord.
4	Signal lines were unfiltered	Although filtering was included on the power supply lines, none were included on the signal lines. Radiated emission could therefore result from these signal lines. Due to the placement of lightning protection components, just after the connectors, PCB mounted filters would be too far from the edge of the enclosure to be effective. Signal line filters incorporated in the connecters would therefore have been the best option.

5	Enclosure was inefficiently shielded	The enclosure of the Widget was not manufactured precisely enough to ensure that seams make good electrical contact. Additionally, around the connectors large cut-outs were used. Probably due to cost considerations none of the seams of the enclosure made use of gaskets. All these factors ensured that the enclosure was not an efficient shield.

Since the Widget did not meet the expectations of the client and marketing team, another design cycle was initiated, as the product was important for the company. To say that Frank was unimpressed with the state of the project would be a huge understatement. Proof of this can be found in the talk that he gave to Pieter after the meeting. Pieter was told, amongst other things, to make sure that Pedro approves the design before he proceeds to the next stage. Pieter in turn felt frustrated by the fact that he was blamed for the failure of the Widget. He was given very little time to design a product, the specifications of which kept changing.

The EMI failures could at this time be hidden from the client who wanted some expansions to the capabilities of the Widget. These changes to the specification have now increased in frequency over the last three weeks. The other problem that occurred without anybody noticing is that company procedures such as reviews, and scheduled feedback were skipped as the project was restarted a number of times. Pieter started to feel that he would never be able to finish the Widget. The EMC measures that had to be introduced are proving problematic, as they are difficult to implement at such an advanced phase of the project`s development cycle. These measures, like signal line filters, shielded connectors and a shielded enclosures are very expensive. At this stage he could have done without such changes, because it causes a drastic increase in the product cost, and development time.After reading a book on project management [1] he sits down and makes a list of the things that went wrong.

The problems he identified are listed in table 3.

Table 3: Problems in the product development cycle

No	Description of problem
1	No feasibility study and risk analysis were done [1]. If these were done then he would have known about the potential EMC problems, and he could have made suitable changes. A feasibility study would also have shown whether a product with the required specifications could be made for the required price.
2	A clear project outline was not drawn up. The scope of the project was therefore not clearly defined as is suggested in [1]. This allowed constant changes to occur that badly affected the accuracy of the project plan and the ability of the project to meet the expectations of the customer.
3	The internal quality control procedures of the company were not followed, causing the project to be delayed due to documents that had to be written in retrospect. Other delays were also experienced since vital parts of the project development cycle was skipped.
4	Not enough consideration was given to EMC in the first development phases necessitating many changes at a later stage, causing expensive delays.
5	According to an article on the inclusion of EMC in project plans [2], the process of diverting the bulk of the resource intensive work to the start of a project is concurrent engineering. The department could definitely benefit from the implementation of a concurrent engineering program.
6	Not enough commitment and understanding in the department for complying with EMC requirements. General training might be advisable. It would also be necessary to convince management that it is worthwhile to insist on the inclusion of EMC measures in products.

Now that he has a list of the problems that he encountered during the previous design cycle he must just find somebody who can help him to solve these problems.

4.3 Case study 2: A partial EMC management plan

M&M Engineers have been designing electronic circuits for the last 20 years and have been very successful at it. However, over the last few years they have been having more and more problems with the EMC compliance of their products. When Mike and Mitchell started M&M Engineers, EMC was something with which they had few problems. If they think back now, they know that they probably always had problems with EMC but they did not know about it. At the time there was also very little legislation in the world that required EMC compliance to standards. Most of M&M`s products are simple, cost effective solutions to problems and therefore the products are very price sensitive. Due to this problem they have been unable to implement the EMC management plan that Joe, a consultant, developed for them.

The only solution at this stage was thus to tailor Joe`s plan in such a way that it fits in with their methods, budgets and development time scales. Since Mitchel is busy completing another big project they decide that Mike has to head the project team for a new request they have just received.

4.3.1 Find a way to manage the design

To begin Mike looks at the project stages that are normally implemented. He firstly concludes, that although they normally start with a feasibility study, this is a very informal process that is combined with the conceptual design phase referred to in the PMI body of knowledge [1]. After deliberating the issue he decides that the best approach would be to, firstly, assume that EMC presents a sizeable risk to the successful completion of the project and, secondly, to make provision for additional components or experimental changes to the first prototype boards. In this way problems can be solved during the early testing phases. These decisions make sense to him since there could be no arguments regarding the influence on EMC later and they will be able to iron out the existing problem by means of the experimental work they have made provision for. For many other projects it would be uneconomical and very difficult to allow for experimental changes as the circuits and PCB`s are too complex. Because this product is small, relatively inexpensive, and not very complex, such provisions can be made viably.

Mike realises that the main difference between his ideas and a full EMC management plan (see chapter 3) such as the one that Joe proposed, is that this approach is less structured and therefore more flexible. He would, however, have to ensure that consideration is given to EMC throughout the project. This is an extra task, but he realises that the success or failure of the project will depend on whether he can control the implementation of the EMC measures. Another point that Joe stressed in his proposal as being vitally important to the successful implementation of an EMC management plan is the acceptance of a "Design for EMC" culture in the company [4]. With the very autocratic style that he is contemplating, there will be neither time available for general EMC awareness training nor for convincing team members of the importance of EMC compliance - see also table 1, paragraph 3.3. He decides that he will make a point of talking to as many of the project team members as possible regarding EMC issues. He also realises that Since M&M do not have a formal project review process he also decides that on this project he would ask for everybody`s comments regarding the process followed once the project is complete. This would allow him to assess whether the process was successful or not.

4.3.2 Reviewing the process followed

Mike calls the complete project team together and tells them that they have received a request from Teleco Inc. to develop a call monitor for the domestic market. He also tells them that the conditions of the request include a requirement that a prototype of the device has to be delivered in seven week`s time. After describing to them what features the device should have he tells them about his thoughts regarding the design process to be followed. He states: "As time is critical, we cannot afford to have EMC problems. I will, therefore, through regular checks and discussions with you, try and ensure that we do not experience any problems.

If you have any problems with the process that I have outlined then I urge you to come and see me as soon as possible."

After appointing the relevant responsible persons on the project team he adjourns the meeting. The rest of the week the majority of the team enthusiastically starts their assigned tasks. As the first week ends Mike sits down and reviews their work. He hears about one or two complaints regarding his approach. After discussions with these individuals he senses more acceptance as they realise why this process necessary.

At the beginning of the second week Mike experiences the first major problem. The hardware engineer responsible for the I/O-circuitry, Leon, decided that there was only one way to ensure that no noise is transmitted via the I/O-ports. This is to use a brute-force-and-ignorance-approach and add as much filtering as possible. These filters and connectors, although they would work, will increase the product cost too much. After some discussion with Leon, he convinces him to build some of the filters up from surface mount components and to add one or two unpopulated pads that can be used for experiments. They also agree that they will design the board in such a way that it can accept both the filtered and unfiltered connectors. The filtered ones, however, will only be used as a last solution, they agreed. To ensure that the rest of the team do not fall into the same trap he decides to organise a social event for the following afternoon, where they can have some informal discussions about the problems that they have experienced so far, and then relax with some food and drink.

For the next two weeks the design and experiments progress without any major problems. In general Mike is surprised to see how most team members have co-operated during the first four weeks. In one or two cases he had to intervene and help people to stay focussed on the problems. In general, however, the chances of finishing the prototype in the desired timescale look good.

As they are currently waiting for the PCB boards to be delivered and some components to arrive he has organised two brain-storm sessions to discuss the testing process and what they will do if certain scenarios of failures occur.

As they have only two more weeks in which to complete the project Mike starts to increase his interaction with the rest of the team. Apart from one component that is due for delivery tomorrow, all the other parts have been installed. He suggests that they use an in-house manufactured unit for the purposes of initial testing until the correct common mode choke arrives. As Leon and Jaco did most of the hardware design work he suggests that they accompany him to Test House Inc. for the prototype EMC testing. In addition to the model, they have been asked to take the necessary tools and all the components that might be needed for experimental work in the next three days.

After two days of testing Leon, Jaco and Mike knows that they have at last managed to reliably suppress the three emission peaks that were close to the limit. Two of these peaks were due to the grounding method used and the other due to a capacitor in the power supply. Mike decides that, since the unit passes marginally without the filtered output connectors that they will ship the prototype with the normal connector. If they have problems on the first production models then they can just replace it with the filtered one.

After some final instructions to Leon and Jaco regarding documentation and other tasks to be carried out before they can ship the product, he returns home. He realises that it is the first time in six weeks that he has been able to relax properly. Having said that, he realises that one of the reasons why the design was completed on time without major problems was because of this effort. Keeping an eye on the design team and being involved in everything has taken a lot out of him.

4.3.3 EMC Management plans: Concluding remarks

In chapters 3 and 4 we have, through three case studies, seen what could happen to a product if an EMC management plan is not implemented. A significant amount of risk exist in such a case that the product will fail EMC testing and therefore that the project deadlines will not be met. To reduce the risk of failure, it was proposed that a full EMC management plan be implemented. In this plan the product would be completely evaluated and the compliance to all the applicable EMC requirements would be evaluated throughout the project. The problem with a complete EMC management plan is that it is not always economically viable to implement on all projects, especially smaller ones. In such a case it was suggested that a partial EMC management plan be implemented. The question can now rightly be asked: What would the difference be between a partial and a full EMC management plan? The difference is that in a partial EMC management plan, one would identify the main elements of risk and concentrate on these issues, where with a full EMC management plan all elements of risk would be evaluated. The reader must realize that any issue that is not considered in the partial plan will then again increase the risk of failure. Through proper risk management the acceptable amount of risk can, however, be determined, controlled and monitored.

4.4 References

[1] Rory Burke, "Project Management. Planning and Control", Chapter 1, Management Press, Cape Town, Second Edition, 1995, ISBN: 0-6230-16250-3

[2] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[3] Ray Siu, Daniel J. Majewski, EMC Management: An integral part of a company`s quality program", IEEE International Symposium on Electromagnetic Compatibility, pp. 285 - 289, Washington, 2000.

Chapter 5 - Interlaboratory comparisons and practical EMC measurements

5.1 Introduction

The chapter will firstly investigate the options that an EMC laboratory has, apart from traditional methods, to establish its credibility and build up confidence in its methods. The option that will be investigated is to take part in interlaboratory comparisons. This will show how one can use these comparisons in conjunction with equipment calibration, or in some cases without calibration of equipment (where it is not possible), to establish the credibility of certain measurements. It will also show how a manufacturer with in-house test facilities can gain acceptance for his results in a self-certification environment. Comparisons that have been done in South Africa will also be examined. The writer was, at the time of these measurements, working in one of the laboratories whose results are presented in this thesis. The comparisons presented here have however been done afterwards by the writer due too his interest in the benefits and effectivity of interlaboratory comparisons.

Secondly, the chapter will investigate possible alternative test methods that can be used instead of the more traditional and expensive approaches. The measurements presented and the equipment setup were chosen to provide a stable and repeatable set of measurements that closely represent a typical radiator, e.g. a piece of equipment being tested. What the setup does, however, not cater for is a means for common mode current to flow. This is important since it is known [11], [19] that a relationship exists between the common mode current that flows in a circuit and the radiated emission from the circuit. The common mode current, normally, has a larger influence on the radiated field than the differential mode current, because the area of the loop where the common mode current flow is much larger than the loop where the differential mode current flows - see figure 1.

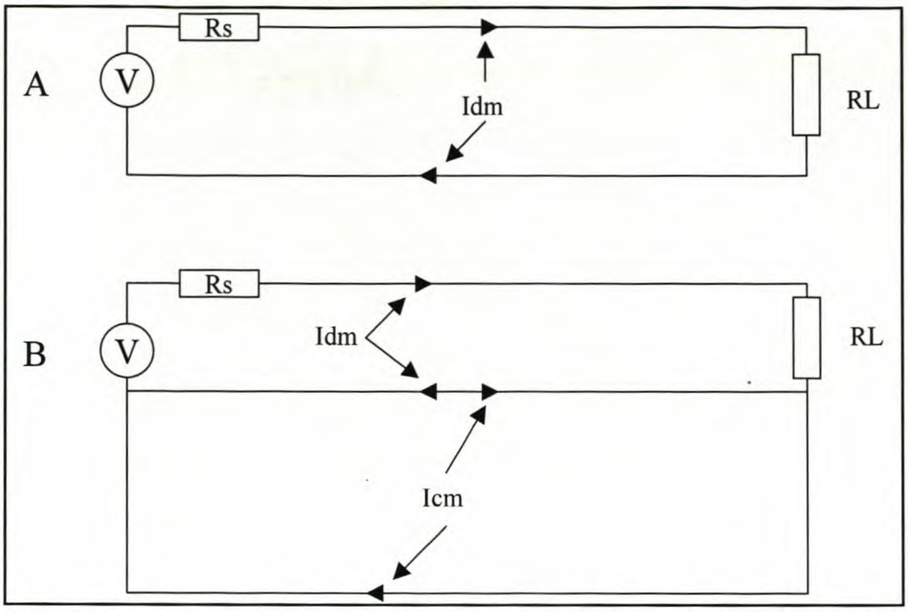

Figure 1: Common and differential mode current - note a CM current component can also flow on the top conductor depending on the configuration.

Although common mode current measurements will not be presented in this thesis, it is important to understand what common mode current is and how it would be measured. For this reason a short overview is presented. In a circuit such as the one showed in figure 1a where a single current loop exists only differential mode current (I_{dm})can flow. If the conductors are close together then the H-field due to this differential mode current would be very small, because of the direction of current flow. In a circuit such as the one showed in figure 1b an additional conductor is present. This conductor can exist for a number of reasons of which the following are some examples: Common ground connection between the source and the load and multiple connections of a conductor to a ground plane. Such a common conductor does not have to be electrically connected (as shown in figure 1b) to the circuit. It can also be capacitively coupled. In the circuit of figure 1b the differential mode (I_{dm}) and common mode (I_{cm}) current components are indicated. Placing a current probe around the top two conductors or the bottom conductor of figure 1b would allow the common mode current to be measured.

As mentioned earlier, the measurements presented in this thesis only shows emission due to differential mode currents. Unfortunately the writer had to change employment during the course of preparing this thesis and after this change the applicable measurement facilities and equipment were no longer available to repeat the measurements with such a common conductor included in the circuit. What can, however, be seen from this thesis is what parameters would be important during radiated emission measurements and what alternatives to standard measurement techniques exist. The main reason for investigating alternative possibilities, is that a manufacturer can perform in-house testing to prove EMC compliance should the legislation in the country allow it. Through in-house testing the manufacturer can gain confidence in the product`s performance, and thereby increase the probability that the product will comply before expensive third party testing is undertaken. It should therefore be noted that even if we refer to a test laboratory in the text below, we can apply these principles to any in-house laboratory.

5.2 Establishing credibility through comparison

Traditionally test laboratories have sent their test equipment to a calibration laboratory where the equipment was evaluated according to the manufacturer`s specifications. If it was found to operate within the manufacturer`s limits, a calibration certificate was issued. Thereafter the user in most cases did not question the measurements or operation of the equipment, until the next calibration. In addition, historically, training of test personnel took place during testing because enough suitably qualified people were available. However, in EMC test laboratories today one cannot rely only on this approach. Due to the increased sensitivity of measurements and equipment and the frequency range where measurements are being made, one has other factors influencing the accuracy of measurements. In addition to these factors one also struggles to prove the competency of EMC test personnel in South Africa due to a lack of appropriate training courses that can be used as a basis. One therefore often needs other means of establishing the credibility of test personnel and test results. In this respect interlaboratory comparisons can be a valuable tool.

Since test equipment for EMC testing is very expensive an in-house laboratory, in the case of a manufacturer or a test laboratory may not always be able to justify the purchase of the necessary test equipment. It is, however, possible for manufacturers to use alternative test equipment for this purpose, to establish the compliance of his products. These, methods and the restrictions that are applicable, will be investigated.

One of the biggest problems that a new test laboratory can have is to establish itself as competent in a field. It is necessary to prove competency to accreditation bodies as well as to the industry. By being involved in interlaboratory comparisons and obtaining equivalent results to laboratories that have already proven their competency, the new laboratory`s credibility is established. It also proves the laboratory`s commitment to quality service.

In South Africa the South African National Accreditation System (SANAS), which is responsible for the accreditation of test and calibration laboratories, established such a programme for EMC test laboratories through a specialist technical committee (STC). The EMC STC consists of representatives of all the EMC test laboratories, accredited and not, in South Africa[1]. In addition to interlaboratory comparisons this STC discusses general issues relating to EMC testing and accreditation during its meetings.

5.2.1 What is an interlaboratory comparison?

An interlaboratory comparison can be defined as: *Two or more test laboratories agreeing to perform the same measurement on the same sample(s).* However, before the laboratories can start testing they have to reach an agreement on the sample to be tested, the test method to be followed, the time each laboratory will have to complete the measurements, as well as the connecting methods and cables.

1

The specific laboratories that took part in the interlaboratory comparison are not named in this thesis as result of a decision by the STC when the programme was started.

It is also good practice to agree beforehand what the limits are for acceptable results and what corrective action will be taken in the case of large discrepancies.

Therefore, after the measurements have been done, the results are compared. It should maybe be noted that an interlaboratory comparison should be seen as a means for a laboratory to gain confidence in its work and not as a means of discrediting other laboratories.

5.2.2 What are the rules of interlaboratory comparisons?

Having now defined an interlaboratory comparison, one should also ask how to go about performing the test work. Rules should be followed or it will be almost impossible to determine what went wrong if any large deviations occur. From interlaboratory comparisons that the writer has been involved in [1], [2],[3], numerous pitfalls were noticed. These pitfalls will now be discussed briefly to establish some "rules" for use during interlaboratory comparisons.

- *Conduct the interlaboratory comparison in exactly the same manner as any other test.* Any "special" measures taken to ensure the accuracy of the measurement should be recorded in the results as they could invalidate the measurement. One should keep in mind that although equipment can often measure more accurately than required one can still have significant errors due to operator mistakes, routing of cables or bad connections. The interlaboratory comparison therefore takes into account all factors affecting the quality of a measurement. It often happens that one does not realise that some of these measurement errors are present until the results are compared with other laboratories. Although laboratories taking part in the comparison should not share the results until everybody has completed their measurements, they should discuss any problems encountered during the measurements. By doing this, unnecessary re-measurement can be avoided.
- *Decide at the start of the comparison how large discrepancies will be handled.* Although it is desirable to have no large discrepancies, they do invariably occur - [1], [2], [3]. It may happen that a laboratory has to

introduce some corrective action, and it is therefore important to decide beforehand how these situations will be handled.

- *A person not involved in the measurements should do the compilation and evaluation of the results.* This avoids any possible questioning of the presentation of the results and interpretation thereof. Since this person has no vested interest in the comparison he can independently assess the results and facilitate the process of corrective action if needed. Although interlaboratory comparisons are done with the intention of proving the credibility of each of the participants, the results should still be treated as confidential. A laboratory should know at the end of the process how it compares to other laboratories and which results are its own. It is however preferable that one laboratory does not know which results belong to the other participants. This is important since problems with competition between laboratories will arise when large differences are present between results. The independent person who is facilitating the process must ensure this confidentiality.
- *Interlaboratory comparisons always have to be done according to an agreed-upon method.* During the comparison described in [1] the test method was not well defined. It resulted in two laboratories following one method and obtaining one set of results and three others following another method that yielded results offset by as much as 30dB. Obviously the results of this comparison could not be used to establish the credibility of the laboratories. For this reason it is necessary to establish the method before any measurements are done.
- *The setup used and results should be reported as completely as possible.* This is also necessary to allow the coordinator to establish the reasons for discrepancies when they arise. In the comparison described in [2] a narrowband generator was measured. If the one laboratory performed its measurements, by accident, with an measurement bandwidth of 10kHz it will obtain results very different from the laboratory using a measurement bandwidth of 120kHz. Depending on the sample used in tests like those described in [1], [2] and [3] one finds that small differences in any one of the following parameters may have a significant influence on the result: measurement bandwidth, frequency step size, measurement

time and detector type.

- *The data comparison method used during the evaluation of the measurements.* Depending on the type of results obtained and the ultimate purpose of the measurements one may choose one, or more, of a number of data comparison techniques. A good overview of some of these techniques are given in [4]. A lot of time on a visual comparison should be sufficient, but one may require more advanced techniques, depending on the application and data. In the next paragraph a few of these techniques will be used to illustrate how they work.

5.2.3 Results of an EMC interlaboratory comparison

During 1999/2000 three interlaboratory comparisons were completed [1], [2] and [3], and another one is in progress within the SANAS STC in South Africa. Some of these results will not be discussed in this thesis but is left for the reader`s own study. Instead only the results of [2] will be discussed, analysed and presented here.

During this comparison the conducted emission of a narrow band noise source was measured. Figure 2 shows the results obtained by the six laboratories. From a visual inspection, all the laboratories, except one, obtained acceptable results - i.e. Lab 5. One of the shortcomings of this interlaboratory comparison was that the acceptance criteria was not defined beforehand. As it turned out the participants discussed the results at a meeting and decided that, since this is one of the first EMC interlaboratory comparisons that results showing the same tendency, without being erratic, would be acceptable. To the purist this criteria might seem to vague. For the laboratories in question this was acceptable, as they only wanted to see what kind of results can be obtained, and what problems one can associate with this kind of measurement campaign. In the writers' opinion the comparison between the laboratories was not very good. The difference between the laboratories' results should be much smaller. The main aim of the comparison, however, was to get an interlaboratory comparison programme started in the country. Results that correlate well would have been a bonus. As a result of the measurements, laboratory 5 will have to implement some corrective action to eliminate the problem. It is, however, not the aim of this thesis to discuss this laboratory`s mistakes.

Another way of comparing the results, apart from visual examination, is to compare each laboratory`s data with a set of reference measurements. Such a reference set of measurements can be the calibration data of the device being measured. Normally the reference data is obtained by comparing it to a more accurate device or standard. For instance one would not use a frequency counter that can display the frequency of a device as 10.002 MHz to calibrate a device up to three decimal placed or more. One would at least use a frequency counter that can display four digits after the decimal point, i.e. 10.0020MHz. The main requirement, however, for the reference measurement is that it should be more accurate than measured data. The data depicted in figure 2, for each laboratory, was therefore plotted with the calibration data (obtained from a SANAS accredited laboratory) as well as with the difference between the measured value and the calibration data. Figures 3 to 8 show these results for each laboratory.

From figure 3 it can be seen that this laboratory`s results compares reasonably well with the calibration data up to 20 MHz (±3dB). Thereafter the difference increases drastically. This is probably due to the fact that the losses in the line impedance stabilization network (LISN) used become significant. One may argue that a 3dB margin is not very good. However, if one remembers that this comparison was done to establish some baselines for future comparisons, and if one compares this laboratory`s results with some of the other laboratory`s efforts, then the 3dB margin is not too bad. The important point to notice is that the difference between the calibration and measured data is a smooth curve. Compensation for the error can therefore be considered, which would make much more accurate measurements possible.

In figure 4, laboratory 2`s results are shown. Although the moving average of the difference might be good, a couple of large errors exist. The shape of the Delta-curve suggest that the measurement equipment (Receiver and/or LISN) have some resonant points or frequencies where accurate measurement is not possible. This laboratory will have to consider the calibration or repair of its equipment.

Figure 5 shows the results for laboratory 3. These results looks very similar to that of laboratory 2 (Figure 4). This laboratory will also have to investigate the reasons for the peaks in the difference between the measured and calibration data. The results in figure 6, laboratory 4, shows exactly the same tendency as figures 3, 4 and 5 with large resonant peaks. As discussed earlier laboratory 5 were unable to produce results that closely resembled the results from the other laboratories. This fact is emphasised by figure 7.

Figure 8 shows the results from laboratory 6. Apart from laboratory 1 this is the only result that showed an error that could be compensated. The difference between the measured and reference data below 20MHz is relatively linear and one could correct for this error by applying a correction factor. Above 20MHz two small resonant points exist. Laboratory 6 might want to adjust these points during the next calibration of the LISN, as it is probably due to components being used at frequencies higher than their capabilities. High capacitance capacitors, typically electrolytic and tantalum are notorious for their resonant peaks at higher frequencies, and this is why it would be advisable to start investigating in this area.

A visual examination of the combined results can sometimes not be sufficient to determine how one data set compares with another. If the difference between data points is very small, the margin is very small or a very accurate comparison is required, then a numerical method would probably be more applicable. This would also be where a number of parameters, that are related to each other, are evaluated. In these cases one would probably be inclined to use a statistical method of comparing the data. It is however important to agree beforehand on the method to be used so that data can be presented in a compatible manner.

For instance, if the selected method requires five measurements at each frequency and it requires a set of reference measurements (calibration data), then it would serve no purpose to produce a set of data that contains one measurement per frequency or not to have reference measurements available [4].

For our purposes, to establish an interlaboratory comparison programme, the visual examinations shown in figures 2-8 were sufficient. Upon completion it was very obvious to each laboratory where its weaknesses lay, and how it performed compared to other laboratories.

At the time that this thesis was written the STC started the third interlaboratory comparison. This interlaboratory comparison is on radiated emissions. It is envisaged by the participants that this comparison will require a large amount of work. Much more preparation is therefore being done. In preparation, references such as [17] and [18] are studied. Radiated emission measurements can easily be influenced by many parameters, like the test setup, ambient conditions, and structures that are in close proximity to the test site. For these reasons, the results are eagerly awaited. It is also, true that with hard work one can obtain comparable radiated emission results on different sites [3].

5.2.4 Interlaboratory comparison figures

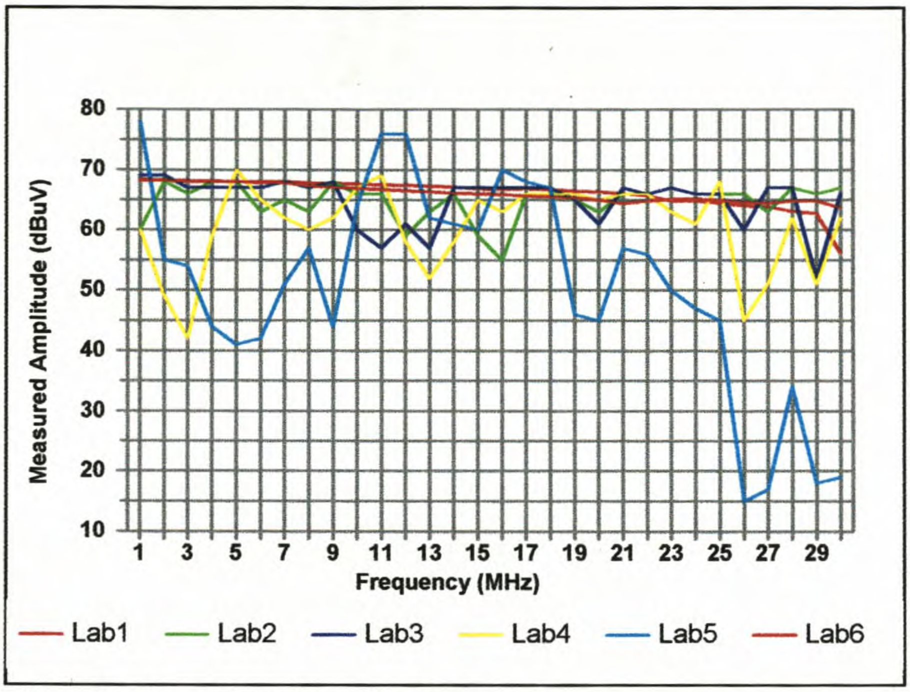

Figure 2: Consolidated results of comparison

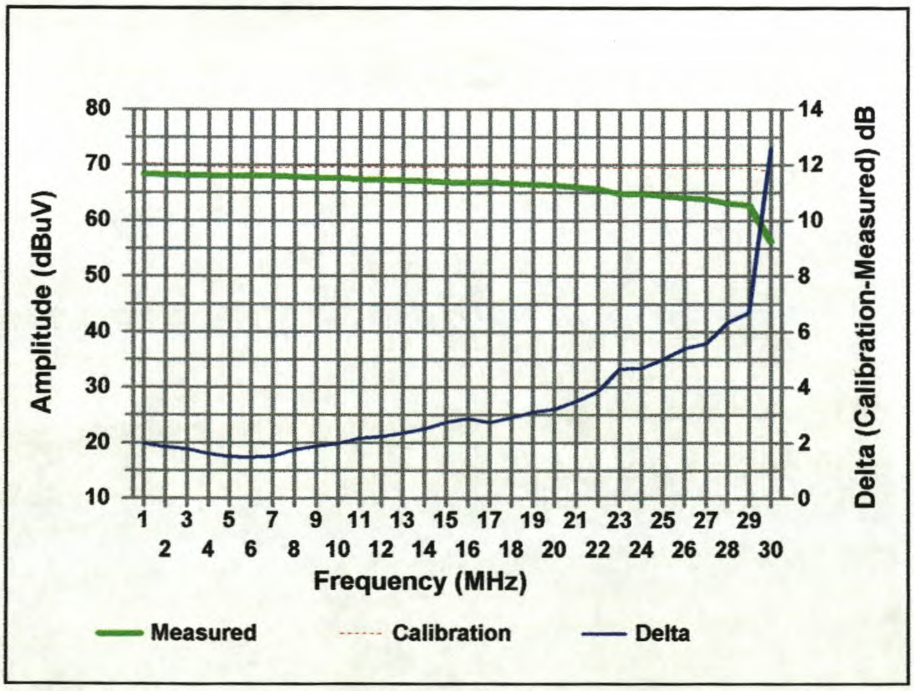

Figure 3: Laboratory 1 vs reference data

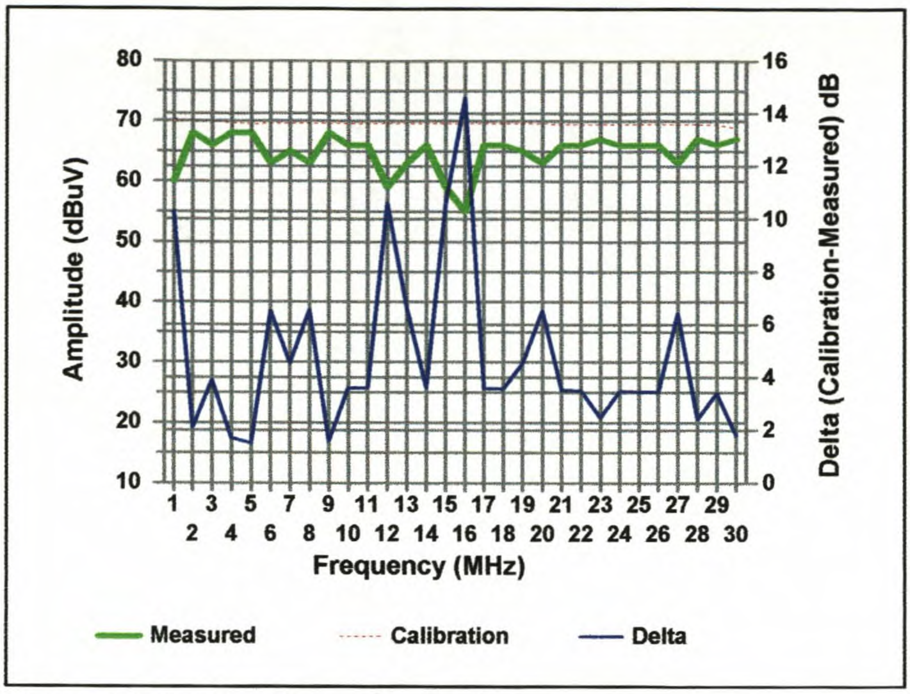

Figure 4: Laboratory 2 vs reference data

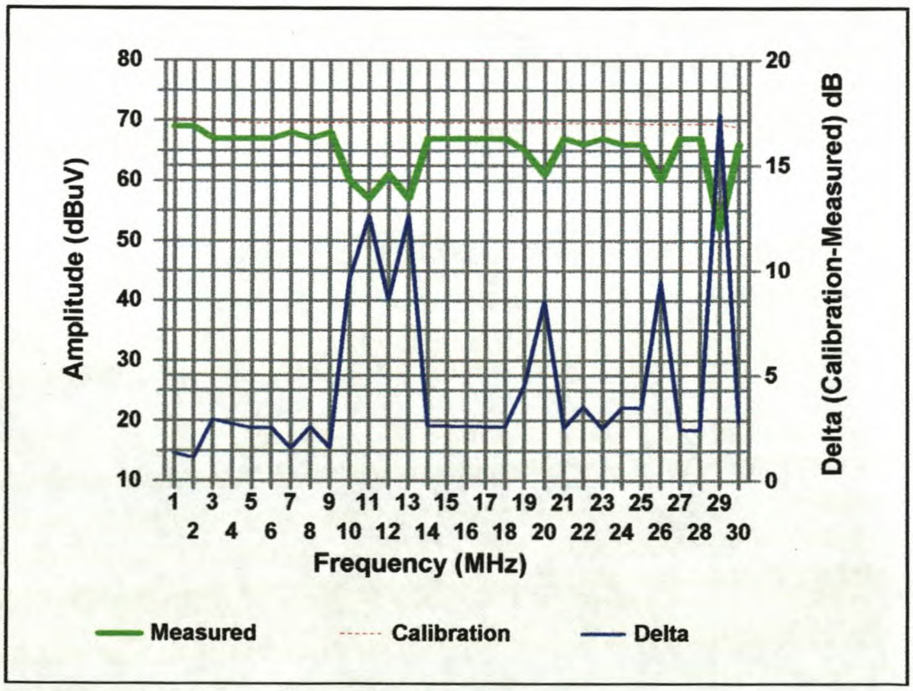

Figure 5: Laboratory 3 vs reference data

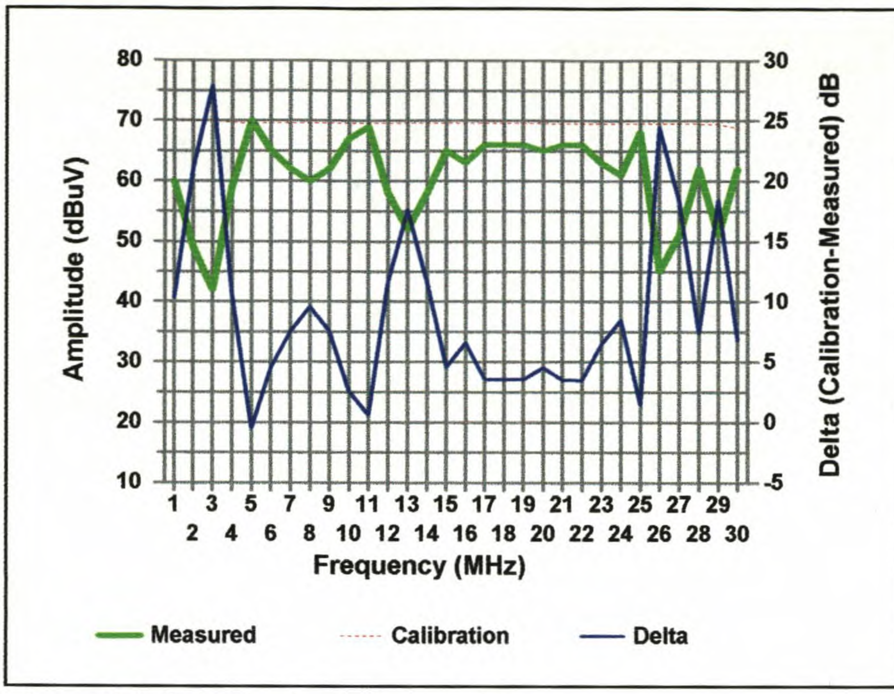

Figure 6: Laboratory 4 vs reference data

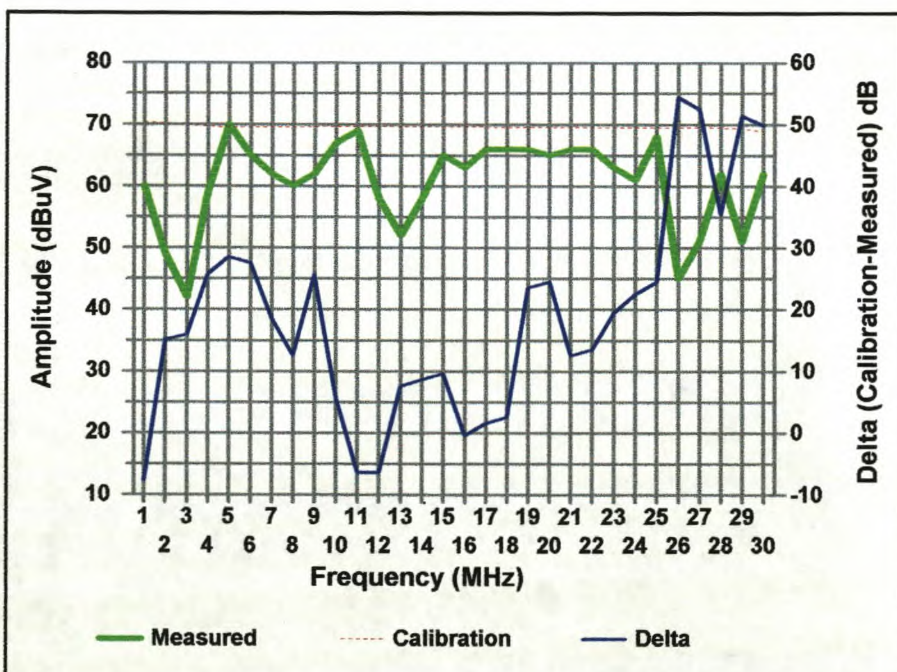

Figure 7: Laboratory 5 vs reference data

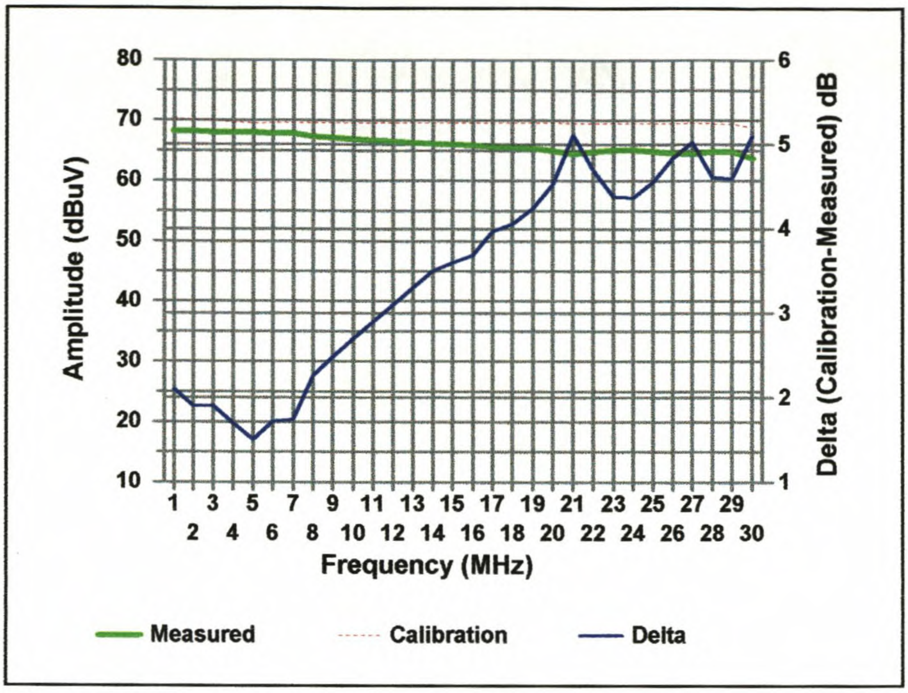

Figure 8: Laboratory 6 vs reference data

5.3 Comparison: "Traditional" vs. "Alternative" methods

5.3.1 Introduction

Unwanted electromagnetic energy that a device emits is traditionally measured in one of two ways. Firstly, at the low frequencies (typically below 30MHz) in terms of conducted emissions and secondly, at the higher frequencies (above 30MHz) in terms of the radiated emissions. Typical international standards that contain the methods are CISPR 11[5], CISPR 13[6], CISPR 14-1[7], CISPR 15[8], CISPR 22[9]. The reader should be aware that these standards are not the only international standards that can be used. Many local deviations to these methods also exist. These are, however, the most widely used standards for the measurement of the emission of electromagnetic energy. Some of these standards have alternative methods for some of the tests, due to operating manner of the equipment under test. An example of such a method is the "click-rate" test of CISPR 13 [6]. Within these measurement methods the measurement of radiated emissions has, over the years, proven to be the more complex one to do in a reliable and repeatable manner. The test setup is more critical and the test equipment more expensive than for many of the other tests.

In the rest of this chapter four alternative measurement techniques, to the standard OATS radiated emission test will be discussed. That is the use of a Bersier probe, Rogowski coil, bare shielded enclosure and the use of a current probe for common-mode current measurements. Practical current probe, shielded enclosure measurements and a comparison of these results with the reference Open Area Test Site (OATS) measurements described in the above-mentioned standards will be presented. The reason why the shielded enclosure is introduced as a possible alternative measurement technique is that it is relatively easy to build such a chamber. Such a chamber can also assist to shield the equipment from the many ambient signals present in most environments. Variations of the shielded enclosures are also given as alternative test sites in standards such as CISPR 16-1 [13].

It is a well published [10], [11] fact that common mode current is a major threat in achieving EMC compliance of equipment. The Bersier probe, Rogowski coil and current probe are three ways of measuring this common mode current. A brief overview of the first two measurement techniques will be given together with a complete experiment with the current probe. If it can be shown that these methods provide a worst case measurement and that the results are comparable with the OATS measurements then these methods can considered as an alternative pre-compliance method or a method that can be used for in-house testing. The main advantage of using one of these three methods is that the cost of the required test equipment is much lower than that of the traditional methods.

During the various measurements the same setup was used. This setup is discussed in paragraph 5.3.2.

5.3.2 Overview: Bersier probe and Rogowski coil methods

5.3.2.1 Bersier probe

At the time when the idea of testing equipment for radiation of unwanted electromagnetic energy (EMI) was developed, the Bersier probe was developed to test audio and video equipment. The probe was initially used for immunity testing of this equipment. There is however no reason why the application of the probe can not be reversed to measure EMI. This suggestion was also made in [11].

From the circuit of the Bersier probe given in figure 9 it can be seen that the EUT is connected to its ancillary equipment via a series common mode choke. The input also has a 100Ω and a 50Ω resistor in series to ground. This 150Ω matches the 150Ω seen by the other side of the EUT ((75Ω//75Ω)+62.5Ω+50Ω). The choke is inserted to block ambient noise from being injected into the EUT and measurement receiver via the ancillary cables. In this case the measurement receiver is connected to the REC inputs. It should be noted that the receiver is connected between the resistor tap of the probe and earth. This earth is connected to the reference earth plane of the test setup.

Three important facts to notice from this circuit is that the input impedance of the probe is 150Ω, physical components are used and the measurement is done in-line. This can be a problem in some applications as intrusive measurements may be difficult or inconvenient to do at times. The fact that physical components are used will cause a limited frequency range that a specific probe can be used in. One would therefore require a range of Bersier probes to cover a frequency band. A positive note regarding the Bersier probe that can be noted, is that the probe isolates the loop through the probe and thereby it removes uncertainties from different loop sizes from the measurement. From basic antenna theory [11], [14] the E-field at a distance **r** from a half-wave dipole when a maximum current of **Im** flows is given by:

$$|E| = \frac{60 * I_m}{r} \qquad (1)$$

Substituting 30dBuV/m (limit value for radiated emission in CISPR standards below 200MHz) for **E** and 10m (standard CISPR measurement distance) for **r** gives a maximum current, **Im** of 5uA. With this fact in mind one can consider the claims [19] that when less than 5uA common mode current is measured then the radiated field is not likely to exceed 30dBuV at 10m. The aim of using the Bersier probe would therefore be to measure the common mode current to decide whether the EUT will, with a high probability, meet the limits of the CISPR standards. The one fact that one must however also keep in mind is the fact that, although many EMI problems are caused by common mode currents, one does have other scenarios where other factors cause the equipment to fail. Examples of these scenarios are harmonics of clock frequencies, differential mode problems and general oscillations or resonances. It would also be impossible to use the Bersier probe to measure emissions from a cellular telephone for instance. The phone runs off a battery and, since it is an intentional radiator, one would find that the bulk of the radio frequency energy in the phone would be related to the transmit frequency (carrier) and the data on the carrier. In such a case the OATS measurement scenario would probably be the best to use.

Another possibility that one must consider is the possibility of simulation. In equation 1 we have seen that the electric field can be calculated when the common mode current in a radiator is known. In the cellular example above, one should be able to predict a large component of the radiated field if the sum of all the common mode currents on the phone is known. Substituting this current into equation 1 yields one of the major electric field components. The use of simulation will however not be investigated further in this thesis as it is considered a subject on its own.

5.3.2.2 Rogowski coil

Another alternative measurement tool that can be used is the Rogowski coil - see figure 10. This air-cored toroidal pickup coil originated in the power measurement field. It works on the principle that when a current carrying conductor is passed through the probe an electromagnetic field will be generated due to the current in the conductor. This field is then measured by the probe. The main difference between this probe and a normal magnetic current probe is that it has a air core instead of a metal core.

To this there are some positive and negative. The air filled core can handle more power where the normal current clamp will saturate at a point. The current clamp will however allow you to measure smaller signals due to better coupling. The biggest advantage of the Rogowski coil over the Bersier probe is that it is non-intrusive. The Rogowski coil can also easily be manufactured and is much cheaper than an off-the-shelf current clamp.

More information regarding the theory of operation and the design of Rogowski coils can be found in texts such as [11] and [12]. The method of calibration of the Rogowski coil and the method of use is exactly the same as that of the current clamp discussed later. The same type of curve is also found when the amplitude of the transfer impedance is plotted against frequency [11]. This curve varies and may need to be adjusted for optimum performance depending on the application.

According to [11] parameters such as the radius of the loop ($R \propto 1/Zt$), radius of a winding ($r \propto Zt$) and the number of turns ($n \propto 1/Zt$) can be adjusted to obtain different transfer impedances versus frequency curves.

5.3.3 Current probe calibration

For the purposes of this thesis a Rhode & Schwarz EZ-17 current probe was used. A photograph of the probe is given in figure 11. The probe clips around a cable, and has a quoted operating range of 20 Hz -200MHz. When connected to an EMI receiver a voltage is returned, which in turn can be converted to a current. The relationship between this voltage and the current is given by the transfer impedance (Z_t) of the probe. The calibration of the probe entails calculating this transfer impedance from the measured s-parameters of the probe over the frequency band in question.

The EZ-17 is supplied with its calibration fixture. This is done to ensure that more reliable and repeatable results can be obtained. In figure 12 a photograph can be seen of the probe inserted in this fixture. From the photograph it can also be seen that the probe is connected to port 2 of an Automatic Network Analyser (ANA) and that the conductor passing through the probe, which is terminated in a wide-band 50 Ω load, is connected to port 1. The ANA was setup to return, in a text file, the real and imaginary parts of the four s-parameters. These s-parameter files were in turn used as input files to a MATLAB program. From this program a output file was obtained that returned the transfer impedance of the probe. The equations used in the program can be defined as follows. The s-parameters are placed into a matrix, equation 2, where Z_0 = 50Ω and U is given by equation 3. The Z-parameter matrix, equation 4, can then be calculated from equation 5. The transfer impedance at a frequency, f, is then given by equation 6.

$$S(f) = \begin{bmatrix} S_{11}(f) & S_{12}(f) \\ S_{21}(f) & S_{22}(f) \end{bmatrix} \quad (2) \qquad U = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad (3)$$

$$Z(f) = \begin{bmatrix} Z_{11}(f) & Z_{12}(f) \\ Z_{21}(f) & Z_{22}(f) \end{bmatrix} \quad (4)$$

$$Z(f) = Z_0 * ((U - S(f)) * (U + S(f)))^{-1} \quad (5)$$

$$Z_t(f) = \frac{Z_{21}(f)}{(1 + \frac{Z_{22}(f)}{Z_0})} \quad (6)$$

In figure 13 the quoted transfer impedance (from the manufacturer) as well as the measured transfer impedance of the probe is shown. From the graph it can be seen that a small difference exists between the two sets of data. This difference is probably due to the combined effect of a number of factors, which are listed below:

- Differences in test setups with ground planes between original measurements and these measurements. The main problem being that very little information is available regarding the exact test setup of the manufacturer.
- Inaccuracies in the network analyser used - several problems had to be overcome with the instrument, that caused the writer to question some of the parameters. The error was however constant, and exactly the same results were obtained when the calibration process was repeated.
- Mishandling of the current probe, as the probe is approximately 7 years old. The kind of handling that the probe was to subjected to is unknown as it took place before the writer joined the company.

These factors are listed as examples of possible problems. Since the difference between the two sets of data is not considered to be significant, a deeper investigation into the problems was not done. Since calibration data for the probe has now been obtained one can use the probe to make a set of measurements.

5.3.4 Setup of device under test

A parallel wire - figure 14 - that is connected to the noise source was chosen as a test sample. The noise source is a RN512 narrowband noise generator. The generator generates a peak every 5MHz in the band 30MHz and 1GHz. In the 30 - 200MHz band where the measurements were made the amplitude of these peaks are 60dBuV±3dB. Since the generator is battery driven the current measurements does not introduce any laboratory common mode paths, which would give unreliable results.

The wire was placed on a non-conductive table 0.8m above a ground plane. The piece of wire on the table, parallel to the ground plane, was 1.2m long. The parallel wires were terminated in a 51Ω ceramic surface mount resistor. It is recognised that the characteristic impedance of the wire is not terminated by the 51Ω. The common-mode impedance termination of both wires to ground was therefore an open circuit. This fact therefore prevented common mode measurement data from being gathered from this experiment

The reasons for choosing this setup were:

- The setup contains a horizontal (wire lying on top of the table) and vertical component (wire running from tabletop to generator) that represents both types of polarisations that one will find on normal test samples.
- The setup is easy to assemble and can reliably be transferred to another location for the purpose of doing more measurements.
- The setup is well defined and can be reassembled without accidentally changing a critical parameter.
- Only one variable exists in the setup that may significantly influence the measurements. That is the voltage level of the generator`s batteries. To counteract this effect the batteries were charged approximately every two hours. According to their specifications they should last for in excess of four hours without a significant drop in signal output.
- The generator gives out distinct stable frequency peaks that could be measured and re-measured.
- In order not to introduce unnecessary variables during the tests the sample was placed on a table of height as described in CISPR 22 [9]. This setup would be identical to the setup used for the radiated emission test on the OATS.

From figure 14 the reader would notice that three measurement positions exist on the wire These positions are 300mm apart and position 3 is 300mm from the

51Ω resistor. Position 0, at the generator, can be seen in figure 15. During current probe measurements described later in the chapter, measurements were made at the three positions to determine the nature of any position-dependent components - figure 16. The height of the non-conductive table was 0.8m, as per the requirements of standards such as CISPR 22[9].

The reason for using this test setup for the experiments was to create a standard radiator whose characteristics such as differential mode signal current are well defined. Measurements of this standard radiator could then be compared between an OATS and other test methods.

5.3.5 Current probe measurements

A graph depicting the measured values with the current probe, for each position, is given in figure 16. As can be seen from figure 16, good correlation between results has been obtained for all positions except position 0. The reason for this might be coupling between the source and clamp or the different orientation of the probe with respect to the ground plane. One way to obtain a higher confidence level in the measurements, and probably a smaller difference would be to compare the average of five to ten sets of data for each position. This is however not a viable long-term practice as too much time will be spent on the measurements. In a normal laboratory one set of data will be taken, and therefore only one set of data at each position is used in this thesis.

5.3.6 Shielded enclosure: Radiated emission measurements

In CISPR 16-1[13], the international standard that describes the test equipment and environment that is to be used during radiated emission testing alternative test sites (to an OATS) may be used as long as the normalised site attenuation (NSA) of these sites is within ±4dB of the NSA of an OATS. The procedure for performing NSA measurements is described in paragraph 16.6 of CISPR 16-1 [13]. Many companies have found it necessary to consider using alternative test sites. Two main reasons exist for this. Firstly the frequency spectrum is extremely congested between 80MHz and 200MHz due to two-way radios, radio stations and television stations. Secondly the ambient noise floor varies by as much as 10dB at certain frequencies in this band. The reason for this is that the amplitude of the signals mentioned in the first point is not stable. These factors make it extremely difficult to accurately and reliably make measurements on an OATS.

The solution would then be to go into a shielded enclosure for measurements. Although the ambient signals are now not present, or highly attenuated, one finds that other problems exist. One such a problem is the presence of reflections from the chamber walls, and ceiling. The use of a non-absorber lined chamber is not an allowable method for full compliance testing in standards such as CISPR 16-1[13]. The main reason for this is that during comparative testing performed around the world, the measurements were very dependent upon the size of the chamber and the equipment under test. Reliable, accurate measurement could not be made. There are, however, other methods where chamber testing are allowed in CISPR 16-1[13]. The first is where a full-anechoic chamber is used. The main requirement for this chamber is that the measurements made inside the chamber should be traceable to measurements made on an OATS. The reason for the absorbers is to stop reflections from the walls, ceiling and floor from reaching the measurement antenna. These absorbers are, however, very expensive and decreases the usable size of the chamber considerably.

It would therefore be significant if a method can be found for which extensive absorbers would not be required and where the effect of the reflection from the walls, ceiling and floor of the chamber can be compensated for or cancelled out. Such a technique does exit and is allowable in terms of CISPR 16-1[13] for full compliance EMI measurements. This technique utilises a Mode-stirred chamber. The basic principle of operation of this chamber is: If one can excite and scatter the reflections inside the chamber enough then one would be able to obtain a stable, nearly uniform electromagnetic field inside the chamber. Measuring a stable uniform field is simple and it has been shown [15], [16], that such measurements can be made very accurately. Mode-stirred chambers warrants a separate study. For this reason only this short introduction is given in this thesis. More information can be found in texts such as [15] and [16] compiled by the leading world expert in mode stirred chambers, M.O. Hatfield.

Let`s now consider the bare shielded enclosure, to establish how large the problem of reflections are and whether there is any use for the chamber in the pre-compliance test scenario. Therefore if a shielded enclosure (absorber-lined or not) is to be used for radiated measurements then it is necessary to know how the range of results taken inside enclosure, relates to those taken on an OATS. Once this understanding is established, one has the ability to predict whether equipment tested in a chamber would pass or fail when tested on an OATS.

With this knowledge one can then specifically focus on the peaks close to the limit line (prescribed by the relevant product standard, eg. CISPR 22) on the OATS. By doing this one can avoid problems from some of the ambient signals. A more rigorous approach would be to adopt a fully fledged mode stirred chamber [15], [16].

The measurements inside the chamber were done with the antenna and sample 3m apart and the horizontal part of the sample on a non-conductive table 0.8m above a the floor (ground plane). The tests were done along the long axis of the enclosure. The dimensions of the shielded enclosure was 6.0m (length) x 3.6m (width) x 2.44m (height). The antenna, a Chase Bilog antenna, was installed in such a way that the middle beam was 1.2m above the floor. The measurements were done in both the horizontal and vertical polarisations. No height variations were done due to the restrictions that the chamber poses. The measurement results are given in figure 17.

5.3.7 OATS measurements

When comparing results from tests conducted on an OATS with those in a chamber the sample being used can introduce a number of variables. Such variables include additional reflections or at least different reflection patterns, different results if measurements are taken from the one side instead of from the other, and differences in cable routing. The most influential factor on an OATS that influences results is the ambient noise. To try and minimize these factors a simple, repeatable test setup was used. The same setup, as was described for the chamber measurements, was used on the OATS except that the antenna height was varied between 1m and 4m - as required by standards such as CISPR 22[9].

The OATS used for the measurements is located at ITC Services in Pretoria, and was chosen due to its availability and the fact that it has a better ambient noise profile than other sites in Pretoria. From figure 18 it should be clear to the reader that when measurements have to be taken in the region of 100MHz that the noise would overshadow and signal. This is especially true when the fact is considered that the CISPR 22 class B limit is 30dBuV at 100MHz at a test distance of 10m. Other peaks often also cause problems. An example can be seen at 120MHz. In a case where the 3rd, 5th or 7th harmonics of and oscillator in the EUT is significant it could easily overlap with this signal. Therefore the real problem is: According to a standard such as CISPR 16-1 one is required to measure on an OATS that cannot be used over the total frequency band. Alternative methods are also difficult to qualify as their correlation with an OATS must be proven. Some test laboratories have tried to use an approach where they measure the ambient signals prior to the actual test and then subtract these values from the EUT with ambient results. In the writers' opinion this is very inaccurate as this calculation is often only done by subtracting the amplitudes and ignoring the phase. This cannot be done as phase differences would exist between the two sets of data. A secondary problem is that ambient signal levels are not stable, making it difficult to know exactly what level to subtract.

For the test setup described earlier in the chapter the radiated emission results are given in figure 19. The results for the two polarizations have been maximized for height as required by standards such as CISPR 22[9]. Maximizing a measurements for height entails taking measurements with the antenna moved between 1m and 4m above the ground. The maximum measurement for the frequencies close or above to the limit line is then recorded. Each of these frequencies are also measured with the antenna horizontal and vertical. It could therefore happen that the maximum amplitude for one frequency is in the vertical polarization at a height 1m above the ground and for another frequency 2m above the ground in the horizontal polarization. A couple of points should be noted when looking at figure 19:

- The results show emission in excess of the CISPR 22 class A and B limits.
- Large amounts of emission are present in the 100MHz region where significant ambient signals are present.
- The horizontally polarized results are much smoother than the vertically polarized results. For instance at approximately 70MHz the vertically polarized results shows a significant peak. This peak may be due to a reflection from a cable or building or it may be from an intermittent ambient signal.

5.3.8 Discussion

Figure 20, depicting all the results from the previous paragraphs shows some very interesting facts. The first fact to notice is that both the chamber measurements are significantly higher than the other three measurements. The chamber measurements are also much more erratic than the other three measurements. This is purely due to the reflections inside the chamber that cause resonances. The second point to notice is the close proximity of the probe measurements to the two OATS measurements. This especially true of the vertically polarized measurements. The reason for this is probably test setup related as the test setup has a 0.8m vertical wire above a ground plane. The emission from this wire is picked up in the vertical antenna polarization. From the writer`s own experience this is an important point as power cables of desktop equipment, was often found to be a significant source of emission. This would therefore result in an accurate measurement from the cable in a vertical polarization mode.

The main fact that the reader should notice is that it seems possible to predict with a reasonable amount of certainty, that when the measurements taken in a bare chamber are above the CISPR limit then there is very little chance of the equipment passing when tested on a OATS. One fact that is also true is that if a piece of equipment has very low emission levels then the chamber and OATS measurements would be much closer to each other, as the influence of the reflections in the chamber would be significantly reduced. It is possible to mathematically model a bare chamber and the test setup to predict the frequency and size of reflections. Theoretically one could then subtract - with due consideration to real and imaginary components of signals - the measured values from the calculated value to obtain the contribution of the UUT. Practically this would be a tedious exercise as this mathematical model will have to be adjusted for every test setup as cable orientations and the UUT shape and size would differ. This might however be a good subject for further study.

It is at this point where the real benefit of interlaboratory comparisons should become visible to the reader. If an alternative method, such as the chamber measurements, is compared with the standard measurements of a number of laboratories, then in-house testing , to such an alternative method becomes very viable. From the writer`s own experience the operator should be able to say with a large degree of certainty whether a units passes or fails the requirements of a standard such as CISPR 22[9], after a few interlaboratory campaigns. This sample principle can be applied to any other alternative method to prove the method.

5.3.9 Conclusion

In the first part of the chapter we have established some guidelines regarding interlaboratory comparisons. We have also looked at some practical results from an interlaboratory and we have seen how the data can be analysed. The main reason for presenting the interlaboratory comparison introduction and data was to show how a laboratory can use an interlaboratory comparison to establish the accuracy of his methods. This will be especially important to a laboratory using alternative measurement techniques as discussed in the second part of the chapter. As some of the laboratories that took part in the presented interlaboratory comparison realised, it is a very valid means of verifying standard measurement techniques, as well.

In our case one laboratory realised that they have serious problems that need to be addressed and the others got confirmation of how their results compare with that of the other laboratories in South Africa. Some of the laboratories can see that their equipment shows some resonant peaks which they may need to rectify. To the writer it proved that his newly established in-house laboratory could produce results comparable to the other (commercially) established laboratories. This gave him confidence in his methods and it established his credibility with the other commercial laboratories. In this lies the greatest benefit of interlaboratory comparisons.

Although the correlation that was obtained from the results could be much better, this showed many of the participants how to undertake an interlaboratory comparison, and where typical pitfalls can be found. This by itself is very important information.

In the second part of this chapter we have seen that the OATS measurements are considered to be the reference measurements. We have also seen that a significant ambient noise problem exit when using an OATS. From this a need exists to find suitable alternative measurement techniques. However, before such techniques can be qualified a representative test setup has to be found that is suitable for both the alternative methods and the reference OATS measurements. For instance, a common impedance connection was required between the parallel wires of the test setup and the ground plane. This would have allowed common mode current measurements that could be compared with radiated emission measurements. From the one, suggested alternative measure ment possibility, the bare shielded enclosure, it was clear that it is difficult to obtain results that correlates well - within ±4dB as per CISPR 16-1 - with the OATS measurements, due to reflections. During the measurements we have also noted a number of problems that an operator is likely to experience. Knowing about these problems he can compensate for them.

5.3.10 EMC Measurement figures

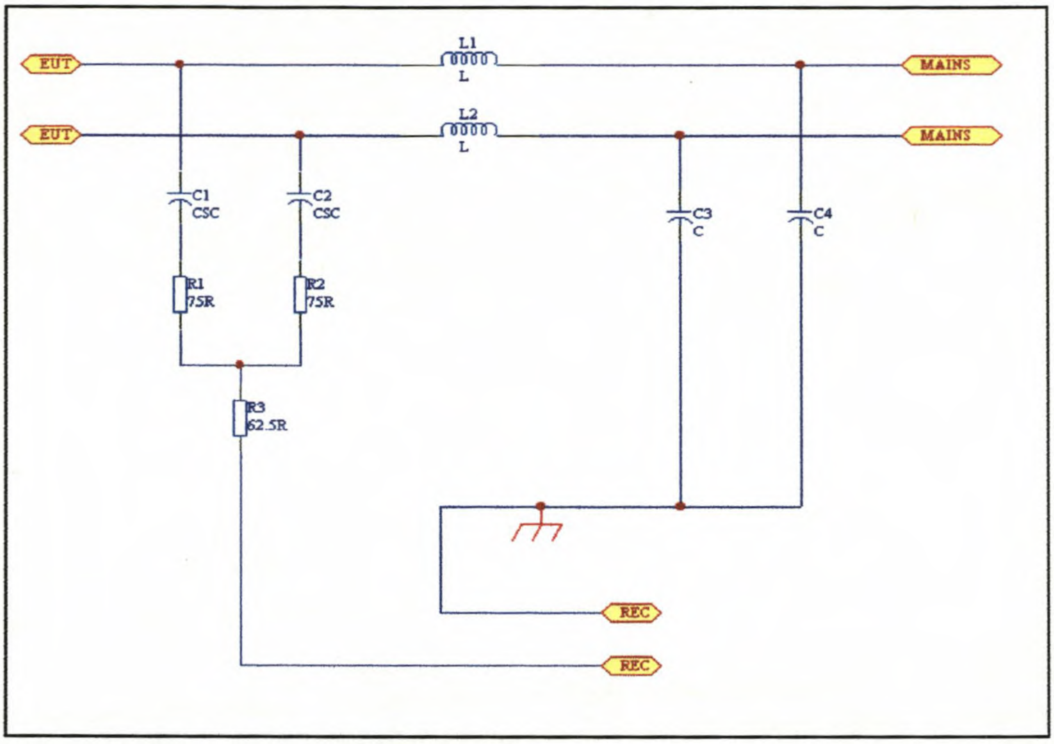

Figure 9: Bersier probe circuit

Figure 10: A typical Rogowski coil

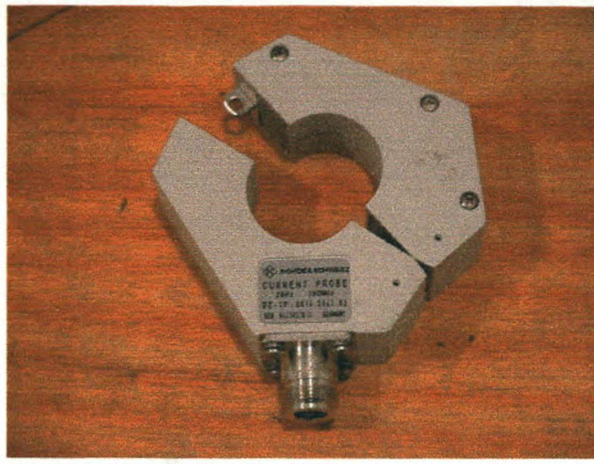

Figure 11: EZ-17 current probe

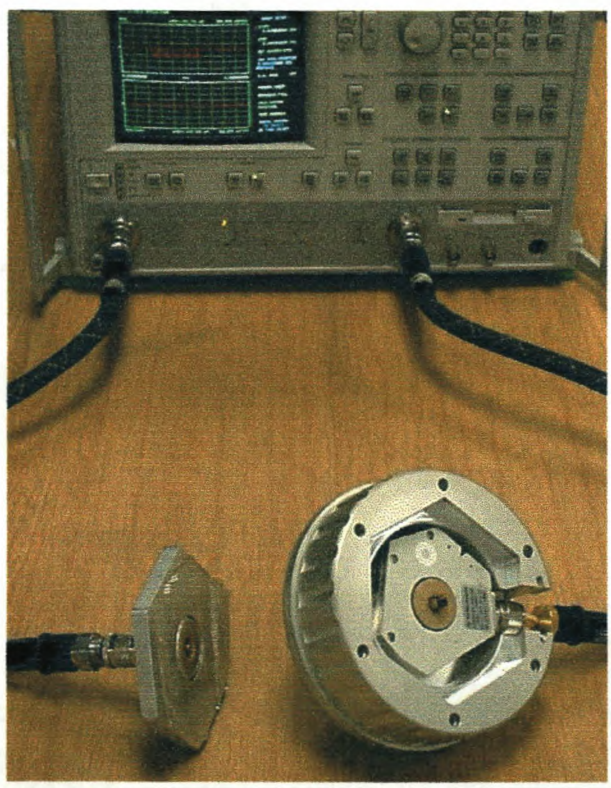

Figure 12: EZ-17 in its calibration kit

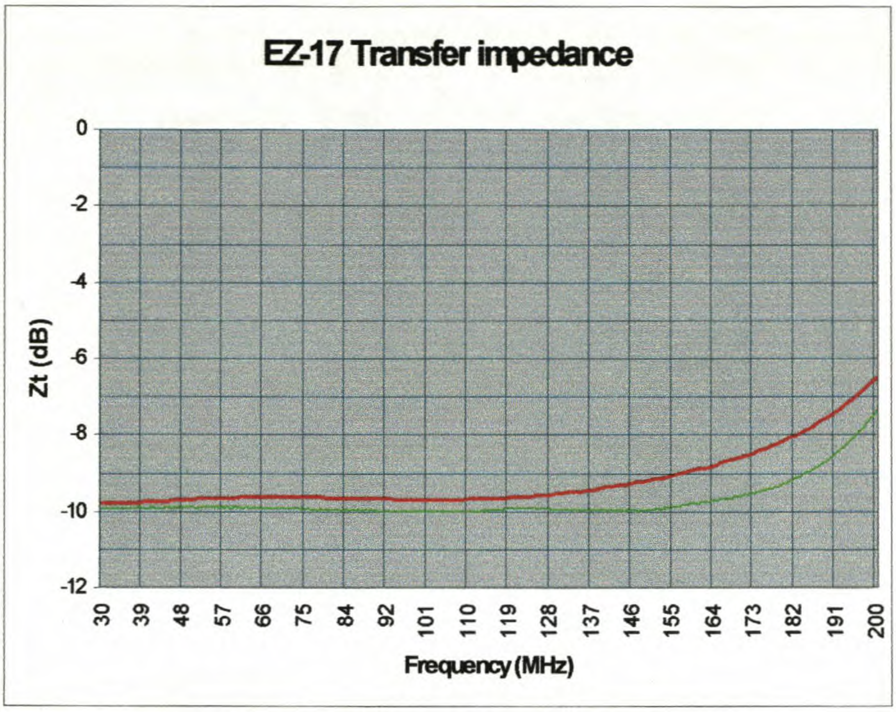

Figure 13: Measured probe data versus manufacturer`s data

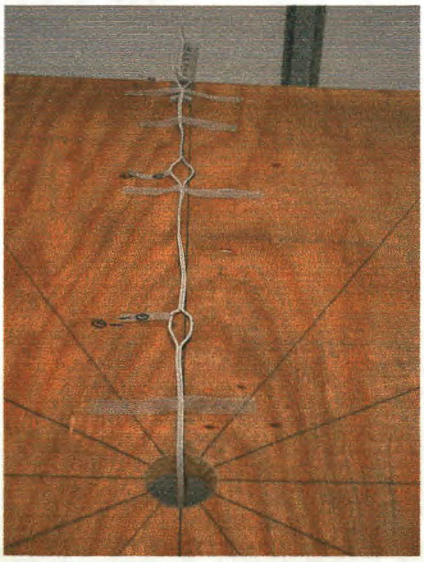

Figure 14: Test setup for current probe measurements.

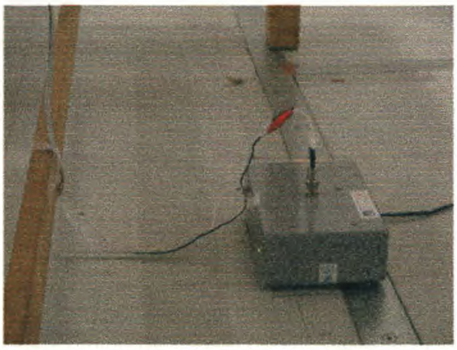

Figure 15: Generator used for current probe measurements

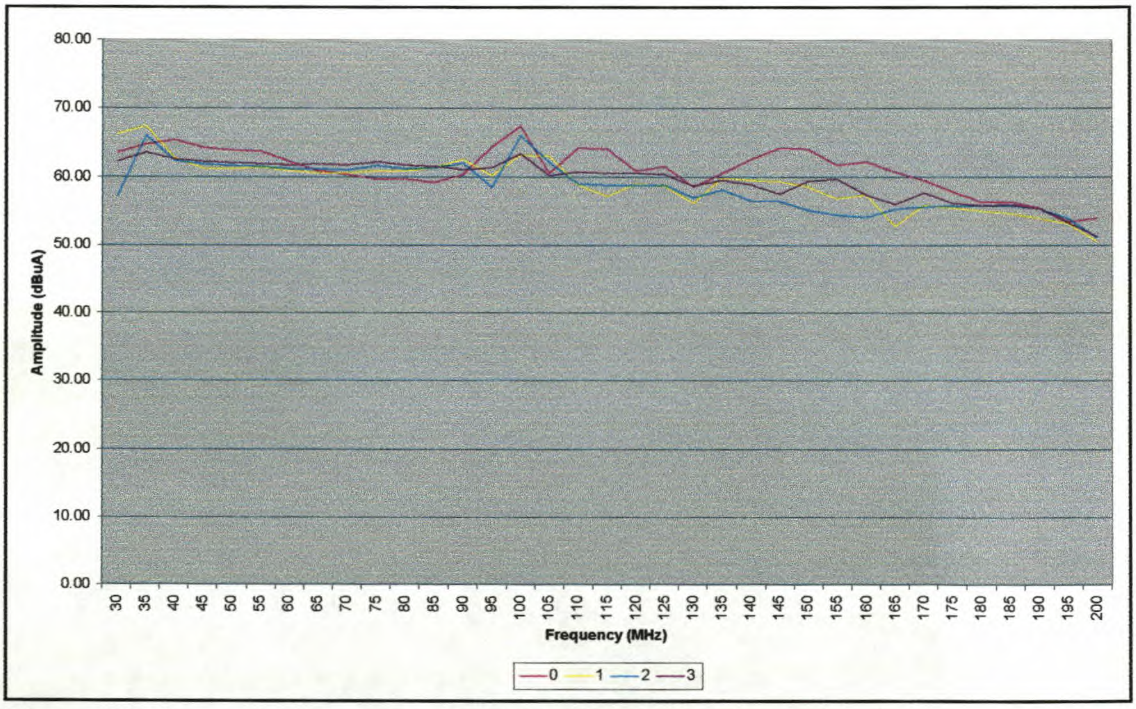

Figure 16: Current probe measurement: Position dependancy

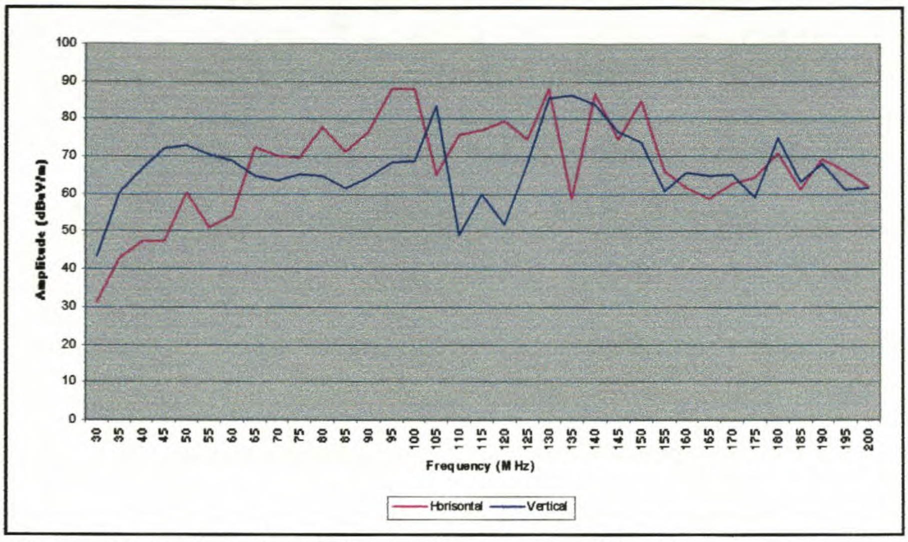

Figure 17: Radiated emission measurements: Chamber

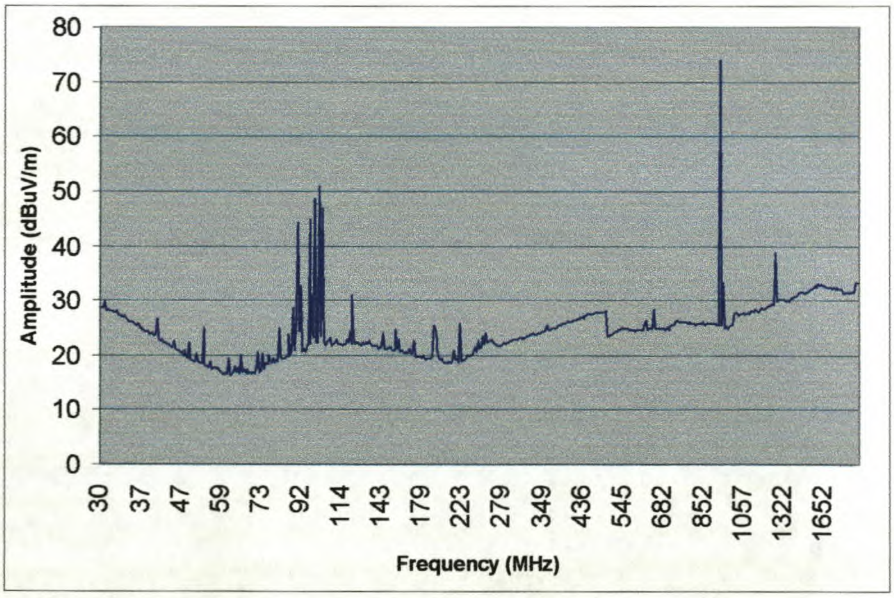

Figure 18: OATS Ambient measurements

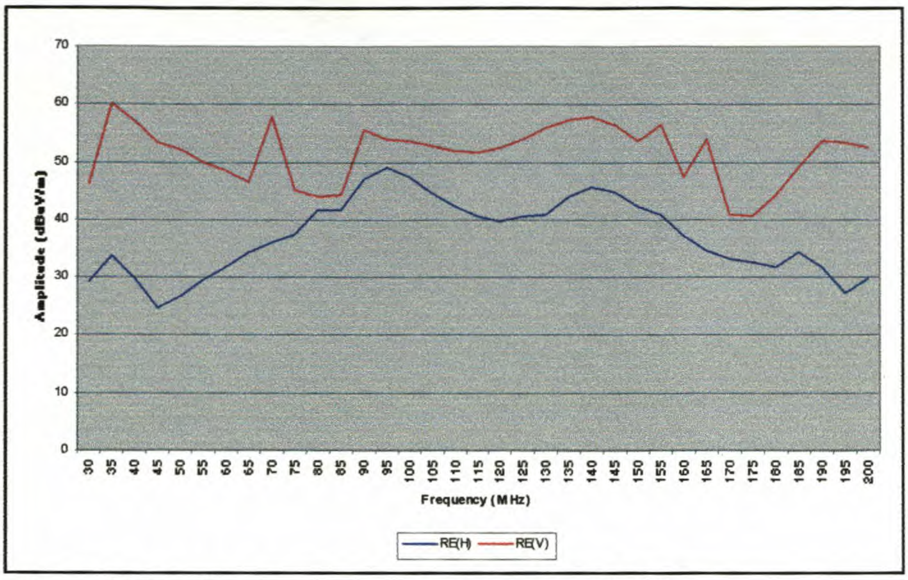

Figure 19: Radiated emission measurements: OATS

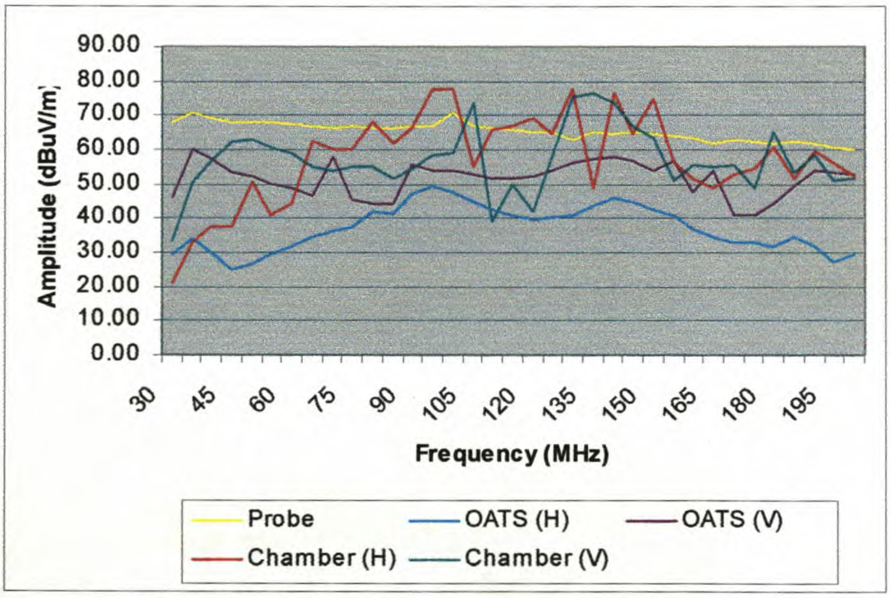

Figure 20: Consolidated measurement results

Notes:

1. The probe measurements were converted to field strength using equation 1. This is an approximation as the current in equation 1 is supposed to be the common mode current. As explained earlier, common mode current were not measured, and the conversion is therefore only for illustration purposes.
2. The unit of measure for the probe measurement was dBuV and for the OATS measurements dBuV/m @ 10m and for the Chamber measurements dBuV/m @ 3m converted to 10m with the following ratio:

$$dB_{10m} = 20 * \frac{Log_{10}(10)}{Log_{10}(3)}$$

5.4 References

[1] "EMC Interlaboratory Comparison 1 - Light ballast", Conducted Emission, SANAS, 1999

[2] "EMC Interlaboratory Comparison 2a - Narrowband sample", Conducted Emission, SANAS, 2000

[3] "EMC Interlaboratory Comparison 2b - Broadband sample", Conducted Emission, SANAS, 2000

[4] "An advanced reliability function for data comparisons", AJM Martin, AP Duffy, MS Woolfson, TM Benson, Satcam 2000, Somerset-West South Africa, October 2000

[5] "CISPR 11: Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 1999

[6] "CISPR 13: Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 2001

[7] "CISPR 14-1: Electromagnetic compatibility - Requirements for household appliances , electric tools and similar apparatus - Part 1: Emission", International Electrotechnical Commission, Geneva, 2000

[8] "CISPR 15: Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment", International Electrotechnical Commission, Geneva, 2000

[9] "CISPR 22: Information technology equipment - radio disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 1997.

[10] "EMC for product designers - Meeting the European EMC Directive", Tim Williams, Second edition, 1996, ISBN: 07506 24663

[11] "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", JB Maree, University of Stellenbosch, December 1998

[12] "Machinable Rogowski coil, design and calibration", IEEE Transactions Instrumentation and Measurement, vol 45, no 2, pp 511-515, April 1996.

[13] "CISPR 16-1 including Amendment 1: Radio disturbance and immunity measuring apparatus and methods. Part 1: Radio disturbance and immunity measuring apparatus", International Electrotechnical Commission, Geneva, 1997

[14] "Electromagnetic concepts and applications", Stanley V. Marshall, Gabriel G. Skitek, Third edition, Prentice-Hall, 1990, ISBN: 013 247 8420

[15] "Reverberation characteristics of a large welded steel shielded enclosures", Michael o. Hatfield, Gustav J. Freyer, Michael B. Slocum, IEEE Symposium on electromagnetic compatibility, August 1997

[16] "Reverberation chamber theory/experiment short course", Naval Surface warfare center, Dahlgren, USA

[17] "Assessment of Uncertainties of Measurement in calibration and testing laboratories", Ron Cook, NATA, Australia, 1999

[18] "ILAC G17-2002: Introducing the concept of uncertainty of Measurement in Testing, in association with the application of standard ISO/IEC 17025", ILAC, Australia, 2002

[19] "Electromagnetic compatibility", Jasper Goedbloed, Prentice Hall, 1990, ISBN: 013-249293-8

Chapter 6 - Proposed EMC framework

6.1 Introduction

Now that we have considered what philosophy other countries applied when they created their EMC legislation (Chapter 2), with what standards they require compliance (Chapter 2), how the probability of obtaining compliance through design can be increased (Chapter 3 and 4) and what testing options we have (Chapter 5), we can consider some options for South Africa. As was mentioned earlier, South Africa`s legislation is very old and does not cater for modern equipment and the modern certification environment. The main need for updating the legislation therefore lies in the fact that we need to align South Africa`s legislation with that of the rest of the world. It is necessary to consider that the South African market is unique in the respect that it is much smaller - due to our smaller economy - than markets such as Europe, USA and Australia. In addition only portions of our market is exposed to and understand the latest technology, where this is not the case in the above mentioned markets. Certain unique considerations, and special provisions would therefore be appropriate.

6.2 Standards

Almost all the legislated EMC standards in the world today have their origin in the international standards developed and published by international organisations such as the IEC and ETSI. In terms of the GATT agreement, of which South Africa is a signatory, one may not restrict trade due to compulsory standards that are legislated. Signatories of this agreement are encouraged to make it as easy as possible for importers to gain approval for their products in the country, without compromising the safety and EMC of the products. The easiest way of doing this is to follow most other countries in the world in terms of EMC legislation and base our standards on the same international standards.

We can achieve this in one of three ways. Firstly by publishing requirements, based on the EMC standards, in the law for products. This is basically what South Africa has at this stage with the Radio Regulations Act. The problem with this approach would be that requirements will become outdated quickly because it takes time to obtain parliamentary approval for new laws. One also runs the risk that local legislation may start to deviate from international legislation, since two different bodies are responsible for the two sets of standards. The second way would be to write our own standards based on the IEC standards.

This is also not a good idea as once again two parallel development paths exist, which may result in diverging standards. The third and best option in the writer`s opinion is that South Africa declares the applicable international standards as compulsory after they have been adopted, without modification, as South African standards. South Africa has the option, which we should use, to add national deviations to such standards where required. The national deviations are used to cater for specific conditions in the country that they are applicable to, and is done through our involvement in the committees that write the international standards - refer to chapter 1.

Adopting international standards as national standards is not a new approach anymore as it has been used in many countries in the world, even in South Africa. Where South Africa is however still lacking is that many of these standards that were adopted as national standards have not been made compulsory through law. Before we can list any standards we need to consider the approval structure and specific requirements of each class of equipment.

6.3 Approval structure

When one considers the South African market then one quickly realises that it is relatively small and very price sensitive. It would therefore not be beneficial to introduce a very expensive approval process. The approval structure proposed below is therefore a combination of a number of structures used in other countries.

6.3.1 General structure

The proposed structure is based on the following five main principles:

6.3.1.1 *EMC Compliance is compulsory for all products manufactured in South Africa or imported into South Africa.*

No exceptions to this principle should be allowed. The onus is therefore on the manufacturer or importer to ensure that his product is compliant prior to placing it on the market. It will also ensure that for all products, without exception, retailers would know that they need to ask for compliance. One can use one of two approaches regarding policing the principle. The first way is to allow retailers to place a product on the market and when the inspection authority checks then they have to prove the compliance of the product. This is how South Africa`s current legislation is written. The onus is therefore on the policing authority to prove the non-compliance of the product. The second option is to explicitly require that a manufacturer or importer have proof available of the compliance of the product prior to it being offered for sale in the country. Overall this approach will ensure that the task of the policing body would be easier and less expensive.

6.3.1.2 *A product shall be assumed to be non-compliant until proof of compliance is produced.*

This principle would force manufacturers and importers to obtain approval for the product before it is sold to retailers. The policing authorities would also be able to remove a product from the shelves immediately if proof of compliance is not available.

6.3.1.3 *A product shall be assumed to be in compliance with the requirements only when a complete test report, showing compliance with all the requirements, is available from a test facility recognised by the South African National Accreditation Service (SANAS). Exceptions to this principle are envisaged for some products, as shown below.*

This principle is suggested to be applied as a basic principle to all products. Provision should however be made for some deviations. For instance, is it really necessary to test a kettle for radiated susceptibility? Probably not. However, if a dispute arises then at least the basic requirements listed below should be met.

6.3.1.4 *If a specific product standard exist for a product then compliance is verified according to the requirements contained in this standard.*
Where a specific product standard exists, compliance has to be tested to that standard. Examples of such standards are: EMI: CISPR 22 - Information technology equipment; EMC and safety: IEC 60601: Medical equipment.

6.3.1.5 *Where no specific product standard exists the basic requirements listed below shall at least met.*
Since products are developed much faster than standards are developed it often happens that an appropriate standard is not available. It can also happen that equipment falls into more than one category, making testing extremely difficult. In cases such as these, this principle would be applied.

6.3.2 Basic requirements

6.3.2.1 No equipment should generate emissions that adversely affect the operation of other equipment in the intended environment of use. Compliance with this requirement is verified by testing to all the relevant group 1 standards listed by the legislating authority.
6.3.2.2 If the safety of users, or people in general, depends on the ability of the device under test to withstand electromagnetic fields in its intended environment of use then the device shall comply with all the relevant listed group 2 standards, see below.
6.3.2.3 In general the device under test should be capable of operating safely and according to its intended operating parameters, in its intended operation environment. If the policing authority of EMC legislation[2] deems it necessary to

2 At the time of publication of this thesis this authority in South Africa was ICASA (Independent Communications Authority of South Africa)

enforce additional requirements to ensure safe and correct operation of equipment then they should have the procedures and abilities to do so.

6.3.3 Proposed standard groups[3]

The groups below have been formed by grouping emission related standards in one group and susceptibility related standards in the second group. The first 8 standards listed for group 1 are standards for specific product groups, e.g. CISPR 22 - Information Technology Equipment.

The second group of standards in group 1 are generic standards for harmonic emission. Group 2 contains only generic standards for susceptibility testing.

6.3.3.1 Group 1

- ✓ CISPR 11, CISPR 12, CISPR 13, CISPR 14-1, CISPR 15, CISPR 22, CISPR 25, CISPR 61000-6-3
- ✓ IEC 61000-3-2, IEC 61000-3-3

6.3.3.2 Group 2

- ✓ CISPR 14-2, CISPR 20, CISPR 24
- ✓ IEC 61000-4-2, IEC 61000-4-3, IEC 61000-4-4, IEC 61000-4-5, IEC 61000-4-6, IEC 61000-4-8, IEC 61000-4-9, IEC 61000-4-10, IEC 61000-4-12

---

3 The lists given in this paragraph are not intended to be complete lists. The international versions of the standards are listed, as all of the standards have not been adopted as South African standards yet. The final legislation will however refer to the South African standards.

6.3.4 Special requirements for medical devices

Medical devices, even those that are not used in operating theatres or those implanted or connected to patients, can easily cause the death of a patient. It is therefore important to ensure that all medical devices in the field comply with the basic requirements above. In an attempt to achieve this, it would be recommended that a manufacturer of medical devices be required to have a quality system compliant with the relevant parts of ISO 9001, or an equivalent standard (e.g. EN45001) in place. This requirement would also apply to devices used without the supervision of a medical practitioner. This requirement is in addition to those given in the relevant EMC requirements and/or product standards.

6.3.5 Special requirements for telecommunication equipment

Telecommunication equipment is critical equipment in most countries in the world. It is therefore important to ensure that these devices comply with the basic requirements above. This is also true since telecommunication equipment is very much exposed to natural phenomena such as lightning. In an attempt to achieve this, it would be recommended that a manufacturer of telecommunication equipment be required to have a quality system compliant with the relevant parts of ISO 9001, or an equivalent standard (e.g. EN45001), in place. This requirement is in addition to those given in the relevant EMC requirements and/or product standards.

6.3.6 Exceptions to the general rules

In some cases, that we will define now, it may be acceptable if equipment is tested according to other methods than those listed above. In order to understand why one can allow this we will draw the following analogy. Let us consider the structure of calibration standards and laboratories around the world. A laboratory in, for instance South Africa, would calibrate a customer`s voltmeter against his laboratory standard. This standard may be for instance, another voltmeter or a reference power supply. His laboratory standard is calibrated at regular intervals against the national standard. The national standard is in turn verified according to international standards. In this manner the calibration of the customer`s voltmeter is traceable to at least the national standard of the country. This national standard is at least of the same accuracy but most of the time more accurate than the voltmeter calibrated. If we now consider the case of radiated emission. The international standard is the OATS test, prescribed by CISPR 16-1. If you draw an analogy between the traceability example above and the OATS versus an alternative measurement method then the alternative method should compare well with the OATS measurement. The question can now be asked: How well should it compare? This answer can also be found in CISPR 16-1. According to CISPR 16-1, any method used should still be withing the accuracy limits given for the OATS measurements.

Therefore if a manufacturer uses an alternative measurement such as a current clamp or Rogowski coil and he can relate his measurements to OATS measurements of the same sample, then he should be allowed to use this alternative method to prove compliance. Examples of these alternative methods were discussed in chapter 5.

It is therefore proposed that a manufacturer be allowed to use alternative methods provided that:

- ✓ It is not used to prove compliance for products listed in 4.3.3 and 4.3.4, where public safety will be jeopardised by EMC failures.
- ✓ If any dispute arises regarding the results then the prescribed standards should be followed to prove compliance.
- ✓ The alternative method should have been compared with the reference measurement in the prescribed standard and proof of this should be available.
- ✓ The alternative method should produce measurements with the same degree of accuracy required by the reference measurement and proof of this should be available.
- ✓ The use of the alternative method should be registered at the policing authority.

6.4 Introduction of the scheme into the country

One of the biggest problems, in the writers' opinion with the current legislation in South Africa is that many retailers and manufacturers have no idea how the safety legislation operates. This opinion emanates from four years' experience that the writer had working in a testing and certification environment. Therefore in order for a new scheme like this to have the desired affect and be accepted by the industry it will have to be well marketed.

The starting point of such marketing should be at the technical committees in the country. Examples of such committees are TC 77, TC74, TC73. Through the international liaisons of these committees one could also make presentations at international committees. Another important place where marketing should take place is at local conferences such as Africon and SATNAC. Through SANAS workshops one can also reach a different but very important part of the industry, the testing and calibration industry.

A body that would also be important to provide with the necessary information is the Department of Customs and Excise.

6.5 Conclusion

We have seen from chapter 2 and this chapter that South African legislation is currently lacking as it is outdated and there is no means of constantly updating the standards. We have also seen how South African legislation can be aligned with international standards by rather adopting international standards as South African instead of writing our own.

As mentioned at the start of this chapter South Africa has all the facilities in place to adopt international standards. The principle of using such adopted standards in South African legislation is also an accepted practice by industry and government departments - South Africa`s safety legislation is based upon this exact principle.

The only problem is that not all the necessary standards have been adopted and that no legislation exist to make compliance with these EMC standards compulsory.

Through the rest of the chapter we have seen how the basis of such legislation should look. In this legislation we have covered grouping of standards, grouping of products, alternative methods for "simple" equipment and additional requirements such as an ISO 9000 compliant quality system in the factory. We have also briefly touched on the need for introducing such a scheme to industry through the correct forums.. We have also started to address issues surround alternative test methods and methods for establishing credibility (Chapter 5) that can be used in the case of less critical products (6.3.6).

Chapter 7 - Conclusion

Over the six chapters of this thesis we have seen that there is much more to legislating EMC standards in a country that just writing legislation. We have seen that different regions in the world have different requirements. We have however also seen that the basis of most of these requirements are international standards. In addition to standards it was shown that one must consider the industry in the country where the legislation will be implemented. If the industry cannot support the legislation then it will not be successful. Consideration must also be given to trade and trade agreements such as the GATT agreement, as the country`s legislation may not be seen as to restrict trade.

We have also looked at EMC management plans as a means of ensuring that products comply by design and that the minimum amount of testing and retesting would be required. The risk of EMC failure is hereby minimized.

Thirdly we have looked at means of testing products. These methods included the standard methods as well as some alternatives. In a country like South Africa that has a relatively small industry alternative methods needs to be investigated to allow the small business to prove the compliance of its products.

We have lastly made some suggestions, taken from the legislation of other countries regarding legislation for South Africa. The proposals were made in such a way that the small business can also buy in to the legislation and compliance process, without jeopardizing the correct and safe operation of other systems such as telecommunication and medical. These systems and equipment operating close to them obviously has more stringent requirements.

As mentioned in paragraph 6.4 of the thesis, serious consideration would also have to be given to the introduction of the new legislation into the country. Without proper introduction the policing of the legislation would become more difficult and the industry would be less willing to comply.

Appendix A - OATS measurement photographs

Figure 1: OATS side view, 10 m test distance

Figure 2: OATS, from behind antenna, 10m test distance

Figure 3: OATS, Unit under test

Figure 4: OATS, Perspective view

An EMC Framework for South Africa

by

Francois A Venter

Thesis presented in fulfilment of the requirements for the degree of MSc Ing (Elektronies) at the University of Stellenbosch

March 2003

Supervisor: Prof. H.C. Reader

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

------------------------   2003-02-19

FA Venter   Date

Abstract

This thesis pursues the establishment of a new Electromagnetic Compatibility (EMC) framework for South Africa. The aim of this framework is to ensure that the user is protected from sub-standard products as well as to ensure that products such as medical devices operate safely within the electromagnetic environment.

The thesis presents a basic introduction into EMC and then overviews current worldwide legislation. After this information is studied a new framework is proposed for South Africa. This framework covers all areas of industry and the standards with which one has to comply as well as the procedure for demonstrating the compliance of the product.

In order to establish the basis whereby smaller manufacturers can show compliance by means of in-house testing, a method for establishing measurement accuracy is also presented. In conclusion some standard measurements and an overview of some alternative measurement techniques are presented.

Opsomming

Hierdie tesis ondersoek en stel 'n nuwe Elektromagnetiese Versoenbaarheids (EMV) raamwerk voor vir Suid Africa. Die doel van die raamwerk is om 'n eenvormige stelsel daar te stel waarteen produkte getoets kan word om die publiek teen onder standaard produkte te beskerm. In sekere gevalle help die raamwerk ook om te verseker dat produkte soos mediese toerusting veilig werk in die Elektromagnetiese omgewing.

Die tesis lê 'n basiese inleiding oor EMV voor en gee 'n opsomming van huidige wêreldwye wetgewing as inleiding tot 'n raamwerk vir Suid Afrika. Nadat die inligting bestudeer is, word 'n nuwe raamwerk vir Suid Afrika voorgestel. Die raamwerk dek die hele elektroniese industrie, spesifiseer die toepaslike standaarde en voorsien die metodes hoe voldoenning aan die vereistes bewys moet word.

Die tesis verskaf ook riglyne hoe kleiner vervaardigers kan bewys dat hulle voldoen aan die vereistes, deur in-huis toetsing. Tesame met 'n oorsig oor basiese meet tegnieke en alternatiewe tegnieke word 'n metode daar gestel vir sulke vervaardigers om hul metings se akuraatheid te bewys.

Acknowledgements

- Prof Howard Reader (University of Stellenbosch) : For making it possible for me to complete the degree, despite me being in Pretoria and him being in Stellenbosch. All his support and advice is also appreciated.
- Johan Pieters, John Wood (Alcatel Altech Telecoms) : Firstly for giving me the opportunity to enroll for the degree and for the financial support that accompanies such a commitment. Secondly for their continued support, the use of company facilities and the opportunity to work on this thesis during work hours.
- Carol Gibson (Alcatel Altech Telecoms) : For the time that she spent, without reward, checking the grammar and spelling in this document.
- Suzan van der Meulen (Omnigo) : For the time that she spent, without reward, checking the grammar and spelling in this document.
- Hans Joubert (ITC Services) : For the use, at no cost, of the Open Area Test Site at the ITC's premises in Pretoria.
- Thank you to the examining panel for their constructive remarks that led to the completion of the thesis.

Table of contents

Chapter 1 - Introduction

1.1 Introduction

As the 21st century dawns one notices that most developed countries in the world have legislation in place specifying some EMC requirements for products sold and used in the country. The legislation of the electromagnetic spectrum has become necessary due to the increasing number of electrical products that are being manufactured. A drastic decrease in the size of components, products and level of control signals over the last few years, coupled with a drastic increase in product complexity, make products potentially more vulnerable to EMC problems [1]. An increase in the operating frequency of products has also increased the likely emission frequency range. For these reasons it has become important to investigate stricter control of the EMC performance of products. There is however one pitfall that one must guard against and that is to ensure that one does not over regulate EMC. It is therefore important to ensure that the right type of legislation is implemented and that this legislation is in line with legislation in other countries and trade partners. It is also not beneficial to have legislation that restricts trade. A proposal for discussion, of new legislation is presented is chapter 6. This proposal is presented in terms of an EMC framework, covering, in addition to the legislative issues, implementation (chapter 6), testing/compliance (chapters 3, 4 and 5) and industry/public awareness (chapter 6) considerations.

The process of legislating the amount of electromagnetic energy that may be emitted by electrical products in certain frequency bands, called emissions, started in 1952 in South Africa[2]. At the time the South African Post Office, under the signature of the Postmaster General, published the first act in the Government Gazette often referred to as the Radio Regulations Act - Hereafter referred to as The Act. Between this date and 1996 The Act was amended a number of times. Unfortunately these amendments have not been sufficient if one compares South Africa's current legislation with other developed country's. The first few versions of The Act specified limits for the allowable emissions without specifying any test methods. These early versions of The Act also did not cater for different types of products and their special considerations and was therefore not always very easy to use. After South Africa took up its rightful place in the international community after the 1994 elections some of these problems were solved in that the new versions of international standards were used for test method references. All of the initial problems have however not been solved and it is therefore necessary to update South Africa's legislation again to bring it in line with world trends.

Another country or region's legislation cannot just be copied, as South Africa has unique requirements in terms of its population, economy, testing capabilities, environmental effects and equipment used in the country. One may therefore need to adjust some requirements to make them fit in with the South African environment.

This thesis was published in March 2003 and it should therefore be noted that references to standards and authorities can only be considered accurate up to this date.

1.2 International, regional standards and Standards Bodies

Any person that is confronted with the task of finding a technical standard in a standards library or on the Internet, realises quickly that hundreds of these standards exist in the world. The question is therefore often asked: "How do I decide which standards to use or where to look?". In the following chapters of this thesis, reference will be made to a number of standards bodies and series of standards and even to some specific standards. It is therefore necessary to consider who these bodies are.

It is firstly important to know that there are mainly three groups of standards bodies, namely International, Regional and Local. Examples of these are given in figure 1. In the first row, examples of three international standards bodies can be seen: ISO (International Organisation for Standardisation), IEC (International Electrotechnical Commission) [3] and ITU (International Telecommunication Union).Beneath these bodies one finds the regional standards bodies such as

CENELEC (European Committee for Electrotechnical Standardisation) and ETSI (European Telecommunications Standards Institute). These two bodies are responsible for standardisation within the European union. The latter being responsible specifically for Telecommunication standards in the European union.

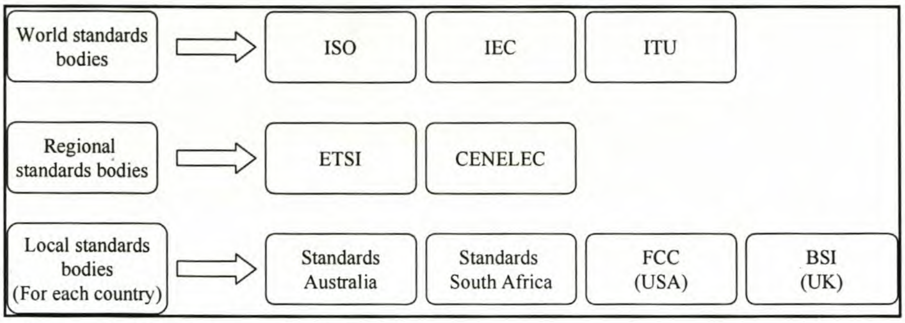

Figure 1: World standards bodies

The last level of standards bodies are national standards bodies such as Standards Australia, Standards South Africa (previously SABS), FCC (Federal Communication Commission) in the USA and British Standardisation Institute. These local bodies are responsible for national standards in their respective countries. Each of the bodies mentioned above have their own internal structure of technical and sub-committees responsible for writing and maintaining standards.

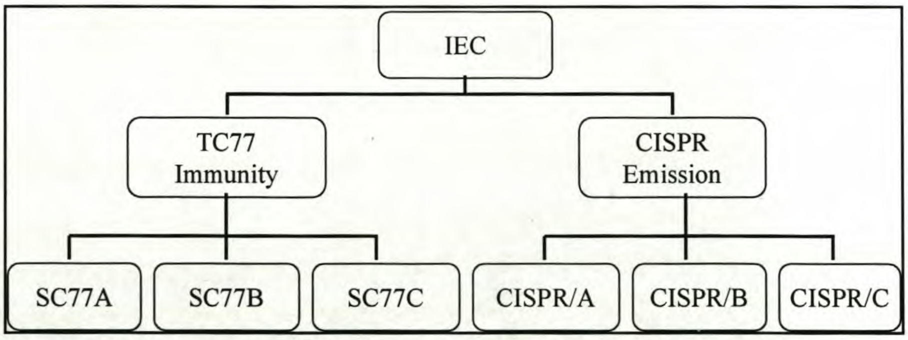

Figure 2: Examples of IEC Technical & sub-committees

Figure 2 gives examples of some of the technical committees of the IEC pertinent to this thesis . In the IEC, two EMC related technical committees exist, namely TC 77 and CISPR (International Special Committee on Radio Interference). As can be seen from figure 2 each of these committees have sub-committees under them looking into specific areas such as SC77A which is tasked with low frequency phenomena and CISPR SC/A which is tasked with Radio-interference Measurements and Statistical Methods. Within the IEC, TC 77 is responsible for the existence of the IEC 61000-series of standards and CISPR for the CISPR-series of standards. The IEC 61000-series of standards contains mainly immunity requirements such as lightning surges and electrostatic discharges, where the CISPR-series of standards contains mainly Electromagnetic Interference requirements (EMI).

By co-operation between national standards bodies such as the Standards South Africa and International bodies such as the IEC, international standards are being written and maintained. Later in this thesis we will consider some of these standards in more detail.

1.3 General EMC Background

Before legislation can be considered Electromagnetic Compatibility (EMC) should be explained. EMC is firstly, in most cases, a term used to group a number of Electromagnetic phenomena with which a product has to comply. Different EMC phenomena that can be encountered will now be discussed. Possible sources and possible weak points of some equipment for these phenomena will also be considered.

In ensuring that a product meets EMC requirements one needs to comply with requirements that can be divided into two basic categories, i.e. Emissions and Susceptibility. Emission, in this case, can be described as unwanted electromagnetic energy that is transmitted from a product to a victim. The energy can be transmitted in one of three ways, namely: radiated (loosely referred to as coupling through the air), conducted (along a signal or power cable) or some combination of the two. Although radiated emission can be generated from any electrical source, it is known that the most common sources are oscillators, switching circuits and high current tracks or wires. Conducted emission can also originate from any source. The most common source is switching circuits such as switching power supplies. Requirements also exist for conducted emission resulting from the harmonics of the power frequency.

In general, susceptibility can be described as the inverse of emission. When testing for susceptibility, an attempt is made to verify whether the equipment can withstand the likely emissions from other sources. Common susceptibility sources that are tested for are lightning surges, transients pulses, mains voltage interruptions, radiated and conducted electromagnetic fields as well as electrostatic discharges. When the requirements for an environment and product are defined, one must consider the likely sources and recipients of emission in close proximity of the equipment in question as well as the likely susceptibility levels of this equipment. Therefore if equipment operates close to or on the same supply network as circuits where high current, power frequency switching occurs then one may need to consider mains harmonic interference testing.

Solving EMC problems is unfortunately not done by looking up the applicable phenomena in a table and implementing certain quick measures. One can predict the likely sources of emission or areas of susceptibility in most cases. It does however often happen that unexpected additional sources exist. It has however been proven [8] many times that most EMC problems can be avoided by applying some good basic design rules. References [1], [6], [7] and [8] are four of a number of publications that elaborate on this subject. The question can now rightly be asked: "When do we need to consider the EMC requirements of a system?".

1.4 EMC Management plans

Many companies have realised by now that testing products for EMC can be very time consuming and expensive. One must therefore ensure that one makes optimal use of the money available for testing. Most products that fail catastrophically do so because no or little consideration was given to good EMC practice during the design and/or construction of the product. Since electromagnetic radiation cannot be seen, people may not realise how serious the problems can be. It is therefore necessary to create a general awareness of EMC in a company. This fact is underlined in [1]. Once this foundation has been laid one can more easily implement changes to ensure EMC compliance.

It is important to introduce a management system for EMC since uncontrolled changes for EMC can prove unnecessary and very costly to the price of the product.

Changes must also be introduced at the correct stage of the product development cycle. For instance one must introduce PCB layout changes as early in the development cycle as possible, where shielding changes and filtering, provided provision has been made for them, can be introduced at a later stage. It has been shown in [1], [4] and [5] that the designer has more measures available when the product is being designed compared to when it is in production. For instance if the oscillator is noisy then he might have to change to a different oscillator that might not be pin compatible or he might have to add filtering, both options necessitating a PCB change. As may be envisaged, this can be fatal for the future success of a product that is already in production. To make these changes during the design phase would be trivial and cost virtually nothing compared to the expensive nature of the other option. Figure 3 gives a graphical representation of these facts.

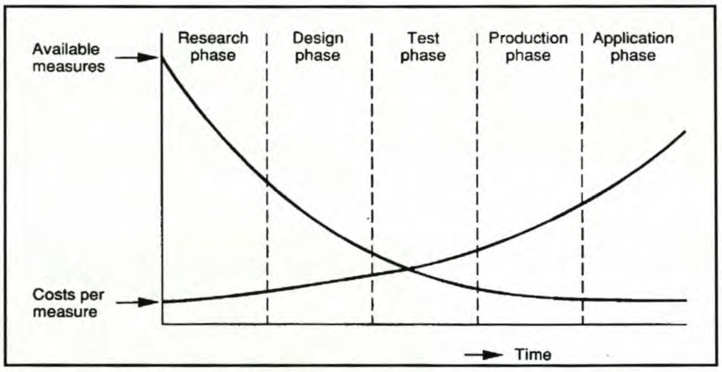

Figure 3: EMC measures & cost vs. time

As can be seen in [4] EMC consideration must be included in every stage of the product`s development cycle. There are considerations such as the environment within which the product has to operate ~~in~~, that must be included in the feasibility stage. In the design phase for instance more attention to decoupling, filtering and segregation of circuits has to be considered. This philosophy can be applied to all of the other phases of the project[4].

1.5 Overview of thesis

The thesis consist of seven chapters. This chapter gives an introduction to EMC, EMC management plans and the history of legislation in the country. Chapter two presents an overview of worldwide EMC legislation including South Africa`s current legislation. Chapters three and four presents two ways of introducing an EMC management plan and the consequences of not considering EMC management, by means of three case studies. Chapter five provides some measurements made. Chapter six contains the proposal of a new EMC framework for South Africa, inclusive of certification, special requirements for certain products and related quality issues. The testing issues in chapter 5 and the case studies in chapters 3 and 4 are important in the context of the framework as it shows how companies, especially small ones, can minimize their testing costs, by ensuring that the product comply by the time that it is submitted for testing. The thesis concludes with an overall summary in Chapter 7. Appendix A is supplementary to the text of the thesis as it contains additional photographs of measurements.

1.6 References

[1] Tim Williams, "EMC for Product Designers - Meeting the European EMC Directive", Second Edition, ISBN: 0750624663, Newnes publishing, Great Britain, 1996.

[2] "Telecommunications Act of 1996", State Press, Pretoria, South Africa, Act 103, Government Gazette No 17581 of 15 November 1996

[3] Georges Goldberg and Hans Teichmann, "Electromagnetic Compatibility. The role and contribution of IEC Standards", First Edition, IEC, Geneva, Switzerland, 1999

[4] JB Maree "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", Chapter 3, pp. 3-1 - 3-14, University of Stellenbosch, December 1998

[5] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[6] K Armstrong, "Design Techniques for EMC", Hyperlink: http://www.emc-journal.co.uk, December 2000

[7] M O'Hara, "EMC at component level", First edition, pp. 118 - 160, ISBN: 0750633557, Newnes, Great Britain, 1998

Chapter 2 - Establishing the need for a new EMC framework

2.1 Introduction

Before any suggestions can be made as to new EMC legislation for South Africa one needs to understand what is currently in place in the country and where these laws can be improved. It is also necessary to consider other countries and world trends when deciding on new legislation as one would not want to restrict trade due to unnecessary or incorrect legislation. For these reasons the legislation of a number of regions and countries in the world will be investigated.

2.2 Overview of current South African legislation

In 1952 the South African Post Office, under the signature of the Postmaster General, published the first EMC control legislation as an act in the Government Gazette often referred to as the Radio Regulations Act. Although this act was amended a number of times between 1952 and 1996 the main focus of the law remained unchanged. In 1996 a new Telecommunications Act[1] was published establishing the South African Telecommunication Regulatory Authority. In paragraph 95 of this act SATRA was tasked with the enforcement of the Radio Regulations Act of 1952 (Act No. 3 of 1952). On 5 May 2000 SATRA was dissolved and the Independent Communications Authority of South Africa (ICASA) was formed by the promulgation of a new Telecommunications Act[2]. After all these changes the basis of the technical EMC requirements are still the same as those published in 1952.

As one can see from [3] and the other references listed in paragraph 1of [3] the Radio Regulations Act only specifies limits for different classes of equipment. The classes of equipment includes but is not limited to "portable tools incorporating electric motors...", "gas discharge lamps, neon signs and filament lamps" and "television and radio receivers". One of the problems with the way in which this legislation has been written is that it does not cater for new technology that has been developed since the law was promulgated. The question could therefore be asked: "What class would be appropriate for an electric fence controller or a multimedia personal computer with a built in television/radio receiver?" The answer is that the law provides no guidance in such a case. Tables 2.1 and 2.2 give extracts from the limits specified by [3].

Table 2.1 - Requirements for Household and similar appliances

Class	Notes	Frequency Range	Interference signal voltage at mains terminals (dB/uV)	Radiated power, dB relative to 1pW (dB/pW)
(a) (iii)	[1] The limit increases linearly with frequency from the lower specified value at the low frequency to the higher specified value at the high frequency.	150 to 500 kHz	66 to 56 + $20Log_{10}C^1$	-
		0.5 to 5 MHz	56 + $20Log_{10}C^1$	-
		5to 30 MHz	60 + $20Log_{10}C^1$	-
		0.03 to 1GHz	-	45 to 55 + $20Log_{10}C^1$

where $C = \frac{30}{f * N}$, f is a factor obtained from Table 3 of [3] and N is the click rate

(for N > 30 or for continuous interference N = 30 and for N < 0.2, C = 25 000).

Table 2.2 - Requirements for Information technology equipment (ITE) (Class A)

Class	Notes	Frequency Range	Interference voltage at mains terminals (dB/uV)	Radiated interference field (dB/uV)
(g) (i)	[1] The first value is the limit when measured with a Quasi-peak detector and the second when measured with an Average detector.	150 to 500kHz	79/66[1]	
		500 kHz to 30 MHz	73/60[1]	
		30 to 230 MHz	-	30
		230 MHz to 1GHz	-	37

Table 2.3 - Requirements for Information technology equipment (ITE) (Class B)

Class	Notes	Frequency Range	Interference voltage at mains terminals (dB/uV)	Radiated interference field (dB/uV)
(g) (ii)	[1]The first value is the limit when measured with a Quasi-peak detector and the second when measured with an Average detector. [2] The limit increases linearly with frequency from the lower specified value at the low frequency to the higher specified value at the high frequency.	150 to 500 kHz	(66-56)/(56-46)[1,2]	
		500 kHz to 5 MHz	56/46[1]	
		5 MHz to 30 MHz	60/50[1]	
		30 MHz to 230 MHz	-	30
		230 MHz to 1GHz	-	37

Another common problem that occurs due to legislation that contains specific requirements and methods is that it always seems to be lagging behind world trends. The reason for this is that legislation generally takes a long time to pass all the parliamentary structures before it becomes a law. It has also happened quite often in the past that this kind of legislation is considered of less importance to other legislation in the country. By the time it is promulgated into law one may already need to amend it again due to other world trends. The current legislation of South Africa has a third major problem in that no methods are specified. This becomes a big problem in cases where disputes need to be resolved between different test laboratories, between the legislator and owner of a product or between users.

2.3 Overview of worldwide trends in EMC legislation

2.3.1 Australasia

As discussed in detail in [4] the first EMC regulations introduced by the Australian Communications Authority (ACA), and which became mandatory on 1 January 1997, were requirements that demanded compliance with Australian standards, based on international (CISPR) EMI standards. According to [4] the ACA experienced some problems with the definitions given in standards such as CISPR 22 for Class A and Class B environments in the first year of the implementation of this legislation. They therefore amended the legislation on 11 November 1998 to mandate the applicability of standards without reference to a particular environment. With this amendment they ensured that if a product falls within the scope of one of the compulsory standards and is not specifically excluded from the framework then it has to comply. This change made the practical implementation of the legislation easier. In terms of implementation dates for the legislation the ACA issued the legislation in such a manner that products placed on the market before 1 January 1997 had until 1 January 1999 to comply. Since products placed on the market after that date had to comply immediately one saw the date of 1 January 1999 as the final implementation date for all products[5]. It should therefore be noted that until this day Australia has only legislation in place that regulates the emission from equipment. No immunity regulations are as yet in place.

The Australian standards that have been promulgated in the above-mentioned legislation are based on the CISPR-series of international standards. It should however be noted that they are not exactly the same. National deviation from the CISPR standards are therefore used. For example one will find that AS/NZA 2064.1/2 is the emission standard for Industrial, scientific and medical equipment based on CISPR 11.

2.3.2 Far East - Taiwan, Korea, People's republic of China

In Taiwan R.O.C (Republic of China) a BMSI (Bureau for Standards Metrology and Inspection) approval mark is required to show compliance with EMC and safety requirements. Testing for this purpose can be done at any BMSI accredited laboratory. Such laboratories can be found in Taiwan, the United States or in Europe[6]. It should also be remembered that countries like Taiwan have a 120V supply network and would therefore require that products be tested at 120V and not at a nominal supply of 230V.

From 1991 until 1 July 2000 Korea used a Korean standard for EMI requirements [7]. Thereafter their standards were aligned to international standards [7],[8]. Originally testing could only be done at a government laboratory but recently this changed and now testing can be done at any RRL (Korean government department that accredits laboratories) accredited laboratory. From 1 January 2000 immunity requirement based on the IEC 1000 immunity standard series has also become compulsory.

The People's Republic of China presents one of the largest emerging markets of the 21st century as it opens up to industrial development. It does seem that the bureaucracy of the Chinese State Government and interference from provincial authorities makes the approval process tedious [9]. By 1 January 2000 all ITE products had to be certified for EMC. The resulting CCIB (China Inport & Export Inspection Bureau) mark includes a small "S & E" to indicate both safety and EMC approval [10].

2.3.3 Russian Federation

In the Russian Federation Gosstandart is the Federal Administration for Standardization, equivalent to the NIST in the USA and South African National Accreditation Service (SANAS) and the National Metrology Laboratory (NML) in South Africa. Rostest, located in Moscow, is one of the few Russian centres accredited by Gosstandart for EMC certification of products. The Russian mark to demonstrate safety and EMC compliance is GOST-R. In general, it seems that the Russian product certification system is not very well defined. When asking certification experts what the Russian requirements entail they produce a variety of different results. There are, however, two things that came out of everybody's views and that is that it can be very expensive and tedious if you do not know what you are doing. A lot of bureaucratic red tape is involved.

It was not possible for the writer to confirm whether certification of products is mandatory, i.e. GOST-R mark. What was however clear was that the certification will consist of an inspection of existing Compliance Documentation including ISO 9000 certification, EMC test data, safety test data, environmental test data along with other inspections of calibration equipment and methods. To accomplish this a trip for Gosstandart and Department of Communication officials to the factory is necessary. In this described process no actual testing is done. It should however be clear that this can be a tedious and very expensive exercise (US$ 44,000[11]).

2.3.4 Americas

A number of countries in South America are currently in the process of establishing safety and EMC legislation. A number of them have however implemented legislation that will now be reviewed.

In Argentina EMC and safety approval is required for electrical equipment. This approval is managed through the CNC (Comision Nacional de Comunicaciones). During the approval of products safety, EMC and in some cases functional compliance will be evaluated. The standards being used are national and national testing is of course also mandatory. These standards are, however, mainly based on international standards like IEC European and CISPR standards. Argentina introduced regulation 92/98 on August 18th, 1998 which requires the safety compliance [12]. This regulation is being introduced gradually from the above mentioned date up to April 2002 when it will be completely implemented [13]. EMC compliance is however, seemingly only required for products such as telecommunication equipment.

Although Brazil has some EMC legislation in terms of compliance criteria and test methods published in Government Gazette's for RF transmitters no formal EMC framework exists [14]. It is also clear that a lot of emphasis is being placed on acceptance of results from elsewhere. When testing has been done elsewhere an engineer with CREA registration must state that the equipment is what the importer/manufacturer say that it is, when it is put in the market. Wider EMC requirements are being introduced at the moment. For other South American countries like Argentina, Mexico, Peru, Ecuador, Uruguay and Venezuela approval is required to connect telecommunication equipment to the PSTN, and in some cases safety approval is required. No EMC approval is required. For most other Latin American countries, foreign certificates are accepted or no approval requirements exist.

In the USA, EMC legislation is initiated and policed by the Federal Communications Commission under title 47 of the Code of Federal Regulations [15]. Part 15 contains the limits for intentional and unintentional radiators. A most important point is that emission from domestic appliances (excluding microwave ovens) is not regulated. The only time when restrictions due to emission will be applicable to these devices is when it can be shown that the equipment generates harmful interference. Requirements for digital devices are also contained in part 15. Digital devices include, amongst others things, information technology equipment and certain industrial, scientific and medical equipment. Under certain conditions the limits of standards such as CISPR 22 will be accepted. Testing is however required above 1GHz.

In the last few years the FCC rules have changed significantly. From a system where type approval was the norm they moved to a system where a declaration of conformity can be used or the product can be tested either by the manufacturer or a third party laboratory. The routes available for a specific product are still dictated by the FCC. Where third party testing is done, it can be done at a laboratory outside the USA. In the past testing was in most cases only done in the USA.

2.3.5 Europe

The European Union (EU) started in the late1980's to develop a self declaration system generally referred to as the CE Mark (Taken from the French, translated: European Conformity). From 1 January 1997 the application of the CE mark has become compulsory for all products sold in the EU [16]. In Europe a manufacturer has two choices namely, complete self declaration and testing at a third party laboratory. For some products the route to be followed is prescribed by the legislation, but in most cases any one of the routes can be followed. In the complete self declaration case a manufacturer tests the product himself and issues a declaration of conformity based on a technical construction file containing the proof that the product complies. In the second case the product is submitted to a third party laboratory that performs the tests and issues the declaration on behalf of the manufacturer.

Although the system seems to work very well, numerous complaints [17] are in circulation, of products that bear the mark but do not comply. This seems to be mainly because the CE Directive requires compliance with the "essential requirements" of the directive and not full compliance with the limits and methods of the standards. In the writer's opinion this is probably the weak point of the CE Mark. This method of writing legislation makes the application easier for manufacturers, but it makes the policing more difficult. The fact that the policing of the CE Mark directive seems to be effective and that the directive allows for corrective action in a case where the essential requirements are met, but interference with other systems do still exist, seems to make amends for the "deficiency".

Countries like Hungary, Estonia, Latvia and Lithuania, accept CE mark declarations of conformity and test results to European standards notwithstanding the fact that they are not officially part of the European union.

2.3.6 Other

Although very severe safety regulations are in place in Saudi Arabia no specific EMC regulations are in place [18]. India has EMC and safety legislation in place that are based on international standards, such as CISPR 22 for Information Technology Equipment [19]. Standardisation Activities in India is controlled by the Bureau of Indian Standards.

2.4 References

[1] "Telecommunications Act", Department of Communication, Government Gazette 17581, Act No. 10 of 15 November 1996

[2] "Telecommunications Act", Department of Communication, Government Gazette 21154, Act No. 13 of 5 May 2000

[3] "Amendment of the Radio Regulations", Department of Posts and Telecommunications, Government Gazette No. 10158, Act No. R 587 of 27 March 1986

[4] "Australian EMC Regulation and Routes to Compliance", Chris Zombolas, Compliance Engineering, 1999

[5] "Australian EMC Overview", http://www.ets-telecom/tics/global/au/au_cert_emc.htm, 19 September 2000

[6] EMAIL correspondence, Ted Eckert, American Power Conversion Corporation, 14 January 2000.

[7] "Korea aligns itself with international standards", John Whaley, YS Kwon, Young Kim, Approval Magazine, pp. 10,11, January/February 2000, ISSN: 1359 1991

[8] EMAIL correspondence, Sang-Man Kim, Samsung Electro-Mechanics Co., Ltd., 21 July 2000.

[9] "Conflict of authorities makes Chinese approval difficult", John Whaley, Approval Magazine, pp. 10,11, January/February 1999, ISSN: 1359 1991

[10] EMAIL correspondence, George Alspaugh, Lexmark International Inc., 14 October 1999

[11] EMAIL correspondence, Chris Maxwell,GN Nettest, 15 March 2000

[12] "Argentina Compliance Services page", http://www.nccrc.com/textfiles/argentina.htm, 26 October 2000

[13] "Argentinian certification overview", http://www.ul.com/argentina/overview.htm, 9 October 2000

[14] EMAIL correspondence, Sérgio Rocha Loures, Siemens Ltda., 10 February 2000

[15] "Approval routes for EMC compliance", http://www.approval.co.uk/emcusa.htm, 27 October 2000

[16] "Concise guide to the EMC Directive", http://www.approval.co.uk/emcinfo1.htm, 27 October 2000

[17] "The EMC Directive - Necessary interpretation", http://www.emc-journal.co.uk/current/000807.html, 31 October 2000

[18] "Extra requirements in Saudi regime", Nigel Harvey, Approval Magazine, pp16 -17, Mar/April 1999, ISSN: 1359 1991.

[19] EMAIL correspondence, KevinNewland, 1 May 2000

Chapter 3 - Case study: A complete EMC Management plan

3.1 Introduction

The case study presented in this chapter shows how a full EMC management plan should be implemented on a large project. Consideration is given in chapter 4 to a more compact version of this plan. The main point that must, however, be realized when reading chapters 3 and 4 is the potential value of an EMC management plan. In the writers' opinion the value of such an EMC management plan is still greatly underestimated by the industry in general [5]. Although these case studies are hypothetical, the technical aspects as well as the problems and solutions described in them are based on real life experiences. The reader must also realize that the implementation of an EMC management plan and the solution to an EMC problem will in practice not always be as easy as it may seem from the case studies presented.

3.2 Case study - Implementing a full EMC management plan

Eugene, a new appointee, at Telecom Inc., has been given the task to find a way to properly manage the design of a large new system that Telecom Inc. wants to develop. The appointed project manager, Lisa, motivated his appointment at the company since she felt that they needed somebody who has some project management experience as well as some EMC design experience. She could have managed the project, but felt that she needed some help to find a way of stopping EMC problems from delaying the completion of the project, as it did in the past. The required system consists of a hundred line telephone line monitoring module and RF transmission module for the recorded data.

3.3 Finding a solution

Eugene therefore sets out on this project, knowing that his career will be made if he can find a solution that works. He has the chance to save the company thousands of rands and a lot of embarrassment. This was very clear to him from the extracts of their general project review meeting minutes, showed to him by Lisa:

Project 176539: **Project start date** : 1999-04-17
Delivery due: 1999-11-01
Actual delivery : None
Notes: Client cancelled order on 2000-01-16, due to late delivery of product. Product experienced severe emission problems during pre- and full-compliance EMC testing

Project 176543: **Project start date :** 1999-12-01
Delivery due: 2000-04-11
Actual delivery : 2000-06-01
Notes: Delivery late due to emission and surge failures during EMC compliance testing.

Project 176546: **Project start date :** 2000-01-02
Delivery due: 2000-08-01
Actual delivery : 2000-11-06
Notes: Delivery late due to emission failures during compliance testing. An extra design cycle had to be undertaken to solve the problems.

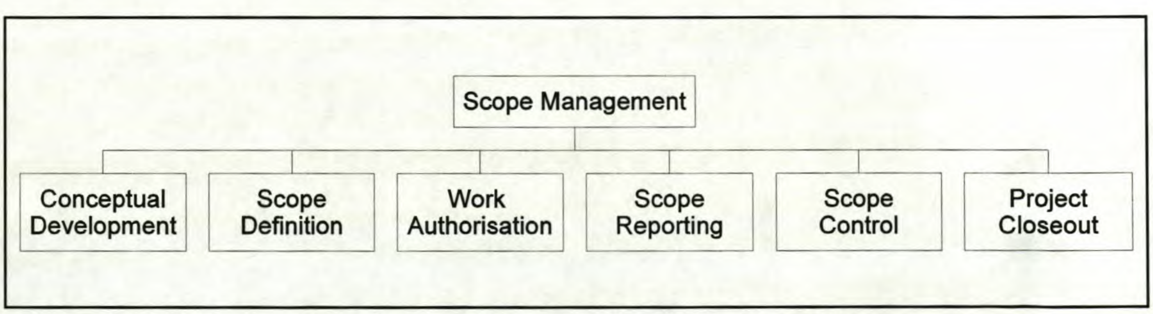

Figure 1: PMI Body of knowledge ([1] Chapter3, Figure 1 pp. 45)

For Eugene the first order of business is to investigate the design cycle stages that their projects go through. After he had a look at the last ten projects he concludes that they follow, almost to the letter, the guidelines of the Project Management Institute (PMI) body of knowledge [1] that he learned about during his Project management Diploma course - copied in figure 1. Following on these overlying principles, one could say that each project plan has to have the following stages:

★ Feasibility study & Conceptual design, Feasibility review*
★ Detailed design, Design review*
★ Model build, Compliance testing, Project review**
★ Project closeout*

* Project milestone where the project stages, since the last milestone, is reviewed and where approval is given to proceed to the next stage.
** A project milestone as described in *. Additionally, however, a decision is made regarding the necessity of another design cycle or whether the project can be allowed to proceed to the next stage.

Since the project stages used and the management of these stages seems to be in order he deduces that a lack of project management is not the problem. A quick overview of some EMC test reports shows him that the laboratories being used for EMC testing are also acceptable. Since all of the EMC problems have been solved in the projects that he reviewed he must conclude that the problem can not lay in the EMC measures that are being used. The problem must therefore be that these measures are only introduced during compliance testing or during a redesign cycle. The next week Eugene spends most of his time studying literature that he obtained from the university library.

After paging through a pile of material he decides that most of what he needs he can find in the material that lay in front of him. It contains all the information he requires to draw up a proposal. He decides to call his proposal an EMC management plan. His proposal hi given in table 1.

Table 1: Proposals for the essential elements of an EMC management plan

No	Proposal	Justification
1	Create a general awareness of EMC in the company[2], [4].	If designers, sales representatives and managers are not aware of the implications of EMC non-compliance and generally what EMC is, then they will not grasp the reasons for the rest of the proposal.
2	Consider the implications of EMC on the larger system and not just on the individual components [2], [4].	If a product consists of more than one component, one will have to realise that interconnections or a combination of components may cause problems
3	Review EMC performance and measures during every project review meeting[2].	Since a good project management foundation exists within the company one can easily add a check during the review meetings where the EMC performance and measures are considered. By doing this the collective input of the design team can be obtained regarding the measures. Everybody will also stay informed regarding the measures being used. This will ensure that the general EMC knowledge will improve and that everything possible is being done to obtain effective EMC solutions.

No	Proposal	Justification
4	Consider EMC performance from the start of the project [2], [3], [4], [Chapter 1 (Figure 3)]	It is possible to introduce virtually every measure in the feasibility stage of a project, where one does not want to make design changes during the latter stages. It is also cheaper to introduce, for example, a filter in the initial design, than at the end, because the PCB layout would probably have to be changed.
5	Distribute the effort of incorporating measures for EMC compliance over the complete development cycle[2], [3], [4].	This process is called concurrent engineering [3] and places the bulk of the effort at the start of the design cycle with a gradual decrease in effort through the cycle. This will ensure that as many problems as possible are solved early in the early design cycle.
6	Introduce an EMC control plan [2]	An EMC control plan is a plan that is drawn up, preferably during the feasibility study, that summarises the EMC phenomena that have to be considered, and ways how the perceived problems can be prevented. This plan should also form the basis of the EMC design rules for the person doing the circuit layout. Such a control plan can be a determining factor regarding the feasibility of the project within the parameters specified.

No	Proposal	Justification
7	Introduce an EMC test plan [2], [4]	An EMC test plan must be introduced to define the EMC requirements that have to be met, as well as the points in the development cycle where compliance will be measured. This test plan must be drawn up during the feasibility study. It is also an indicator of the feasibility of the project within the parameters specified.
8	Appoint an EMC coordinator [2], [4].	An EMC co-ordinator is required to ensure that the correct measures are introduced and that the control plan and test plan requirements are being met.

The last phase of Eugene`s project has now arrived. Since he obtained approval from Lisa and the rest of the management team to try and implement this EMC management plan, he now has to find some practical way of implementing his ideas.

3.4 Testing the proposal on a project

As Eugene starts to implement the plan he realises that the feasibility study of the project has virtually been completed, by John, with whom the idea for the product originated. After some discussion he convinces John to allow him a week to draw up control and test plans based on the written requirement specification that they obtained from marketing. He will then table these plans with the feasibility report next week. After a week of work he came up with the following plans.

Table 2: Eugene`s EMC control plan[2]

No	Definition of risks
1	Switching noise from power supply
2	Harmonic noise from reference clock
3	Supply noise from fast switching circuits
4	Cable routing and noise from the inter-module cables and unshielded I/O lines
5	General radiated emission
6	Lightning protection

No	Suggested design practices
1	Use a supply filter with a 3dB cut-off frequency 20 times higher than the switching frequency. The filter should be placed as close as possible to the entry point of the power supply.
2	Keep reference clock tracks as short as possible and frequency as low as possible. Use the slowest (rise time) clock possible. Keep all other tracks as far away as possible form the clock. Do not route tracks underneath reference clock.
3	Decouple every power entry of each IC with a 100nF ceramic capacitor. Additionally, use a non-electrolytic capacitor of approximately 1uF as a tank capacitor on the supplies of components drawing in excess of 5mA.
4	Use chip filters and shielded cables on the inputs and outputs of interconnecting circuits. Use filtered connectors where unshielded I/O lines enter and exist the equipment.

5	All PCB`s should be at least four layers with two layers being power layers. Give preference, when routing busses, in terms of the shortest route, to least significant bits. Keep tracks as far away from the edges of the board as possible and place a guard track around the edge of all layers, that is connected to earth. Provide a reliable chassis connection between components and for the system as a whole. During this stage care should be taken to minimize ground loops on the PCB.
6	Place lightning protection devices for primary protection as close as possible to I/O connectors of the system. Secondary protection should follow the primary protection. On interconnecting lines provision should be made for secondary protection. Interconnecting lines should be kept away from I/O connectors and cable/connector shields should be connected to chassis.

Table 3: Eugene`s EMC test plan

No	Test description	Complete after which project stage
1	Conducted emission CISPR 22B, ETS 300 386-1	Model build
2	Radiated emission CISPR 22B, ETS 300 386-1	Model build
3	Lightning and transient surge protection ETS 300 386, ITU K.20	Pre-release
4	Conducted emission CISPR 22B, ETS 300 386-1	Post release
5	Radiated emission CISPR 22B, ETS 300 386-1	Post release
6	Lightning and transient surge protection ETS 300 386, ITU K.20	Post release

Since Eugene`s EMC management plan was accepted by management he was also considered to be the EMC coordinator. As the project progresses he carefully monitors the implementation of the EMC measures in his EMC control plan. During the weekly progress meetings opportunities arise to make slight modifications and additions to the plan, which he does. Since everything seems to be moving ahead speedily and without any significant problems he notices a change in the attitude of the rest of the design team members towards him. He almost senses a general acceptance of his ideas. This he realises was the fruit of his hard work during the past months. What he does however know is that he has the opportunity in the next few days to either cast this new found trust of his co-workers in concrete or to wipe it out completely. In the next two to three days he will perform the pre-compliance testing after the complete system model has been built.

As he starts testing the next day he realises that he might just succeed as the initial results looked very promising. There is only one hump at approximately 2MHz that fails marginally. The rest of the peaks are well below the limit. He should be able to find the origin of this one problem fairly easily, he thinks. That was until the radiated emission scan reached 915MHz, the IF frequency of the RF transmitter, where a massive peak was visible. As he counted the divisions on the graph - three and a half in total, which represent 35dB over the limit - he knows that he is in trouble. Although he knows that nobody could have anticipated all the possible problems, he still feels dejected. In conclusion he informs the rest of the team that he will investigate the problem and try to give them a solution by the next day.

Eugene has just made himself some coffee, hoping that it might wake him up. He worked until 7pm last night, without success, when he went home just to lie awake the whole night trying to find out what the problem was. As he places his coffee on the desk he looks at the RF circuit lying on the table. The RF circuit was enclosed in its own metal box for shielding purposes. As he picks the box up he notices a grey substance on the corner opposite from the earth wire connection. "That`s it," he yells!! "I've got it". He looks at his watch, which reads 7:15am. He has an hour and forty-five minutes to prove that the problem can be solved. He sets out by covering the top, bottom and both sides of the RF box in masking tape. What he realised, is that the rails of rack where the system components like the RF circuit, are housed in, are metal. Placing an earthed metal enclosure on a metal rail might cause a ground loop with earth connection on the box, that can act as an antenna for the IF frequency of the RF circuit. The masking tape should isolate the enclosure from the slides and thereby breaking the loop. The only earth connection would then be the earth wire at the back of the box. As he runs the test again he sips his coffee. He is staring at the screen like somebody who is watching a gripping movie. At 910MHz he stops breathing, or so it feels to him. As the scan reaches 920MHz he knows that he found the solution: Plastic rails instead of metal ones.

An hour later he describes the events of the morning and the solution to the rest of the development team. He concludes that there was probably a resonant loop present on the box between the intentional earth at the back and the front corner that was scraping into the metal rail. Happy that he found a solution to the main problem he asks the team for permission to search for the source of the emissions at 2MHz. He states that he suspects that it is a power supply problem which he should be able to fix in a day or two. After some resistance from a few people it was agreed that he would have three days, until Friday, to come up with a solution, while they complete the outstanding documentation.

Full of confidence he sets out to find the one remaining problem. By four o'clock he starts to notice an improvement in the level of the frequencies around 2MHz. By the time the clock on the laboratory wall reaches going home time, he knows what the solution to the problem is. For the last thirty minutes Lisa has been watching over Eugene`s shoulder with a smile on her face as he soldered and de-soldered capacitors on the board. As the last scan passes the 5MHz point she realises that Eugene has suppressed the peaks at 2MHz to 5dB under the limit. Reluctantly she asks him what he did. Full of confidence Eugene explains that he replaced the line to chassis capacitors on the input of the power supply filter with polypropylene capacitors.

He continues to explain that somebody showed him some graphs the other day of ceramic capacitors that had resonant peaks frequencies in the 1-5MHz band. That was probably the case with their supply of ceramic chip capacitors as well.

3.5 The closing out meeting

A month later - three days after the successful completion of the compliance EMC tests he sits in the closing out meeting. As he looks at the pad in front of him he realises that somebody is talking to him. He must have been day dreaming. He looks up from the pad just in time to realise that Lisa has asked him for the second time whether he had any comments about the project. Now fully awake he states that he is satisfied with the project outcome. He also states that he was surprised by the failure at 915MHz. He thought at that stage that those kind of problems should not occur as they have taken every measure possible to ensure EMC compliance. What he did learn, he states, is that one must be prepared for some problems at the testing phase, as one can easily miss something during the design. In conclusion he expresses the wish that all of the problems that they have in future, at the testing phase, be as easy to solve as the ones they had with this project. At 11:15am, on Friday the 15th of June 2001, a content project team leaves the meeting room for a pub lunch, feeling satisfied with the work of the last five months.

3.6 References

[1] Rory Burke, "Project Management. Planning and Control", Chapter 1, Management Press, Cape Town, Second Edition, 1995, ISBN: 0-6230-16250-3

[2] Tim Williams, "EMC for product designers - Meeting the European EMC Directive", Chapter 8, Newnes, Oxford, Second edition, 1996, ISBN: 0-7505-2466-3

[3] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[4] JB Maree, "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", Chapter 3, pp. 3-1 - 3-14, University of Stellenbosch, December 1998

[5] JB Maree, "External Examiners' observation", January 2003

Chapter 4 - Case studies: Implementation of a partial EMC management plan versus no EMC management plan

4.1 Introduction

The first case study in this chapter is presented to show what can happen to a product development cycle if a good EMC management plan is not in place or if such a plan is not followed. From these problems, valuable lessons can be learnt, which can be implemented in future projects.

The second case study shows how a partial EMC management plan can be introduced. Plans like these will typically be used on projects which do not warrant the expense or effort of a full EMC management plan but cannot afford to run into the kind of problems described in 4.2.

4.2 Case study 1 : No EMC management plan

This case study was drawn up from a real situation. However, for obvious reasons of confidentiality, product specific information is withheld and names have been changed. In order to maintain the required confidentiality level only phenomena will be discussed instead of specific practical implementation data. What went wrong in the development cycle of "The Widget" will now be investigated.

4.2.1 The product request and design

Frank le Roux, a Chief engineer at Widget and Gadget Inc. is looking perplexed as he walks down the passage to the office of some of the engineers that report to him. In his hand he holds an A4 sheet of paper containing the notes he wrote during a meeting with John Bagger, the Marketing Manager. He has been asked to develop a product for delivery in ten weeks time based upon these notes. As he tells his engineers about the request he knows that they will probably struggle to meet the deadline. After considering the already heavy workload of his engineers he assigns the project to Pieter Fourie, a young engineer. Since this is his first project as project leader, Pieter gladly accepts the task.

Trying to piece the puzzle of this product together Pieter starts by drawing up a project plan. He knows that he cannot spend too much time on "luxuries" like the project plan, because he needs to do the design. As he speaks to Karl, a Senior Sales Engineer, he finds out that some of the technical specifications supplied, came from what the marketing team were told about the competition`s product. Whether this information was accurate he would never know as neither a set of their features nor a sample of their product could be obtained. Following these discussions Pieter did the design. Another problem that Pieter faces is that he keeps on getting new information from Karl. The effect of these changes in requirements is that he has to re-do the design a number of times.

As Pieter is still young and inexperienced, and since he has wasted some time in re-designing the product he moves forward rapidly with the design. He does this without considering the implications of EMC requirements on the product. After he receives the completed PCB layout from the drawing office he is asked to show it to the EMC specialist in the division, Pedro da Silva. Pedro briefly looks at the layout and concludes that certain modifications have to be made, otherwise the product, appropriately named The Widget, would fail to meet the EMI requirements. His concerns are listed in table 1.

Table 1: Pedro`s concerns regarding the design

No	Concern	Reason for the concern
1	Tracks from the input/output (I/O) connector pass too close to the mains filtering	Coupling to the primary side of the supply filters may occur
2	The enclosure seams are not electrically well joined	The screening effect of the enclosure might not be good enough to ensure that the circuit passes

3	The I/O connectors are unfiltered	Unshielded lines connected to the outside of the I/O connectors will radiate any noise inside the system that is coupled to the connectors
4	The board is not wide enough to separate effectively sensitive circuits from each other.	Coupling between circuits will occur because circuits cannot effectively be separated. This might increase the amount of emission

Since Pedro was given little time to evaluate this design, he realised that he might have overlooked some critical aspects, and that the measures that one can introduce at the current stage of the project might be limited, due to time constrains. Frank and Pieter decided at this stage that most of Pedro`s suggestions should not be implemented as this would delay the project even further, and would drastically increase the cost of the product.

4.2.2 Testing and Re-designing the Widget

Two weeks later Pedro was asked by Pieter to test the Widget for EMI. The end result was that the Widget failed radiated emission by a substantial margin. Although Pedro expected this to happen, he was also surprised to see the margin by which it failed. It is now time for Pedro to spend a bit of time testing and experimenting with changes to the design. After a week of changing component values, cutting tracks and re-routing them, shielding connectors and building boxes he came up with the list of problems in table 2, that caused the Widget to fail.

Table 2: Causes of emission failure of the Widget

No	Causes of failure	Reasons for causing failure
1	Signal tracks were routed under the crystal	These tracks picked up the crystal harmonics and transported them over the board causing emission to be radiated from them. They also, through crosstalk, coupled to the power supply tracks causing the frequencies to be radiated from the power supply cord. The power supply filter was optimised to work up to 2MHz and subsequently not at these high frequencies.
2	Decoupling capacitors were too far from IC`s	As the IC`s switch, they draw a current pulse from the supply that has a fast rise time. The high frequency spectrum generated by this pulse is not effectively decoupled due to the placement of the decoupling capacitors.
3	Power supply filters were incorrectly placed	Signal lines were routed close to both sides of the power filter. This allowed noise on these tracks to be coupled onto the "clean" filtered tracks, which in turn radiated the noise to the outside world through the supply cord.
4	Signal lines were unfiltered	Although filtering was included on the power supply lines, none were included on the signal lines. Radiated emission could therefore result from these signal lines. Due to the placement of lightning protection components, just after the connectors, PCB mounted filters would be too far from the edge of the enclosure to be effective. Signal line filters incorporated in the connecters would therefore have been the best option.

5	Enclosure was inefficiently shielded	The enclosure of the Widget was not manufactured precisely enough to ensure that seams make good electrical contact. Additionally, around the connectors large cut-outs were used. Probably due to cost considerations none of the seams of the enclosure made use of gaskets. All these factors ensured that the enclosure was not an efficient shield.

Since the Widget did not meet the expectations of the client and marketing team, another design cycle was initiated, as the product was important for the company. To say that Frank was unimpressed with the state of the project would be a huge understatement. Proof of this can be found in the talk that he gave to Pieter after the meeting. Pieter was told, amongst other things, to make sure that Pedro approves the design before he proceeds to the next stage. Pieter in turn felt frustrated by the fact that he was blamed for the failure of the Widget. He was given very little time to design a product, the specifications of which kept changing.

The EMI failures could at this time be hidden from the client who wanted some expansions to the capabilities of the Widget. These changes to the specification have now increased in frequency over the last three weeks. The other problem that occurred without anybody noticing is that company procedures such as reviews, and scheduled feedback were skipped as the project was restarted a number of times. Pieter started to feel that he would never be able to finish the Widget. The EMC measures that had to be introduced are proving problematic, as they are difficult to implement at such an advanced phase of the project`s development cycle. These measures, like signal line filters, shielded connectors and a shielded enclosures are very expensive. At this stage he could have done without such changes, because it causes a drastic increase in the product cost, and development time.After reading a book on project management [1] he sits down and makes a list of the things that went wrong.

The problems he identified are listed in table 3.

Table 3: Problems in the product development cycle

No	Description of problem
1	No feasibility study and risk analysis were done [1]. If these were done then he would have known about the potential EMC problems, and he could have made suitable changes. A feasibility study would also have shown whether a product with the required specifications could be made for the required price.
2	A clear project outline was not drawn up. The scope of the project was therefore not clearly defined as is suggested in [1]. This allowed constant changes to occur that badly affected the accuracy of the project plan and the ability of the project to meet the expectations of the customer.
3	The internal quality control procedures of the company were not followed, causing the project to be delayed due to documents that had to be written in retrospect. Other delays were also experienced since vital parts of the project development cycle was skipped.
4	Not enough consideration was given to EMC in the first development phases necessitating many changes at a later stage, causing expensive delays.
5	According to an article on the inclusion of EMC in project plans [2], the process of diverting the bulk of the resource intensive work to the start of a project is concurrent engineering. The department could definitely benefit from the implementation of a concurrent engineering program.
6	Not enough commitment and understanding in the department for complying with EMC requirements. General training might be advisable. It would also be necessary to convince management that it is worthwhile to insist on the inclusion of EMC measures in products.

Now that he has a list of the problems that he encountered during the previous design cycle he must just find somebody who can help him to solve these problems.

4.3 Case study 2: A partial EMC management plan

M&M Engineers have been designing electronic circuits for the last 20 years and have been very successful at it. However, over the last few years they have been having more and more problems with the EMC compliance of their products. When Mike and Mitchell started M&M Engineers, EMC was something with which they had few problems. If they think back now, they know that they probably always had problems with EMC but they did not know about it. At the time there was also very little legislation in the world that required EMC compliance to standards. Most of M&M`s products are simple, cost effective solutions to problems and therefore the products are very price sensitive. Due to this problem they have been unable to implement the EMC management plan that Joe, a consultant, developed for them.

The only solution at this stage was thus to tailor Joe`s plan in such a way that it fits in with their methods, budgets and development time scales. Since Mitchel is busy completing another big project they decide that Mike has to head the project team for a new request they have just received.

4.3.1 Find a way to manage the design

To begin Mike looks at the project stages that are normally implemented. He firstly concludes, that although they normally start with a feasibility study, this is a very informal process that is combined with the conceptual design phase referred to in the PMI body of knowledge [1]. After deliberating the issue he decides that the best approach would be to, firstly, assume that EMC presents a sizeable risk to the successful completion of the project and, secondly, to make provision for additional components or experimental changes to the first prototype boards. In this way problems can be solved during the early testing phases. These decisions make sense to him since there could be no arguments regarding the influence on EMC later and they will be able to iron out the existing problem by means of the experimental work they have made provision for. For many other projects it would be uneconomical and very difficult to allow for experimental changes as the circuits and PCB`s are too complex. Because this product is small, relatively inexpensive, and not very complex, such provisions can be made viably.

Mike realises that the main difference between his ideas and a full EMC management plan (see chapter 3) such as the one that Joe proposed, is that this approach is less structured and therefore more flexible. He would, however, have to ensure that consideration is given to EMC throughout the project. This is an extra task, but he realises that the success or failure of the project will depend on whether he can control the implementation of the EMC measures. Another point that Joe stressed in his proposal as being vitally important to the successful implementation of an EMC management plan is the acceptance of a "Design for EMC" culture in the company [4]. With the very autocratic style that he is contemplating, there will be neither time available for general EMC awareness training nor for convincing team members of the importance of EMC compliance - see also table 1, paragraph 3.3. He decides that he will make a point of talking to as many of the project team members as possible regarding EMC issues. He also realises that Since M&M do not have a formal project review process he also decides that on this project he would ask for everybody`s comments regarding the process followed once the project is complete. This would allow him to assess whether the process was successful or not.

4.3.2 Reviewing the process followed

Mike calls the complete project team together and tells them that they have received a request from Teleco Inc. to develop a call monitor for the domestic market. He also tells them that the conditions of the request include a requirement that a prototype of the device has to be delivered in seven week`s time. After describing to them what features the device should have he tells them about his thoughts regarding the design process to be followed. He states: "As time is critical, we cannot afford to have EMC problems. I will, therefore, through regular checks and discussions with you, try and ensure that we do not experience any problems.

If you have any problems with the process that I have outlined then I urge you to come and see me as soon as possible."

After appointing the relevant responsible persons on the project team he adjourns the meeting. The rest of the week the majority of the team enthusiastically starts their assigned tasks. As the first week ends Mike sits down and reviews their work. He hears about one or two complaints regarding his approach. After discussions with these individuals he senses more acceptance as they realise why this process necessary.

At the beginning of the second week Mike experiences the first major problem. The hardware engineer responsible for the I/O-circuitry, Leon, decided that there was only one way to ensure that no noise is transmitted via the I/O-ports. This is to use a brute-force-and-ignorance-approach and add as much filtering as possible. These filters and connectors, although they would work, will increase the product cost too much. After some discussion with Leon, he convinces him to build some of the filters up from surface mount components and to add one or two unpopulated pads that can be used for experiments. They also agree that they will design the board in such a way that it can accept both the filtered and unfiltered connectors. The filtered ones, however, will only be used as a last solution, they agreed. To ensure that the rest of the team do not fall into the same trap he decides to organise a social event for the following afternoon, where they can have some informal discussions about the problems that they have experienced so far, and then relax with some food and drink.

For the next two weeks the design and experiments progress without any major problems. In general Mike is surprised to see how most team members have co-operated during the first four weeks. In one or two cases he had to intervene and help people to stay focussed on the problems. In general, however, the chances of finishing the prototype in the desired timescale look good.

As they are currently waiting for the PCB boards to be delivered and some components to arrive he has organised two brain-storm sessions to discuss the testing process and what they will do if certain scenarios of failures occur.

As they have only two more weeks in which to complete the project Mike starts to increase his interaction with the rest of the team. Apart from one component that is due for delivery tomorrow, all the other parts have been installed. He suggests that they use an in-house manufactured unit for the purposes of initial testing until the correct common mode choke arrives. As Leon and Jaco did most of the hardware design work he suggests that they accompany him to Test House Inc. for the prototype EMC testing. In addition to the model, they have been asked to take the necessary tools and all the components that might be needed for experimental work in the next three days.

After two days of testing Leon, Jaco and Mike knows that they have at last managed to reliably suppress the three emission peaks that were close to the limit. Two of these peaks were due to the grounding method used and the other due to a capacitor in the power supply. Mike decides that, since the unit passes marginally without the filtered output connectors that they will ship the prototype with the normal connector. If they have problems on the first production models then they can just replace it with the filtered one.

After some final instructions to Leon and Jaco regarding documentation and other tasks to be carried out before they can ship the product, he returns home. He realises that it is the first time in six weeks that he has been able to relax properly. Having said that, he realises that one of the reasons why the design was completed on time without major problems was because of this effort. Keeping an eye on the design team and being involved in everything has taken a lot out of him.

4.3.3 EMC Management plans: Concluding remarks

In chapters 3 and 4 we have, through three case studies, seen what could happen to a product if an EMC management plan is not implemented. A significant amount of risk exist in such a case that the product will fail EMC testing and therefore that the project deadlines will not be met. To reduce the risk of failure, it was proposed that a full EMC management plan be implemented. In this plan the product would be completely evaluated and the compliance to all the applicable EMC requirements would be evaluated throughout the project. The problem with a complete EMC management plan is that it is not always economically viable to implement on all projects, especially smaller ones. In such a case it was suggested that a partial EMC management plan be implemented. The question can now rightly be asked: What would the difference be between a partial and a full EMC management plan? The difference is that in a partial EMC management plan, one would identify the main elements of risk and concentrate on these issues, where with a full EMC management plan all elements of risk would be evaluated. The reader must realize that any issue that is not considered in the partial plan will then again increase the risk of failure. Through proper risk management the acceptable amount of risk can, however, be determined, controlled and monitored.

4.4 References

[1] Rory Burke, "Project Management. Planning and Control", Chapter 1, Management Press, Cape Town, Second Edition, 1995, ISBN: 0-6230-16250-3

[2] FA Venter, "Catering for Electromagnetic Compatibility Requirements in the Project Plans of Products", Africon IEEE Conference, Volume 2, pp. 1131 - 1134, Cape Town, October 1999

[3] Ray Siu, Daniel J. Majewski, EMC Management: An integral part of a company`s quality program", IEEE International Symposium on Electromagnetic Compatibility, pp. 285 - 289, Washington, 2000.

Chapter 5 - Interlaboratory comparisons and practical EMC measurements

5.1 Introduction

The chapter will firstly investigate the options that an EMC laboratory has, apart from traditional methods, to establish its credibility and build up confidence in its methods. The option that will be investigated is to take part in interlaboratory comparisons. This will show how one can use these comparisons in conjunction with equipment calibration, or in some cases without calibration of equipment (where it is not possible), to establish the credibility of certain measurements. It will also show how a manufacturer with in-house test facilities can gain acceptance for his results in a self-certification environment. Comparisons that have been done in South Africa will also be examined. The writer was, at the time of these measurements, working in one of the laboratories whose results are presented in this thesis. The comparisons presented here have however been done afterwards by the writer due too his interest in the benefits and effectivity of interlaboratory comparisons.

Secondly, the chapter will investigate possible alternative test methods that can be used instead of the more traditional and expensive approaches. The measurements presented and the equipment setup were chosen to provide a stable and repeatable set of measurements that closely represent a typical radiator, e.g. a piece of equipment being tested. What the setup does, however, not cater for is a means for common mode current to flow. This is important since it is known [11], [19] that a relationship exists between the common mode current that flows in a circuit and the radiated emission from the circuit. The common mode current, normally, has a larger influence on the radiated field than the differential mode current, because the area of the loop where the common mode current flow is much larger than the loop where the differential mode current flows - see figure 1.

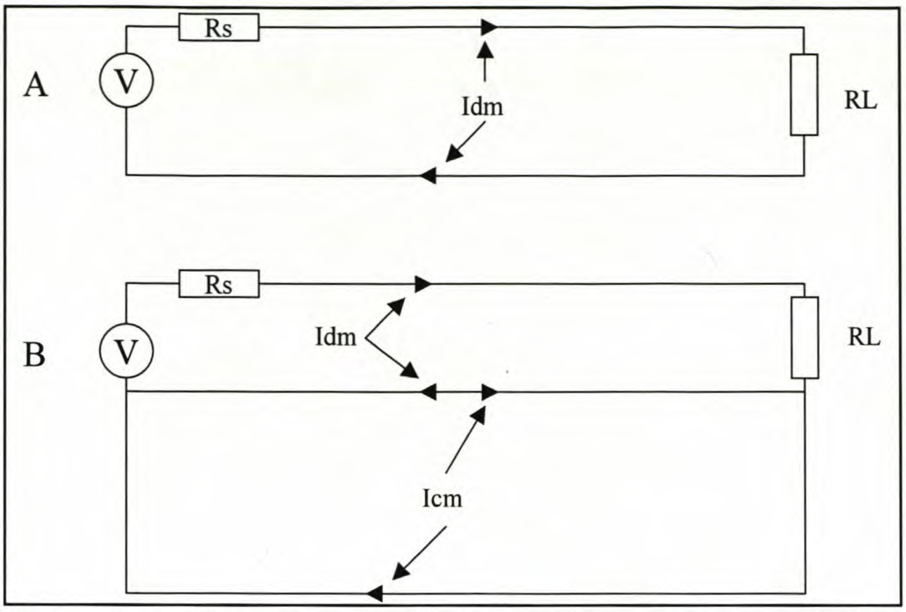

Figure 1: Common and differential mode current - note a CM current component can also flow on the top conductor depending on the configuration.

Although common mode current measurements will not be presented in this thesis, it is important to understand what common mode current is and how it would be measured. For this reason a short overview is presented. In a circuit such as the one showed in figure 1a where a single current loop exists only differential mode current (I_{dm})can flow. If the conductors are close together then the H-field due to this differential mode current would be very small, because of the direction of current flow. In a circuit such as the one showed in figure 1b an additional conductor is present. This conductor can exist for a number of reasons of which the following are some examples: Common ground connection between the source and the load and multiple connections of a conductor to a ground plane. Such a common conductor does not have to be electrically connected (as shown in figure 1b) to the circuit. It can also be capacitively coupled. In the circuit of figure 1b the differential mode (I_{dm}) and common mode (I_{cm}) current components are indicated. Placing a current probe around the top two conductors or the bottom conductor of figure 1b would allow the common mode current to be measured.

As mentioned earlier, the measurements presented in this thesis only shows emission due to differential mode currents. Unfortunately the writer had to change employment during the course of preparing this thesis and after this change the applicable measurement facilities and equipment were no longer available to repeat the measurements with such a common conductor included in the circuit. What can, however, be seen from this thesis is what parameters would be important during radiated emission measurements and what alternatives to standard measurement techniques exist. The main reason for investigating alternative possibilities, is that a manufacturer can perform in-house testing to prove EMC compliance should the legislation in the country allow it. Through in-house testing the manufacturer can gain confidence in the product`s performance, and thereby increase the probability that the product will comply before expensive third party testing is undertaken. It should therefore be noted that even if we refer to a test laboratory in the text below, we can apply these principles to any in-house laboratory.

5.2 Establishing credibility through comparison

Traditionally test laboratories have sent their test equipment to a calibration laboratory where the equipment was evaluated according to the manufacturer`s specifications. If it was found to operate within the manufacturer`s limits, a calibration certificate was issued. Thereafter the user in most cases did not question the measurements or operation of the equipment, until the next calibration. In addition, historically, training of test personnel took place during testing because enough suitably qualified people were available. However, in EMC test laboratories today one cannot rely only on this approach. Due to the increased sensitivity of measurements and equipment and the frequency range where measurements are being made, one has other factors influencing the accuracy of measurements. In addition to these factors one also struggles to prove the competency of EMC test personnel in South Africa due to a lack of appropriate training courses that can be used as a basis. One therefore often needs other means of establishing the credibility of test personnel and test results. In this respect interlaboratory comparisons can be a valuable tool.

Since test equipment for EMC testing is very expensive an in-house laboratory, in the case of a manufacturer or a test laboratory may not always be able to justify the purchase of the necessary test equipment. It is, however, possible for manufacturers to use alternative test equipment for this purpose, to establish the compliance of his products. These, methods and the restrictions that are applicable, will be investigated.

One of the biggest problems that a new test laboratory can have is to establish itself as competent in a field. It is necessary to prove competency to accreditation bodies as well as to the industry. By being involved in interlaboratory comparisons and obtaining equivalent results to laboratories that have already proven their competency, the new laboratory`s credibility is established. It also proves the laboratory`s commitment to quality service.

In South Africa the South African National Accreditation System (SANAS), which is responsible for the accreditation of test and calibration laboratories, established such a programme for EMC test laboratories through a specialist technical committee (STC). The EMC STC consists of representatives of all the EMC test laboratories, accredited and not, in South Africa[1]. In addition to interlaboratory comparisons this STC discusses general issues relating to EMC testing and accreditation during its meetings.

5.2.1 What is an interlaboratory comparison?

An interlaboratory comparison can be defined as: *Two or more test laboratories agreeing to perform the same measurement on the same sample(s).* However, before the laboratories can start testing they have to reach an agreement on the sample to be tested, the test method to be followed, the time each laboratory will have to complete the measurements, as well as the connecting methods and cables.

1

The specific laboratories that took part in the interlaboratory comparison are not named in this thesis as result of a decision by the STC when the programme was started.

It is also good practice to agree beforehand what the limits are for acceptable results and what corrective action will be taken in the case of large discrepancies.

Therefore, after the measurements have been done, the results are compared. It should maybe be noted that an interlaboratory comparison should be seen as a means for a laboratory to gain confidence in its work and not as a means of discrediting other laboratories.

5.2.2 What are the rules of interlaboratory comparisons?

Having now defined an interlaboratory comparison, one should also ask how to go about performing the test work. Rules should be followed or it will be almost impossible to determine what went wrong if any large deviations occur. From interlaboratory comparisons that the writer has been involved in [1], [2],[3], numerous pitfalls were noticed. These pitfalls will now be discussed briefly to establish some "rules" for use during interlaboratory comparisons.

- *Conduct the interlaboratory comparison in exactly the same manner as any other test.* Any "special" measures taken to ensure the accuracy of the measurement should be recorded in the results as they could invalidate the measurement. One should keep in mind that although equipment can often measure more accurately than required one can still have significant errors due to operator mistakes, routing of cables or bad connections. The interlaboratory comparison therefore takes into account all factors affecting the quality of a measurement. It often happens that one does not realise that some of these measurement errors are present until the results are compared with other laboratories. Although laboratories taking part in the comparison should not share the results until everybody has completed their measurements, they should discuss any problems encountered during the measurements. By doing this, unnecessary re-measurement can be avoided.
- *Decide at the start of the comparison how large discrepancies will be handled.* Although it is desirable to have no large discrepancies, they do invariably occur - [1], [2], [3]. It may happen that a laboratory has to

introduce some corrective action, and it is therefore important to decide beforehand how these situations will be handled.

- *A person not involved in the measurements should do the compilation and evaluation of the results.* This avoids any possible questioning of the presentation of the results and interpretation thereof. Since this person has no vested interest in the comparison he can independently assess the results and facilitate the process of corrective action if needed. Although interlaboratory comparisons are done with the intention of proving the credibility of each of the participants, the results should still be treated as confidential. A laboratory should know at the end of the process how it compares to other laboratories and which results are its own. It is however preferable that one laboratory does not know which results belong to the other participants. This is important since problems with competition between laboratories will arise when large differences are present between results. The independent person who is facilitating the process must ensure this confidentiality.
- *Interlaboratory comparisons always have to be done according to an agreed-upon method.* During the comparison described in [1] the test method was not well defined. It resulted in two laboratories following one method and obtaining one set of results and three others following another method that yielded results offset by as much as 30dB. Obviously the results of this comparison could not be used to establish the credibility of the laboratories. For this reason it is necessary to establish the method before any measurements are done.
- *The setup used and results should be reported as completely as possible.* This is also necessary to allow the coordinator to establish the reasons for discrepancies when they arise. In the comparison described in [2] a narrowband generator was measured. If the one laboratory performed its measurements, by accident, with an measurement bandwidth of 10kHz it will obtain results very different from the laboratory using a measurement bandwidth of 120kHz. Depending on the sample used in tests like those described in [1], [2] and [3] one finds that small differences in any one of the following parameters may have a significant influence on the result: measurement bandwidth, frequency step size, measurement

time and detector type.

- *The data comparison method used during the evaluation of the measurements.* Depending on the type of results obtained and the ultimate purpose of the measurements one may choose one, or more, of a number of data comparison techniques. A good overview of some of these techniques are given in [4]. A lot of time on a visual comparison should be sufficient, but one may require more advanced techniques, depending on the application and data. In the next paragraph a few of these techniques will be used to illustrate how they work.

5.2.3 Results of an EMC interlaboratory comparison

During 1999/2000 three interlaboratory comparisons were completed [1], [2] and [3], and another one is in progress within the SANAS STC in South Africa. Some of these results will not be discussed in this thesis but is left for the reader`s own study. Instead only the results of [2] will be discussed, analysed and presented here.

During this comparison the conducted emission of a narrow band noise source was measured. Figure 2 shows the results obtained by the six laboratories. From a visual inspection, all the laboratories, except one, obtained acceptable results - i.e. Lab 5. One of the shortcomings of this interlaboratory comparison was that the acceptance criteria was not defined beforehand. As it turned out the participants discussed the results at a meeting and decided that, since this is one of the first EMC interlaboratory comparisons that results showing the same tendency, without being erratic, would be acceptable. To the purist this criteria might seem to vague. For the laboratories in question this was acceptable, as they only wanted to see what kind of results can be obtained, and what problems one can associate with this kind of measurement campaign. In the writers' opinion the comparison between the laboratories was not very good. The difference between the laboratories' results should be much smaller. The main aim of the comparison, however, was to get an interlaboratory comparison programme started in the country. Results that correlate well would have been a bonus. As a result of the measurements, laboratory 5 will have to implement some corrective action to eliminate the problem. It is, however, not the aim of this thesis to discuss this laboratory`s mistakes.

Another way of comparing the results, apart from visual examination, is to compare each laboratory`s data with a set of reference measurements. Such a reference set of measurements can be the calibration data of the device being measured. Normally the reference data is obtained by comparing it to a more accurate device or standard. For instance one would not use a frequency counter that can display the frequency of a device as 10.002 MHz to calibrate a device up to three decimal placed or more. One would at least use a frequency counter that can display four digits after the decimal point, i.e. 10.0020MHz. The main requirement, however, for the reference measurement is that it should be more accurate than measured data. The data depicted in figure 2, for each laboratory, was therefore plotted with the calibration data (obtained from a SANAS accredited laboratory) as well as with the difference between the measured value and the calibration data. Figures 3 to 8 show these results for each laboratory.

From figure 3 it can be seen that this laboratory`s results compares reasonably well with the calibration data up to 20 MHz (±3dB). Thereafter the difference increases drastically. This is probably due to the fact that the losses in the line impedance stabilization network (LISN) used become significant. One may argue that a 3dB margin is not very good. However, if one remembers that this comparison was done to establish some baselines for future comparisons, and if one compares this laboratory`s results with some of the other laboratory`s efforts, then the 3dB margin is not too bad. The important point to notice is that the difference between the calibration and measured data is a smooth curve. Compensation for the error can therefore be considered, which would make much more accurate measurements possible.

In figure 4, laboratory 2`s results are shown. Although the moving average of the difference might be good, a couple of large errors exist. The shape of the Delta-curve suggest that the measurement equipment (Receiver and/or LISN) have some resonant points or frequencies where accurate measurement is not possible. This laboratory will have to consider the calibration or repair of its equipment.

Figure 5 shows the results for laboratory 3. These results looks very similar to that of laboratory 2 (Figure 4). This laboratory will also have to investigate the reasons for the peaks in the difference between the measured and calibration data. The results in figure 6, laboratory 4, shows exactly the same tendency as figures 3, 4 and 5 with large resonant peaks. As discussed earlier laboratory 5 were unable to produce results that closely resembled the results from the other laboratories. This fact is emphasised by figure 7.

Figure 8 shows the results from laboratory 6. Apart from laboratory 1 this is the only result that showed an error that could be compensated. The difference between the measured and reference data below 20MHz is relatively linear and one could correct for this error by applying a correction factor. Above 20MHz two small resonant points exist. Laboratory 6 might want to adjust these points during the next calibration of the LISN, as it is probably due to components being used at frequencies higher than their capabilities. High capacitance capacitors, typically electrolytic and tantalum are notorious for their resonant peaks at higher frequencies, and this is why it would be advisable to start investigating in this area.

A visual examination of the combined results can sometimes not be sufficient to determine how one data set compares with another. If the difference between data points is very small, the margin is very small or a very accurate comparison is required, then a numerical method would probably be more applicable. This would also be where a number of parameters, that are related to each other, are evaluated. In these cases one would probably be inclined to use a statistical method of comparing the data. It is however important to agree beforehand on the method to be used so that data can be presented in a compatible manner.

For instance, if the selected method requires five measurements at each frequency and it requires a set of reference measurements (calibration data), then it would serve no purpose to produce a set of data that contains one measurement per frequency or not to have reference measurements available [4].

For our purposes, to establish an interlaboratory comparison programme, the visual examinations shown in figures 2-8 were sufficient. Upon completion it was very obvious to each laboratory where its weaknesses lay, and how it performed compared to other laboratories.

At the time that this thesis was written the STC started the third interlaboratory comparison. This interlaboratory comparison is on radiated emissions. It is envisaged by the participants that this comparison will require a large amount of work. Much more preparation is therefore being done. In preparation, references such as [17] and [18] are studied. Radiated emission measurements can easily be influenced by many parameters, like the test setup, ambient conditions, and structures that are in close proximity to the test site. For these reasons, the results are eagerly awaited. It is also, true that with hard work one can obtain comparable radiated emission results on different sites [3].

5.2.4 Interlaboratory comparison figures

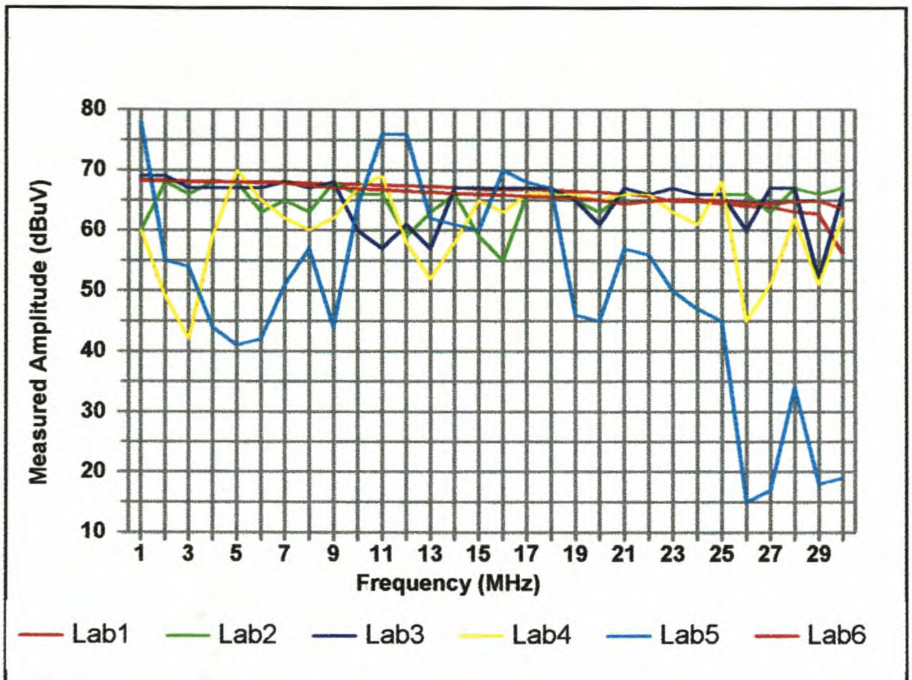

Figure 2: Consolidated results of comparison

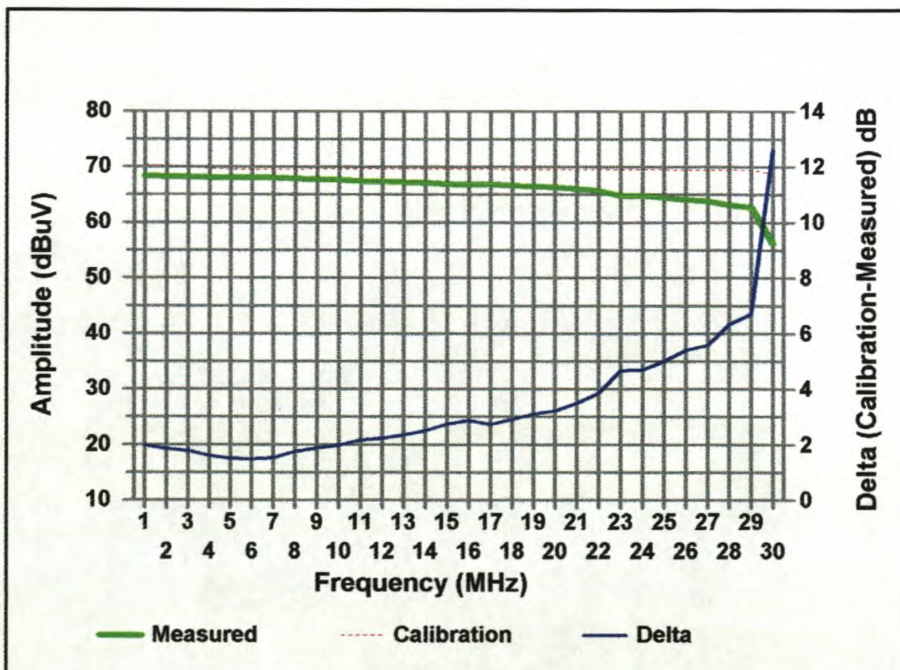

Figure 3: Laboratory 1 vs reference data

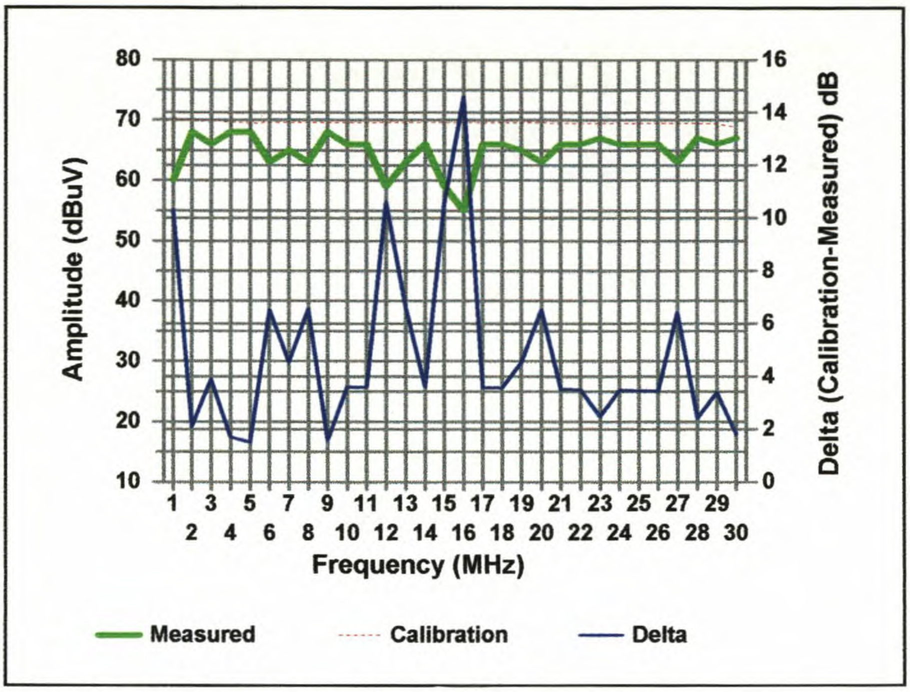

Figure 4: Laboratory 2 vs reference data

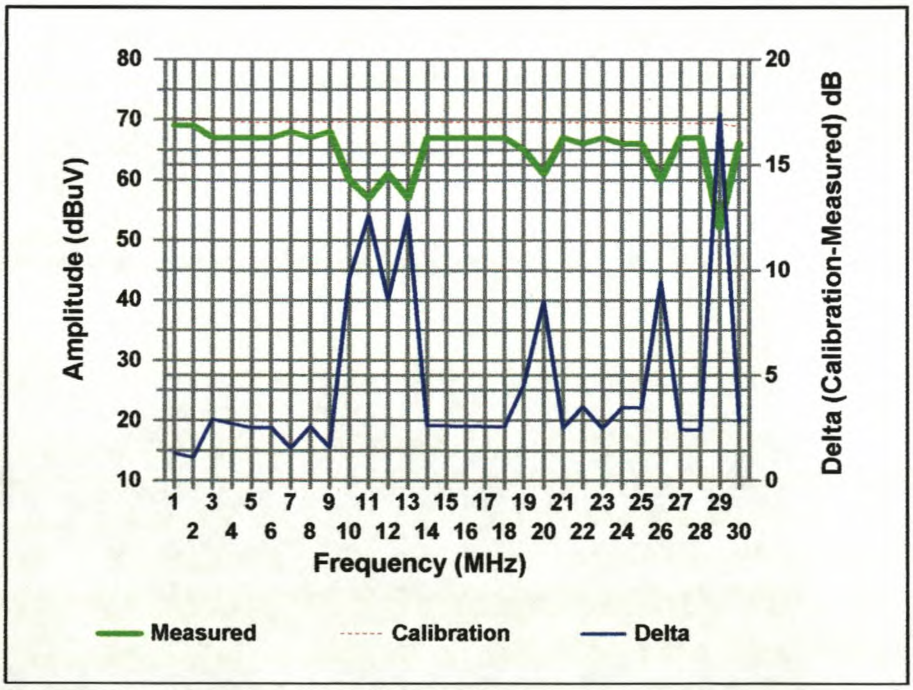

Figure 5: Laboratory 3 vs reference data

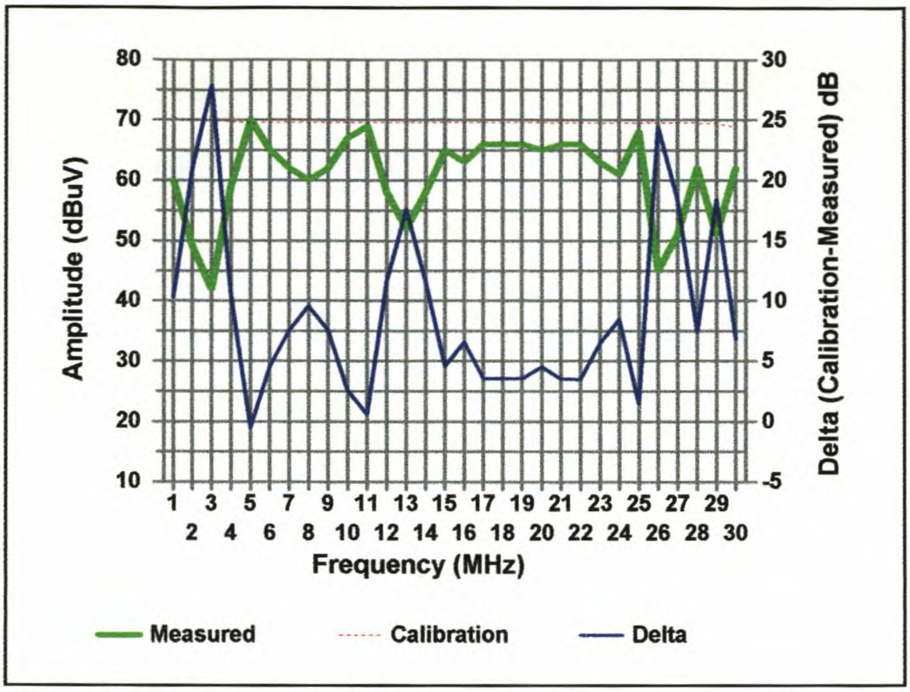

Figure 6: Laboratory 4 vs reference data

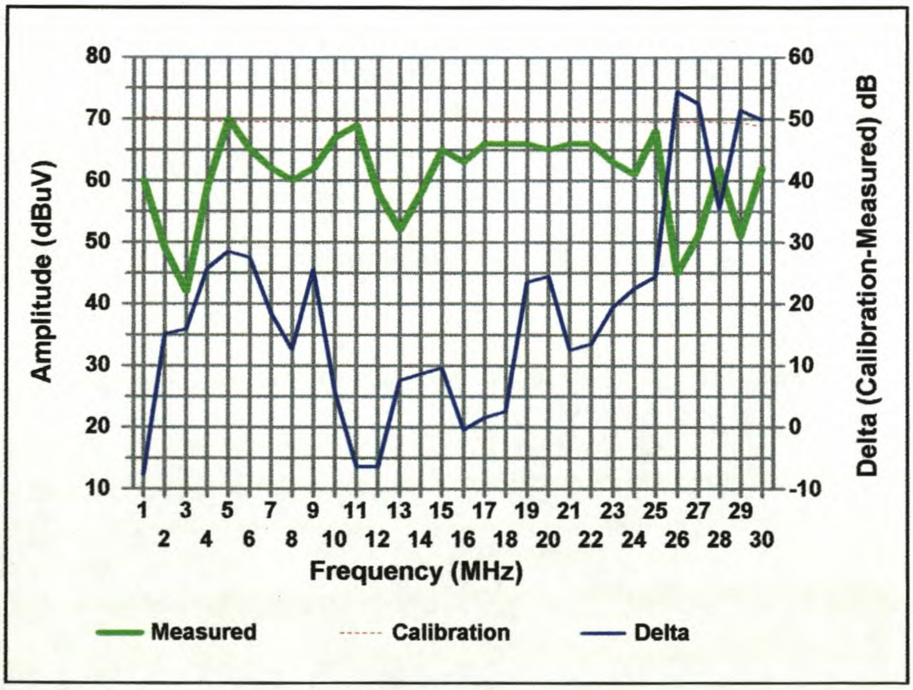

Figure 7: Laboratory 5 vs reference data

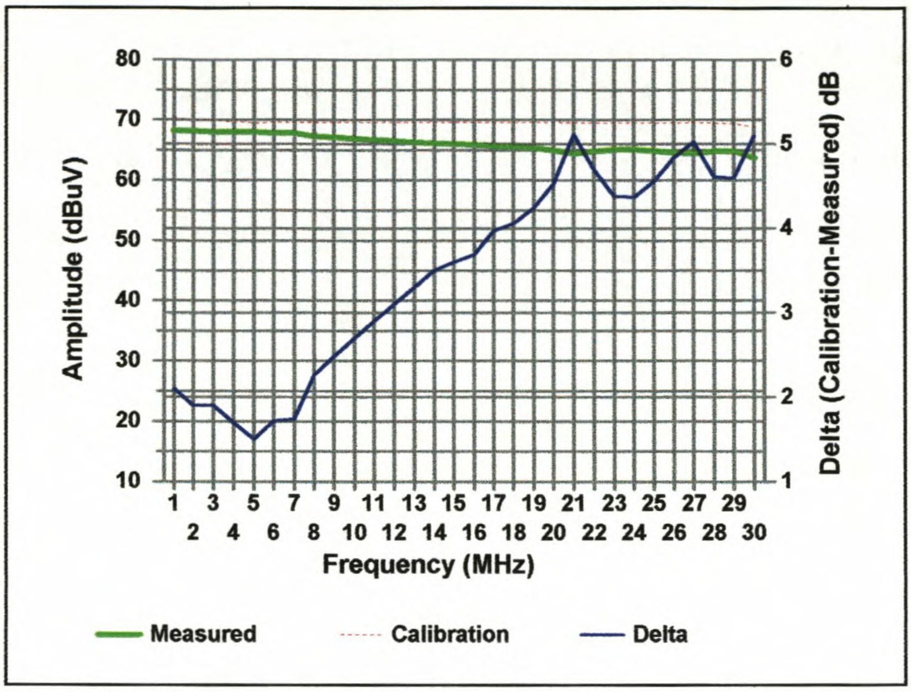

Figure 8: Laboratory 6 vs reference data

5.3 Comparison: "Traditional" vs. "Alternative" methods

5.3.1 Introduction

Unwanted electromagnetic energy that a device emits is traditionally measured in one of two ways. Firstly, at the low frequencies (typically below 30MHz) in terms of conducted emissions and secondly, at the higher frequencies (above 30MHz) in terms of the radiated emissions. Typical international standards that contain the methods are CISPR 11[5], CISPR 13[6], CISPR 14-1[7], CISPR 15[8], CISPR 22[9]. The reader should be aware that these standards are not the only international standards that can be used. Many local deviations to these methods also exist. These are, however, the most widely used standards for the measurement of the emission of electromagnetic energy. Some of these standards have alternative methods for some of the tests, due to operating manner of the equipment under test. An example of such a method is the "click-rate" test of CISPR 13 [6]. Within these measurement methods the measurement of radiated emissions has, over the years, proven to be the more complex one to do in a reliable and repeatable manner. The test setup is more critical and the test equipment more expensive than for many of the other tests.

In the rest of this chapter four alternative measurement techniques, to the standard OATS radiated emission test will be discussed. That is the use of a Bersier probe, Rogowski coil, bare shielded enclosure and the use of a current probe for common-mode current measurements. Practical current probe, shielded enclosure measurements and a comparison of these results with the reference Open Area Test Site (OATS) measurements described in the above-mentioned standards will be presented. The reason why the shielded enclosure is introduced as a possible alternative measurement technique is that it is relatively easy to build such a chamber. Such a chamber can also assist to shield the equipment from the many ambient signals present in most environments. Variations of the shielded enclosures are also given as alternative test sites in standards such as CISPR 16-1 [13].

It is a well published [10], [11] fact that common mode current is a major threat in achieving EMC compliance of equipment. The Bersier probe, Rogowski coil and current probe are three ways of measuring this common mode current. A brief overview of the first two measurement techniques will be given together with a complete experiment with the current probe. If it can be shown that these methods provide a worst case measurement and that the results are comparable with the OATS measurements then these methods can considered as an alternative pre-compliance method or a method that can be used for in-house testing. The main advantage of using one of these three methods is that the cost of the required test equipment is much lower than that of the traditional methods.

During the various measurements the same setup was used. This setup is discussed in paragraph 5.3.2.

5.3.2 Overview: Bersier probe and Rogowski coil methods

5.3.2.1 Bersier probe

At the time when the idea of testing equipment for radiation of unwanted electromagnetic energy (EMI) was developed, the Bersier probe was developed to test audio and video equipment. The probe was initially used for immunity testing of this equipment. There is however no reason why the application of the probe can not be reversed to measure EMI. This suggestion was also made in [11].

From the circuit of the Bersier probe given in figure 9 it can be seen that the EUT is connected to its ancillary equipment via a series common mode choke. The input also has a 100Ω and a 50Ω resistor in series to ground. This 150Ω matches the 150Ω seen by the other side of the EUT ((75Ω//75Ω)+62.5Ω+50Ω). The choke is inserted to block ambient noise from being injected into the EUT and measurement receiver via the ancillary cables. In this case the measurement receiver is connected to the REC inputs. It should be noted that the receiver is connected between the resistor tap of the probe and earth. This earth is connected to the reference earth plane of the test setup.

Three important facts to notice from this circuit is that the input impedance of the probe is 150Ω, physical components are used and the measurement is done in-line. This can be a problem in some applications as intrusive measurements may be difficult or inconvenient to do at times. The fact that physical components are used will cause a limited frequency range that a specific probe can be used in. One would therefore require a range of Bersier probes to cover a frequency band. A positive note regarding the Bersier probe that can be noted, is that the probe isolates the loop through the probe and thereby it removes uncertainties from different loop sizes from the measurement. From basic antenna theory [11], [14] the E-field at a distance **r** from a half-wave dipole when a maximum current of **Im** flows is given by:

$$|E| = \frac{60 * I_m}{r} \qquad (1)$$

Substituting 30dBuV/m (limit value for radiated emission in CISPR standards below 200MHz) for **E** and 10m (standard CISPR measurement distance) for **r** gives a maximum current, **Im** of 5uA. With this fact in mind one can consider the claims [19] that when less than 5uA common mode current is measured then the radiated field is not likely to exceed 30dBuV at 10m. The aim of using the Bersier probe would therefore be to measure the common mode current to decide whether the EUT will, with a high probability, meet the limits of the CISPR standards. The one fact that one must however also keep in mind is the fact that, although many EMI problems are caused by common mode currents, one does have other scenarios where other factors cause the equipment to fail. Examples of these scenarios are harmonics of clock frequencies, differential mode problems and general oscillations or resonances. It would also be impossible to use the Bersier probe to measure emissions from a cellular telephone for instance. The phone runs off a battery and, since it is an intentional radiator, one would find that the bulk of the radio frequency energy in the phone would be related to the transmit frequency (carrier) and the data on the carrier. In such a case the OATS measurement scenario would probably be the best to use.

Another possibility that one must consider is the possibility of simulation. In equation 1 we have seen that the electric field can be calculated when the common mode current in a radiator is known. In the cellular example above, one should be able to predict a large component of the radiated field if the sum of all the common mode currents on the phone is known. Substituting this current into equation 1 yields one of the major electric field components. The use of simulation will however not be investigated further in this thesis as it is considered a subject on its own.

5.3.2.2 Rogowski coil

Another alternative measurement tool that can be used is the Rogowski coil - see figure 10. This air-cored toroidal pickup coil originated in the power measurement field. It works on the principle that when a current carrying conductor is passed through the probe an electromagnetic field will be generated due to the current in the conductor. This field is then measured by the probe. The main difference between this probe and a normal magnetic current probe is that it has a air core instead of a metal core.

To this there are some positive and negative. The air filled core can handle more power where the normal current clamp will saturate at a point. The current clamp will however allow you to measure smaller signals due to better coupling. The biggest advantage of the Rogowski coil over the Bersier probe is that it is non-intrusive. The Rogowski coil can also easily be manufactured and is much cheaper than an off-the-shelf current clamp.

More information regarding the theory of operation and the design of Rogowski coils can be found in texts such as [11] and [12]. The method of calibration of the Rogowski coil and the method of use is exactly the same as that of the current clamp discussed later. The same type of curve is also found when the amplitude of the transfer impedance is plotted against frequency [11]. This curve varies and may need to be adjusted for optimum performance depending on the application.

According to [11] parameters such as the radius of the loop ($R \propto 1/Zt$), radius of a winding ($r \propto Zt$) and the number of turns ($n \propto 1/Zt$) can be adjusted to obtain different transfer impedances versus frequency curves.

5.3.3 Current probe calibration

For the purposes of this thesis a Rhode & Schwarz EZ-17 current probe was used. A photograph of the probe is given in figure 11. The probe clips around a cable, and has a quoted operating range of 20 Hz -200MHz. When connected to an EMI receiver a voltage is returned, which in turn can be converted to a current. The relationship between this voltage and the current is given by the transfer impedance (Z_t) of the probe. The calibration of the probe entails calculating this transfer impedance from the measured s-parameters of the probe over the frequency band in question.

The EZ-17 is supplied with its calibration fixture. This is done to ensure that more reliable and repeatable results can be obtained. In figure 12 a photograph can be seen of the probe inserted in this fixture. From the photograph it can also be seen that the probe is connected to port 2 of an Automatic Network Analyser (ANA) and that the conductor passing through the probe, which is terminated in a wide-band 50 Ω load, is connected to port 1. The ANA was setup to return, in a text file, the real and imaginary parts of the four s-parameters. These s-parameter files were in turn used as input files to a MATLAB program. From this program a output file was obtained that returned the transfer impedance of the probe. The equations used in the program can be defined as follows. The s-parameters are placed into a matrix, equation 2, where $Z_0 = 50\Omega$ and U is given by equation 3. The Z-parameter matrix, equation 4, can then be calculated from equation 5. The transfer impedance at a frequency, f, is then given by equation 6.

$$S(f) = \begin{bmatrix} S_{11}(f) & S_{12}(f) \\ S_{21}(f) & S_{22}(f) \end{bmatrix} \quad (2) \qquad U = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad (3)$$

$$Z(f) = \begin{bmatrix} Z_{11}(f) & Z_{12}(f) \\ Z_{21}(f) & Z_{22}(f) \end{bmatrix} \quad (4)$$

$$Z(f) = Z_0 * ((U - S(f)) * (U + S(f)))^{-1} \quad (5)$$

$$Z_t(f) = \frac{Z_{21}(f)}{(1 + \frac{Z_{22}(f)}{Z_0})} \quad (6)$$

In figure 13 the quoted transfer impedance (from the manufacturer) as well as the measured transfer impedance of the probe is shown. From the graph it can be seen that a small difference exists between the two sets of data. This difference is probably due to the combined effect of a number of factors, which are listed below:

- Differences in test setups with ground planes between original measurements and these measurements. The main problem being that very little information is available regarding the exact test setup of the manufacturer.
- Inaccuracies in the network analyser used - several problems had to be overcome with the instrument, that caused the writer to question some of the parameters. The error was however constant, and exactly the same results were obtained when the calibration process was repeated.
- Mishandling of the current probe, as the probe is approximately 7 years old. The kind of handling that the probe was to subjected to is unknown as it took place before the writer joined the company.

These factors are listed as examples of possible problems. Since the difference between the two sets of data is not considered to be significant, a deeper investigation into the problems was not done. Since calibration data for the probe has now been obtained one can use the probe to make a set of measurements.

5.3.4 Setup of device under test

A parallel wire - figure 14 - that is connected to the noise source was chosen as a test sample. The noise source is a RN512 narrowband noise generator. The generator generates a peak every 5MHz in the band 30MHz and 1GHz. In the 30 - 200MHz band where the measurements were made the amplitude of these peaks are 60dBuV±3dB. Since the generator is battery driven the current measurements does not introduce any laboratory common mode paths, which would give unreliable results.

The wire was placed on a non-conductive table 0.8m above a ground plane. The piece of wire on the table, parallel to the ground plane, was 1.2m long. The parallel wires were terminated in a 51Ω ceramic surface mount resistor. It is recognised that the characteristic impedance of the wire is not terminated by the 51Ω. The common-mode impedance termination of both wires to ground was therefore an open circuit. This fact therefore prevented common mode measurement data from being gathered from this experiment

The reasons for choosing this setup were:

- The setup contains a horizontal (wire lying on top of the table) and vertical component (wire running from tabletop to generator) that represents both types of polarisations that one will find on normal test samples.
- The setup is easy to assemble and can reliably be transferred to another location for the purpose of doing more measurements.
- The setup is well defined and can be reassembled without accidentally changing a critical parameter.
- Only one variable exists in the setup that may significantly influence the measurements. That is the voltage level of the generator`s batteries. To counteract this effect the batteries were charged approximately every two hours. According to their specifications they should last for in excess of four hours without a significant drop in signal output.
- The generator gives out distinct stable frequency peaks that could be measured and re-measured.
- In order not to introduce unnecessary variables during the tests the sample was placed on a table of height as described in CISPR 22 [9]. This setup would be identical to the setup used for the radiated emission test on the OATS.

From figure 14 the reader would notice that three measurement positions exist on the wire These positions are 300mm apart and position 3 is 300mm from the

51Ω resistor. Position 0, at the generator, can be seen in figure 15. During current probe measurements described later in the chapter, measurements were made at the three positions to determine the nature of any position-dependent components - figure 16. The height of the non-conductive table was 0.8m, as per the requirements of standards such as CISPR 22[9].

The reason for using this test setup for the experiments was to create a standard radiator whose characteristics such as differential mode signal current are well defined. Measurements of this standard radiator could then be compared between an OATS and other test methods.

5.3.5 Current probe measurements

A graph depicting the measured values with the current probe, for each position, is given in figure 16. As can be seen from figure 16, good correlation between results has been obtained for all positions except position 0. The reason for this might be coupling between the source and clamp or the different orientation of the probe with respect to the ground plane. One way to obtain a higher confidence level in the measurements, and probably a smaller difference would be to compare the average of five to ten sets of data for each position. This is however not a viable long-term practice as too much time will be spent on the measurements. In a normal laboratory one set of data will be taken, and therefore only one set of data at each position is used in this thesis.

5.3.6 Shielded enclosure: Radiated emission measurements

In CISPR 16-1[13], the international standard that describes the test equipment and environment that is to be used during radiated emission testing alternative test sites (to an OATS) may be used as long as the normalised site attenuation (NSA) of these sites is within ±4dB of the NSA of an OATS. The procedure for performing NSA measurements is described in paragraph 16.6 of CISPR 16-1 [13]. Many companies have found it necessary to consider using alternative test sites. Two main reasons exist for this. Firstly the frequency spectrum is extremely congested between 80MHz and 200MHz due to two-way radios, radio stations and television stations. Secondly the ambient noise floor varies by as much as 10dB at certain frequencies in this band. The reason for this is that the amplitude of the signals mentioned in the first point is not stable. These factors make it extremely difficult to accurately and reliably make measurements on an OATS.

The solution would then be to go into a shielded enclosure for measurements. Although the ambient signals are now not present, or highly attenuated, one finds that other problems exist. One such a problem is the presence of reflections from the chamber walls, and ceiling. The use of a non-absorber lined chamber is not an allowable method for full compliance testing in standards such as CISPR 16-1[13]. The main reason for this is that during comparative testing performed around the world, the measurements were very dependent upon the size of the chamber and the equipment under test. Reliable, accurate measurement could not be made. There are, however, other methods where chamber testing are allowed in CISPR 16-1[13]. The first is where a full-anechoic chamber is used. The main requirement for this chamber is that the measurements made inside the chamber should be traceable to measurements made on an OATS. The reason for the absorbers is to stop reflections from the walls, ceiling and floor from reaching the measurement antenna. These absorbers are, however, very expensive and decreases the usable size of the chamber considerably.

It would therefore be significant if a method can be found for which extensive absorbers would not be required and where the effect of the reflection from the walls, ceiling and floor of the chamber can be compensated for or cancelled out. Such a technique does exit and is allowable in terms of CISPR 16-1[13] for full compliance EMI measurements. This technique utilises a Mode-stirred chamber. The basic principle of operation of this chamber is: If one can excite and scatter the reflections inside the chamber enough then one would be able to obtain a stable, nearly uniform electromagnetic field inside the chamber. Measuring a stable uniform field is simple and it has been shown [15], [16], that such measurements can be made very accurately. Mode-stirred chambers warrants a separate study. For this reason only this short introduction is given in this thesis. More information can be found in texts such as [15] and [16] compiled by the leading world expert in mode stirred chambers, M.O. Hatfield.

Let`s now consider the bare shielded enclosure, to establish how large the problem of reflections are and whether there is any use for the chamber in the pre-compliance test scenario. Therefore if a shielded enclosure (absorber-lined or not) is to be used for radiated measurements then it is necessary to know how the range of results taken inside enclosure, relates to those taken on an OATS. Once this understanding is established, one has the ability to predict whether equipment tested in a chamber would pass or fail when tested on an OATS.

With this knowledge one can then specifically focus on the peaks close to the limit line (prescribed by the relevant product standard, eg. CISPR 22) on the OATS. By doing this one can avoid problems from some of the ambient signals. A more rigorous approach would be to adopt a fully fledged mode stirred chamber [15], [16].

The measurements inside the chamber were done with the antenna and sample 3m apart and the horizontal part of the sample on a non-conductive table 0.8m above a the floor (ground plane). The tests were done along the long axis of the enclosure. The dimensions of the shielded enclosure was 6.0m (length) x 3.6m (width) x 2.44m (height). The antenna, a Chase Bilog antenna, was installed in such a way that the middle beam was 1.2m above the floor. The measurements were done in both the horizontal and vertical polarisations. No height variations were done due to the restrictions that the chamber poses. The measurement results are given in figure 17.

5.3.7 OATS measurements

When comparing results from tests conducted on an OATS with those in a chamber the sample being used can introduce a number of variables. Such variables include additional reflections or at least different reflection patterns, different results if measurements are taken from the one side instead of from the other, and differences in cable routing. The most influential factor on an OATS that influences results is the ambient noise. To try and minimize these factors a simple, repeatable test setup was used. The same setup, as was described for the chamber measurements, was used on the OATS except that the antenna height was varied between 1m and 4m - as required by standards such as CISPR 22[9].

The OATS used for the measurements is located at ITC Services in Pretoria, and was chosen due to its availability and the fact that it has a better ambient noise profile than other sites in Pretoria. From figure 18 it should be clear to the reader that when measurements have to be taken in the region of 100MHz that the noise would overshadow and signal. This is especially true when the fact is considered that the CISPR 22 class B limit is 30dBuV at 100MHz at a test distance of 10m. Other peaks often also cause problems. An example can be seen at 120MHz. In a case where the 3rd, 5th or 7th harmonics of and oscillator in the EUT is significant it could easily overlap with this signal. Therefore the real problem is: According to a standard such as CISPR 16-1 one is required to measure on an OATS that cannot be used over the total frequency band. Alternative methods are also difficult to qualify as their correlation with an OATS must be proven. Some test laboratories have tried to use an approach where they measure the ambient signals prior to the actual test and then subtract these values from the EUT with ambient results. In the writers' opinion this is very inaccurate as this calculation is often only done by subtracting the amplitudes and ignoring the phase. This cannot be done as phase differences would exist between the two sets of data. A secondary problem is that ambient signal levels are not stable, making it difficult to know exactly what level to subtract.

For the test setup described earlier in the chapter the radiated emission results are given in figure 19. The results for the two polarizations have been maximized for height as required by standards such as CISPR 22[9]. Maximizing a measurements for height entails taking measurements with the antenna moved between 1m and 4m above the ground. The maximum measurement for the frequencies close or above to the limit line is then recorded. Each of these frequencies are also measured with the antenna horizontal and vertical. It could therefore happen that the maximum amplitude for one frequency is in the vertical polarization at a height 1m above the ground and for another frequency 2m above the ground in the horizontal polarization. A couple of points should be noted when looking at figure 19:

- The results show emission in excess of the CISPR 22 class A and B limits.
- Large amounts of emission are present in the 100MHz region where significant ambient signals are present.
- The horizontally polarized results are much smoother than the vertically polarized results. For instance at approximately 70MHz the vertically polarized results shows a significant peak. This peak may be due to a reflection from a cable or building or it may be from an intermittent ambient signal.

5.3.8 Discussion

Figure 20, depicting all the results from the previous paragraphs shows some very interesting facts. The first fact to notice is that both the chamber measurements are significantly higher than the other three measurements. The chamber measurements are also much more erratic than the other three measurements. This is purely due to the reflections inside the chamber that cause resonances. The second point to notice is the close proximity of the probe measurements to the two OATS measurements. This especially true of the vertically polarized measurements. The reason for this is probably test setup related as the test setup has a 0.8m vertical wire above a ground plane. The emission from this wire is picked up in the vertical antenna polarization. From the writer`s own experience this is an important point as power cables of desktop equipment, was often found to be a significant source of emission. This would therefore result in an accurate measurement from the cable in a vertical polarization mode.

The main fact that the reader should notice is that it seems possible to predict with a reasonable amount of certainty, that when the measurements taken in a bare chamber are above the CISPR limit then there is very little chance of the equipment passing when tested on a OATS. One fact that is also true is that if a piece of equipment has very low emission levels then the chamber and OATS measurements would be much closer to each other, as the influence of the reflections in the chamber would be significantly reduced. It is possible to mathematically model a bare chamber and the test setup to predict the frequency and size of reflections. Theoretically one could then subtract - with due consideration to real and imaginary components of signals - the measured values from the calculated value to obtain the contribution of the UUT. Practically this would be a tedious exercise as this mathematical model will have to be adjusted for every test setup as cable orientations and the UUT shape and size would differ. This might however be a good subject for further study.

It is at this point where the real benefit of interlaboratory comparisons should become visible to the reader. If an alternative method, such as the chamber measurements, is compared with the standard measurements of a number of laboratories, then in-house testing , to such an alternative method becomes very viable. From the writer`s own experience the operator should be able to say with a large degree of certainty whether a units passes or fails the requirements of a standard such as CISPR 22[9], after a few interlaboratory campaigns. This sample principle can be applied to any other alternative method to prove the method.

5.3.9 Conclusion

In the first part of the chapter we have established some guidelines regarding interlaboratory comparisons. We have also looked at some practical results from an interlaboratory and we have seen how the data can be analysed. The main reason for presenting the interlaboratory comparison introduction and data was to show how a laboratory can use an interlaboratory comparison to establish the accuracy of his methods. This will be especially important to a laboratory using alternative measurement techniques as discussed in the second part of the chapter. As some of the laboratories that took part in the presented interlaboratory comparison realised, it is a very valid means of verifying standard measurement techniques, as well.

In our case one laboratory realised that they have serious problems that need to be addressed and the others got confirmation of how their results compare with that of the other laboratories in South Africa. Some of the laboratories can see that their equipment shows some resonant peaks which they may need to rectify. To the writer it proved that his newly established in-house laboratory could produce results comparable to the other (commercially) established laboratories. This gave him confidence in his methods and it established his credibility with the other commercial laboratories. In this lies the greatest benefit of interlaboratory comparisons.

Although the correlation that was obtained from the results could be much better, this showed many of the participants how to undertake an interlaboratory comparison, and where typical pitfalls can be found. This by itself is very important information.

In the second part of this chapter we have seen that the OATS measurements are considered to be the reference measurements. We have also seen that a significant ambient noise problem exit when using an OATS. From this a need exists to find suitable alternative measurement techniques. However, before such techniques can be qualified a representative test setup has to be found that is suitable for both the alternative methods and the reference OATS measurements. For instance, a common impedance connection was required between the parallel wires of the test setup and the ground plane. This would have allowed common mode current measurements that could be compared with radiated emission measurements. From the one, suggested alternative measure ment possibility, the bare shielded enclosure, it was clear that it is difficult to obtain results that correlates well - within ±4dB as per CISPR 16-1 - with the OATS measurements, due to reflections. During the measurements we have also noted a number of problems that an operator is likely to experience. Knowing about these problems he can compensate for them.

5.3.10 EMC Measurement figures

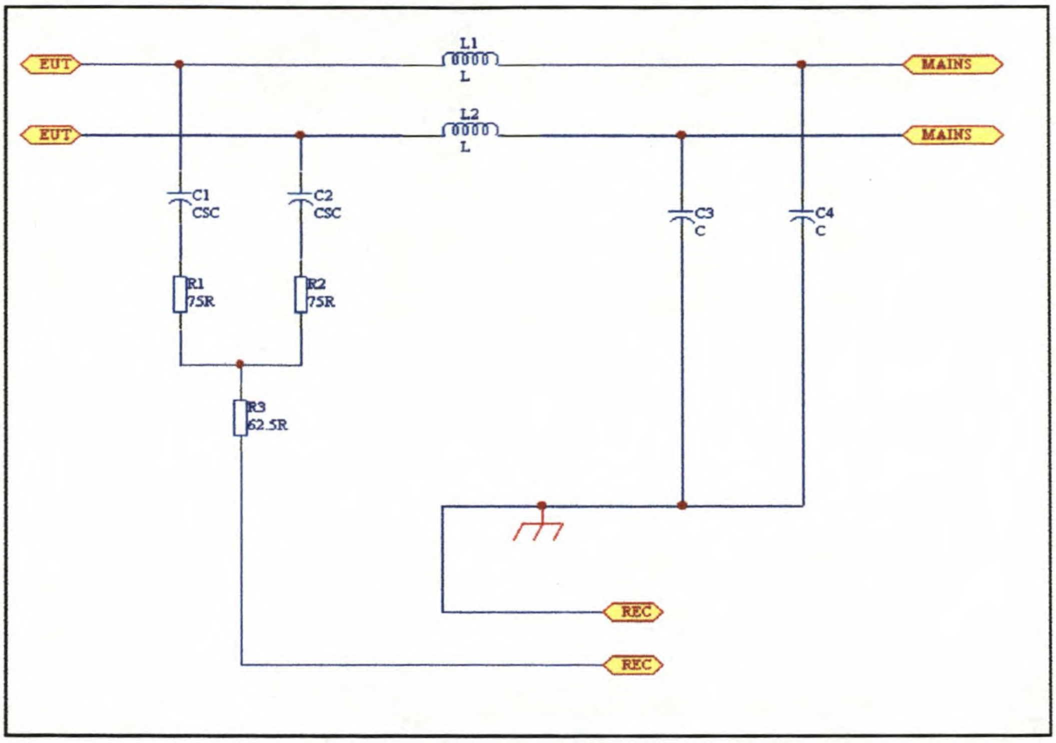

Figure 9: Bersier probe circuit

Figure 10: A typical Rogowski coil

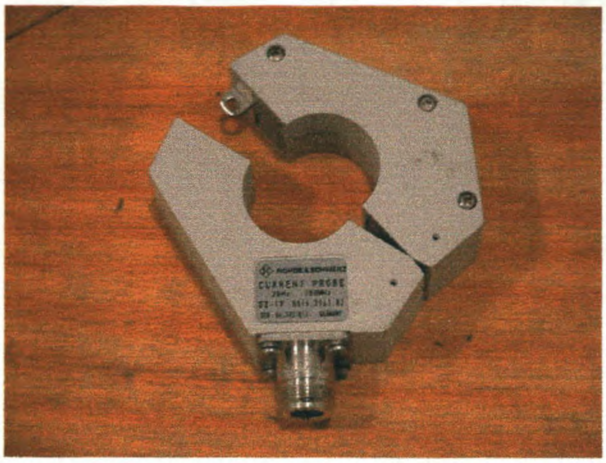

Figure 11: EZ-17 current probe

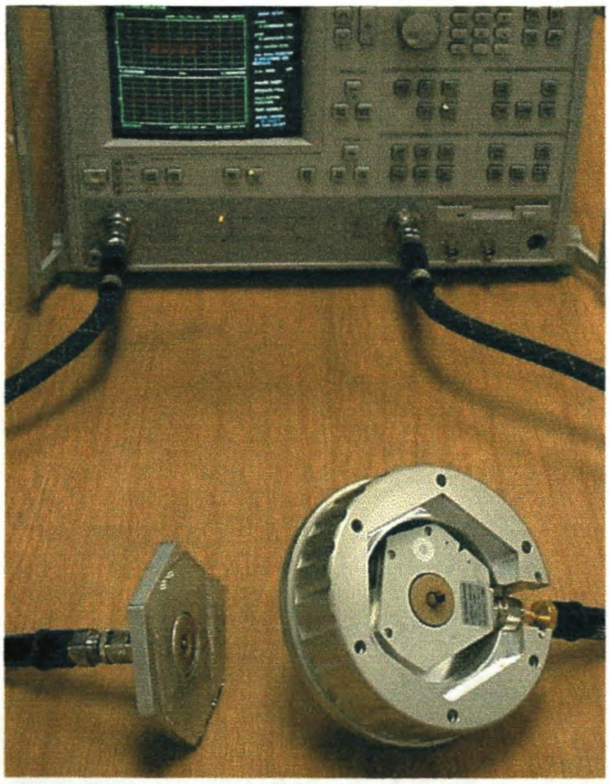

Figure 12: EZ-17 in its calibration kit

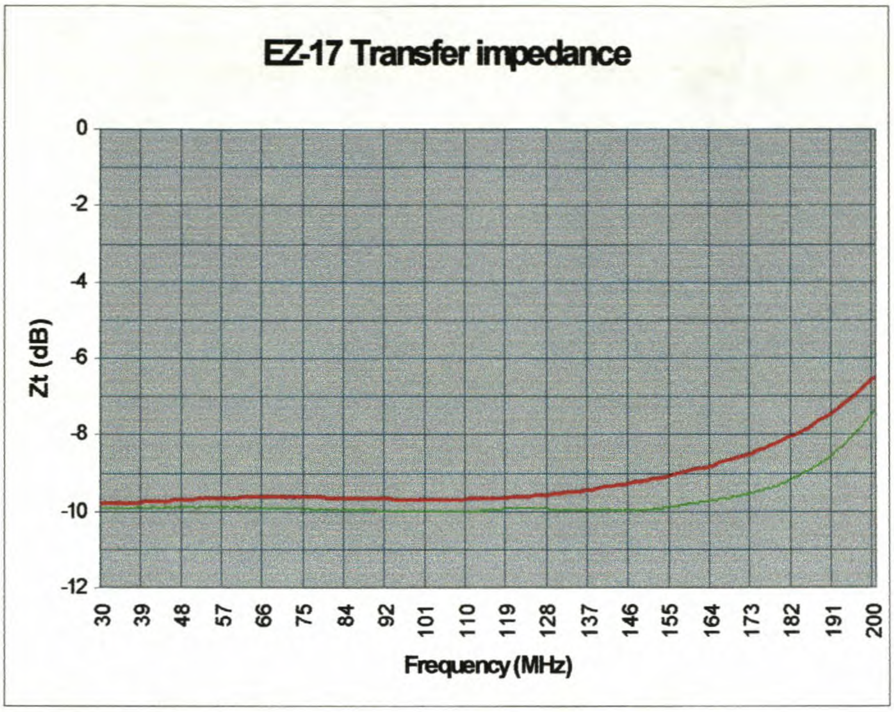

Figure 13: Measured probe data versus manufacturer`s data

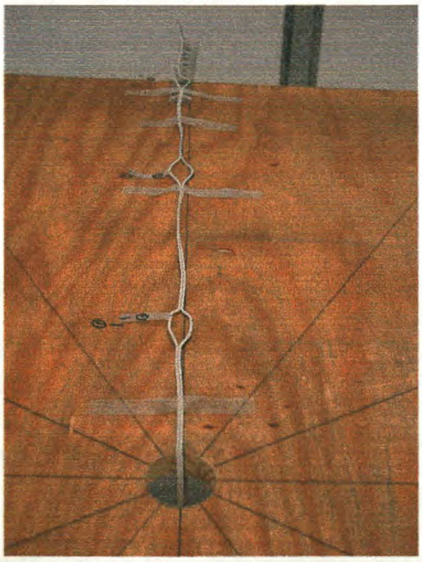

Figure 14: Test setup for current probe measurements.

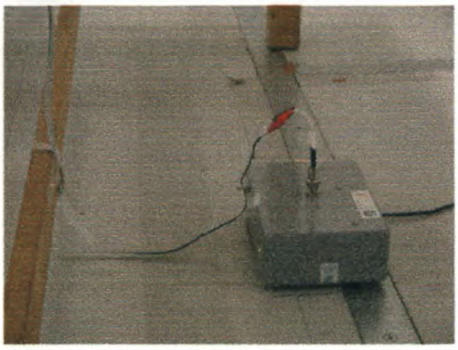

Figure 15: Generator used for current probe measurements

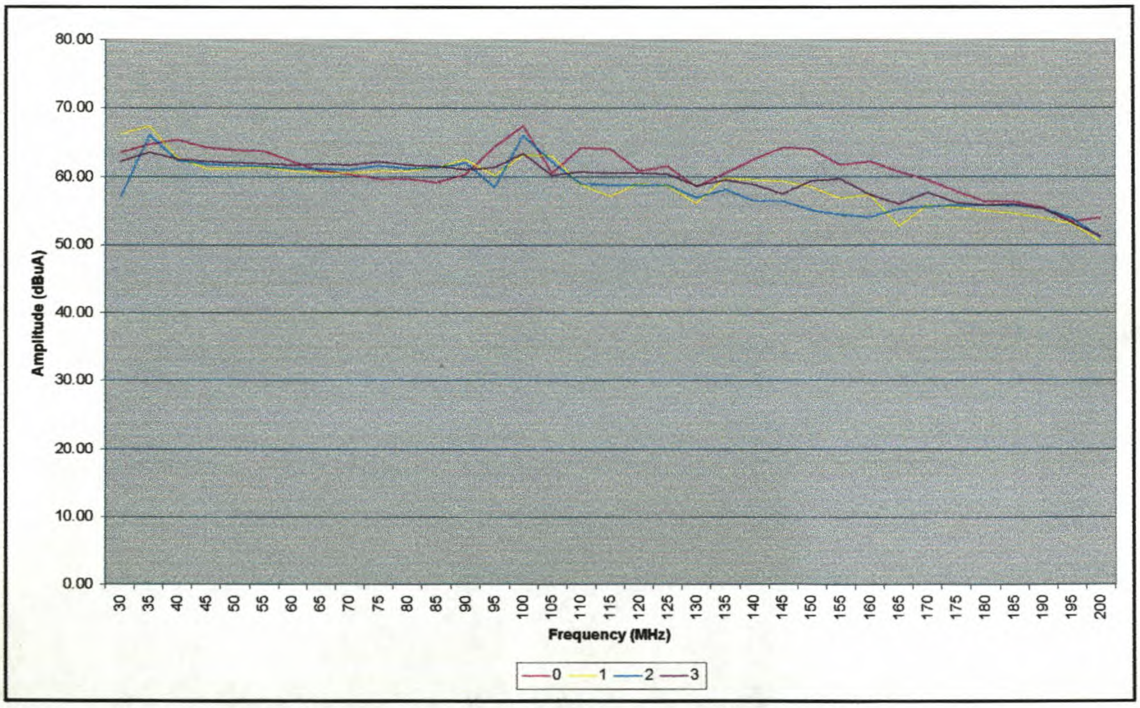

Figure 16: Current probe measurement: Position dependancy

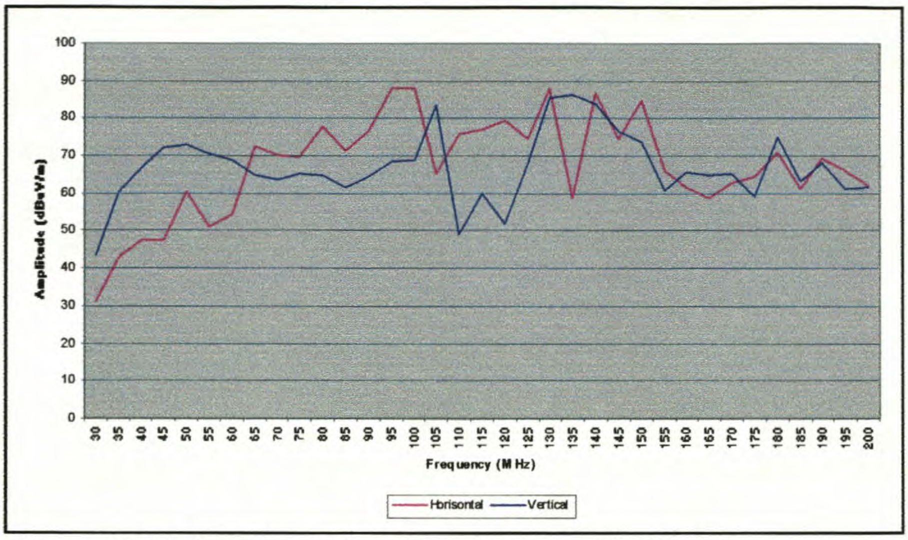

Figure 17: Radiated emission measurements: Chamber

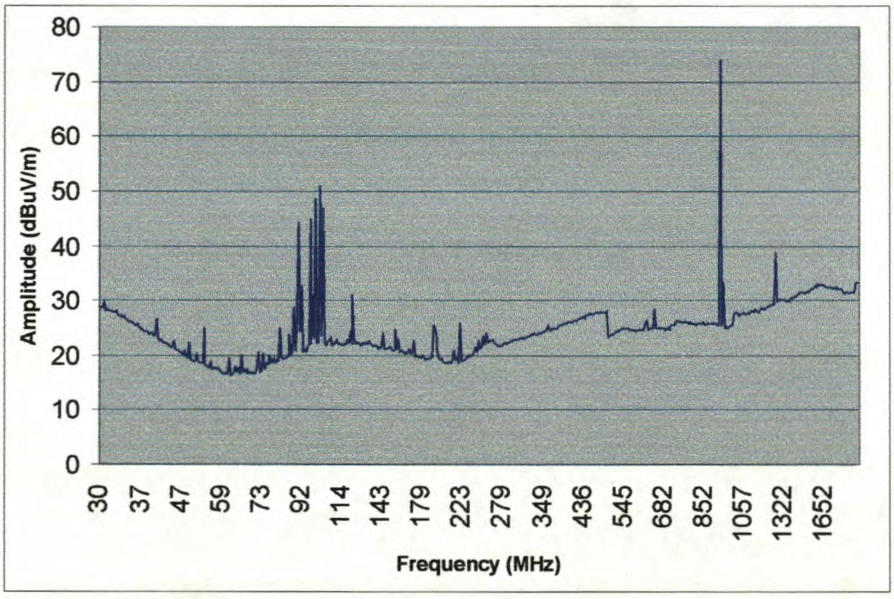

Figure 18: OATS Ambient measurements

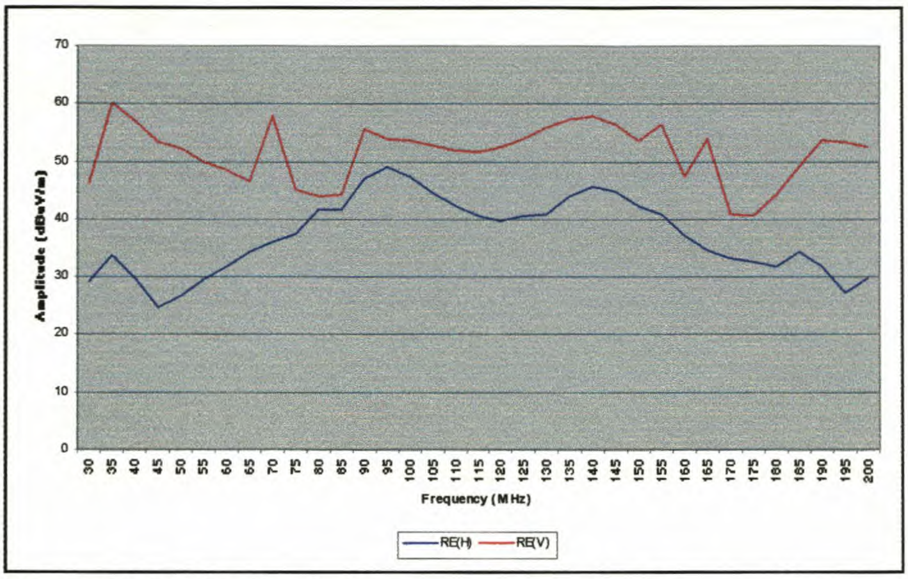

Figure 19: Radiated emission measurements: OATS

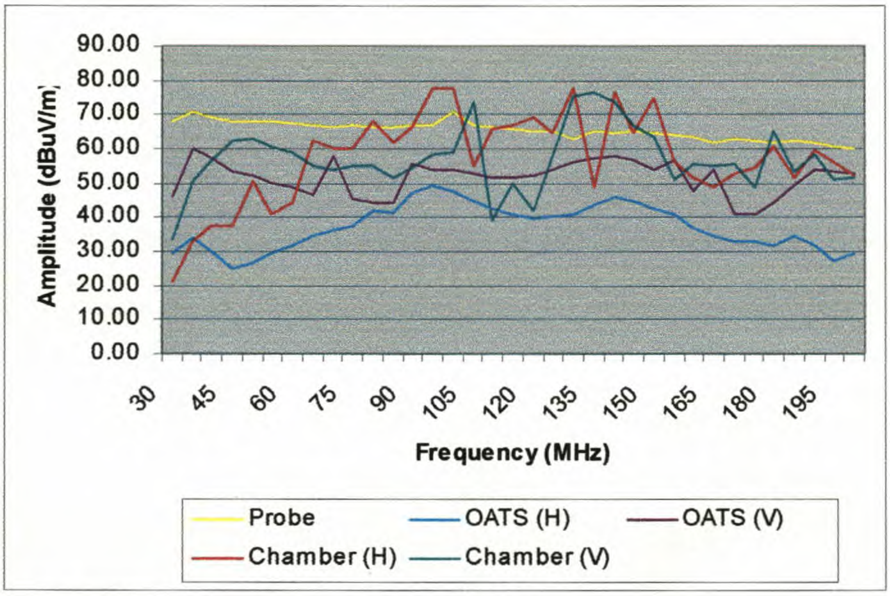

Figure 20: Consolidated measurement results

Notes:

1. The probe measurements were converted to field strength using equation 1. This is an approximation as the current in equation 1 is supposed to be the common mode current. As explained earlier, common mode current were not measured, and the conversion is therefore only for illustration purposes.
2. The unit of measure for the probe measurement was dBuV and for the OATS measurements dBuV/m @ 10m and for the Chamber measurements dBuV/m @ 3m converted to 10m with the following ratio:

$$dB_{10m} = 20 * \frac{Log_{10}(10)}{Log_{10}(3)}$$

5.4 References

[1] "EMC Interlaboratory Comparison 1 - Light ballast", Conducted Emission, SANAS, 1999

[2] "EMC Interlaboratory Comparison 2a - Narrowband sample", Conducted Emission, SANAS, 2000

[3] "EMC Interlaboratory Comparison 2b - Broadband sample", Conducted Emission, SANAS, 2000

[4] "An advanced reliability function for data comparisons", AJM Martin, AP Duffy, MS Woolfson, TM Benson, Satcam 2000, Somerset-West South Africa, October 2000

[5] "CISPR 11: Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 1999

[6] "CISPR 13: Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 2001

[7] "CISPR 14-1: Electromagnetic compatibility - Requirements for household appliances , electric tools and similar apparatus - Part 1: Emission", International Electrotechnical Commission, Geneva, 2000

[8] "CISPR 15: Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment", International Electrotechnical Commission, Geneva, 2000

[9] "CISPR 22: Information technology equipment - radio disturbance characteristics - Limits and methods of measurement", International Electrotechnical Commission, Geneva, 1997.

[10] "EMC for product designers - Meeting the European EMC Directive", Tim Williams, Second edition, 1996, ISBN: 07506 24663

[11] "An Electromagnetic Compatibility Philosophy and appropriate techniques - A low cost approach", JB Maree, University of Stellenbosch, December 1998

[12] "Machinable Rogowski coil, design and calibration", IEEE Transactions Instrumentation and Measurement, vol 45, no 2, pp 511-515, April 1996.

[13] "CISPR 16-1 including Amendment 1: Radio disturbance and immunity measuring apparatus and methods. Part 1: Radio disturbance and immunity measuring apparatus", International Electrotechnical Commission, Geneva, 1997

[14] "Electromagnetic concepts and applications", Stanley V. Marshall, Gabriel G. Skitek, Third edition, Prentice-Hall, 1990, ISBN: 013 247 8420

[15] "Reverberation characteristics of a large welded steel shielded enclosures", Michael o. Hatfield, Gustav J. Freyer, Michael B. Slocum, IEEE Symposium on electromagnetic compatibility, August 1997

[16] "Reverberation chamber theory/experiment short course", Naval Surface warfare center, Dahlgren, USA

[17] "Assessment of Uncertainties of Measurement in calibration and testing laboratories", Ron Cook, NATA, Australia, 1999

[18] "ILAC G17-2002: Introducing the concept of uncertainty of Measurement in Testing, in association with the application of standard ISO/IEC 17025", ILAC, Australia, 2002

[19] "Electromagnetic compatibility", Jasper Goedbloed, Prentice Hall, 1990, ISBN: 013-249293-8

Chapter 6 - Proposed EMC framework

6.1 Introduction

Now that we have considered what philosophy other countries applied when they created their EMC legislation (Chapter 2), with what standards they require compliance (Chapter 2), how the probability of obtaining compliance through design can be increased (Chapter 3 and 4) and what testing options we have (Chapter 5), we can consider some options for South Africa. As was mentioned earlier, South Africa`s legislation is very old and does not cater for modern equipment and the modern certification environment. The main need for updating the legislation therefore lies in the fact that we need to align South Africa`s legislation with that of the rest of the world. It is necessary to consider that the South African market is unique in the respect that it is much smaller - due to our smaller economy - than markets such as Europe, USA and Australia. In addition only portions of our market is exposed to and understand the latest technology, where this is not the case in the above mentioned markets. Certain unique considerations, and special provisions would therefore be appropriate.

6.2 Standards

Almost all the legislated EMC standards in the world today have their origin in the international standards developed and published by international organisations such as the IEC and ETSI. In terms of the GATT agreement, of which South Africa is a signatory, one may not restrict trade due to compulsory standards that are legislated. Signatories of this agreement are encouraged to make it as easy as possible for importers to gain approval for their products in the country, without compromising the safety and EMC of the products. The easiest way of doing this is to follow most other countries in the world in terms of EMC legislation and base our standards on the same international standards.

We can achieve this in one of three ways. Firstly by publishing requirements, based on the EMC standards, in the law for products. This is basically what South Africa has at this stage with the Radio Regulations Act. The problem with this approach would be that requirements will become outdated quickly because it takes time to obtain parliamentary approval for new laws. One also runs the risk that local legislation may start to deviate from international legislation, since two different bodies are responsible for the two sets of standards. The second way would be to write our own standards based on the IEC standards.

This is also not a good idea as once again two parallel development paths exist, which may result in diverging standards. The third and best option in the writer`s opinion is that South Africa declares the applicable international standards as compulsory after they have been adopted, without modification, as South African standards. South Africa has the option, which we should use, to add national deviations to such standards where required. The national deviations are used to cater for specific conditions in the country that they are applicable to, and is done through our involvement in the committees that write the international standards - refer to chapter 1.

Adopting international standards as national standards is not a new approach anymore as it has been used in many countries in the world, even in South Africa. Where South Africa is however still lacking is that many of these standards that were adopted as national standards have not been made compulsory through law. Before we can list any standards we need to consider the approval structure and specific requirements of each class of equipment.

6.3 Approval structure

When one considers the South African market then one quickly realises that it is relatively small and very price sensitive. It would therefore not be beneficial to introduce a very expensive approval process. The approval structure proposed below is therefore a combination of a number of structures used in other countries.

6.3.1 General structure

The proposed structure is based on the following five main principles:

6.3.1.1 *EMC Compliance is compulsory for all products manufactured in South Africa or imported into South Africa.*

No exceptions to this principle should be allowed. The onus is therefore on the manufacturer or importer to ensure that his product is compliant prior to placing it on the market. It will also ensure that for all products, without exception, retailers would know that they need to ask for compliance. One can use one of two approaches regarding policing the principle. The first way is to allow retailers to place a product on the market and when the inspection authority checks then they have to prove the compliance of the product. This is how South Africa`s current legislation is written. The onus is therefore on the policing authority to prove the non-compliance of the product. The second option is to explicitly require that a manufacturer or importer have proof available of the compliance of the product prior to it being offered for sale in the country. Overall this approach will ensure that the task of the policing body would be easier and less expensive.

6.3.1.2 *A product shall be assumed to be non-compliant until proof of compliance is produced.*

This principle would force manufacturers and importers to obtain approval for the product before it is sold to retailers. The policing authorities would also be able to remove a product from the shelves immediately if proof of compliance is not available.

6.3.1.3 *A product shall be assumed to be in compliance with the requirements only when a complete test report, showing compliance with all the requirements, is available from a test facility recognised by the South African National Accreditation Service (SANAS). Exceptions to this principle are envisaged for some products, as shown below.*

This principle is suggested to be applied as a basic principle to all products. Provision should however be made for some deviations. For instance, is it really necessary to test a kettle for radiated susceptibility? Probably not. However, if a dispute arises then at least the basic requirements listed below should be met.

6.3.1.4 *If a specific product standard exist for a product then compliance is verified according to the requirements contained in this standard.*
Where a specific product standard exists, compliance has to be tested to that standard. Examples of such standards are: EMI: CISPR 22 - Information technology equipment; EMC and safety: IEC 60601: Medical equipment.

6.3.1.5 *Where no specific product standard exists the basic requirements listed below shall at least met.*
Since products are developed much faster than standards are developed it often happens that an appropriate standard is not available. It can also happen that equipment falls into more than one category, making testing extremely difficult. In cases such as these, this principle would be applied.

6.3.2 Basic requirements

6.3.2.1 No equipment should generate emissions that adversely affect the operation of other equipment in the intended environment of use. Compliance with this requirement is verified by testing to all the relevant group 1 standards listed by the legislating authority.

6.3.2.2 If the safety of users, or people in general, depends on the ability of the device under test to withstand electromagnetic fields in its intended environment of use then the device shall comply with all the relevant listed group 2 standards, see below.

6.3.2.3 In general the device under test should be capable of operating safely and according to its intended operating parameters, in its intended operation environment. If the policing authority of EMC legislation[2] deems it necessary to

---

2

At the time of publication of this thesis this authority in South Africa was ICASA (Independent Communications Authority of South Africa) enforce additional requirements to ensure safe and correct operation of equipment then they should have the procedures and abilities to do so.

6.3.3 Proposed standard groups[3]

The groups below have been formed by grouping emission related standards in one group and susceptibility related standards in the second group. The first 8 standards listed for group 1 are standards for specific product groups, e.g. CISPR 22 - Information Technology Equipment.

The second group of standards in group 1 are generic standards for harmonic emission. Group 2 contains only generic standards for susceptibility testing.

6.3.3.1 Group 1

- ✓ CISPR 11, CISPR 12, CISPR 13, CISPR 14-1, CISPR 15, CISPR 22, CISPR 25, CISPR 61000-6-3
- ✓ IEC 61000-3-2, IEC 61000-3-3

6.3.3.2 Group 2

- ✓ CISPR 14-2, CISPR 20, CISPR 24
- ✓ IEC 61000-4-2, IEC 61000-4-3, IEC 61000-4-4, IEC 61000-4-5, IEC 61000-4-6, IEC 61000-4-8, IEC 61000-4-9, IEC 61000-4-10, IEC 61000-4-12

3

The lists given in this paragraph are not intended to be complete lists. The international versions of the standards are listed, as all of the standards have not been adopted as South African standards yet. The final legislation will however refer to the South African standards.

6.3.4 Special requirements for medical devices

Medical devices, even those that are not used in operating theatres or those implanted or connected to patients, can easily cause the death of a patient. It is therefore important to ensure that all medical devices in the field comply with the basic requirements above. In an attempt to achieve this, it would be recommended that a manufacturer of medical devices be required to have a quality system compliant with the relevant parts of ISO 9001, or an equivalent standard (e.g. EN45001) in place. This requirement would also apply to devices used without the supervision of a medical practitioner. This requirement is in addition to those given in the relevant EMC requirements and/or product standards.

6.3.5 Special requirements for telecommunication equipment

Telecommunication equipment is critical equipment in most countries in the world. It is therefore important to ensure that these devices comply with the basic requirements above. This is also true since telecommunication equipment is very much exposed to natural phenomena such as lightning. In an attempt to achieve this, it would be recommended that a manufacturer of telecommunication equipment be required to have a quality system compliant with the relevant parts of ISO 9001, or an equivalent standard (e.g. EN45001), in place. This requirement is in addition to those given in the relevant EMC requirements and/or product standards.

6.3.6 Exceptions to the general rules

In some cases, that we will define now, it may be acceptable if equipment is tested according to other methods than those listed above. In order to understand why one can allow this we will draw the following analogy. Let us consider the structure of calibration standards and laboratories around the world. A laboratory in, for instance South Africa, would calibrate a customer`s voltmeter against his laboratory standard. This standard may be for instance, another voltmeter or a reference power supply. His laboratory standard is calibrated at regular intervals against the national standard. The national standard is in turn verified according to international standards. In this manner the calibration of the customer`s voltmeter is traceable to at least the national standard of the country. This national standard is at least of the same accuracy but most of the time more accurate than the voltmeter calibrated. If we now consider the case of radiated emission. The international standard is the OATS test, prescribed by CISPR 16-1. If you draw an analogy between the traceability example above and the OATS versus an alternative measurement method then the alternative method should compare well with the OATS measurement. The question can now be asked: How well should it compare? This answer can also be found in CISPR 16-1. According to CISPR 16-1, any method used should still be withing the accuracy limits given for the OATS measurements.

Therefore if a manufacturer uses an alternative measurement such as a current clamp or Rogowski coil and he can relate his measurements to OATS measurements of the same sample, then he should be allowed to use this alternative method to prove compliance. Examples of these alternative methods were discussed in chapter 5.

It is therefore proposed that a manufacturer be allowed to use alternative methods provided that:

- ✓ It is not used to prove compliance for products listed in 4.3.3 and 4.3.4, where public safety will be jeopardised by EMC failures.
- ✓ If any dispute arises regarding the results then the prescribed standards should be followed to prove compliance.
- ✓ The alternative method should have been compared with the reference measurement in the prescribed standard and proof of this should be available.
- ✓ The alternative method should produce measurements with the same degree of accuracy required by the reference measurement and proof of this should be available.
- ✓ The use of the alternative method should be registered at the policing authority.

6.4 Introduction of the scheme into the country

One of the biggest problems, in the writers' opinion with the current legislation in South Africa is that many retailers and manufacturers have no idea how the safety legislation operates. This opinion emanates from four years' experience that the writer had working in a testing and certification environment. Therefore in order for a new scheme like this to have the desired affect and be accepted by the industry it will have to be well marketed.

The starting point of such marketing should be at the technical committees in the country. Examples of such committees are TC 77, TC74, TC73. Through the international liaisons of these committees one could also make presentations at international committees. Another important place where marketing should take place is at local conferences such as Africon and SATNAC. Through SANAS workshops one can also reach a different but very important part of the industry, the testing and calibration industry.

A body that would also be important to provide with the necessary information is the Department of Customs and Excise.

6.5 Conclusion

We have seen from chapter 2 and this chapter that South African legislation is currently lacking as it is outdated and there is no means of constantly updating the standards. We have also seen how South African legislation can be aligned with international standards by rather adopting international standards as South African instead of writing our own.

As mentioned at the start of this chapter South Africa has all the facilities in place to adopt international standards. The principle of using such adopted standards in South African legislation is also an accepted practice by industry and government departments - South Africa`s safety legislation is based upon this exact principle.

The only problem is that not all the necessary standards have been adopted and that no legislation exist to make compliance with these EMC standards compulsory.

Through the rest of the chapter we have seen how the basis of such legislation should look. In this legislation we have covered grouping of standards, grouping of products, alternative methods for "simple" equipment and additional requirements such as an ISO 9000 compliant quality system in the factory. We have also briefly touched on the need for introducing such a scheme to industry through the correct forums.. We have also started to address issues surround alternative test methods and methods for establishing credibility (Chapter 5) that can be used in the case of less critical products (6.3.6).

Chapter 7 - Conclusion

Over the six chapters of this thesis we have seen that there is much more to legislating EMC standards in a country that just writing legislation. We have seen that different regions in the world have different requirements. We have however also seen that the basis of most of these requirements are international standards. In addition to standards it was shown that one must consider the industry in the country where the legislation will be implemented. If the industry cannot support the legislation then it will not be successful. Consideration must also be given to trade and trade agreements such as the GATT agreement, as the country`s legislation may not be seen as to restrict trade.

We have also looked at EMC management plans as a means of ensuring that products comply by design and that the minimum amount of testing and retesting would be required. The risk of EMC failure is hereby minimized.

Thirdly we have looked at means of testing products. These methods included the standard methods as well as some alternatives. In a country like South Africa that has a relatively small industry alternative methods needs to be investigated to allow the small business to prove the compliance of its products.

We have lastly made some suggestions, taken from the legislation of other countries regarding legislation for South Africa. The proposals were made in such a way that the small business can also buy in to the legislation and compliance process, without jeopardizing the correct and safe operation of other systems such as telecommunication and medical. These systems and equipment operating close to them obviously has more stringent requirements.

As mentioned in paragraph 6.4 of the thesis, serious consideration would also have to be given to the introduction of the new legislation into the country. Without proper introduction the policing of the legislation would become more difficult and the industry would be less willing to comply.

Appendix A - OATS measurement photographs

Figure 1: OATS side view, 10 m test distance

Figure 2: OATS, from behind antenna, 10m test distance

Figure 3: OATS, Unit under test

Figure 4: OATS, Perspective view