# GUIDELINES FOR THE DESIGN OF AN EMI SUSCEPTIBILITY TEST SYSTEM

## INTRODUCTION

Faced with the many recent advances in EMI susceptibility testing, and the wide selection of equipment available, many in the field may have trouble choosing the optimum test setup for their needs. The following provides an overview and an approach to the startup of a general-purpose EMI susceptibility test facility where the sizes of test samples and conditions under which they must be tested are generally foreseeable.

A couple of early rules of thumb can help in making equipment selection for EMI susceptibility testing. Near-term needs are minimum requirements, and, when possible, equipment that best provides for future increased capability is recommended. To avoid duplicating expensive equipment, a plan to avoid bandwidth gaps and power inadequacies requiring expensive remedies and overlaps in capability is imperative. On the other hand, inexpensive system components must not impose system limitations, particularly when a small additional investment can vastly increase system capability.

The best planned systems exhibit good balance in equipment performance, are well matched in bandwidth and power capabilities, and invite an easy climb to additional system capability for minimum additional cost.

## VITAL SPECIFICATIONS, IMPORTANT CAPABILITIES EXTRAS

Vital specifications must be considered from the outset in order to obtain the system performance needed. For example, in a system that will employ a radiating antenna, field strength and bandwidth are the first important specifications for which to establish values. Implicit in this is another critical specification, the output of the RF power amplifier, which is the output (in watts) necessary to achieve desired field strength (in volts per meter) in a radiated RF environment. Also, because the operation of a test system begins with signals at very low levels that must be amplified, often to extremely high levels, gain (in dB) becomes a necessary specification in selecting amplifiers and radiators.

Important capabilities are the next priority. Again, these depend upon the present and foreseeable requirements of a testing procedure. These capabilities can include pulsing, blanking, sweeping, calibration-quality accuracy, and perhaps computer interfacing. These, like bandwidth, output power, and field strength, pertain to systemic capabilities, and should be established from the start. Safety features should also be given high priority, including those that protect personnel, as well as those that protect the equipment from potentially destructive effects of overloads, impedance mismatches, short circuit, and operator error. Especially important in the selection of high-power RF amplifiers, these safety features can be a good yardstick by which to measure the overall quality of the instrument.

Differences in performance and important features, which can be substantial, should be the deciding factors in equipment selection. Extras (or nonessentials) should rarely decide the matter.

## BASIC SYSTEM REQUIREMENTS

Usually not just one test method or one equipment configuration is aptly suited to conducting an EMI susceptibility test. Often many setups are used to reveal the specific susceptibilities of a test sample. In the early stages of system setup, foreseeable requirements should be defined and a plan devised to ensure compatible operation of all testing equipment to meet these requirements. The groundwork can be done with a few general considerations.

## TEST SAMPLE SIZE

Size of the test sample largely determines the type of enclosure in which the item can be tested. Some items are so large they can be tested only outdoors. However, FCC permission must be obtained for outdoor testing, and this is very difficult to accomplish, even in the most geographically isolated areas.

Small test items (up to roughly the size of a clock radio) may be tested in a TEM (transverse electromagnetic wave) cell, provided the cell (often termed a Crawford cell) can accommodate the bandwidth requirements of the test. The larger the cell, the larger the sample item it can test, but the narrower the cell's operating bandwidth. Table 1 illustrates this concept with two sample TEM cells.

The dimensions and taper of TEM cells provide a 50 ohm impedance from end to end, and, when supplied with RF power terminated into 50 ohms, produce a uniform high-impedance field approximating that of free space throughout the test-sample location. Because of their highly controllable and measurable characteristics as EMI test chambers, TEM cells are often used to calibrate field-strength and power-density meters. TEM cells also eliminate the need for a radiating antenna, and can be used in an otherwise unshielded work environment. They may also permit the use of an RF amplifier of lower output power, to achieve necessary field strength within their small chambers.

If projected test-item sizes exceed those which can be accommodated within a TEM cell, or if bandwidth requirements cannot be met, use of a shielded room or an anechoic chamber is most often indicated, and therefore the use of an RF radiating antenna and perhaps a need for greater output power from the RF amplifier. Several types and sizes of shielded and anechoic rooms are available from several suppliers. These rooms offer great bandwidth flexibility for EMI susceptibility testing (to 1000 MHz and above), and can be used for testing larger products and systems.

## BANDWIDTH AND POWER

Bandwidth and power requirements are the critical specifications that must be accommodated by several components in the system working together.

Those components that initiate and condition the RF signal prior to amplification to the power levels needed for testing should offer very wide bandwidths. Chosen correctly, one or two signal sources and two leveling preamplifiers can cover the band from 10 kHz to 1000 MHz.

| TEM Cell Dimensions | Test Item Maximum Size | Operating Bandwidth |
|---|---|---|
| 2 M X 60 cm x 1 M | 30 cm X 10 cm X 20 cm | dc to 250 MHz |
| 1 M X 30 cm X 50 cm | 15 cm X 5 cm X 10 cm | dc to 500 MHz |

**Table 1. TEM Cell Bandwidth Capability.**

Amplification of the signal to the necessary power levels is where tradeoffs in bandwidth and power output usually begin. High power RF amplifiers have narrower operating bandwidths than low power RF amplifiers. In a system that requires levels of output of more than one watt, it is unlikely that one amplifier will be able to accommodate all necessary bandwidths and power output levels. However, even for up to 1000 watts of output power over a 10 kHz-1000 MHz bandwidth, no more than three RF power amplifiers should be necessary.

Radiating antennas also operate under set specifications for bandwidth and input power, but here again, two or perhaps one antenna may cover all the desired power bandwidth regions for the expected RF testing.

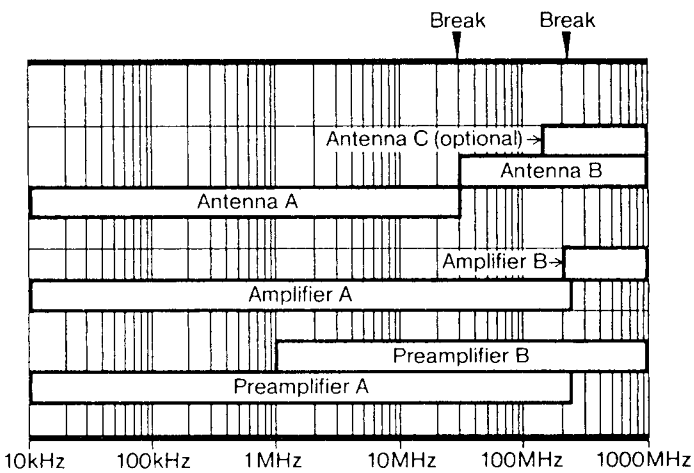


**Figure 1. 10 kHz-to-1000 MHz testing at nV/m showing two interruptions.**

## BAND BREAKS

If all the components in a test system had exactly the same bandwidths, there would be no problem of "band breaks." This of course is not so. Band breaks are divergences in the operating frequencies of the various system components. To avoid outright gaps in system bandwidth, components must be selected with the same or overlapping frequency ranges. Band breaks can also cause unfortunate interruptions in an RF test. Figure 1 shows a selection of equipment that would require only two interruptions for 10 kHz-to-1 GHz testing at an arbitrary field strength of nV/m. Figure 2 shows a selection of equipment that would require five interruptions for the same test.

Thus, equipment that offers maximum available ranges of operating frequencies will decrease the number of band

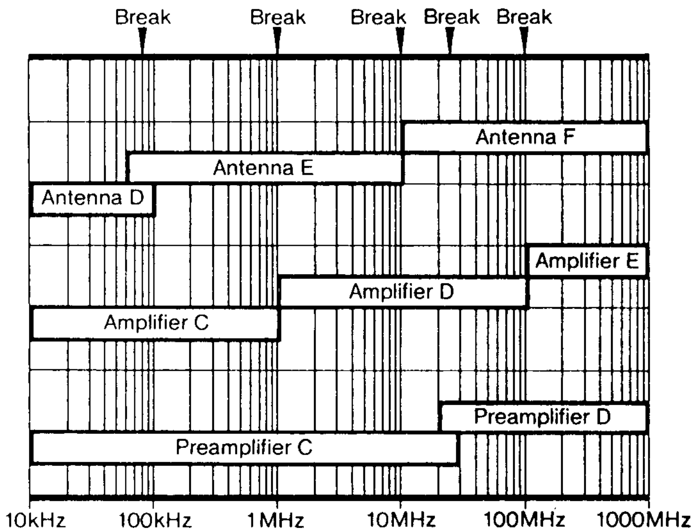


**Figure 2. 10 kHz-to-1000 MHz testing at nV/m showing five interruptions.**

breaks in testing. Specific operating bandwidth characteristics should also be closely examined to ascertain equipment compatibilities.

## COMPATIBILITY

Impedance matching is not difficult with today's RF testing equipment—50 ohms is the standard. However, many types of general scientific testing devices, such as oscilloscopes and other metering devices, may operate at other impedances and necessitate the use of 50 ohm terminating resistors or matching transformers.

Maximum output and minimum input levels are two other important specifications to focus upon in setting up a system. Obviously output and input levels must be compatible.

Some special system capabilities require compatibility of all the components in the system. For example, use of sweep output (increasing or decreasing frequency output) from a signal source strongly suggests the need for an amplifier with instant bandwidth (full operating bandwidth without need for bandswitching or tuning). Pedestal and blanking outputs from a preamplifier or laboratory function generator require an RF amplifier capable of responding to these inputs, which are useful for pulse testing at very high levels. For field-strength leveling, accomplished by a sensor within the RF environment transmitting readings to a leveling preamplifier, the monitor-input-polarity requirements of the preamplifier should be checked with regard to the output of the sensor system—the two must match. Also, the response times of the sensor, the preamplifier, the amplifier—in effect, the entire system—must be matched in order to prevent feedback-loop oscillation. The leveling preamplifier should offer these adjustments.

## CONVENIENCE

A comprehensive EMI susceptibility test can be just a two-person operation: one to operate and oversee the test equipment, and one to assist and closely follow the effects of the RF environment on the test sample and record results. Today's equipment easily permits this, including RF power amplifiers with complete load mismatch immunity, which can sustain severe load mismatches including infinite VSWR without damage or shutdown. Amplifiers without this capability must be protected with an automatic-shutdown feature (a less costly design alternative). Test interruptions caused by a shutdown amplifier, or by the inability to perform adequately in critical areas of the test band, often prove more costly than higher initial investments in amplifiers with complete load mismatch immunity.

## AN EMI SUSCEPTIBILITY TEST SYSTEM

Figure 3 shows a typical EMI susceptibility test system. The RF signal originates in the signal source—a laboratory signal generator, a sweep generator, or a frequency synthesizer. The leveling preamplifier can be used simply to amplify the source signal, although this function alone is generally not necessary. In a broadband system, all the components exhibit variations as a function of frequency, and the leveling preamplifier's major role is that of a compensating device. By raising or lowering its output to the RF amplifier, and thus causing the power level of the signal to be amplified, the leveling preamplifier can cause increases or decreases in the output power from the RF amplifier. In conjunction with signal input from a field-strength meter placed in the RF environment or from a powermeter placed at the output of the power amplifier, the leveling preamplifier can respond with varying levels of input to the amplifier in order to achieve leveled field strengths or leveled output power. In Figure 3, the field sensor and its repeater, the leveling preamplifier, and the power amplifier form a complete feedback loop. The power amplifier increases the level of the RF signal to the

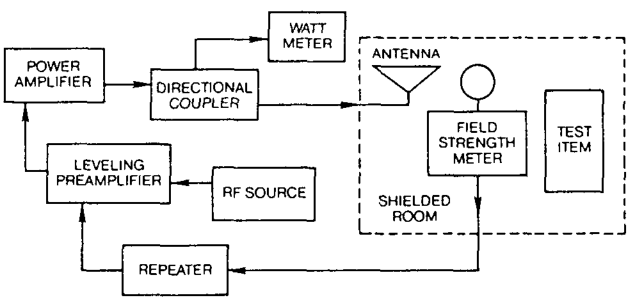


**Figure 3. Typical EMI susceptibility test configuration.**

output power needed to achieve the desired field strength. A directional coupler provides a port for coupling a powermeter to the output of the RF amplifier for measuring forward or reflected power. A dual-directional coupler provides two ports for measuring forward power, reflected power, or both. The antenna radiates RF power into the shielded enclosure and onto (and perhaps into) the test sample. The field sensor measures the field strength of the electric or magnetic RF environment, and provides a readout to the operator. Its repeater transmits this information back to the preamplifier for leveling. This system has few frills, yet includes all of the equipment necessary for a wide range of EMI susceptibility tests.

## THE SIGNAL SOURCE

Two types of signal source are generally used in EMI susceptibility testing.

The frequency synthesizer can provide either simple or complex waveforms, the latter with several wave-component characteristics. Amplitude, frequency, and phase modulation are among the synthesizer's capabilities. The waveform selected can be supplied at extremely accurate frequencies. Synthesizers are not specifically intended for EMI susceptibility testing, and therefore may or may not be capable of preprogrammed automatic sweeping (from low to high or from high to low frequencies, within specified intervals). Relatively high cost and lack of this sweeping ability are negative factors in considering a frequency synthesizer. However, its output of precise frequencies makes the synthesizer a valuable tool for specialized RF testing applications, particularly those requiring computer control.

The sweep generator puts out a single-component wave. It can provide a progressively increasing or decreasing frequency output (a "sweep" output). For example, a sweep may consist of 100 kHz gradually increasing to 1 MHz over a period of two minutes, or thirty seconds, or less. This automatic sweep feature eliminates the need for the operator to manually control and change test frequencies while conducting a test. An economical and commonly-used signal source, the sweep generator also permits manual sweeping, to help identify a specific frequency once a sample failure has been identified within a bandwidth region. Here, the capability of instantly available bandwidth in the preamplifier and the amplifier is of great importance in eliminating the need for bandswitching and tuning during sweep tests.

## THE LEVELING PREAMPLIFIER

The function of the leveling preamplifier—to help attain leveled field strengths within the RF test environment or leveled output power from the power amplifier—has already been explained. The importance of this function has not. In susceptibility testing, the test band is usually established first. Desired field levels are then set, perhaps gradually increasing with each series of sweeps through the band. The leveling preamplifier assists in accurately producing those conditions of field strength or output specified in the test format. (See Figure 4.)

In a system that employs a high-power amplifier in a reduced-output mode, followed by other system components (or the test item) incapable of sustaining occasional high-level peaks, the leveling preamplifier can help to assure the safe operation of this system within these lower power levels. In this instance the leveling preamplifier would be used in combination with a directional coupler and detector at the output of the power amplifier. This system configuration could eliminate the need for a lower-output power amplifier.

Convenience is another benefit provided by the leveling preamplifier. It can permit testing at a wide range of input-signal levels, from one setting of the power amplifier, via adjustment of the threshold control of the preamplifier.

Blanking and pedestal outputs, important for pulse testing, are other options available with some leveling preamplifiers.

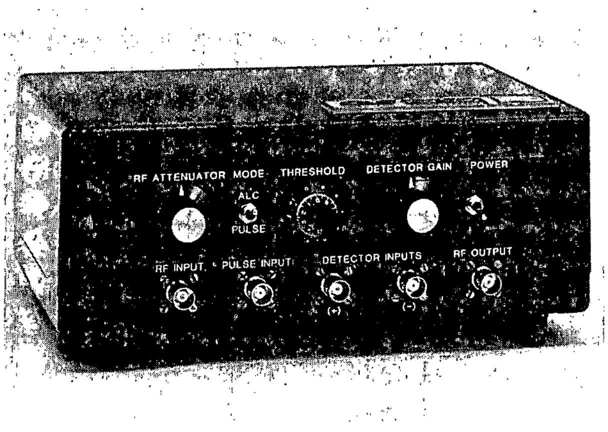


**Figure 4. Leveling, pulsing, blanking, RF-delay, and pedestal outputs of adjustable widths are among the numerous options for RF testing provided by some gated leveling preamplifiers.**

## THE RF POWER AMPLIFIER

The performance of an RF power amplifier can be assessed by using four general considerations: output power, bandwidth, stability, and load tolerance.

The method of power specification varies among amplifier manufacturers. Some publish *peak* or *maximum* output power specifications, which indicate performance in optimum conditions, usually within a small portion of rated bandwidth, and with gain control set at maximum. This maximum power specification offers no indication of linearity, flatness, or even of estimated performance at less-than-maximum input signal levels.

*Nominal* power ratings, combined with flatness specifications (given as ± values), are a bit more useful. Here a calculation is needed to establish the amplifier's true output range. The output will never be more than the nominal rating *plus* the flatness specification, and, conversely, it will never be less than the nominal rating *minus* the flatness specification—a confusing procedure, to say the least. (See Figure 5.)

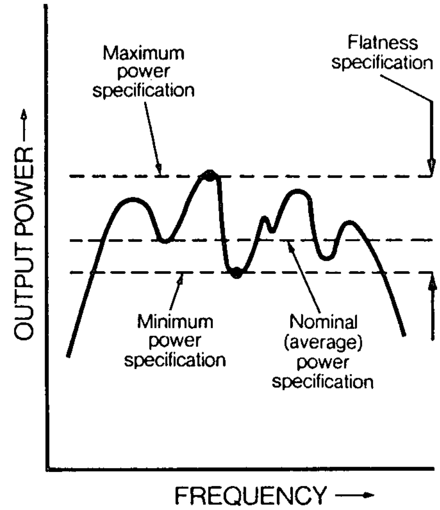


**Figure 5. Minimum power, nominal power, maximum power, and flatness specifications. Minimum power is assured output over the amplifier's operational bandwidth.**

For susceptibility testing, the most useful specification is *minimum power,* which ensures that the amplifier will deliver *at least* this output across its entire bandwidth when driven with a specified input signal level. Only if the drive is reduced at the signal source or at the amplifier's attenuator control will the output fall below the amplifier's minimum rated power.

Of course, in EMI susceptibility testing, the concern is actual power output at each frequency within the test band. Reliance on any power specification other than minimum power may result in inadequate output, thus invalidating the test.

It should be emphasized that there is an inverse relationship between clean, instant bandwidth and power output. Those amplifiers which can supply the highest possible power output over the widest bandwidth demonstrate the ideal sought after in power amplifier design. Greater system capability with fewer amplifiers and fewer band breaks are obvious benefits here. (See Figure 6.)

The most fundamental specification of a power amplifier is *gain.* Like power output ratings, minimum gain ratings are most reliable because they are guaranteed across the bandwidth. Gain specifications typically range from less than 25 dB for 1-watt amplifiers to 70 dB for 10,000-watt amplifiers. An amplifier should have enough gain to maintain rated output from 1 milliwatt input.

*Linearity* is a variation of gain with changes in power. Commonly, linear output is the output level at which gain falls off (known as gain compression) by a given amount, usually 1 dB. Particularly for low power RF amplifiers, good linearity is a major design consideration, as amplifiers with good linearity will always prove more versatile than non-linear amplifiers. Linearity specifications are also useful for assessing the degree of saturation to which the amplifier is being driven to obtain its output power rating.

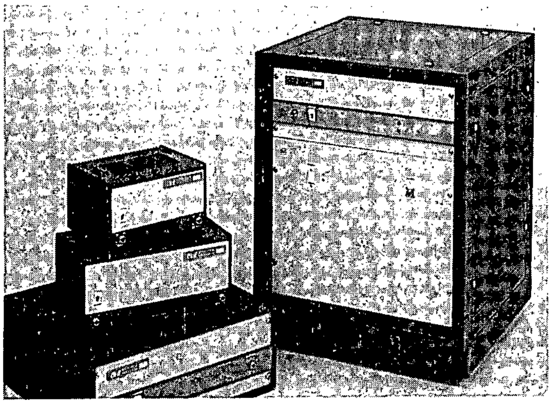

**Figure 6. Broadband RF amplifiers range widely in power output and operational bandwidths. Those that produce rated output over the broadest frequency ranges exhibit optimum design.**

*Flatness* is a variation in gain with changes in frequency, and can be a major factor in susceptibility testing with an unleveled test configuration (as indicated in Figure 5). Flatness is a quantitative measure of an amplifier's gain throughout its bandwidth. It can also serve as a quality check for evaluating performance at the limits of this bandwidth. When considering amplifiers with comparable output, bandwidth, and gain, an amplifier with poor flatness may indicate a questionable outlook on bandwidth specifying by the designer.

*Mismatch immunity* is an amplifier's ability to survive under the adverse conditions it is helping to create. In susceptibility testing, loads are (almost by definition) rarely matched to the amplifier, and often resemble open-output or short-circuit conditions. The amplifier must be able to absorb reflected power from high-VSWR loads and continue to function as though everything were perfectly matched. It should also be unconditionally stable; that is, free from oscillation under any load. The ability of an amplifier to operate under these conditions without sustaining damage to itself or shutting down indicates good design.

## THE ANTENNA

Input power-handling capacity and bandwidth are important factors in the selection of a radiating antenna. Also, the type of antenna (parallel-plate, biconical, monopole, log-periodic, cavity-exciting, parallel-element, ridge-guide) and its radiating characteristics are important factors. Some antenna types are highly directional, while others radiate isotropically (multi-directionally). Both have their particular applications in shielded-room testing. Cavity-exciting antennas use a wall or ceiling of the shielded room itself as a ground plane for optimum radiating efficiency. This type of antenna is especially valuable in the difficult 30-200 MHz band where other antennas fall short.

In EMI susceptibility testing, specified field strengths should be introduced on the sample from as many incident angles as possible. In real-life conditions, interference can come from any direction, and how the antenna or test setup simulates this phenomenon will determine the true comprehensiveness of the test.

## THE FIELD SENSOR SYSTEM

When RF power becomes a transmitted RF field, difficulties come into play. In shielded room testing, for example, the enclosure's reflective and absorptive characteristics change with each differing radiated wavelength, and the actual RF field at the test sample location is a summation (both additive and subtractive) of all incident field polarizations at the site, at that instant.

Monopole field-sensing systems that respond to field polarizations from just one direction are adequate for outdoor testing or heavily-damped shielded-room testing characterized by few reflective polarizations. However, such sensor systems can serve only as gages, not as accurate measuring instruments in the excited, highly reflective shielded room.

Isotropic field sensor systems, on the other hand, respond to any incident field polarization. Their readings are the summation of all incident magnetic or electric fields, sensed from all directions at the probe location. These sensor systems serve as much better field strength monitors in a highly reflective RF environment. (See Figure 7.)

Frequency range, field strength range, sensitivity, and accuracy are important specifications in the selection of a field sensor system, which, it must be emphasized, should meet all bandwidth and field strength requirements.

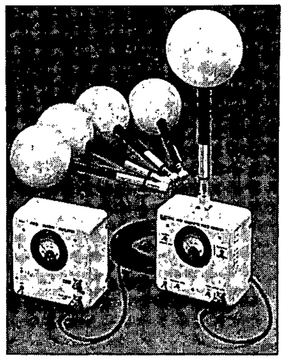

**Figure 7. An RF field strength sensor system with balanced isotropic probes sums incident "E" and "H" fields from all directions, important in a highly reflective shielded room test environment.**

## CONCLUSION

A basic understanding of the electromagnetic environment is necessary for system design and informed susceptibility testing. Help is readily available from designers and manufacturers of test equipment for those with serious system-building intentions. Foresight and imagination will help prevent shortcomings in the test system, and in the range of procedures it can perform.

Finally, system setup is by no means an inexpensive matter, in either dollars or time. Laboratories specifically dedicated to susceptibility testing should be considered as an important alternative, and should always be the first step before any serious project is undertaken by the inexperienced.

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*This article was written for* ITEM 85 *by Donald R. Shepherd, President, Amplifier Research Corporation, Souderton, PA.*