Annals of the Academy of Romanian Scientists
Series on Science and Technology of Information
ISSN 2066 - 8570 Volume **4** Number **1**/**2012**

ELECTROMAGNETIC COMPATIBILITY DESIGN OF TELECOMMUNICATIONS SYSTEM

Alexandru Ionuț CHIUȚĂ[1], Liviu Mihai SIMA[2],
Nicoleta Doriana SECĂREANU[3], Marius Andrei RONCEA[4]

Rezumat. *Compatibilitatea Electromagnetică (EMC) este o condiţie necesară pentru performanţa unui sistem de comunicaţii electronice (CE). EMC este abilitatea echipamentelor dintr-un sistem de funcţii create şi menite să funcţioneze fără efecte adverse sau, să fie afectate de alte echipamente sau sisteme. Trebuie să se cunoască tehnicile care le permit să identifice sau localizeze interferenţa electromagnetică (EMI). Identificarea problemelor este necesară înainte ca în proces să se piardă timp şi efort, iar tehnicile de evidenţiere a acestor probleme să fie arătate. În acest articol sunt prezentate exemple de elemente de bază (sursă de EMI, transmisia sau cuplarea echipamentului sau a sistemului afectat), care trebuie să fie luate în considerare în analiza sursei de EMI.*

Abstract. *Electromagnetic compatibility (EMC) is a necessary condition for effective communication-electronic (CE) system performance. EMC is the ability of equipment and systems to function as designed in their intended operational environment without adversely affecting of, or being affected adversely by, other equipment or systems. Techniques which permit them to identify, localize and define electromagnetic interference (EMI) problem areas before rather after they waste time and effort must be available. In this article are presented examples of the basic elements (EMI source, transmission or coupling media and susceptible device), that must be considered in EMI predictions and analysis.*

Keywords: electromagnetic design, prediction analysis, compatibility, interference

1. Introduction

Electromagnetic compatibility is a necessary condition for effective communication-electronic system performance.

Electromagnetic compatibility is the ability of equipment and systems to function as designed in their intended operational environment without adversely affecting of, or being affected adversely by, other equipment or systems.

Techniques which permit to identify, localize and define electromagnetic interference problem areas before rather after they waste time and effort must be available.

We present examples of the basic elements (electromagnetic interference source, transmission or coupling media and susceptible device), that must be considered in electromagnetic interference predictions and analysis.

[1]Ph.D. (ABD), Eng., University ”Politehnica” of Bucharest, Romania (inchiuta@gmail.com).
[2]Ph.D. (ABD), Eng., Academy of Romanian Scientists, (e-mail: liviusima@gmail.com).
[3]Eng., S.C. Metroul S.A., Bucharest, Romania (anemona_2027@yahoo.com).
[4]Eng., S.C. Metroul S.A., Bucharest, Romania (ronceam@yahoo.com).

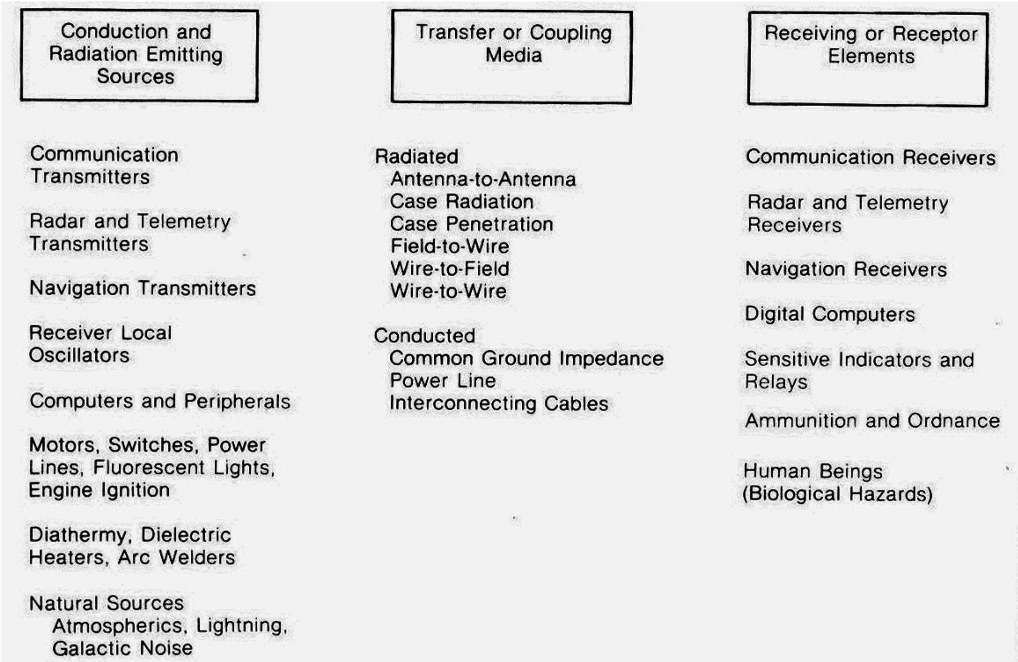

Fig.1. Three basic elements of an Emitting-Susceptibility Situation.

Figure 2 shows an organization Sources of Electromagnetic Interference and **Table 1** lists many specific EMI sources. **Figure 3** illustrates the interrelationship between levels of EMC design and analysis and system life cycle phases.

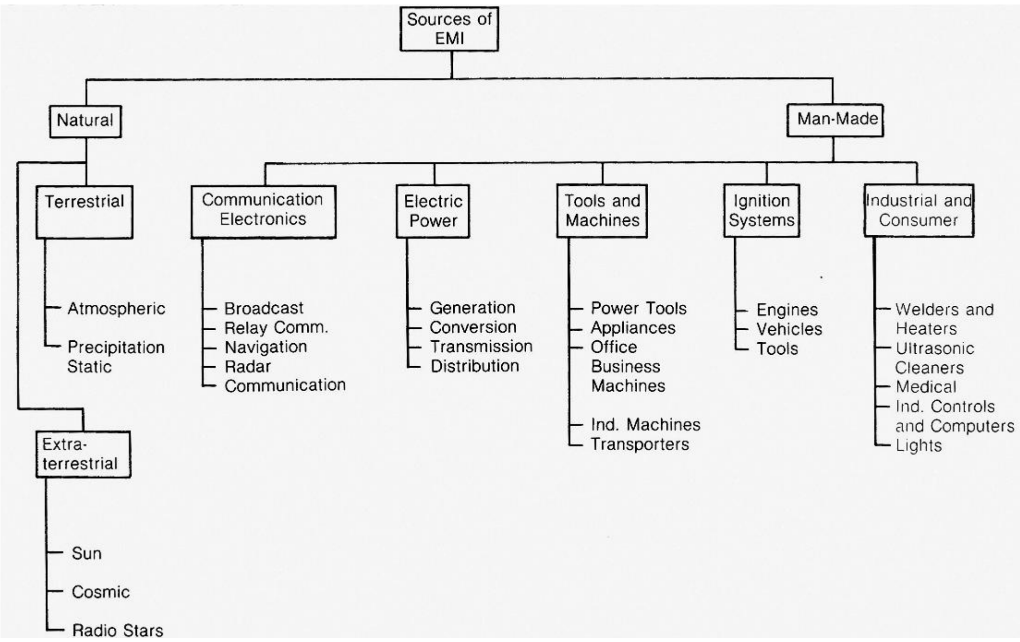

Fig.2. Sources of electromagnetic interference (EMI).

The final phase in the life cycle system shown in **Figure 4**. is the operational phase.

During this phase, a system that has been designed and developed is placed into operation.

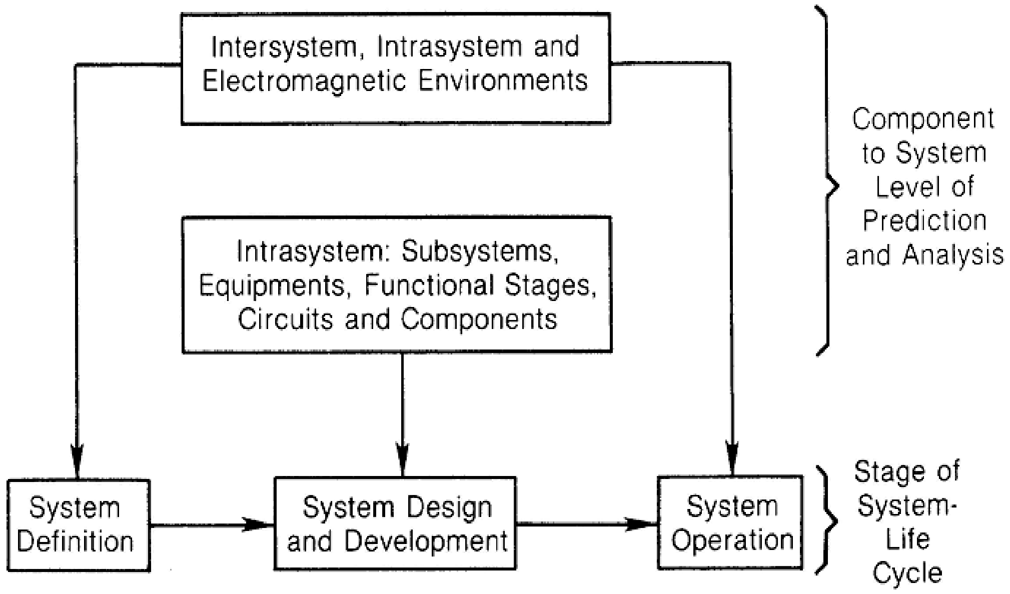

Fig.3. Interrelationship between System Life and Level of EMI Prediction and Analysis.

It's necessary to consider electromagnetic compatibility from various operational aspects such as:

- sting effects,
- frequency assignment,
- effective radiated power limits
- antenna coverage.

This is more generally illustrated in Fig. 5 as operational EMI control tools under the four main headings:

- frequency,
- time,
- location,
- direction management.

Figure 5 also contains EMI - control techniques.

Table 1. Examples of Sources of Electromagnetic Interference

I. Natural Sources
A. Terrestrial Sources
1. Atmospherics (thunder storms around the world)
2. Lightning Discharges (local storms)
3. Precipitation Static
4. Whistlers
B. Extraterrestrial Sources
1. Cosmic Noise
2. Radio Stars
3. Sun:
Disturbed
Quiet
II. Man-Made Sources
A. Electric Power
1. Conversion (Step Up/Down)
Faulty/Dirty Insulators
Faulty Transformers
2. Distribution
Faulty/Dirty Insulators
Faulty Transformers
Faulty Wiring
Pickup and Reradiation
Poor Grounding
3. Generators
4. Transmission Lines
Faulty/Dirty Insulators
Pickup and Reradiation
B. Communication Electronics (CE)
1. Broadcast
MF Amplitude Modulation
VHF/FM
VHF/UHF TV
2. Communications (non-relay)
Aeronautical Mobile
Amateurs (hams)
Citizens Radio
Facsimile
HF Telegraphy
HF Telephony
Land Mobile
Maritime Mobile
Radio-Control Devices
Telemetry
Telephone Circuits
3. Navigation (non-radar)
Aircraft Beacons
Instrument Landing Sys.
Loran
D. Ignition Systems
1. Engines
2. Tools
Auxiliary Generators
Lawn Mowers
Portable Saws
3. Vehicles
Aircraft
Automobiles
Farm Machinery
Inboard Motors
Minibikes
Motorcycles
Outboard Motors
Tanks
Tractors
Trucks
E. Industrial & Consumer (non-motor/engines)
1. Heaters and Gluers
Dielectric Heaters
Plastic Preheaters
Wood Gluers
2. Industrial Controls & Computers
4. Radar
Air Search
Air Surface Detection
Air Traffic Control
Harbor
Mapping
Police Speed Monitor
Surface Search
Tracking/Fire Control
Weather
5. Relay Communications
Ionospheric Scatter
Microwave Relay Links
Satellite Relay
Tropospheric Scatter
C. Tools and Machines
1. Appliances
Air Conditioners
Blenders
Deep Freezers
Fans
Lawn Mowers, Electric
Mix Masters
Ovens, Electric
Ovens, Microwave
Refrigerators
Sewing Machines
Vacuum Cleaners
Water Pumps
2. Industrial Machines
Electric Cranes
Fork-Lift Trucks
Lathes
Milling Machines
Printing Presses
Punch Presses
Rotary Punches
Screw Machines
3. Office/Business Machines
Adding Machines
Calculators
Cash Registers
Electric Typewriters
Reproduction Equipment
4. Power Tools
Band Saws
Drill Presses
Electric Drills

Card Punches
Card Readers
Computers
Machine Controllers
Peripheral Equipment
Process Controllers
Silicon-Controlled Rectifiers
Teletypewriters
3. Lights
Faulty Incandescent
Fluorescent Lamps
Light Dimmers
Neon Lights
4. Medical Equipment
Diathermy
X-Ray Machines
5. Ultrasonic Cleaners
6. Welders & Heaters
Arc Welders
Heliarc Welders
Induction Heaters
Plastic Welders
RF Stabilized Welders

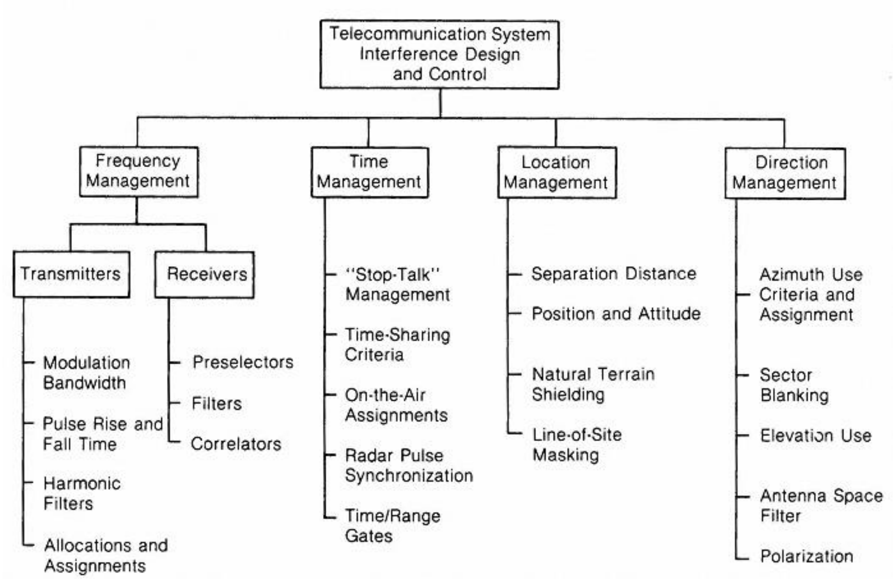

Fig.4. Telecommunication System Electromagnetic Interference Control Techniques.

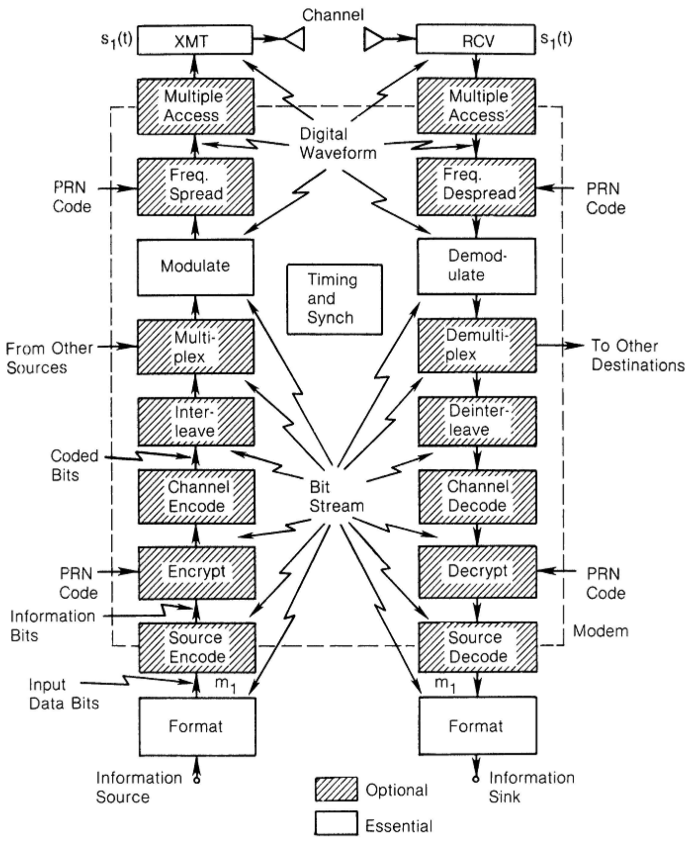

Fig.5. Typical Modern Digital Communication System.

2. EMC Analysis

EMC analysis provides an engineering tool that is a valuable asset in various phases in communication-electronic (CE) equipment, as well as system design and development such as:

1) preliminary equipment or system planning and design;
2) the preparation of equipment or system requirements and specifications;
3) the preparation of specification compliance test plans;
4) the evaluation of the results;
5) the revision of either specifications or equipments for conditions of noncompliance;
6) the evaluation of systems in a specific operational environment.

Typical EMC design problems that may be handled analysis include the following:

1. Examine the EMC situation for a complex of equipments and identify problem areas;
2. Examine the impact of changing the operating frequency of one or more equipments in the complex;
3. Examine the impact of adding an emitter to an existing system or complex of equipment;
4. Examine the interference produced in a susceptible device when added to a system or an existing complex;
5. Determine which one of several possible locations or an emitter or receptor provides the least probable interference;
6. Determine the source and cause of a known interference problem;
7. Determine the type and the degree of suppression required to correct a specified interference situation;
8. Obtain site survey or EMC environment for a given location.
9. Obtain susceptibility information for a given receptor or group of receptors;
10. Determine coupling loss over a specified path;
11. Assist in the selection of system parameters such as power, sensitivity and selectivity;
12. Provide information regarding the adequacy of given specifications for an equipment;

13. Provide information as to the best frequency band to use for a system which is best defined;
14. Provide information in frequency distance separation requirements for co-site equipments;
15. Perform frequency assignments for compatible operation;
16. Evaluate system effectiveness in an operational environment.

Some specific types of analysis include:

1. A preliminary analysis at the system definition stage to identify potential EMI problem areas and to define equipment EMC specification requirements.
2. An analysis based on statistical summaries of data to identify potential EMI problems between classes of equipment.
3. An analysis based on specification limits to determine their adequacy for assumed operational configurations of systems.
4. An analysis of system performance or operational effectiveness to define the effect of EMI and the overall ability of a system to accomplish its objectives or missions.

A basic telecommunication system may consist of simple of single channel analogue – amplitude or frequency modulated transmitter and receiver. A typical digital communication system is illustrated in **Figure 5**. A given system may not provide all of the function indicated in **Figure 5**.

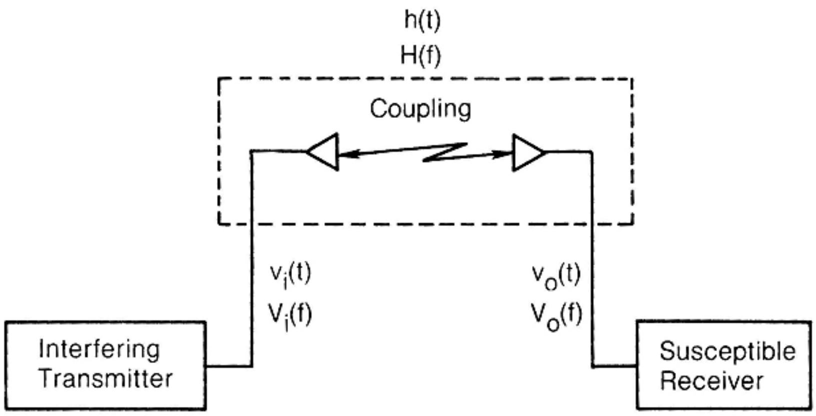

Fig.6. Overall EMC Analysis Elements.

The overall EMC analysis elements are illustrated in fig. 6. The source is an interfering transmitter with an output which may be described either as a function of time $v_i(t)$ or as a function of frequency $V_i(f)$.

The coupling media may be described in terms of a transfer function in either the time domain $h(t)$ or the frequency domain $H(f)$. If the source is deterministic and the coupling media is linear and time invariant the output $v_0(t)$ or $V_0(f)$, of the coupling media (which is the input to the potentially susceptible devices) may be calculated as follows.

$$v_0(t) = \int_{-\infty}^{\infty} h(\tau) \cdot v(t-\tau) d\tau \qquad (1)$$

or

$$V_0(f) = H(f) \cdot V(f)$$

In analyzing telecommunication systems it is usually possible to use the frequency domain equations and to make assumptions that simplify the equations to make assumptions that simplify the equations for specific situations of interest.

The system designer must be able to analyze the interactions between his system and all emitters and receptors in the environments.

In order to perform the required systems analysis, it is necessary to develop system equations which relate appropriate electromagnetic source (emitter output) characteristics to appropriate responses. The responses might be in the form of:

1) waveforms such as in time varying voltage at receptor inputs;
2) waveforms parameters such as average power;
3) interference indicators such as average power susceptibility margins.

Two categories of systems equations are presented here:

(1) "waveform system equations" defined as those relating arbitrary time waveforms between emitters and receptors and

(2) "parameter system equations" defined as those relating emitter outputs to receptor waveform parameters or interference indicators.

Table 2 shows the basic systems equations which result for each of the cases of interest. General equations are provided only for the linear deterministic transfer process. They are given for three different types of temporal dependencies and for both continuous and discrete spectrum emissions.

Table 3 gives equations for various waveform parameters. The definitions of all quantities in **table 3** are included in list below.

The term "switched stationary" as a susceptibility margin for total energy sensitive receptors indicates that the input waveform is an otherwise stationary process that is "turned" on and off at regular intervals.

In order to determine whether an EMI problem exists between a potentially interfering transmitter and a receiver it is necessary to consider the susceptibility of the receiver to both the design and spurious outputs (individually and collectively) of potentially interfering transmitters. The fractions that must be included in the analysis for each transmitter output (or group of transmitter outputs) include: the transmitter power (P_T), the transmitting antenna gain in the direction of the receiver (G_T), the propagation loss between the transmitter and receiver (L), the receiver antenna gain in the direction of the transmitter (G_R) and the amount of power required to produce interference in the receiver (P_R) in the presence of the desired signal.

Table 2. Waveform System Equation

Transfer / Emission	Linear and Deterministic		
	Time Variant		Time Invariant
	General	Special Case (Time & Frequency Separable)	
Aperiodic (Continuous Spectrum)	$v_o(t) = \int_{-\infty}^{\infty} v_i(\tau) h_g(t-\tau, t)\, d\tau$ $V_o(f) = \int_{-\infty}^{\infty} V_i(f') H_g(f', f-f') df'$	$V_o(t) = \int_{-\infty}^{\infty} a(t) v_i(\tau) h(t-\tau) d\tau$ $V_o(f) = A(f) * [V_i(f) H(f)]$	$v_o(t) = \int_{-\infty}^{\infty} v_i(\tau) h(t-\tau) d\tau$ $V_o(f) = V_i(f) H(f)$
Periodic (Discrete Spectrum)	$v_o(t) = \frac{1}{T} \sum_{n=-\infty}^{\infty} h_g\left(\frac{n}{T}, t\right) v_n^i e^{j \frac{2\pi n}{T} t}$ $V_o(f) = \frac{1}{T} \sum_{n=-\infty}^{\infty} V_n^i H_g\left(\frac{n}{T}, f - \frac{n}{T}\right)$	$v_o(t) = \frac{a(t)}{T} \sum_{n=-\infty}^{\infty} h\left(\frac{n}{T}\right) v_n^i e^{j \frac{2\pi n}{T} t}$ $V_o(f) = \frac{1}{T} \sum_{n=-\infty}^{\infty} H\left(\frac{n}{T}\right) V_n^i A\left(f - \frac{n}{T}\right)$	$v_o(t) = \frac{1}{T} \sum_{n=-\infty}^{\infty} h\left(\frac{n}{T}\right) v_n^i e^{j \frac{2\pi n}{T} t}$
Random	General solution not available. Solution may be obtained for special case of a Gaussian random process.		

Nonlinear	Random
General solution not available. Time-domain analysis methods are available for special cases that may be considered as piecewise linear, e.g., hard limiting, mixing, etc. Effort should be directed toward developing computer programs for these special cases. Volterra analysis may be used for periodic signals that have a limited number of frequency components. Aperiodic or periodic signals may be represented in either time domain or frequency domain, and Fourier transforms may be used. In general, random signals must be described in terms of their N-Dimensional joint probability distribution functions. A stationary Gaussian random process may be described in terms of the autocorrelation function or power spectral density.	Monte Carlo method offers general solution. Methods for solving cable bundle problems, where relative wire locations and terminals loads are random, are discussed in Morgan, Feb. 1978.

v_i, V_i = the input voltage as a function of time (t) or frequency (f)
h = the impulse response of the coupling media
H = the transfer function of the coupling media
τ = delay
T = the period of a waveform
a, A = the time variation of the coupling media

Table 3. Susceptibility Margin

	Deterministic	Stochastic
Average Power	$\int_{f_a}^{f_b} \frac{G_r(f)}{\lvert I_r^S(f)\rvert^2} df$	$\int_{f_a}^{f_b} \frac{G_r(f)}{\lvert I_r^S(f)\rvert^2} df$
Total Energy	Periodic: Use average power margin Aperiodic: $\int_{f_a}^{f_b} \frac{\lvert I_r(f)\rvert^2}{E_r^S(f)^2} df$	Stationary: Use average power margin "Switched" Stationary: $\Delta \int_{f_a}^{f_b} \frac{G_r(f)}{E_r^S(f)} df$
Peak Current	$\int_{f_a}^{f_b} \frac{\lvert I_r(f)\rvert}{\lvert I_r^S(f)\rvert} df$	Stationary: $\frac{\sigma_r^2}{\alpha \lvert I_r^S(f_p)\rvert^2}$

$i_r(t)$ = detector output current;
$I_r(f)$ = Fourier transformation or $i_r(t)$ (finite energy);
$I_r^S(f)$ = level of $I_r(f)$ which induces the interference threshold level at the detector;
$G_r(f)$ = spectral power density at the receptor input;
(*note*: $G_r(f)$ is defined for negative f)
$E_r^S(f)$ = the CW energy at frequency f which generates the energy equal to the standard response energy level at the detector input with cooling included;
Δ = duration of interference on receptor;
τ_r^2 = variance of detector input waveform;
α = fraction of time that a stochastic waveform peak at detector input must exceed to trigger interference;
f_a, f_b = lower, upper frequencies defining common frequency band between interferer and receptor;
f_p = frequency for which receptor input is maximum.

The procedure that is used for each transmitter output emission can be demonstrated by considering the interference situation that exists between a particularly output of one of a number of potentially interfering transmitters and specimen receivers. In the case of a particularly transmission output (which may be either a fundamental or a spurious emission) the power available at the receiver is given by:

$$P_A(f,t,d,p) = P_T(f,t) + C_{TR}(f,t,d,p) \tag{2}$$

where: $P_A(f,t,d,p)$ = power available at the receiver (in dB_m) is a function of frequency (f), time (t), distance separation (d) and direction (p) of both transmitter and receiver and their antennas.

$P_T(f,t)$ = transmitter power (in dB_m)
$C_{TR}(f,t,d,p)$ = transmission coupling between the transmitter and receiver (in dB_m)

In intersystem EMC analysis problems, the function $C_{TR}(f,t,d,p)$ includes the effects of both the transmitting and receiving antenna characteristics, G_T and G_R and the intervening propagation media.

For some situations (emphasis certain radars), the antenna performance is not readily separable from the transmitter/receiver characteristics.

When this exists, the transmitter antenna characteristics are grouped with P_T (unit now dB_m/m^2) and backed out of the C_{TR} term.

By comparing the power available at the receiver at the frequency in question $P_R(f,t)$ to determine the interference situation for the particular transmitter output being considered.

The requirement for EMC is that the power available at the receiver be less than the power required to produce interference at the receiver.

Thus the condition for electromagnetic compatibility is:

$$P_A(f,t,d,p) < P_R(f,t) \tag{3}$$

On the other hand, if the power available at the receiver input terminals is equal to or greater than the power required to produce interference in the receiver, as given below, an electromagnetic interference problem may exist:

$$P_A(f,t,d,p) \geq P_R(f,t) \tag{4}$$

While the foregoing may seem basic, it is the essence of all intersystem EMI situations.

To perform an EMC analysis it is necessary to provide certain basic information on each source and responding equipment to be included in the analysis.

Examples of information that are usually required include equipment nomenclature, geographical location and operating or assigned frequency.

Nominal equipment data such as the following are required:

1. transmitter power output emission typed and emission bandwidth;

2. receiver sensitivity, bandwidth, IF an local oscillator frequencies and anti-jamming logic, if applicable;

3. antenna gain, polarization, height, orientation and beamwidth.

The use of synthesized data permits the user to perform EMC analysis of a system containing equipment for which specific interference characteristic are not available.

Figure 7 shows the interrelationship between various types of required and synthesized data.

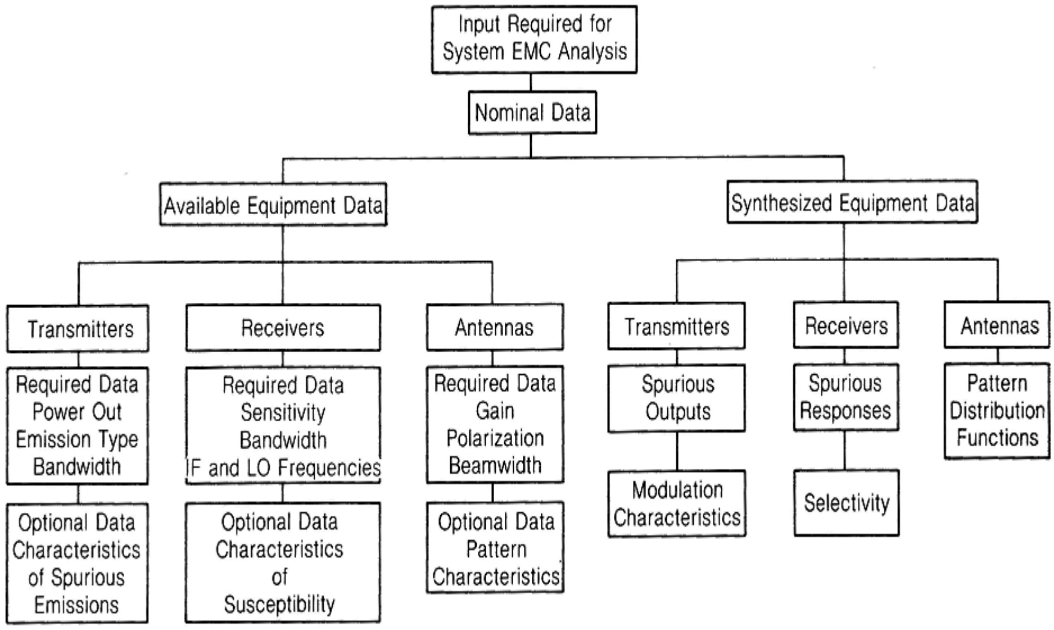

Fig.7. EMC Analysis input.

EMC analysis will yield a variety of answers.

If only a preliminary analysis is performed, the results may (1) identify potentially interfering equipment transmitter-receiver pairs by nomenclature, (2) define the frequency range over which interference problems may exist and (3) specify the interference margin over each frequency range of interest.

3. Problem definition – Conclusions

The first step in EMC analysis is problem definition. During this stage, it is necessary to define the analysis frequency range, geographical area, equipment involved, relative geometry, prediction detail, sources of input date, output results required and related considerations.

Regarding frequency range limitations, the fundamental interference margin (FIM) is usually considered for situations in which the transmitter and receiver frequencies are separated by percent or less. FIM refers to situations resulting from the transmitter fundamental emissions interfering with the receiver fundamental response.

Hence consideration of transmitter interference margin (TIM) and receiver interference margin (RIM) is usually limited to cases for which the transmitter and receiver fundamental frequencies are separated by more than 20 percent but less than one decade.

Spurious interference margin (SIM) is usually considered in cases for which transmitter and receiver fundamental frequencies are separated by more than one octave but less than two decades.

The separation for which is necessary to consider TIM and RIM is defined in Fig. 8 as a function of radio frequencies and effective power margin (EPM) in dB which is:

$$EPM = P_T + G_{TR} + G_{RT} - P_R \tag{5}$$

where:

P_T = transmitter power in dB_m

G_{TR} = transmitting gain in direction of the receiver in dB

G_{RT} = receiving antenna gain in direction of the transmitter in dB

P_R = receiver sensivity in dB_m

Relationships in **Figure 8** are based on rejection level of 60dB for transmitter and receiver spurious emissions and responses.

In EMC analysis it is necessary to consider RIM and TIM cases for disturbances less than those specified by the appropriate relationships in **Figure 8**, SIM separation distances that must be considered are illustrated in **Figure 9**.

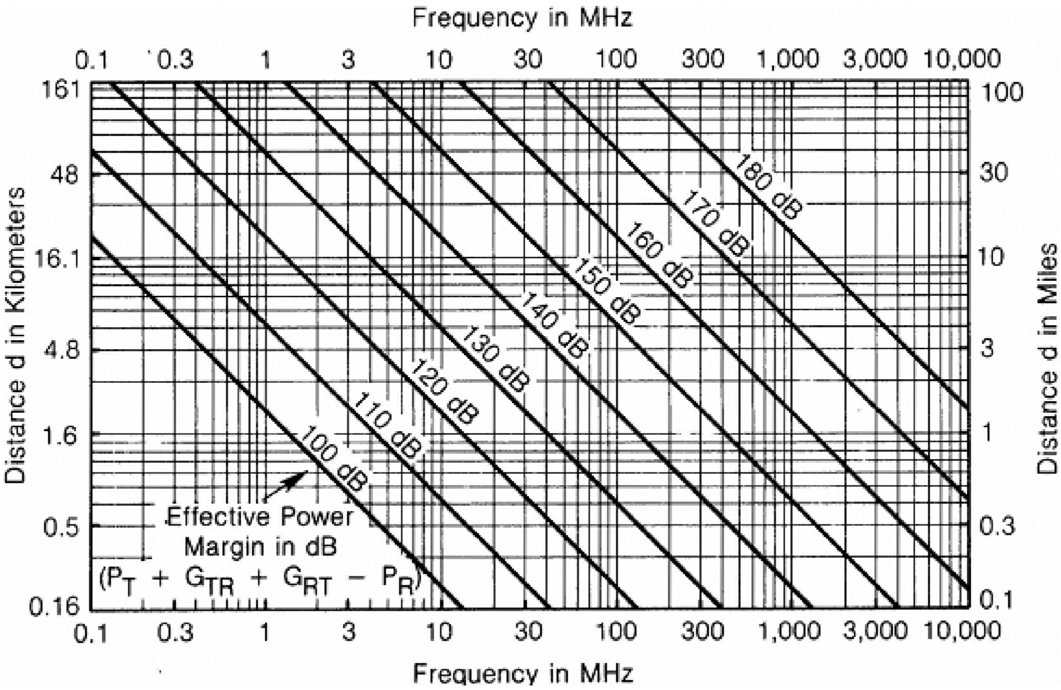

Fig. 8. Distance Separation Criteria for RIM and TIM.

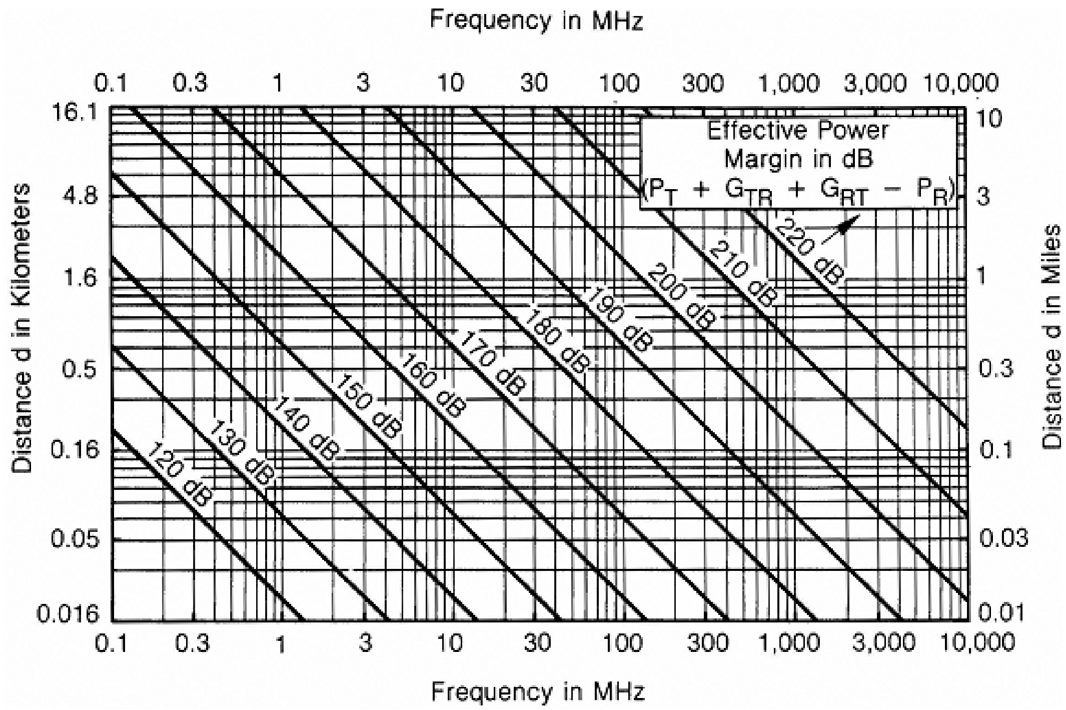

Fig. 9. Distance Separation Criteria for SIM.

R E F E R E N C E S

[1] Duff G. William, *Electromagnetic Compatibility in Telecommunications, Interference Control Technologies,* Inc. Gainesville Virginia, 1988;

[2] Wall, R.A., and Hutchinson G.K., *An Interference Prediction Model,* IEEE Transaction on EMC, EMC-8, No 3, September, 1966, pp 130 – 342.