RECEIVERS AND SPECTRUM ANALYZERS

Electromagnetic interference (EMI) receivers years ago were more popularly called radio-frequency interference (RFI) receivers or simply RI-FI (radio-interference/field-intensity) meters. They are tunable frequency selective audio and RF voltmeters which measure the voltage delivered to the input terminals by a suitable conducted or radiated sensor or pick-up device. The EMI receiver is basically a superheterodyne receiver with emphasis placed upon internal self calibration of input signals by substitution techniques. They also differ from other superhet receivers in that a selection of several weighted detector functions are provided to permit some signal recognition but mostly to support the calibration process of the input signal or noise. This also implies a somewhat different array of pick-up sensors, RF attenuators, IF bandpass shape, and the like.

EMI receivers are commercially available which cover the frequency spectrum from 20 Hz to 26 GHz. They are basically one of two types: (1) separate self-contained complete receivers covering a portion of the spectrum or (2) a basic RF attenuator, calibrator, IF amplifier, detector function and meter display unit with separate plug-in RF heads, each of which covers portions of the spectrum. EMI receivers are to some extent standardized, although both the standards differ and different suppliers incorporate their own features. Instruments in the 15 kHz to 1 GHz spectrum are standardized by the American National Standards Institute (ANSI) while the International Electrotechical Commission has set up standards for the 15 kHz to 300 MHz frequency spectrum. These standards are now somewhat obsolescent.

APPLICATIONS

The very nature of the EMI problem implies that for control to be possible, a special calibrated RF voltmeter must be available with a number of features to facilitate measurements. EMI emission measurements are basically performed to help accomplish one or more of the following applications:

Specification Testing are those associated with either first-look or development test specimens or final quality assurance compliance or production specimens. They involve either conducted and/or radiated emission measurements to determine if the test specimen is within procurement or regulatory specification limits. Most of the MIL-SPECS involve testing inside shielded enclosures while the FCC rules and regulations involve mostly open-field tests on the specimen(s).

Electromagnetic Ambient Surveys are applications which search and record radiated spectrum emissions at one or more sites in order to:

(a) determine on-the-air RF traffic and associated spectrum amplitudes for emission control such as test ranges.

(b) assist in selecting an electromagnetically quiet site from several candidate pieces of real estate.

(c) assist in identifying relatively quiet portions of the frequency spectrum for co-locating proposed new equipment or reassigning frequencies of existing C-E equipment.

C-E Equipment Spectrum Signatures involve making transmitter mesurements at fundamentals, harmonics, their emission sidebands, and other spurious radiations. The calibrated data are needed for procurement compliance of specifications and for EMI prediction and analysis.

Culprit Emitter Identification develops from the outcome of ambient surveys and specification testing in which the sources of EMI are to be localized, often using uncalibrated probes. The object is to identify the culprit source(s), and the nature of the emissions. Examples include either interfering or illegal radiators; RF leaky cabinet joints; hot cables or wires; noisy power-line insulators; disturbing industrial, scientific, and medical equipments.

Peripheral Applications include propagation studies, discrete antenna pattern measurements, filter and shielded enclosure spectrum attenuation tests, circuit cross-talk measurements, and establishing wire shield and grounding EMC performance.

SIGNAL BANDWIDTH AND SENSITIVITY CONSIDERATIONS

The term broadband is used relative to the bandwidth of the viewing receiver. For example, Figure 1 shows the spectral distribution of a single pulse modulating a carrier, f_c. The figure also shows two different R-F bandpass windows of a receiver tuned to the center of the main hump. When a receiver bandwidth, B_1, is much broader than the main (sin x)/x hump, it yields the full amplitude of the pulse as shown in the upper right. Only a small rounding (integration) of the leading edge of the corners is evident. Thus, the signal is *narrowband* relative to the receiver bandwidth ($2/\tau < B_1$).

When a receiver bandwidth, B_2, is much narrower than the main hump, the detected signal amplitude shows a significant integration and has an amplitude proportional to its bandwidth as shown. Thus, the signal is *broadband* relative to the receiver bandwidth ($2/\tau < B_2$). Transitional bandwidths crossing over between broad and narrowband, occur for which $B \approx 2/\tau$.

The notion of a broadband or narrowband signal (relative to a receiver bandwidth) has several different important EMI connotations, two of which are: (1) selection and interpretation of the receiver calibration process to be used; and (2) the rating of receiver sensitivity in both narrowband (dBμV) and broadband (dBμV/MHz) units. The second connotation is reviewed here since these units are somewhat peculiar to the EMI Community.

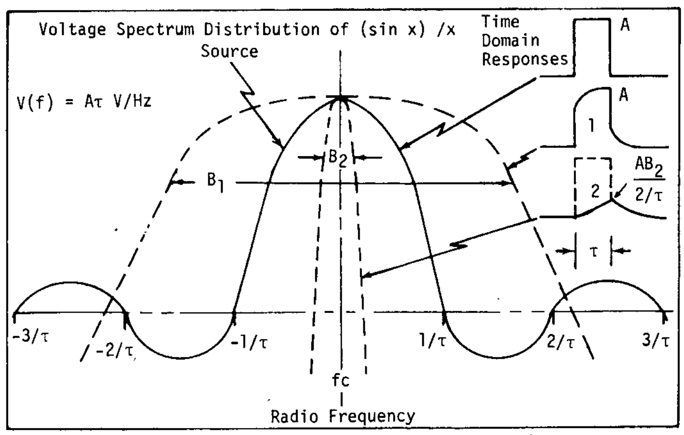

Figure 1 - Illustrating Broad and Narrowband Signals

NARROWBAND SENSITIVITY

The telecommunications, radar, navigation, and related C-E Communities rate receiver sensitivity in units of dBm. One such rating corresponds to the internal noise power, N_r, referred to the receiver input terminals:

$$N_r = \text{FKTB watts} \tag{1}$$

where: F = Noise factor of receiver (a ratio)
K = Boltzmann's constant = 1.38×10^{-23} W/°K/Hz
T = Thermal temperature of receiver front end in °K
B = receiver bandwidth in Hz

For a receiver front end at typical room temprature (T ≈ 70°F = 21°C ∓ 293° Kelvin), Eq. (1) becomes:

$$N_r \approx 4 \times 10^{-21} \text{ FB watts} \tag{2}$$

$$= 4 \times 10^{-18} \text{ FB milliwatts} \tag{3}$$

Expressed in units of dBm, Eq. (3) becomes:

$$N_{dBm} = -174 \text{ dBm} + 10 \log_{10}(FB) \tag{4}$$

$$= -174 \text{ dBm} + F_{dB} + 10 \log_{10} B_{Hz} \tag{5}$$

$$= -114 \text{ dBm} + F_{dB} + 10 \log_{10} B_{MHz} \tag{6}$$

Eq. (5) is useful in quickly determining the receiver noise power in units of dBm (dB above 1 mw) for any specified receiver noise figure and bandwidth. These relations are shown in Figure 2 where the right Y-axis is in units of dBm, the X-axis is receiver 3-dB bandwidth, and the parameter is noise figure in units of dB. In fig. 2, receiver sensitivity is defined as $S = N_r$, which is about 10 dB above minimum discernable signal.

BROADBAND SENSITIVITY

Where a signal or reference calibrating source is broadband such as shown in Case B_2 in Fig. 1, a different reference unit, special intensity in dBμV/MHz, is used to express receiver sensitivity. The reason for this change in units is the *coherent phase* relationship that exists between adjacent incremental frequency units in a *broadband* signal. The amplitude and phase vector associated with the Laplace transform of an impulsive or transient-like broadband source (without carrier frequency) may be illustrated from Fig. 1 for a single pulse and with $f_c = 0$:

$$\mathcal{L}\left[A(t)\right] = A\tau \frac{\sin \pi f \tau}{\pi f \tau} e^{j\pi f \tau/2} \qquad (9)$$

where: A = amplitude of pulse in volts
f = frequency in Hz
τ pulse width in seconds

From Eq. (9) it is seen that for receiver bandwidth s less than $f = B \leq 1/\tau$, the maximum phase variation is less than 90°. Accordingly all voltage elements corresponding to incremental frequencies can be added in phase over the receiver bandwidth to produce the resultant voltage response.

The foregoing means that for coherent signals, voltages must be summed first and then squared to obtain power in contrast to incoherent signals where power is obtained by summing the square of the voltages. Consequently, to obtain a net broadband voltage, V_b, the incremental voltage elements are summed over the band:

$$V_b = \int_{f_c - B/2}^{f_c + B/2} V(f)\, df \quad \text{volts} \qquad (10)$$

where: $V(f)$ is the broadband signal intensity in V/Hz (see Fig. 1)
f_c is the center frequency of the tuned receiver,
$B/2$ is one half the receiver bandwidth in Hz.

Since the signal is broadband, i.e., $V(f)$ changes very little over the receiver bandwidth as shown for B_2 in Fig. 1, Eq. (10) becomes:

$$V_b \mp V(f)B \quad \text{volts} \qquad (11)$$

Thus, the resultant voltage is directly proportional to receiver bandwidth.

For convenience, the V/Hz units may be changed to μV/MHz in Eq. (11). Converting this also to logarithms and substituting S for sensitivity, yields:

$$V_{dB\mu V} = V_{dB\mu V/MHz} + 20 \log_{10} B_{MHz} \qquad (12)$$

$$S_{dB\mu V/MHz} = S_{dB\mu V} - 20 \log_{10} B_{MHz} \qquad (13)$$

Eq. (12) or (13) allows one to calibrate a narrowband signal measured by a receiver with a substituted broadband noise source and to convert the calibration to a narrowband equivalent signal by knowing impulse§ bandwidth, B_{MHz}. The broadband sensitivity may be obtained explicitly by substituting Eqs. (8), (5), and (6) into Eq. (13) to yield:

$$\begin{aligned} S_{dB\mu V/MHz} &= N_{dBm} + 107 \text{ dB} - 20 \log_{10} B_{MHz} \\ &= -7 \text{ dBm} + F_{dB} - 10 \log_{10} B_{MHz} \end{aligned} \qquad (14)$$

The above article has been taken from Volume 4, "EMI Test Instrument and Systems" written & published by Donald R. J. White, Germantown, Maryland. Volume 4 is part of a six volume series of handbooks on EMC

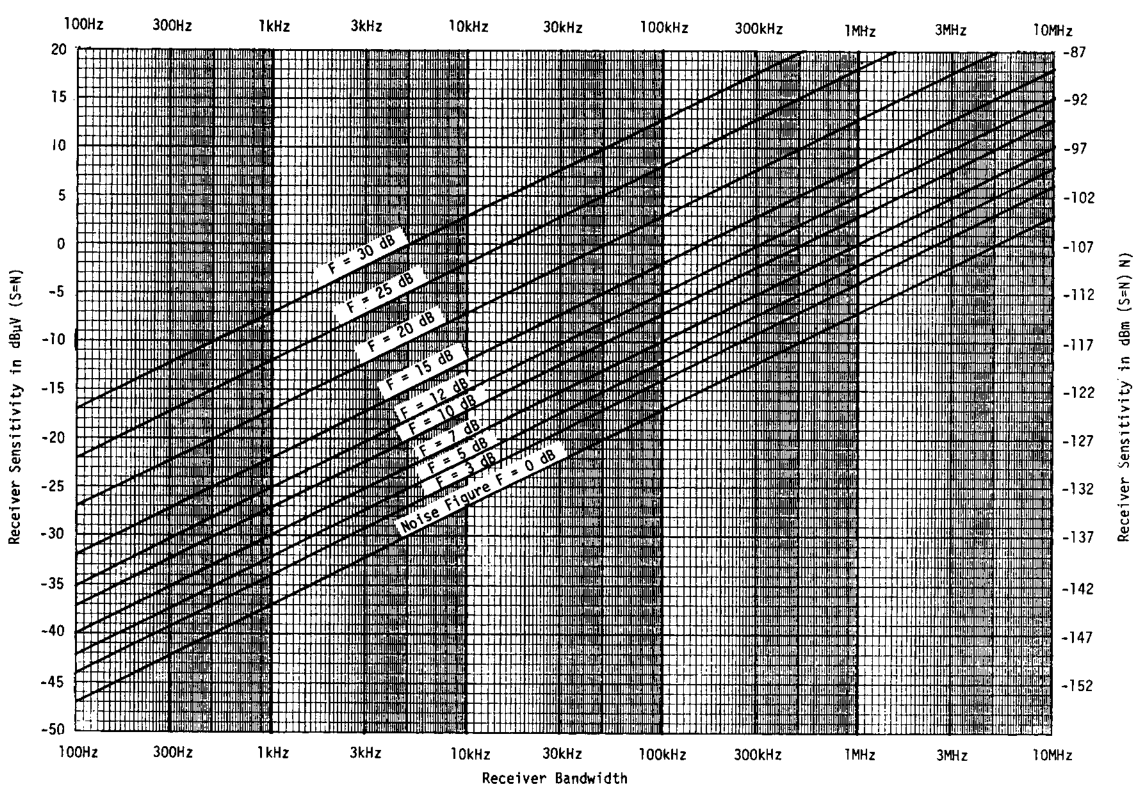

Fig. 2. Receiver Narrowband Sensitivity vs Bandwidth and Noise Figure

Spectrum Analyzers

Spectrum analyzers were introduced during World War II in order to facilitate the enormous amount of development on communications-electronic systems including radar and navigation equipments. The low-frequency spectrum analyzers of that day often covered at most one octave of the frequency spectrum. At higher frequencies, however, and in contrast to the block diagram shown in Fig. 8, they covered a relatively narrow portion of the spectrum for any one spectrum display. Final sweep process was often that of a pan adapter whereby the last stage of the superheterodyne used a narrow-band filter to examine the spectrum spread offered by previous stage broadband IF amplifiers.

The microwave spectrum analyzer was developed at Lincoln Laboratories in the early 1940s. It consisted basically of sweeping the reflector voltage of a local oscillator klystron over a very small portion of the spectrum. The microwave receiver, using a crystal mixer, converted the incoming signal to an IF amplifier which developed the RF resolution. Typical RF sweep ranges for S- and X-band klystrons varied from about 40 to 100 MHz for a narrow bandwidth I-F amplifier from 50 to 120 Khz. Thus, only approximately one percent of the RF frequency could be examined at one time and with a resolution of approximately 1/1000 of this. No pre-selection was used.

Significant development of spectrum analyzers followed during the 1950's. Spectrum analyzers of that era were typically two or three stage superheterodyne receivers in which the microwave local oscillator was frequency modulated over a few percent. All of the spectrum analyzers, even including most of today, did not use pre-selectors because of both cost and the difficulty of tracking pre-selector with an LO. During the 1950's economical voltage-tuned oscillators (VTO) were not available above about 300 MHz. Backward-wave oscillators (BWO) were available at that time due to EMW developments, but the cost was enormous and the life expectancy was short. Consequently spectrum analyzers suffered from many spurious responses which were often confusing to the operator and they lacked many operational features of today.

One of the greatest impetus was given to the spectrum analyzer field during 1963 when Hewlett-Packard introduced its first generation of the now modern version spectrum analyzer. The unit included a BWO which scans 2-4 GHz. It up-converts the incoming signal below this frequency range to an IF amplifier operated at approximately 2 GHz. Thus, a spectrum from 10 MHz to 2 GHz could be swept out and displayed on the scope at one time. Frequencies from 2 GHz to 10 GHz and higher are obtained by harmonic mixing action. One serious drawback of this analyzer is the number of ambiguous signals presented on the analyzer scope face at one time. The analyzer offers several resolutions, viz., IF bandwidths, of 1 kHz, 3 kHz, 10 kHz, 100 kHz and 1 MHz. Equivalent noise figure below 2 GHz is about 34 dB.

In order to help reduce the spurious responses a number of low-pass and inter digital band-pass filters were made available for the spectrum analyzer. However, a later option offered is a pre-selector in the form of a voltage-tuned YIG filter driven by the horizontal output from the display section. The pre-selector, governing 2-12 GHz tracks the tuning of the RF section and reduces undesired responses by about 20 dB - 6 dB/octave beyond 100 MHz off center tuning. Since the pre-selector offers an additional 5 dB of insertion loss, the sensitivity of the spectrum analyzer from 2-4 GHz results in an equivalent noise figure ranging from 39-51 dB.

A second generation spectrum analyzer was introduced in the late 1960's which incorporated many of the better features of the first generation together with continuing advances in the state-of-the-art. One analyzer composed basically of three units in its ensemble: an RF section, and IF section and a display section. The RF plug-in section, any portion of the 10 MHz - 12 GHz spectrum, covered by the up-conversion process similar to the previous vintage. Maximum dispersion 2 GHz. Two lower frequency RF heads are available. IF bandwidth choices varies from 100 Hz to 300 kHz in a 1 - 3 - 10 sequence. A 70 dB logarithmic IF amplifier with a flat frequency response permited presenting narrowband signals over this dynamnic range. Broadband signals however, tend to saturate the analyzer and produce a considerably reduced useful dynamic range depending upon the bandwidth occupancy of the emission source. In a limiting case, such as when driven by an impulse generator, the spectrum analyzer is reduced to virtually no broadband dynamic range.

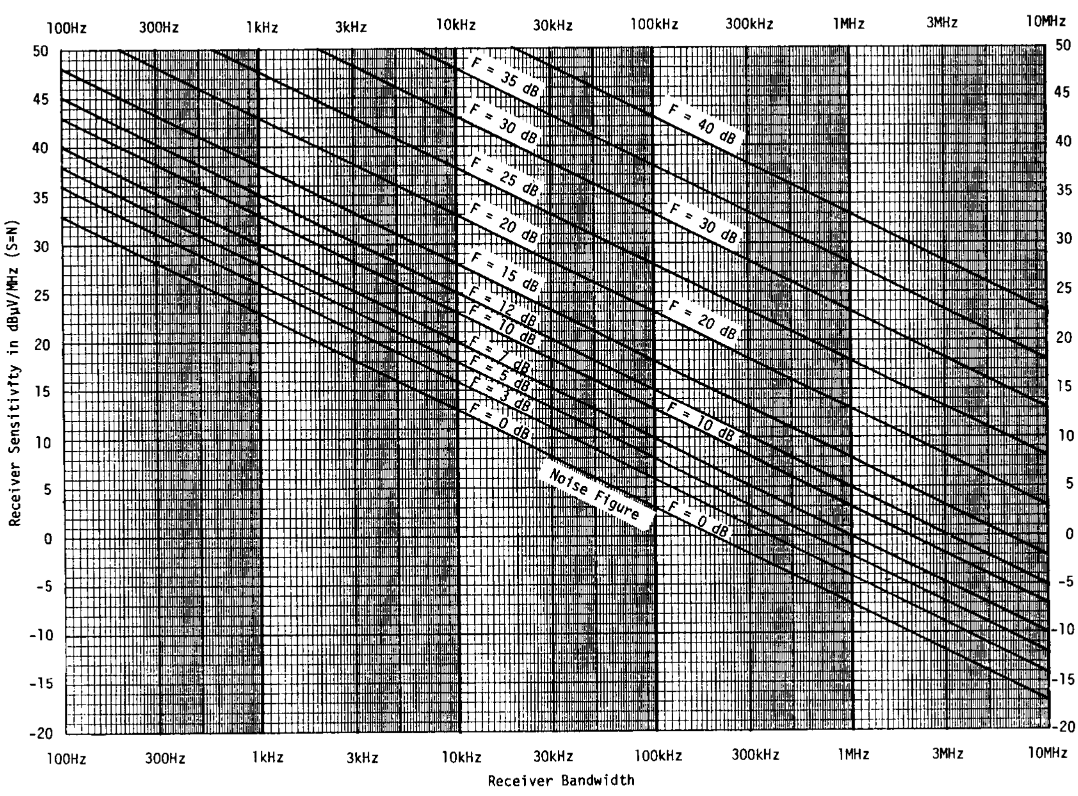

Figure 3. Simplified Block Diagram of RF Spectrum Analyzer