Measuring fields – Truth or what?

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MPR-II
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Abstract

The MPR-II or TCO recommendations were developed to remedy the problems the VDT users had in the early eighties. The MPR-I recommendation was replaced in 1990 with MPR-II as we know it today. The TCO recommendations are a direct copy of MPR-II with small adjustments of levels, but using the same methodology. During 1995 a Swedish standard that in reality is MPR-II formalized will be published. This will have far-reaching consequences since the standard is expected to be adopted world-wide.

This will present a problem. The market assumes that the concept of a "low-radiation" VDT means that it is safe to use, what else can it mean? This is however not the case, there is no guarantee what-so-ever that a MPR-II approved VDT does not affect the users health. MPR-II is only based on technical assumptions of VDTs, not on knowledge or empirical facts of human health in front of VDTs.

MPR-II like methods measure the RMS mean-value of the integrated field in a restricted frequency intervall, this is strictly speaking *not* a measure of radiation[1]. Is the term "lowradiation" on a monitor just "green-wash"?

[1]The definition of "radiation" can shortly be described as transfering energy.

1 Introduction

The methodology is basically the same for MPR-II, TCO-90, TCO-92, TCO-95, and the coming Swedish standard SS 436 14 90, and the critisism put forth in this paper is equally valid for all of these. All said henceforth is in regard to the basic MPR 1990:8, also called MPR-II, standard[3].

The present report tries to answer the question "How come that a 'low-radiation' VDT that passes the MPR-II requirements, can have a time-derivative that breaks the MPR-I[2] recommendation?".

At first this seems trivial:
One cannot from a rms mean-value draw any conclusions of the underlying signal's time-variations. But, the question that arises is why do we at all measure MPR-II like?

The history behind the development of MPR-II is long and interesting. At the end, we today use MPR-II like instruments to measure not only VDTs, but a vast range of electrical installations. In what sense is a survey of office equippment with an MPR-II like instrument a good view of the true fields? Is it good science? By critically examining the measurement method, it should be clear that it is not well suited for scientific conclusions.

It seems that we have lost the connection to why, how, and for what these recommendations were developed.

[2]MPR-I is a retroactive renaming of MPR-P 1987:1.

2 Background

At the end of the seventies and in the beginning of the eighties, more and more cases of various problems with VDTs began to arise. The symptoms were

- An unnatural warmth or burning sensation in the face.
- A tingling, stinging or pricking sensation in the face or other areas of the body.
- Dryness of the upper respiratory tract or eye irritation.
- Problems with concentration, dizziness and loss of memory.
- Swollen mucus membranes resulting in nonviral/bacterial swelling of nose, throat, ear and sinuses.

Some compared their feeling like a "sunburn". What was the source to these symptoms?

A political statement was taken by Anna-Greta Leijon. The National Board on Occupational Safety and Health[3], the Swedish Radioation Protection Institute – SSI[4], and MPR[5] was 5th September 1989 given the task to investigate the "need for, the requirements and the consequenses of the introduction of – compulsory or obligatory – testing of VDTs". The measurement method was meant to help employers and employees alike to evaluate VDTs in respect to the *working enviroment*.

The government commissioned MPR to develop rules for a compulsory testing of VDTs. A group, consisting of members from MPR[6], SSI, Arbetarskyddsstyrelsen, the Office and Data Processing Trade Association – LKD[7], SEMKO[8], and the Swedish Foundation for Occupational Health for State Employees[9], was setup 22nd May 1986. In the defined task from the government it was further ruled that the task was to be done in near cooperation with the unions and other interested parties of the market.

The discussion at this time was open to what to measure and how to do it. Of some reason, today unclear, the focus was set on low-frequency[10] fields. The measurements were concentrated on the line-frequent magnetic and electric fields. Common terminals used at that time had harmonics which declined to small values well before the upper limit of 400KHz. There were of course also higher frequency signals (hundreds of MHz), mostly harmonics to the video signal, but these were not included in the MPR draft. A proposal[2] was defined and it was decided that the method should be evaluated for three years. During 1990 the method was redesigned and is now called MPR-II[4, 3] [11]. Afterwards the first proposal MPR-P 1987:1 is consequently called MPR-I.

3 MPR-I

The method used at the beginning measured both the time derivates peak value (see eq. 15) and the field strength (see eq. 12) within the frequency interval 0-400 KHz. The measurement was performed at a number of points around the object in a spherical geometry. It was soon realized that the method was clumsy and took long time per object. There were problems with the defined geometry, it sometimes happened that larger VDTs had measurement points inside the cabinett. When the method was revised, the spherical geometry was therefore exchanged to cylindrical coordinates. There was also some concern over the quality of the measured values of the time derivates. The measurement was made with the help of an oscilloscope. Of course the error was lower for the integrated RMS-value than for the time derivate.

When the method was constructed, the most probable interaction with the human body was thought to be the induced currents. Therefore it was decided to measure the line-trace and it's backtrace. The induction from the backtrace is high

[3] Arbetarskyddsstyrelsen

[4] Svenska Strålskyddsinstitutet

[5] Mät- och Provningsrådet

[6] Today called Sveriges Ackrediteringsanstalt – Swedac

[7] Leverantörsföreningen för Kontors- och Datautrustning

[8] Swedish Institute for testing and certification of electrical equippment

[9] Statshälsan, today called Previa

[10] A certain amount of misinterpretation of terms exists in this area. In connection with MPR measurements many, confusingly, talk about high frequency when they mean Band II 2-400KHz, even though it is in the LF (Low frequency) band.

[11] Or more precisely, MPR 1990:8

since the flank (fly-back) time is short. It is evident that time varying fields induce currents, but their significance for human health has yet to be determined.

Lars-Erik Paulsson from SSI made a litterature search that today is given as one reason why induced currents wasn't interesting for explaining the symptoms.

By assuming that all VDTs are similar in construction, the ratio between the field RMS-strength and the derivatives peak-value should be approximately similar between VDTs. When MPR-II was set the time derivate measurements were omitted.

In MPR-I one tried to block the instrument during the vertical blanking period when measuring the line trace. This was done to avoid having the vertical blanking affect the measurement value of the line trace. This complicated the measurement, and it was only later realized that there is no need to differentiate between different factors, especially if the important thing is to compare VDTs with each other.

The next step was to define some kind of limit value. MPR stated that no scientific proof for any health effects existed. It was thus not possible to define *hygienic* limit values. The recommended value was set to the median of a number of VDT terminals on the market at that time (1986).

At first, the feeling probably was that it was going to be easy to find the mechanisms behind the complaints about VDT usage. Unfortunately this was not to be the case, the chosen measurements revealed no consistent patterns.

MPR set out its course, the method was to be used to compare VDTs with each other. The human was out of the loop.

4 MPR-II

MPR-I was recognized as too cumbersome and hard to evaluate. A new committe was formed by Swedac, SSI, Semko, Combinova, TCO, SEF[12], IBM, EIZO, HP, ICL/Nokia, LKD, Previa, Radians Innova, SEK and others[3].

As previously mentioned, the method was changed, time derivate was rejected, peak value was exchanged with the RMS-value, the gemoetry switched to cylindrical. The recommended values for band II from MPR-I were recalculated to reflect the changes in the method. New emission characteristics were added by also measuring the picture frequent electric and magnetic fields in Band I (5-2000Hz). The varying magnetic field induces a current into three orthogonal coils. These currents are amplified and integrated. Thereafter the three signals are filtered and combined to give the magnitude of the vector, and then presented as an RMS-value. The result is what we today call MPR-II[4, 3].

TCO published its own guidelines TCO'90, succeeded by TCO'92 and TCO'95, which in reality is a copy[13] of MPR-II with small adjustments . MPR-II excluded the special measurement points at 30cm in front of the VDT, while TCO retained it. TCO also lowered the numbers. TCO then had the pretext to claim that "Certification requires that the equippment must meet very severe demands for low electrical and magnetic fields" [1].

The recommended values have no real correlation with the factor they were set for, that is, to reduce symptoms in front of a VDT.

According to Hjalmar Bondestam of Combinova, it was a mistake that the measurement point at 30cm in front of the VDT is missing in MPR-II.

According to Yngve Hamnerius, Chalmers, the geometry recalculations done by Lars-Erik Paulsson at the SSI must be wrong. "It was not the intention that MPR-II should be easier to achieve than MPR-I."

But as far as I can tell from the reports about MPR-I and MPR-II[4, 3, 2], it seems to be a simple assumption of a fly-back of 2μs and a recalculation between mean value and RMS-value as follows:

If we know the peak-to-peak value of the derivate according to eq. 15 and also the trace back time t_f we can calculate the amplitude A of B, and thus B_{RMS}. If we take 25mT/s and 50nT, measured in spherical coordinates, band II from MPR-P 1987:1[2]. We can verify the value of t_f by $A = \int_0^{t_f} B'_{tt}dt = B'_{tt}t_f$ that is 50nT/25mT/s= 2μs which is reasonable. We can thus take 50nT as $B_{tt} = A$, and we get $B_{\text{RMS}} = \frac{1}{\sqrt{3}}1.11 \times 5 \times 10^{-8} =$ 33nT, where we used eq. 12. The factor 1.11 comes from the relation of a instrument calibrated for a sinewave and a true RMS instrument[14]. Then the

[12] Stockholm Energy

[13] With respect to electric and magnetic emissions.

[14] RMS value of a sine wave divided by the rectified mean

correction for the coordinate system change has to be performed. The radius of 0.65m, the angle of 22.5^o and the value of the height along the surface of the cylinder of 0.3m, then gives $R_I = 0.65$, $r_{II} = \sqrt{0.65^2 + 0.3^2}$, and $\frac{B_I}{B_{II}} = \frac{1/r_I^3}{1/r_{II}^3} = 1.336$, ie. we have 33nT/1.336 which is 25nT. This was then set as the recommended value in MPR-II for band II on the magnetic field. TCO has then made an additional arbitrary change of the value for their certification requirements.

A simple calculation fault is not the reason why MPR-II is easier to achieve for the manufacturers.

4.1 Chosen frequency bands

The frequency intervalls, Band I and II were chosen based on a spectral analysis of a VDT 1985-86.

This particular figure[3] shows alternating electric fields at different frequencies from a "typical" VDT, shown together with filter cure characteristics as defined in MPR-II. A typical VDT at this time had a resolution of about 25x80 characters, or maybe an VGA display of 640x480. The refresh rate was 25Hz (interlaced) or 50Hz (non-interlaced)[15].

The frequency intervalls, particularly the upper limit of 400KHz have gained a widespread use. MPR-I, MPR-II, TCO'92, TCO'95, SS 436 14 90, and most of the research, have been restricted in scope to this frequency band.

A modern workstation or PC of today, has a monitor with a refresh rate of 70-100Hz, a resolution of 1024x768, 1280x1024 or maybe 1600x1280. The vertical, horisontal, as well as the pixel frequencies are today substantially different. A workstation monitor emits a spectrum that is not restricted to the band I and II intervalls.

The spectra above is from a SUN3/75 workstation monitor. It is clearly seen that only a few harmonics fall within the defined frequency bands. The harmonics of the line frequency are still detectable at 30MHz!

The assumption that band I covers the vertical trace and the band II covers the horisontal trace, including harmonics, is no longer correct.

4.2 Induction

Why was induced currents deemed uninteresting? The above mentioned litterature study suggested that the induced currents from VDTs would be several magnituds lower than the body's own electric signals, and thus no longer of any interest. All calculations at this time were based on a simplified body model, often a homogenously ellipsoid, exposed to a parallel far-field. The resulting current was assumed to be evenly distributed over the cross-sections. Values of about $1400 nA/cm^2$ of induced currents were reported for a 60Hz field from a normal power line[5]. A simplified formulae for the foot current I_h of a standing standard man was shown[6] to be approximately valid:

$$(1) \qquad \frac{I_h}{E} = 0.108 h_m^2 f_{MHz}, \frac{mA}{V/m}$$

where E is the E-field strength of the incoming plane wave, h_m is the body length, and f_{MHz} is the

value, $\frac{1}{\sqrt{2}}/\frac{2}{\pi}$.

[15] In the US, 30Hz or 60Hz

frequency given in megahertz. The induced current is thus directly proportional to frequency.

A newly published report [8] makes it clear that the induced currents are inhomogeneously distributed in the body. This is due to the different electrical properties of tissues[16]. The better detailed models we are able to simulate, the better understanding we will have of induced currents and possible health effects. In the context of nervecells the range of currents is pikoampere to nanoampere within the structures. For radiofrequency signals, such as RF sealers, a standing man, 1.75m tall, exposed to vertically-polarized electric fields at 40MHz, induces a footcurrent upto 780mA[6]! The fields set as suggested in the ANSI C95.1-1982 RF safety guide. The values scale down for power frequency fields, but what of transients with a high frequency content?

The spectral distribution of a transient is broad, and is able to induce high currents. The fly-back time is short and contains higher harmonics.

When we today use high resolution VDTs the fundamental frequency is higher but so are the harmonics, both factors contributing to higher induced currents. But, as can be easily understood, (see appendix C) the measured RMS-value will be the same. The RMS-value relates to the peak value of the field strength, and that in turn is dominated by the steepest deflection angle of the electron ray. This means that the RMS-value more or less is a measurement of the physical dimensions of the unit (for the same acceleration potential and the same deflection coil). Higher vertical frequency or the resolution does not influence the RMS-value. However it is clear that the time derivate (induced currents) will be higher.

4.3 Are all VDTs equal?

One have to keep in mind that in the committees there were delegates from manufacturers of VDTs. How this may have influenced the development of the method is impossible to tell. One very *fundamental* assumption, supporting MPR-II, that the manufacturers have put forth, and still stand for, is that the VDTs are very similar. The components and technical details are so similar that the signals should be more or less identical. This is the primary defense for using RMS-values in the MPR-II for comparing VDTs with each other.

The President of Combinova, Bondestam, told me that the "RMS-values can be used to compare two VDTs with each other, since all VDTs have the same signal shape. This of course demands the same picture and line frequencies (same resolution), furthermore, the screen should be driven by the same videocard to ensure the same signals..."[17]

With this line of thought it is *not* correct to compare all kinds of VDTs with each other as is done in practice with MPR-II. One cannot, strictly speaking, compare two VGA (640x480) monitors if they have different refresh rates (70-100Hz is commonly used today to reduce flicker). Similary, it is not entirely correct to compare a VGA (640x480) with a SVGA (800x600) or a XGA (1280x1024). This is in striking contrast to the use of one limit value as defined in MPR-II.

The assumption of similarity does not go along well with reported perceived differences between VDTs, or with measurements that sometimes show drastically different values for two VDTs, even of the same model.

What do we have then? A method that assumes the VDTs to be similar to be able to differentiate them?

4.4 RMS is cheap

It is said to be easy to measure RMS values of the magnetic field, it is reproduceable and accurate. Peak values are seen as hard to measure, the peak can in modern VDTs be very short. In MPR-I the peak values were taken from an oscilloscope image, but a fast (expensive) oscilloscope is needed. But on the other hand, when the crest-factor[18] is high, the RMS-value gets hard to measure. It is easy to get the amplifier overloaded at the peaks. This is especially true for measurements of electric fields. A crest factor over ten is common. The derivate dB/dt is hard due to the very wide variations, giving problems with amplifiers, measuring coils, and frequency characteristics.

The chairman, Bondestam, in the MPR-II committee points out that the selection of the RMS

[16] One can only speculate that a structure designed for leading an electrochemical signal fast through the body, also leads externally induced currents.

[17] The citation is translated from Swedish, a telephone conversation 941230.

[18] Peak value divided by RMS-value

measurements was highly motivated by costs.

According to Torbjörn Klittervall, Previa, the choice of RMS was unfortunate. SSI, IBM and HP were strong advocates for switching from the derivate $\frac{d\vec{B}}{dt}$ to the RMS-mean value B_{RMS}. Unfortunately, the RMS-value cannot give a good image of the underlying signals shape. There were also spokesmen for increasing the frequency intervall above 400KHz, but this was not supported by the committe.

5 Standardisation

MPR-II has through the years been copied or adapted in different ways. Organisations such as IEEE, EKMA, and JEDA have adapted their own versions.

During the spring 1994, this situation was questioned, MPR-II isn't even a standard but is today a de facto standard. Pressure from the industry and standardisation organisations initiated work towards a standard. It was decided to revise an old unused Swedish standard SS 436 14 90. This standard was originally set June 7th 1989. By revising an existing standard the process was greatly simplified. In reality, one throws away the old standard completely, reuses the identification number, and MPR-II is put in its place. This work is expected to be completed during 1995.

The standard is expected to be adopted worldwide. The EC has taken a resolution stating that the Swedish standard should be adopted. There is also expectations that IEC will adopt SS 436 14 90.

MPR-II will then be obligatory, There will be two classes, one with and one without limits.

6 Why do we measure?

Why do we measure VDTs? Is it concern over our health? Is it interesting? Is it fast and easy money? Is it a good way to silence people complaining on VDTs?

The bottom line is, that the repeated complaints about VDTs and public concern about possible health hazards gave not only rise to the MPR-II method, but also motivates that the measurements themselves are performed today.

> *It is a fact that most research projects in the EMF field uses MPR-like instruments. This implies a restriction of the scientific search to the domain these instruments surveys. Is it really good science?*

Why use MPR-II, which is not based on health, to measure things due to health concerns?

There are people who have become hypersensitive to electricity, or have got skin symptoms, who blame the "low-radiation" monitor. This is difficult to claim when the company makes a measurement of that monitor and then tells the employee that it is safe to use because it passes MPR-II or TCO requirements.

Who is right? The body or the instrument?

7 What to do?

MPR like methods fails to characterize, among others, factors like timevariations, modulation, phase, vector, bursts or recurrent patterns.

According to Torbjörn Klittervall "one probably have to accept TCO'95. To be able to argue for a broader frequency range one must exhaustively measure a range of VDTs and point to this data. Then there still is a huge and complex task of understanding the mechanisms of interaction."

In 1974 (!) the IVA[19] published a report IVA-210 where the following needs were listed[20]:

- It is neccessary to prioritze research and development of measurement technology to have a solid foundation for research about EMF and health.
- The electromagnetic characteristics of biological tissue needs to be further studied, especially their frequency and amplitude dependency.

[19] Ingenjörsvetenskapsakademin

[20] I would like to add to the list: an exhaustive measurement of a few VDTs chosen by electrical hypersensitive as being "good" and "bad". With this data, models or hypotheses could be set and tested. After that measurement methods could be devised. After measurements have been made in practice and correlation is shown, hygienic limit values could finally be set.

- Risk analysis and doseage calculations require knowledge about disturbed near field conditions and the fields distribution around the human body in the actual enviroment. Simulation and measurement methods for such fields should be developed.

- Among the measurement technics that should be developed or refined, small, easy to use, wide frequency near-field probes that are unsensitive for polarisation, can be mentioned. Dosimeters for surveys of personal doseage in working enviroments with high field intensities, is another example.

We stand at the same point today, over twenty years later. We have to start.

Appendix

A "Mean" peaks – The Basics

Let us study a physical signal $s(t)$.

A.1 Rectified mean value

A rectified mean value of s is calculated as

$$s_{\text{AV}} = \frac{\int_a^{a+T} |s(t)| dt}{T} \tag{2}$$

where T is the measurements length in time with start at the time a. For the special case of a sine wave with a amplitude of A, the rectified mean value is given by $\frac{1}{\pi}\int_0^\pi A \sin \omega t d\omega t = \frac{2A}{\pi}$.

A.2 RMS – Root-mean-squared

The RMS value of $s(t)$ is defined as

$$s_{\text{RMS}} = \sqrt{\frac{\int_a^{a+T} s^2(t) dt}{T}} \tag{3}$$

where T is the measurement time length with start at time a. For the special case of a sine wave with amplitude A the RMS-mean value is given by $\sqrt{\frac{\int_0^\pi A^2 \sin^2 \omega t^2 d\omega t}{\pi}} = \frac{A}{\sqrt{2}}$.

A.3 Peak values

The highest and lowest value of the signal within the measurement period is called peak values. They are often written as s_{p+} and s_{p-}.

$$s_{p+} = \max s(t) \tag{4}$$

$$s_{p-} = \min s(t) \tag{5}$$

The peak-to-peak value is then given by

$$s_{pp} = s_{p+} - s_{p-} \tag{6}$$

For a sine wave with amplitude A we have: $s_{pp} = 2s_p$, där $s_p = |s_{p+}| = |s_{p-}| = A$.

B $\mathfrak{F}$ourier-series

A periodic function f with period T defined in the intervall $[-T/2, +T/2]$ can be written as a fourierseries [7]:

$$f(x) = C_0/2 + \sum_1^\infty C_n \cos n\omega_0 x + \phi_n \tag{7}$$

B.1 Pulstrain

Let a pulse be defined by $g(t)$ and the pulse train by

(8)
$$y(t) = \sum_{n=-\infty}^{\infty} g(t - nT) = [\sum_{n=-\infty}^{\infty} \delta(t - nT)] * g(t)$$

The fouriertransform $\mathfrak{F}$ of $y(t)$ is

(9)
$$Y(f) = \mathfrak{F}y = \frac{1}{T}[\sum_{n=-\infty}^{\infty} \delta[f - nF]G(f), F = \frac{1}{T},$$

and its fourierserie

$$y(t) = \sum_{n=-\infty}^{\infty} D_n e^{in\omega_0 t} \tag{10}$$

$D_n = \frac{1}{T}G(nF)$, and $D_0 = \frac{1}{T}\int_0^T g(t)dt = \frac{G(0)}{T}$. The mean power of a pulsetrain is $\frac{E}{T}$ where

$$E = \int_a^{a+T} g^2(t)dt = \int_{-\infty}^{+\infty} |G(u)|^2 du \tag{11}$$

where $G(u) = \mathfrak{F}g(t)$.

C The Sawtooth

Let us study a sawtooth signal $B(t)$ with amplitude A, rise time t_s and fall time t_f. Let the maximum A be at time 0.

```
|   /|   /|   /|   /|
|  / |  / |  / |  / |
| /  | /  | /  | /  |
|/   |/   |/   |/   |
```

The rectified mean value is $B_{\text{AV}} = A/2$ and the RMS-mean value

$$B_{\text{RMS}} = \sqrt{\frac{\int_{-t_s}^{t_f} B^2(t)dt}{t_s + t_f}} = A/\sqrt{3}. \tag{12}$$

Note that the mean values are *independent* of rise and fall times!

The sawtooths mean power content is

$$\frac{E}{T} = B_{\text{RMS}}{}^2 = \frac{C_o^2}{4} + \frac{1}{2}\sum_{n=1}^{+\infty} C_n^2 \text{ where} \tag{13}$$
$$C_n = 2B_{\text{AV}}\frac{T^2}{\pi^2 n^2 t_s t_f}\left|\sin\frac{n\pi t_s}{T}\right|$$

The timederivate of the sawtooth signal is

```
___ ___________________ _ Positive flank
--| |-----------------| | Mean value
  | |                 | |
  | |                 | |
  | |                 | |
  |_|                 |_| Negative flank
  0 t                t
     f                s
```

This can for one period of the signal be formalized as

$$B' = \frac{dB}{dt} = \begin{cases} \frac{A}{t_s} & \text{if } -t_s < t < 0, \\ -\frac{A}{t_f} & \text{if } 0 < t < t_f. \end{cases} \tag{14}$$

The peak-to-peak value of the derivate is according to eq. 6

$$B'_{tt} = A(\frac{1}{t_s} + \frac{1}{t_f}) \tag{15}$$

which is dominated by the contribution of t_f.

The rectified mean value of the derivate is given by eq. 2

$$B'_{\text{AV}} = \frac{2A}{(t_s + t_f)} = \frac{2A}{T} \tag{16}$$

The RMS-mean value of the derivate is according to eq. 3

$$B'_{\text{RMS}} = A\sqrt{\frac{\int_0^{t_s}(\frac{1}{t_s})^2 dt + \int_{t_s}^{T}(\frac{1}{t_f})^2 dt}{T}} = \frac{A}{\sqrt{t_s t_f}} \tag{17}$$

. In contrast to eq. 12 this is dependent on the frequencies used.

The mean power of the derivate is given by

$$\frac{E}{T} = B_{\text{RMS}}{}^2 = \sum_{n=1}^{+\infty} D_n^2 \text{ where} \tag{18}$$
$$D_n = -\frac{A}{2\pi i n}(\frac{1}{t_s} + \frac{1}{t_f})(e^{-2\pi i n t_s/T} - 1)$$

D Measurement according to MPR-II

In this report the focus has been on the magnetic fields. The method for measuring electric fields as defined in MPR-II disturbs the field severely. The critisism of RMS is still valid for the electric field though, maybe more so because of the high crest factor. A complete rework of the method for electric fields in MPR-II is badly needed.

The induced current in the coils corresponds to the time derivate of the magnetic fields strength along that coils axis. This signal is then amplified and integrated. The signals are then filtered with a bandpass filter θ defined as below.

Band I	Band II	Attenuation
$< 5Hz$	< 2KHz	> 80dB/decade
5Hz	2KHz	3dB
100Hz	30KHz	0dB
2KHz	400KHz	3dB
> 2KHz	> 400KHz	> 40dB/decade

The filtered signals may be converted to RMS first and then the magnitude of the vector, or first converted to the magnitude and then RMS.

The $\mathfrak{F}$ouriertransform of this filter is $\Theta = \mathfrak{F}\theta$. A multiplication in the $\mathfrak{F}$ourierdomain corresponds to a convulotion in the signal domain. We can thus get the filtered signal by

$$B_\theta = \mathfrak{F}^{-1}(\Theta \mathfrak{F} B) \tag{19}$$

This in turn leads to the simple use of the $\mathfrak{F}$ourier-series of our signal and multiply it with the filter Θ. This is easily done by hand while there is only a limited number of coefficients that fall inside the passband. In other words, we can calculate the quotient of a signal's power that is lost in the filter.

If we compare the theoretical RMS value (eq. 12) with the RMS value given by the truncated fourierseries (eq. 13), we have a measure of the error due to the truncation. This a rough upper limit for the loss in the coils, leads, amplifiers, and filters.

For $B(t)$ only a few terms of the series (eq. 13) are needed to approximate the sawtooth shape. The higher the quotient $k = s_s/t_f$ is, the more terms of the series are needed to approximate the sawtooth falling edge (the fly-back). For an old slow VDT we get an error of less than one part in thousand for B_{RMS}. For a fast modern VDT the error can be about one percent for B_{RMS}.

Making the same calculation for the db/dt series (eq. 18) instead, we get an error of more than two percent for the old VDT and 65 percent for the new one! This indicates that the coils and amplifiers have to be broadband to handle the induced currents from a modern VDT without invalidating the measurement even within the 0-400KHz intervall.

Increasing the vertical refresh rate or the resolution increases the peak-to-peak value of the induced current as given by eq. 6 while the RMS value as of eq. 12 will remain the same!

This is why a modern VDT passes MPR-II but fails MPR-I.

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