ANALYSIS, RECORDING AND MEASUREMENT

Introduction

Many of the techniques and instruments used in performing interference measurements are identical to those used in making other radio frequency measurements. In no other area of electromagnetic technology, however, is encountered the extreme range of frequencies and signal levels dealt with by the EMI engineer. As a consequence, certain of the methods and equipments required are indeed specialized and seldom used in other areas of electronic measurements.

To be meaningful, interference measurements must yield data in definitive units with readily verifiable and repeatable numerical results. (These same criteria apply to susceptibility measurements as well.) At this level, EMI technology is eminently practical. Conversely, many of the more complex aspects of interference measurements require thorough knowledge and appreciation of fundamentals. Among these are:

(a) Complete familiarity with theoretical and laboratory aspects of signal measurements in both frequency and time domains
(b) Expertise in working with a great diversity of test equipment, both specialized and general-purpose; and
(c) An adequate knowledge of the functional characteristics of the equipment or system under test.

Recognition of the above has led to the realization that EMI measurements are *not* routine tests, but are definitely *engineering* measurements and must be approached on that basis. Among others, the following factors are of importance in that connection.

(1) Test setup arrangements (may be extremely complex).
(2) Range of frequencies and amplitudes encountered (DC to IR and micromicrowatts to megawatts).
(3) Test equipment (complicated - and expensive!).
(4) Operating characteristics of equipment under test (EUT). (See the section ITEM dealing with documentation for further discussion.)

There are situations where some (or even all) of a series of EMI tests must be performed repetitively on a number of units of the same type, so that procedures may become more or less formalized. However, many projects never reach that phase and therefore the majorityof EMI measurement programs will fall into the "one-of-a-kind" category.

Interference Test Equipment

As hinted above, interference test equipments fall into two general classes:

(1) General laboratory test equipment (oscilloscopes, signal generators, frequency counters, electronic voltmeters, audio oscillators, and the like).
(2) Special EMI test equipment, (frequency-selective voltmeters, spectrum analyzers, impulse generators, current probes, power line impedance stabilization networks (LISN's), broadband antennas, correlation enhancement equipment, tracking generators etc.).

In addition, the special equipment items mentioned in the Equipment Susceptibility section of *ITEM* also fall into the latter class.

When more complex systems, such as space probes, communications satellites, or advanced missiles are involved, an interference test planner will not infrequently find that he must devise special instrumentation arrangements. Many such programs may embody unusual interference requirements; with more stringent limits or with coverage of frequencies outside the range of those stated in the usual DoD or industry requirements documents. Such situations arise quite frequently in connection with space and satellite programs, where ultrasensitive receivers are used and extreme reliability requirements are imposed. When these problems are encountered, the EMI engineer will usually find that it is more economical and expedient to modify existing equipments and/or incorporate ancillary units than to attempt to procure a completely new instrument. For example, increased receiver sensitivity can be achieved by using preamplifiers with better noise figures and thresholds than the "barefooted" interference measuring instruments which might be available at a particular facility. If bandwidth considerations are involved, it is possible with some instruments to use another receiver covering a lower frequency range as a tunable IF amplifier to obtain sharper selectivity (assuming that the procuring activity involved will approve this technique).

EMI Measuring Equipment Characteristics

Sharing the principle burden of interference measurements are two types of instruments:

(1) Frequency-selective voltmeters
(2) Spectrum analyzers

Both of these are basically well-shielded sensitive receivers with wide dynamic ranges and provisions for calibration in terms of standard EMI measurement units. Instruments are available in both categories to cover the range of tens of hertz to tens of gigahertz. Let's look at the block diagram of a typical frequency-selective voltmeter, Figure 1. (This particular diagram depicts just one possible arrangement - many other configurations could be used.) It's evident that this EMI receiver is basically a superheterodyne - but with some added features. Starting at the input, let's follow through with the diagram and see what's involved.

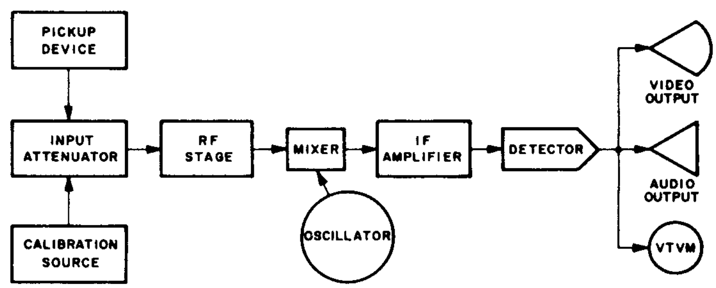

Figure 1. Block Diagram of a Typical Frequency-Selective Voltmeter

Pickup Devices

Here we're dealing with the interface between the receiver and the EUT. The coupling may be conductive or by means of the electromagnetic field. If the measurement is conductive, there must be a means of interfacing the source to the typical 50-ohm input of the receiver. Some of the ways in which this is accomplished are:

(1) Direct (very rarely, indeed!).
(2) Via a powerline impedance stabilization network;
(3) Via a directional coupler, attenuator or possibly some sort of filter;
(4) Via a current probe (or the equivalent thereof).

Powerline Impedance Stabilization Networks

Basically, these are simple LC filter networks which provide the following:

(a) Some measure of isolation between power source and EUT
(b) Impedance characteristics which simulate those of a "typical" operational power system, varying from about 5 ohms at the low ends of their usable ranges to approximately 50 ohms over most of the upper portions of their ranges.
(c) Provisions for coupling between the power line and the EMI receiver input.

A little history may be of interest. The first EMI meters were introduced in the U.S. in the late 1930s. (They were called "radio noise meters" in those days.) For powerline measurements, a resistance-capacitance network was used to isolate the high-impedance meter input from the line voltage. Towards the end of World War II, the Army and the Navy issued a specification, JAN-I-225, in which what might be termed an isolation network was specified. This consisted simply of two 4-microfarad capacitors connected in parallel from the high side of the line to ground at the power source end of a ten-foot length of wire, with the EUT and EMI receiver connected at the far end thereof. This was supposed to simulate a little more realistically the powerline impedance of a typical aircraft 28-volt DC system. Still later, based on some fine investigative work by an engineer at Wright Field by the name of Alan Watton, the first LISN was designed.

Although some minor changes have been made in its circuit values and arrangements, the impedance of this network (and its successors) is quite close to the curve shown in Figure 8 of Notice 3 to MIL-STD-462. Over its design range of 150/kHz to about 25 MHz, it worked out more or less as intended, both for EMI measurements and for injection of susceptibility voltages. However, problems arose when measurements were attempted below 150 kHz. It was found that the impedance curve exhibited some rather irregular variations in that region. Although other networks have been designed and are available commercially which have acceptable impedance characteristics in the ranges below 150 kHz, most powerline conducted measurements are now made using current probes, or some other form of coupling transformer.

Current Probes and Transformers

When the shortcomings of the LISN became apparent in the late 1940s, the same Alan Watton - by this time no longer in the EMC/EMI field, but having access to some R&D budget - decided that some effort should be made to rectify the situation. Thus, Stoddart Aircraft Radio Corp. got a contract to develop both a current probe and a voltage probe. The former effort was successful, culminating in the widely-used toroidal type clamp-on current probe essentially as we know it today. The efforts towards a voltage probe came to nought.

In practical terms, an EMI engineer now had the choice of measuring interference voltages across an artificial (and questionably realistic) impedance which varied more or less predictably with frequency; or of measuring interference currents flowing in a circuit of unknown and widely-varying-impedance. The clamp-on probe was convenient. Test setups were significantly simpler and line current limitations were not as severe. (If you have ever seen a 100-ampere LISN - even a 150 kHz and up model - you will appreciate this more keenly.) Specification writers rushed to incorporate current probe measurements in their documents. The improvements in performance below 150 kHz and above 25 MHz were quite significant! However, sensitivity at the lower end of the spectrum left something to be desired. Spearheaded by the efforts of one of Boeing Aircraft's EMI engineers, Frank Beauchamp, the current probe was applied for broadband measurements in the 30 Hz to 15 kHz range. Because of the decrease in probe pickup capability at the lower end of the range, wideband limits were set up to vary as the inverse of the probe pickup factor. Some improvements in sensitivity were realized by use of special preamplifiers and improved probes, but problems still remained.

The wide-band audio isolation transformer had been developed for powerline susceptibility testing during this period and proved to be a "natural" for making EMI measurements up to about 50 kHz. Major credit for this application should go to one of Philco-Ford's EMI engineers, Sam Shankle, and to Al Parker of Solar Electronics Co. Let's look at Figure 2, which shows an audio isolation transformer connected per Figure CS06-2 of MIL-STD-462 for parallel injection of the spike generator voltage for susceptibility tests on DC power lines. In this application, the transformer secondary acts merely as an inductive reactance to prevent the injected spike from being "swallowed up" by the low impedance of the power source. In Figure 3, the spike source has been removed and an EMI measuring receiver has been connected to the primary of the transformer in parallel with a resistor. With this circuit, if the EMI meter has a sensitivity of 0.1 microvolt and R is 10 ohms, we can measure as little as 0.01 microampere of EMI current in the line down to just about 1 kHz! See the curves in Figure 4. Keep in mind that the upward slope of these curves in their lower ranges actually represents some "high-pass" filtering effect which tends to remove some of the low-order powerline harmonics which can be troublesome in wide-band measurements.

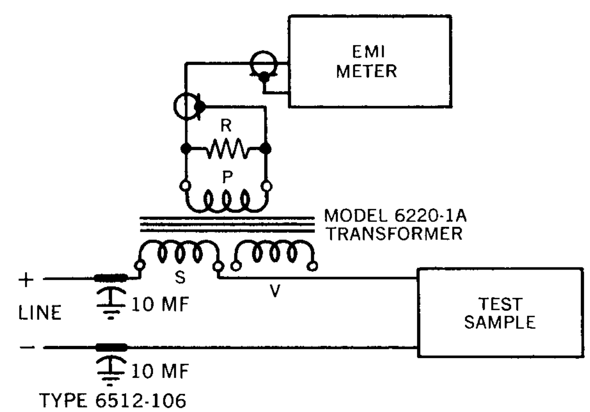

Figure 3 — Test Setup for Measuring Low Frequency, Low Amplitude EMI Current

There are some other limitations when measuring on AC powerlines. The drop across the secondary winding is the major one. This voltage induces twice as much voltage in the output (primary) winding at the power frequency. Power dissipation in the input circuit of a typical EMI receiver should not exceed about 0.5 watt. In the case of a 400 Hz line, this means that the line current must not exceed 16 amperes. Of course, the swamping resistor, R, must be capable of dissipating the power which flows in it - about 50 watts in this case - and should be non-inductive. The 10 uFd feedthrough capacitors used in these setups have about 540 ohms reactance at 30 Hz and some reduction in the EMI current flowing in the circuit is a result thereof. When the circuit is being calibrated, the capacitor(s) should be lifted off-ground. If an EMI meter with a reactive input circuit is being used (e.g., Fairchild EMC-10 series), a minimum loss "T" pad is required at the input. Stoddart NM-10A and NM-40A units do not require the pad with its attendant loss.

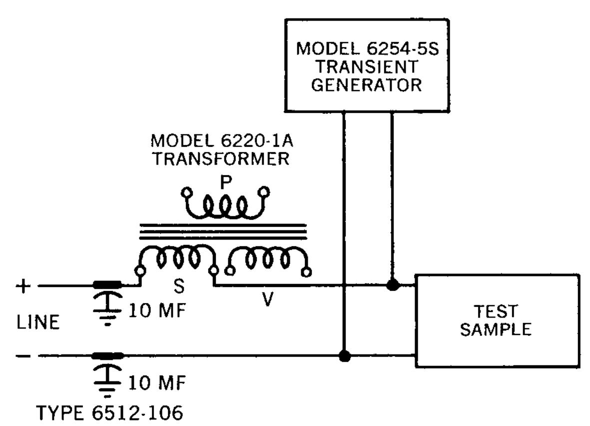

Figure 2 — Transformer Secondary used as Isolating Inductor

ELECTROMAGNETIC FIELD PICKUP DEVICES

Coupling via the electromagnetic field is, of course, accomplished by means of some sort of antenna. Obviously, to facilitate obtaining data in standard units, antennas which can be calibrated easily are desirable. Quite a variety of antennas is available to cover the spectrum, as is indicated below:

Table I

Frequency Range	Antenna Types
Sub-audio	Loops with preamplifiers Capacitive probes with preamplifiers
30 Hz - 30 kHz	Loops, with or without preamplifiers Capacitive probes with preamplifiers Rod antennas with built-in matching networks and preamplifiers
30 kHz - 30 MHz	Loops Rod antennas, with or without built-in preamplifiers and with built-in matching networks
20 MHz - 1 GHz	Dipoles, tuned Dipoles, broadband (e.g., "bowtie" and biconical)
200 MHz - 1 GHz 1 GHz up	Conical log-periodic spirals Conical log-periodic spirals Cavity-backed spirals Log-periodic arrays with parabolic reflectors

Nearly all of the above antennas are furnished with correction factors from EMI instrumentation manufacturers to be used to convert the meter readings to data in the standard units. In some cases, the correction factors supplied are not representative of typical EMI test situations. One example: the correction factors for tunable dipole antennas include 1.6 dB which is presumed to compensate for the difference between the impedance at the center of the dipole and the 50-ohm impedance of the cable which connects to the EMI meter. The fallacy of this is apparent when we consider the effects on dipole impedance of conducting objects (including the walls of the shielded enclosure) in the vicinity, and the fact that the dipoles in reality are far from being infinitely thin. MIL-STD-461A gives constructional details for a broadband biconical antenna covering the range of 20 to 200 MHz. (Because of its configuration, this antenna is referred to by EMI engineers as "the birdcage.") Other broadband antennas are available commercially. If highly accurate data is required, antennas must be calibrated in the actual geometry in which the measurements are being made. SAE Document ARP 958 gives directions for calibration of certain of the broadband EMI measurement antennas. This publication is available from: Society of Automotive Engineers, 2 Pennsylvania Plaza, New York, NY 10001. In almost every case, properly calibrated broadband antennas will prove more practicable than the tunable dipoles, particularly in terms of the savings in test time.

As mentioned in the Electromagnetic Susceptibility section of ITEM, reflections and resonances can be troublesome in EMI testing. One kink for reducing such effects without going to the expense of building or leasing an anechoic facility will be described. It has been found that if the EUT is surrounded on all sides except towards the measuring instrument with blocks of rf absorbing material, then the effects of reflections and resonances are considerably reduced as are changes in indicated levels due to movement of test personnel in the shielded enclosure.

EMI receiver front-end design must take into account the wide range of input amplitudes encountered, and must also provide protection against intermodulation effects. Similar precautions with respect to dynamic range and minimal intermodulation are necessary for the mixer stage of an EMI receiver. The local oscillator must have state-of-the-art spectral purity to minimize both spurious responses and internal noise.

For broadband measurements, the internal impulse generators found in most EMI instruments provide adequate calibration capabilities. If greater accuracy is required for CW measurements than can be realized by use of the impulse generator transfer calibration method, an external signal generator plus a frequency counter (if necessary) will be used.

For IF amplifier stages of the EMI receiver, one major consideration is selectivity. By using narrower bandwidths, CW sensitivity can be improved - within the constraints of receiver and signal stability. However, improved sensitivity for impulsive signals can only be achieved by use of bandwidths consistent with those of the input signals. Let's review a few significant factors. One, a receiver's own random noise voltage, produced mainly in the first one or two stages, varies directly as the square root of the bandwidth. On the other hand, impulse noise voltage increases directly with an increase in bandwidth. Therefore, to achieve maximum sensitivity to impulsive signals, the widest possible bandwidth should be used; up to the actual bandwidth of the signal of interest. This factor is of special importance in working with pulse systems, and has been taken into account in the design of most EMI instruments which cover the higher frequency ranges. For example, in those EMI receivers which cover frequencies above 1 GHz, two IF bandwidths are usually provided. One will be less than 1 MHz, while the other will be of the order of 3 to 5 MHz. Some of the more recently designed EMI receivers for the ranges below 1 GHz also provide more than one IF bandwidth to take advantage of this approach to improving impulsive signal sensitivity.

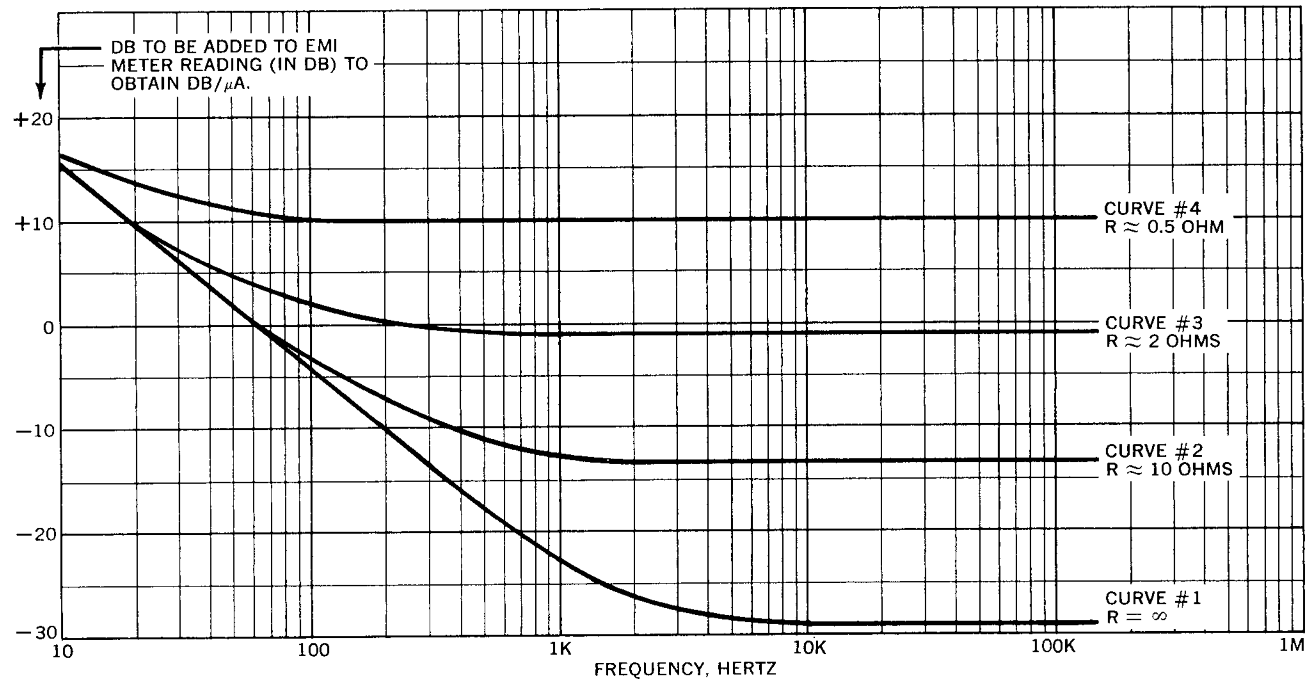

Figure 4 — Typical Correction Data vs. Frequency

Do you have *everything* for performing tests in accordance with MIL-STD-461A/462 ?

Essential Apparatus:

TYPE NO.	DESCRIPTION	CE 01	CE 02	CE 03	CE 04	CE 05	CE 06	CS 01	CS 02	CS 03	CS 04	CS 05	CS 06	CS-08	RE 01	RE 02	RE 03	RE 04	RE 05	RE 06	RS 01	RS 02	RS 03	RS 04
6220-1A	Audio Isolation Transformer	X^1						X					X									X		
6254-5S	RFI Transient Generator												X									X		
6338-5-PJ-50-N	LISN		X^2		X^2				X^2															
6338-57-PJ-50-N	LISN		X^2		X^2				X^2															
6512-106R	Feed-thru Capacitor	X		X									X			X		X						
6550-1	Power Sweep Generator							X														X		
6552-1A	Amplifier, 100 watts							X															X	X
6623-( )	Low Pass Filter, 50 ohms					X	X		X	X	X	X		X										X
6741-1	EMI Current Probe	X	X	X	X	X																		
6815-1	Precision Resistor, .01 ohm																					X		
6824-( )	High Pass Filter, 600 ohms	X	X																					
6920-0.5	Resistive Network	X^1																						
7429-1	Loop Antenna																				X			
7415-1	R.F. Coupler-High Pass Filter								X															
7021-1	Phase Shift Network							X																
7032-1	Isolation Transformer, 800 watts	X	X	X	X	X									X	X	X	X	X	X				
7033-1	Impedance Matching Transformer								X														X	
7054-1	Spike Generator, 10 uS												X											
7054-1A	Spike Generator, 50 uS												X^3									X^3		
7144-1.0	Precision Resistor, 1.0 ohm																				X			
7144-10.0	Precision Resistor, 10.0 ohms																					X^2		
7205-( )	High Pass Filter, 50 ohms	X	X																					
7334-1	Loop Sensor														X			X						

NOTE:

X^1. See Notice 3, MIL-STD-462 for CE-01 in lieu of current probe.

X^2. Required by Notice 3, MIL-STD-462, U. S. Army Contracts.

X^3. Used on B1 aircraft susceptibility tests.

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In the second detector of an EMI receiver, the most important factor is the time constant. Peak-to-average ratios of input signals vary quite widely. Therefore, EMI receivers usually have at least two different selectable charge/discharge time constants in their second detector stages. A relatively long charge time, with moderately fast discharge time, is used for CW, or average, measurements. For peak measurements, shorter charge time and longer discharge time yield a detector which will respond rapidly to a short-duration signal and - in effect "remember" it for a relatively long period. Typical charge times are in the tens of microseconds range, with discharge constants of the order of hundreds of milliseconds. Another widely-used peak detection method is designated "slideback". Detector time constants are about the same as for average measurements, but measurements are made by manual adjustment of a bias voltage which "bucks out" the incoming signal until it is just at the threshold of audibility. Peak level is then read on a meter which monitors the bias voltage; or a substitution-type calibration may be made, using an impulse generator. In the hands of an experienced operator, this technique is particularly valuable, in that it permits discrimination between two or more simultaneous input signals. A few EMI instruments are occasionally encountered which have a "quasi-peak" detector function. These meters have a detector time constant which was selected as representative of the "nuisance value" of interference to an operator listening to CW or voice signals.

Time constant considerations are also important when X/Y plots of interference measurements are being made. Obviously, if a receiver tunes through a CW signal too rapidly, the detector circuits will not reach full charge. Therefore, recorder/receiver scanning rate must be selected so that the highest signal level in the tuned range will be accurately measured. Mechanical inertia effects in the recorder are also of importance.

SPECTRUM ANALYZERS

In recent years, application of spectrum analyzers to EMI measurements has become widespread. Figure 5 is a block diagram of a typical EMI =test grade spectrum analyzer. Note the similarities and differences as compared with Figure 1. Time savings have been one of the principle reasons for the acceptance of the spectrum analyzer. The other significant advantage is that the response time of the oscilloscope display is many orders of magnitude faster than any mechanical recorder. Stored information is readily photographed for permanent record.

With modern spectrum analyzers, accurate EMI data can be obtained quickly. Combined with such ancillaries as superselective preamplifiers, tracking generators, and frequency counters, and controlled by mini-computers, the spectrum analyzer has become quite effective in making EMI measurements. Its ability to provide a "quick-look" over literally hertz-to-gigahertz ranges enables instantaneous spotting of problem areas in an equipment or system. Thus, one can determine where to concentrate efforts in localizing and eliminating interference. In addition, the adaptability of the spectrum analyzer and its versatility as a laboratory tool, make it an unusually cost-effective addition to the inventory of any electronic design facility.

Some Additional Notes on Bandwidth Considerations

First, a few definitions.

Circuit bandwidth: The customary concept of bandwidth in which only frequency-discrimination properties of the networks are considered; as measured by conventional voltage response techniques.

Effective bandwidth: This is an index of the response of the networks to "noise" or other transient phenomena, components of which are sensibly continuous and distributed throughout the spectrum. Often referred to - somewhat misleadingly - as the "noise" bandwidth.

Impulse bandwidth: As differentiated from "random noise bandwidth" (see below), this term refers to response to impulse interference, which is defined as being an electrical transient or series of transients whose duration is very much less than the reciprocal of the bandwidth of the measuring instrument. These assumptions apply: (1) pulse-to-pulse amplitude is essentially constant; (2) pulse-to-pulse intervals are such that the effects of any one pulse have disappeared before the next one is received. It is quantified as the ratio between the maximum value of response and the spectral intensity of noise times mid-band gain.

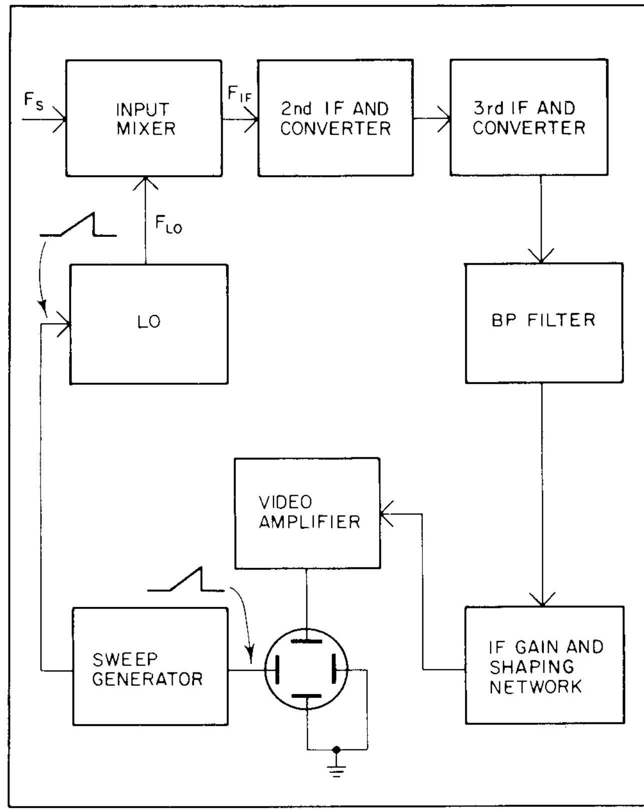

Figure 5. Functional Block Diagram

Random noise bandwidth: This term refers to response to random interference, for which the following assumptions apply: (1) amplitudes and phase angles are stochastic in character; (2) Spacings between succeeding pulses are highly irregular and so short that considerable overlapping occurs. It is quantified as the frequency interval, Δf_r, for which a power gain equal to the gain at midband, f_o, would transmit the same noise energy as does the actual power gain frequency curve.

In most cases, EMI instrument manufacturers supply "effective random noise bandwidth" data. Impulse bandwidth can be obtained by applying a correction factor, which can be determined by simple measurements. Instead of obtaining the data by painstaking point-by-point checks across the IF range, the assumption is made that the shapes of the voltage response curve and the impulse response curve remain sensibly the same. Then all that's involved is the following:

(1) Measure just one of the bandwidth types across the range.
(2) Determine desired bandwidth by calculation, as shown below.

In the example given above, we know the 6 dB bandwidth; so the impulse bandwidth is: BW (kHz) = 6 dB BW x K_I; where:

$$K_I = \frac{7.55 \text{ kHz}}{6.9} = 1.093 \text{ kHz}.$$

In practice, it is only rarely necessary to make such determinations. Calibration of the meter with an impulse generator, using a repetition rate matching thatof the signal of interest will provide quite accurate data.

The above article was prepared by Charles F. W. Anderson, staff writer for Item.