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THE EMC FIGURE OF MERIT IN THE PREDICTION OF RECEPTOR COMPATIBILITY

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With the EMC figure of merit it is possible to predict quantitatively electromagnetic compatibility or incompatibility of the receptor in the unique way if the receptor performances can be characterized in terms of average power.This paper describes a method of calculating the EMC figure of merit.In the second part an example is given of experimental determination of the receptor compatibility.The receptor used was an impulse generator of three-pulse converter.

Introduction

When electromagnetic harmony is not achived we have the problem of electromagnetic compatibility(EMC).The problem of EMC can be solved satisfactorily only if we take care about EMC during all the stages of a device or system developmant (from the first phase of analysing their feasibility to the last production phase).The optimization can be done only if the problem of EMC is analyzed and treated quantitatively.This is the reason why we introduce the EMC figure of merit (F_{EMC}).

For all cases it is not possible to introduce and define the EMC figure of merit in the same way.The definition depends on the way the receptor performances can be characterized.It is believed that for most electronic equipment employing analog signals the receptor performances and susceptibility can be characterized in terms of average power [1].In these cases it is possible to express the level of the achieved receptor compatibility in a unique,quantitative way,with the EMC figure of merit.

Calculation of the EMC figure of merit

A system analyzed from the point of view of EMC can have several receptors,and each receptor can have more interference inputs.However,one receptor can have only one detector sensitive to the total power of EM interferences.It is known that for this receptor with J inputs the EMC figure of merit can be calculated from the expression:

$$F_{EMC} = \sum_{j=1}^{J} F_{EMC} = \sum_{j=1}^{J} \int_{-\infty}^{\infty} \frac{P_j(f)}{O_j(f)}\, df \qquad (1)$$

where: $P_j(f)$ is the power spectrum of the interference signal on j-th receptor input, and

$O_j(f)$ is the susceptibility function of the receptor on that j-th input.

Pearlman [1] called this EMC figure of merit the integrated EMI margin (I.M.).

If we analyze the receptor compatibility in a limited frequency band, the F_{EMC} can be calculated from the expression:

$$F_{EMC} = \int_{f_a}^{f_b} \frac{P_j(f)}{O_j(f)}\, df \qquad (2)$$

where: f_a is the lowest frequency of interest,and

f_b is the highest frequency of interest.

The receptor will not be disturbed if $F_{EMC} \leq 1$.

If we analyze a complex system with several receptors,we must introduce the EMC figure of merit of the complete system (SF_{EMC}).It is possible to connect the system EMC figure of merit and the receptor EMC figure of merit in several ways.One of them is the expression:

$$SF_{EMC} = \prod_{i=1}^{I} F^{*}_{EMCi} \cdot p(\Delta t_i) \cdot \xi_i \qquad (3)$$

where: F^{*}_{EMCi} is the new,changed,EMC figure of merit of i-th receptor

$$F^{*}_{EMCi} = \begin{cases} 1 & \text{if } F_{EMCi} \leq 1 \\ F_{EMCi} & \text{if } F_{EMCi} > 1 \end{cases}$$

$p(\Delta t_i)$ is the probability that

i-th receptor will work when the system works,
ξ_i is the factor that shows the contribution of i-th receptor to the total effectivity of the system (ξ_i is the element of the interval [0 , 1]),and
I is the total number of receptors.

The system of receptors will not be disturbed if $SF_{EMC} \leq 1$.

Example of experimental determination of the receptor compatibility

Experimentally we wanted to determine the following two things:

1. Is it possible to characterize the performances and the susceptibility to interferences of a typical control analog device in terms of the average power ?
2. If we have different combinations of interference sources on various receptor entrances,can we predict quantitatively by using the EMC figure of merit the possible EM compatibility or incompatibility with certain acceptable error ?

The problems of the intra-system EMC is very important in the field of power-electronics,therefore we decided that the receptor in the experiments should be an impulse generator of the three-pulse converter type VR2 2413 OOR1 BBC.

The limitation in the experiments was that we used only conducted interferences and not radiated ones.

From the point of view of EMC,the impuls generator has two possible ports through which the conducted interferences can enter into the receptor
- the power lines,and
- the control lines.

We assumed that the impulse generator is disturbed,when,due to the interferences,the error ε in the phase location of impulses for thyristor gates is greater than 2°.

Measurement of the internal impedance of the receptor inputs

First of all,we wanted to determine the characteristics of the internal impedance on both receptor inputs. We measured the dependence of the injected current and voltage on the receptor inputs for the sinusoidal signals with different frequencies.Some of the results are shown in Figure 1.

The phase-control angle was 96°. From Figure 1. it can be seen that the ratio V/I is constant at a fixed frequency (impedance is linear) above a minimal value of voltage.This minimal value of voltage corresponds to an error in phase location of impulses $\varepsilon_0 = 0.4^{\circ}$.This value is below our measuring range of interest because of

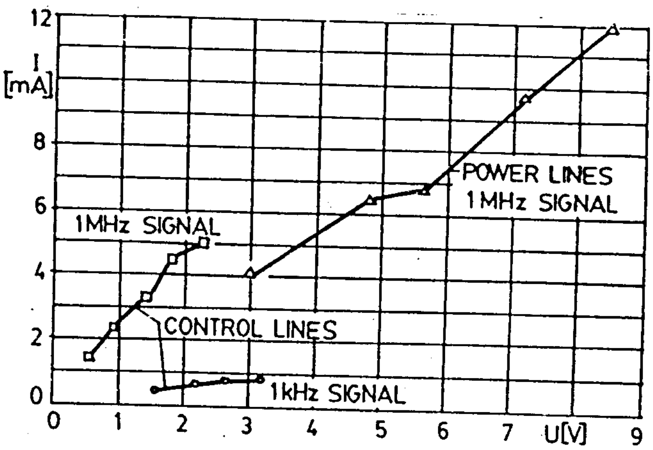

Fig.1: Dependence of the injected current and voltage on the receptor entrances

the measuring equipment limitation.A similar situation was also found at other frequencies [2] .

Thus,we can conclude that the internal impedances of the receptor inputs are linear at each fixed frequency.This is important,because it is sufficient to measure the voltage spectrum of the interference signals and the voltage susceptibility function. The EMC figure of merit can be calculated using the squares of voltages.

Determination of the way the receptor performances can be characterized

We wanted to find whether the receptor performances can be characterized in terms of average power.Therefore we made two experiments:
- we measured the dependence of the error ε and the voltage,current and power of the interference signals,and
- we analyzed the superposition effect when there are some uncoherent signals on the receptor inputs.

Figure 2. shows the dependence of the error ε and the voltage,current and power of a 10 kHz interference signal on the control lines,as well as 1 MHz interference signal on the power lines.We have obtained similar results at other frequencies [2] .

Figure 2. shows that for errors from 0.4° to 6° approximately holds $\varepsilon \sim P$, $\varepsilon \sim U^2$ and $\varepsilon \sim I^2$.So,the performances and the susceptibility to interferences of the impulse generator can be characterized in terms of average power.

If we connect n uncoherent signal sources to the receptor inputs and set the level of each signal to produce the same error $\varepsilon = 2^{\circ}$ the effect of the superposition of all n signals can be either the total error <u>is</u> $n \cdot 2^{\circ}$,or the total error <u>is not</u> $n \cdot 2^{\circ}$.If the total error is $n \cdot 2^{\circ}$ we may conclude that the performances of the receptor can be characterized in terms of average power.This conclusion is derived from equation (1).

We made 20 experiments with up to

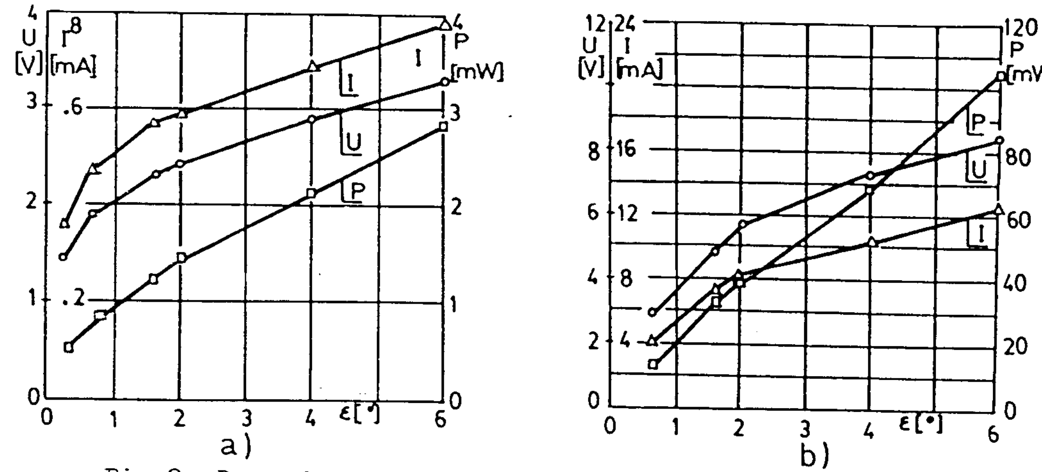

Fig.2: Dependence of error ε and voltage, current and power
a) on control lines for 10 kHz signal, and
b) on power lines for 1 MHz signal

4 uncoherent sources (the sourees of interferences were simulated with function generators), and in all cases the total error was proportional to the number of sources $n \cdot 2^o$.

In this way we have once again confirmed that the susceptibility to interferences of the impulse generator can be characterized in terms of average power.

Measurement of the susceptibility function

The voltage susceptibility function of the impulse generator was measured on the control lines from 100 Hz to 30 MHz. Figure 3. shows the measuring results.

- 2 sinusoidal signals on control lines,
- 1,2 or 3 sinusoidal signals on control lines, 1 sinusoidal signal on power lines,
- 1 square, 1 triangle or 1 AM signal on control lines, and
- 1 sqare or 1 triangle signal on control lines, 1 sinusoidal signal on power lines.

We used equation (1) for calculating the EMC figure of merit. This time, however, because we have measured only discrete frequencies, equation (1) is in the form:

$$F_{EMC} = \sum_{j=1}^{J} \sum_{n=1}^{N} \left[\frac{P_{Uj}(f_n)}{O_{Uj}(f_n)} \right]^2 \qquad (4)$$

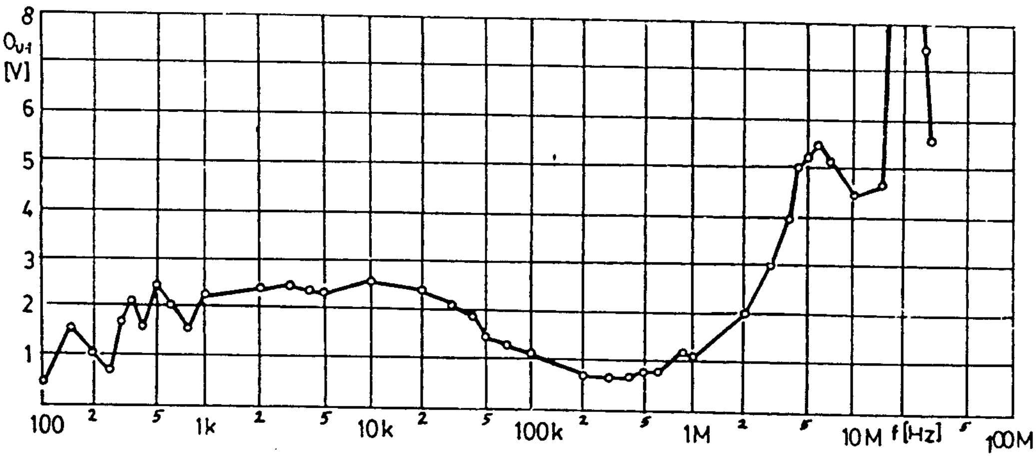

Fig.3: The voltage susceptibility function of the impulse generator on the control lines in frequency range from 100 Hz to 30 MHz

On the power lines the voltage susceptibility function was measured from 100 kHz to 2 MHz. Figure 4. shows the measuring results.

Determination of the EMC figure of merit

In the end we made 22 experiments with the following signal-entrance combinations:

where: $P_{Uj}(f_n)$ is the voltage spectral component of the interference signal at the frequency f_n, and
$O_{Uj}(f_n)$ is the voltage susceptibility function component at the frequency f_n.

In the cases when we had square or triangle signals we used the first 11 harmonics.

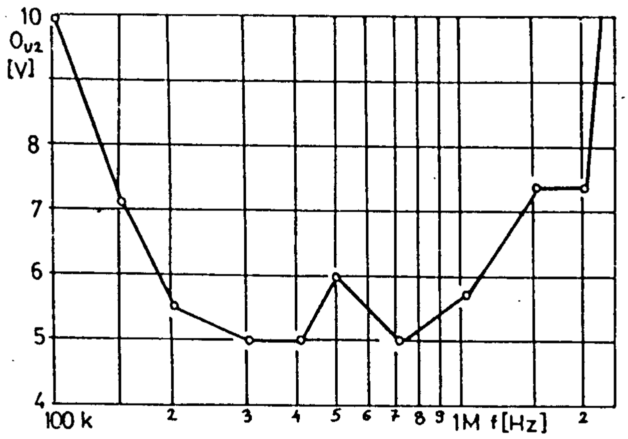

Fig.4: The voltage susceptibility function of the impulse generator on the power lines in the frequency range from 100 kHz to 2 MHz

We wanted to determine the error in the calculation of the EMC figure of merit. Therefore in each case we set that the impulse generator error ε, due to all interferences should be $\varepsilon = 2^0$, accordingly the predicted F_{EMC} for all cases had to be equal one. A difference from one represented the error in determining the EMC figure of merit.

Figure 5. shows the relative error ΔF_{EMC} in determining EMC figure of merit. ΔF_{EMC} was calculated from the expression:

$$\Delta F_{EMC} = (F_{EMC} - 1) \cdot 100\ \% \qquad (5)$$

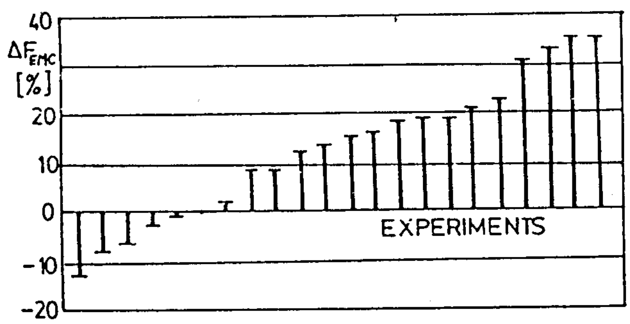

Fig.5: Relative error in determining EMC figure of merit

From Figure 5. it can be seen that the maximum positive error was +35 %, and the maximum negative error was -13 %. The probability of the positive relative error (overestimation of possible EM incompatibility) was $p(\Delta F_{EMC} \geq 0) = 0{,}77$, and the probability of the negative relative error (underestimation of possible EM incompatibility) was $p(\Delta F_{EMC} < 0) = 0{,}23$.

Thus, we can conclude that the amount of relative error in determining the EMC figure of merit, and especially the probability of its sign are acceptable from the point of view of EMC prediction.

Conclusions

If the receptor performances can be characterized in terms of average power, it is possible to express the achieved level of EMC, or to predict the possible EM incompatibility in a unique, quantitative way with the EMC figure of merit.

Experimentally we proved that the performances of a typical analog control device ie. an impulse generator of three-pulse converter, can be characterized in term of average power. Also the internal impedance of each of the two impulse generator EMC inputs being linear at a fixed frequency, it is sufficient to measure the voltage spectra and calculate the EMC figure of merit using the squares of voltages.

The EMC figure of merit was determined for various combinations of different sources (the source of interferences were simulated with function generators) on both receptor entrances. The amount, and espacially the sign of the relative error in determining the EMC figure of merit was acceptable from the point of view of the EMC prediction.

References

[1] Pearlman, R.A., Physical Interpetation of the IEMCAP Integrated EMI Margin, 1978. IEEE Symp. Rec. on EMC, Atlanta, USA, 310-315 (1978)

[2] Stipaničev, D., The Analysis of Possibility to Predict the Level of the Achived Electromagnetic Compatibility, Master's Thesis, ETF, University of Zagreb, Zagreb (1980)