Active Small Broadband Antennas For EMI Testing

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The small size and broadband characteristics of electrically small active antennas make them an excellent choice for EMI testing. Most military and commercial electronic equipment manufactured today require testing for EM emissions and susceptibility.

Much of this testing is performed in small anechoic chambers containing materials for absorbing EM radiation so that accurate field strength measurements can be made. When testing for emissions radiating from electrical equipment, a low-noise, broadband active antenna calibrated to measure EMI over a wide range of frequencies should be used.

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An antenna is labeled electrically small if the largest dimension is less than one-tenth of the free-space wavelength of operation. While this is not a rigid rule, it is accepted in the industry since the early publications by Wheeler[1] and Chu.[2]

Some of the broadband antennas described in this article may become larger than $\lambda/10$ at their highest frequency. The primary intent, however, is to describe the theory, limitations and potential performance of antennas which are truly small over most of their operating frequency range.[3]

Passive Antennas

Before discussing small active antennas, it is appropriate to define fundamental trade-offs which exist with respect to electrically small passive antennas.

When developing a small passive antenna, the designer must choose a priority—size, efficiency, bandwidth or directivity. If an antenna of a certain size and directivity is desired, it is possible to achieve an equitable trade-off between efficiency and bandwidth. Since efficiency usually is of lesser importance in a high-frequency receiving antenna, it is possible to sacrifice this parameter in order to obtain a wide bandwidth.

If a transmitting antenna is desired, efficiency is important, since a transmitter usually is tuned to a single frequency (or an extremely narrow instantaneous bandwidth). It is relatively easy to achieve high efficiency for a small, passive antenna by incorporating a low-loss, high Q tuning network in the circuit.

It is impossible to simultaneously achieve high efficiency and wide bandwidth from any small, passive antenna. To do so would require a violation of the basic laws of nature.[3]

Active Antennas

While the theory of small passive antennas is well documented, the principles involved in the design and applications of small active antennas are not as well understood. An active antenna in its minimum configuration consists of a passive antenna, typically a rod, dipole or loop, integrated with an external low-noise amplifier to improve its performance as a receive-only antenna.

Because of the physical dimensions of electrically small antennas, their applications are very attractive in mobile communications systems and antenna arrays. Active antennas also are extremely broadband and frequency independent as well as having a constant output impedance.

While comparing the performance of passive antennas is a relatively simple task, the analysis of active antennas is not as simple. Active networks generate noise which must be accounted for within the total system.

System performance ultimately is judged on the basis of signal-to-noise ratio, not on how high the receiver S meter reads or how much gain is built into the antenna. Extreme care must be exercised in the design of active antennas to reduce the amount of internal noise generation and distortion while maximizing signal-handling capability.[3]

A criterion for relative performance comparison of active antennas should take into account efficiency and noise generated within the antenna circuit, both referenced to the output terminals. The antenna correction factor requires only simple arithmetic to add the effects of external noise and receiver noise to determine overall system performance. It permits an immediate and easy comparison of the relative sensitivities of active antenna designs.

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Antenna Factor

The antenna correction factor (AF) is a performance characteristic important primarily in receiving applications such as EMI and field-strength measurements. It relates terminal voltage to incident field strength, taking into account the antenna directivity, internal dissipative losses, mismatch loss, frequency and effects of any integral electronic circuitry.[4]

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For example, by using the E-field AF from a calibrated antenna, the electric field immersing the antenna can be calculated using the formula:

$$E(\text{dB V/m}) = V(\text{dB V}) + AFE(\text{dB m}^{-1})$$

where: E = electric field strength at the antenna
V = voltage at terminals of the antenna
AFE = electric field antenna factor

Active Monopole Antenna

An electrically short monopole connected to a low-noise preamplifier is an example of an active EMI test antenna for measuring electric field intensity. The dynamic range of this antenna must be sufficient to allow operation outside shielded rooms where strong signals normally would prohibit the use of such sensitive, active devices.

The preamplifier must be a high-input impedance type, such as a field-effect transistor connected in a source-follower configuration, so as not to load the monopole. Additional stages then may be cascaded to provide further amplification. The antenna should be powered by batteries to prevent the insertion of 60-Hz common-mode interference into the system.

The antenna is so short electrically that the effective height, and hence the open-circuit RF voltage induced at its feed-point, is essentially independent of frequency below $\lambda/10$. Therefore, the open circuit voltage is practically equal to a constant times the strength of the incident field. Since the source-follower configuration exhibits essentially unity voltage gain independent of the frequency, the response of the combination is virtually constant over a very wide band.

Practically no RF current flows at the base of the monopole; hence, only a small counterpoise (ground plane) is necessary for the antenna to function effectively. The counterpoise should be large enough so its capacitive reactance in series with the feed point is negligible when compared to the input impedance of the circuit. A sheet of metal two to three feet square is adequate.

As the frequency decreases, the self-impedance of the monopole rises until it eventually exceeds the high, constant input impedance of the source follower. At this point, the source follower begins to load the monopole significantly, causing a reduction in the voltage available at the base of the monopole. This results in a roll-off in the antenna response at the low end of the band.

The amplification may be emphasized at the low end of the band in order to partially compensate for the loss of voltage due to the rising self-impedance of the monopole. This would result in a reasonably flat response over an exceedingly wide range of frequencies.

Another approach for designing broadband active antennas breaks away from the conventional concept of using a high-input impedance amplifier following the antenna. The noise and distortion performance and the overall antenna transfer function are accurately determined by designing amplifiers with proper feedback at the input and output.

One concept proposes the use of a large amount of negative feedback around several cascaded amplifier stages and the virtual grounding of the input electrode of the input active device.[5] This concept can be extended by optimizing a combination of a series and shunt feedback loop. This combination provides the desired 50-Ω output impedance.

Active Loop Antennas

Whereas a short monopole/active circuit greatly enhances the broadband characteristics of an E-field receiving antenna, a small loop provides the same set of characteristics for a magnetic field antenna. Size reduction in the loop can be imposed by the introduction of a large ferrite rod, which threads the loop. The rod greatly enhances the magnetic-field sensitivity of the loop, permitting the diameter to be electrically very small to minimize E-field coupling.

The high magnetic permeability of the ferrite rod concentrates magnetic flux lines of a passing EM wave within the rod so the flux density through the loop is considerably greater than would exist with the loop alone. The voltage induced into the loop by the magnetic flux can be fed to an active matching network to boost the signal level. To a rough approximation, the introduction of a ferrite rod makes the loop perform magnetically about the same as an air core loop whose diameter is equal to the length of the ferrite rod.

Magnetic-field intensity is related to the antenna terminal voltage by the magnetic field antenna factor:

$$H(\text{dB A/m}) = V(\text{dB V}) + AFH(\text{dB AV}^{-1}\text{m}^{-1})$$

where: H = magnetic field strength at the antenna
V = voltage at terminals of the antenna
AFH = magnetic field antenna factor

Figure 1 shows a typical ferrite-loaded active loop antenna designed to measure magnetic-field intensity from 100 Hz to 100 MHz.

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