ANALYSIS, RECORDING AND MEASUREMENT EQUIPMENT

Introduction

The field of interference measurements, including both susceptibility and emanation, employs many of the same methods and equipments used generally in other areas of radio frequency measurement. There is no other area, however, that covers such a wide range of frequencies and signal levels as does interference measurements. Consequently, some of the equipments and techniques are specialized and seldom used otherwise.

Interference measurements, to be useful, must produce usable answers with absolute numbers and definitive units and the susceptibility of an equipment must be proven or disproven. To this extent, the field of interference measurements is an eminently practical one. On the other hand, there are many complex areas in interference measurements which require an understanding and an appreciation of fundamentals, such as a knowledge of conducted and radiated signal measurements in terms of both signal level and frequency, a knowledge of many diverse test equipments and devices, and a knowledge of the equipment under test.

From these requirements has evolved the recognition that interference measurements are definitely engineering measurements. The problems encountered, the range of frequencies and levels used, the equipment used, and the equipment under examination are factors which preclude interference measurements from being considered as routine tests. There are situations, however, where a certain measurement must be performed repetitively on successive units of the same type, i.e., production-line checking, where the measurement can be refined to become routine. It is not likely that this situation will be experienced to any extent in space programs because with the wide variety of programs and equipments and the rapid progress of its various specialties, the majority of programs and equipments and the rapid progress of its various specialties, the majority of interference measurements will be in the one-of-a-kind category.

Interference test equipment may be divided into two broad categories: (1) general test equipment and (2) special test equipment. General test equipment includes signal generators and electronic voltmeters, while special test equipment is intended to indicate instrumentation developed specifically for interference testing. This latter category is primarily made up various frequency-selective voltmeters and their accessories, plus a few special-purpose units. The more common equipment in the general category will be reviewed from the interference measurement standpoint, while the special equipment will receive brief consideration.

A variety of special devices are required for interference tests. These include impulse generators used for calibration and signal substitution measurements, transient generators for susceptibility tests, and several audio equipments for audio susceptibility tests.

As electronic systems become more complex, the interference test planner will find himself devising his own instrumentation, due either to a difficult test specification requirement or to a special test requirement not necessarily associated with a specification. This will be especially true of space systems with their ultrasensitive receivers and high reliability requirements. In instances of this sort, it is generally more expeditious and economical to use modified existing equipment and perhaps provide additional auxiliary units than to develop a completely new instrument. For instance, there are several arrangements suitable for increasing receiver sensitivity if that becomes necessary. In some frequency ranges, preamplifiers with low noise figures are available. In other instances, the bandwidth may be reduced by using a second lower frequency receiver as a tunable IF amplifier.

Equipment Characteristics

As mentioned previously, the frequency-selective voltmeter is the keystone of the interference measurement field. It is basically a well-shielded sensitive radio receiver with a wide dynamic range and a means of calibration to provide absolute measurements. These instruments are available to cover a frequency range from 30 Hertz to 20 GHz, i.e., from subaudio frequencies to a wavelength of 1-½ centimeters.

From the block diagram in Figure 1, it is evident that the interference receiver is a superheterodyne receiver with some added features. The block diagram depicts only one possible receiver; there are many other configurations. Each of the major blocks on the diagram will be discussed briefly in the following paragraphs.

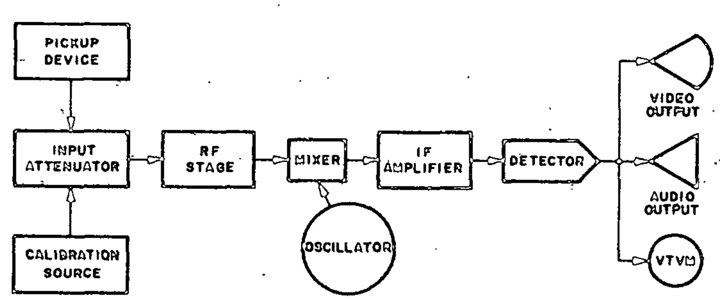


Figure 1. Block Diagram of a Typical Frequency-Selective Voltmeter

Pickup devices provide coupling from the signal source to the interference receiver. Two types of coupling are possible: (1) direct or (2) by means of the electromagentic field.

Direct coupling may be accomplished readily since all currently used interference receivers' have some means of providing 50-ohm inputs. Their inputs may be connected directly to 50-ohm source circuits, or through directional couplers, attenuators, or filters where necessary. Coupling to power lines, ac or dc, is usually accomplished with a particular network termed a line impedance stabilization network (LISN) or a current probe.

Electromagnetic field coupling is provided by an antenna. In some cases, a small uncalibrated probe antenna may be used, for example when a leakage source is under investigation, but calibrated antennas must be used to obtain an RF field measurement in absolute units. A wide variety of these antennas is in current use to cover the required frequency range but there has been a somewhat recent trend to provide antennas which do not require adjustments, i.e., broadband antennas.

To provide absolute field strength measurements from the voltage at the antenna terminals, it is satisfactory to use theoretically calculated antenna factors for the half-wave dipoles. This factor will include the correction for the electrical length of the dipole, λ / π as well as any correction for the mismatch between the antenna impedance (72 ohms) and the interference receiver input impedance (usually 50 ohms). Factors for other antennas must be determined experimentally.

Conventional receiver practice in the past has been to narrow bandwidth to improve receiver sensitivity. While this is a proper approach for CW signals and is only limited by the signal bandwidth and the combined stability of the local oscillator and the signal, it is not the correct approach to improve receiver sensitivity to impulsive signals. With all other parameters constant, the receiver's own random noise voltage, produced in the first one or two stages, will increase as the square root of the bandwidth increases. However, impulsive noise voltage increases directly with an increase in bandwidth, which indicates that to produce maximum receiver sensitivity to impulsive signals requires the widest bandwidth receiver that is possible. There is of course, no benefit if the receiver bandwidth is wider than the bandwidth of the signal. This consideration is particularly important in radar work and has naturally been recognized in the interference receivers designed for this range. They are furnished with two bandwidths, one less than 1 MHz, and the other on the order of 3 to 5 MHz. Future receivers for lower frequency ranges may also be designed with more than one IF bandwidth to take advantage of this method of improving impulsive signal sensitivity.

The detector stage in an interference receiver has the function of separating signals according to modulations, or perhaps more accurately, according to their peak-to-average ratio. This is accomplished by utilizing several different charge and discharge times for the detector. As the charge time is decreased, the detector circuit becomes more responsive to short-duration, fast-rising signals. As the discharge time is lessened, the detector circuit will tend to dump or lose the charge of a signal in a shorter time. Therefore, to provide a detector which responds to CW signals, an "average" function is provided.

By appropriately altering the charge and discharge times, a peak detector may be obtained. This arrangement will have a very short charge time, on the order of tens of microseconds, with a long discharge time, on the order of hundreds of milliseconds. This results in a metering circuit which will respond quickly to the highest signal and "remember" it over a short interval.

There is another widely used peak detecting method, commonly referred to as the "slideback" method. The detector constants are about the same as for the average mode, but there is now a dc bias which is adjusted by the operator until the audio just disappears or is at the threshold of audibility. The operator, in effect, matches the peak of the signal level with a dc level. The dc level is read on the metering circuit. This aural slideback method offers the possibility of measuring one signal in the presence of another when the desired signal may be somewhat lower in level. Otherwise, the visual peak methods referred to as direct peak reading are to be preferred. They reduce the time required for measurement and also reduce the subjectivity experienced in the aural method.

In the past, another detector function was widely used. It was the quasipeak (QP) mode, with a charge time of one millisecond and a discharge time of 600 milliseconds. The idea was to have a detector mode which would measure the effective interference in a communications system or to express it in another way, a measure of the "nuisance value" of the interference. This mode may also be useful for scanning in frequency where it will "stretch" short pulses to the point where they are long enough to be audible.

The detector function must be considered if X-Y recordings are to be made automatically. It is obvious that if the receiver is tuned through a CW signal fast enough, the signal will not fully charge the detector in the average detector mode. The scan rate must be selected so that the largest signal to be measured will be accurately detected. The response of the recorder is also a factor in this problem. It must be fast enough to record the detector output within the required accuracy.

Bandwidths for Interference Measurements

Despite the fact that selective circuits may display the same maximum response and the same frequency selectivity according to the customary definition, they can nevertheless display different sensitivities to noise. The term "circuit bandwidth" will be used for the customary concept of bandwidth wherein only the selectivity or frequency discriminating properties of a network are described.

The term "effective bandwidth" is often referred to. It is an index of the network response to "noise" or other transient phenomena, the components of which are continuous and distributed throughout the frequency spectrum. For this reason, the effective bandwidth is often referred to as the "noise" bandwidth.

There are two basic types of broadband radio "noise" or interference; impulse and random type. "Impulse interference" is defined as one or more electrical disturbances whose duration is very much less than the reciprocal of the bandwidth of the measuring instrument. If a series of such impulses is considered, it is assumed that they are of constant amplitude and that the interval between them is such that the effect of any one impulse has died out by the time the next one is received (i.e., no overlapping). Random interference consists of electrical disturbances of random amplitude and phase angles and of spacing so small that considerable overlapping occurs. A selective circuit will respond differently to these basic interference types. Therefore, the general term "effective bandwidth" is modified to "effective impulse noise bandwidth" (or simply impulse bandwidth) when dealing with impulse type interference and to "effective random noise bandwidth" (or random interference bandwidth) when dealing with random type interference.

The "effective random noise bandwidth" is defined as the frequency interval, Δf_r, for which a power gain equal to the gain at mid-band, f_o, would transmit the same noise energy as does the actual power gain frequency curve. The effective random noise bandwidth of any selective circuit can be obtained by dividing the area under the power response curve by the gain at the center frequency.

The "effective impulse bandwidth" is defined as the ratio between the maximum value of response and the spectral intensity of noise times the gain at mid-band. The effective impulse bandwidth of any selective circuit can be obtained by (1) dividing the area under the pulse response curve by the gain at the center frequency to obtain effective pulse length; (2) converting pulse length into duration in seconds. The reciprocal of the duration in seconds is the impulse bandwidth in hertz.

Several types of bandwidths associated with a bandpass network or amplifier can be resolved from the "circuit bandwidth" data. This can be illustrated with data taken on typical Radio Interference and Field Intensity equipment.

Figure 2 is a plot of the usual voltage response curve. Note the "circuit bandwidth" at the 3 dB and 6 dB reduced voltage gain levels. Figure 3 shows (1) a plot of the power response curve, (2) the voltage response curve, and (3) a rectangle of the same height and area as the power response curve. The area under the power response curve was measured with a planimeter. It can also be done by counting squares. The width of this rectangle in hertz is the effective random noise bandwidth. Note that the random noise bandwidth in this particular example is the same as the 3.3 dB circuit bandwidth.

If a rectangle of same height and area as the voltage response curve were drawn, its width in hertz would be the "integrated bandwidth". If there were no phase shift across the bandpass this bandwidth would be the "impulse bandwidth". Since phase shift is present in a practical amplifier the impulse bandwidth must be obtained by other means. One method is to apply a pulse signal of short duration to the input of the amplifier and to observe the pulse shape at the amplifier output with an oscilloscope. When a suitable second detector is used, the signal for the oscilloscope should be from the detector load resistor. The following precautions must be taken:

1. The pulse duration in seconds must be short with respect to the reciprocal of the bandwidth in hertz. A ratio of 5 to 1, or greater, is recommended, this to assure that the signal appears impulsive.
2. The pulse repetition frequency should be sufficiently high to provide a clear pattern on the oscilloscope.
3. The pulse amplitude should be constant and at a level where linear operation of the amplifier is assured.
4. The oscilloscope time base must be accurately calibrated.
5. When a detector is used its time constant (product of the detector load resistance in ohms by the circuit capacitance in farads) should be smaller than $1/5\ \Delta F$ where ΔF is the 6dB bandwidth of the amplifier in hertz. This detector circuit will provide an accurate reproduction of the pulse envelope as shaped by the amplifier bandpass. If the oscilloscope is connected directly across the detector load resistor the input capacity of the oscilloscope and its connecting cable must be added to the detector circuit capacitance when computing the time constant.

For these tests, a 5 microsecond duration pulse with repetition rate of 1000 was used. The pulse shape (impulse response) observed on the oscilloscope at the output of the second detector is shown in Figure 4. The vertical and horzontal divisions have the same linear length and the oscilloscope horizontal amplifier gain was adjusted so the time base equaled 25 microseconds per division. The effective width of the pulse is the width of a rectangle of the same height and area as the impulse response envelope. The effective pulse duration is 5.3 divisions x 25×10^{-6} or 132.5×10^{-6} seconds. The reciprocal of the pulse width in seconds is the effective impulse bandwidth in hertz.

$$\frac{1}{132.5 \times 10^{-6}} = 7550 \text{ hertz}$$

The several bandwidths for the example discussed, taken from curves of Figures 2, 3, and 4 are:

3 dB bandwidth	4.8 kHz
3.3 dB bandwidth	5.128 kHz
Effective Random Noise Bandwidth	5.128 kHz
6 dB bandwidth	6.9 kHz
Effective Impulse Bandwidth	7.55 kHz

In a tunable bandpass amplifier the bandwidth usually varies over the frequency range under the influence of the tracking and of the Q of the R.F. circuits. An enormous amount of effort would be involved in deriving the effective bandwidth data as outlined above at many points across the frequency range. Instead, an assumption is made that the shape of the voltage response curve and the impulse response curve remain approximately the same. Then, just one of the bandwidth types is measured across the range and the others determined from simple ratios derived from the more comprehensive data taken at one frequency. For example, if the 6dB bandwidth is known, then, for the above example:

$$\text{Impulse BW in Khz} = \text{db BW} \times K_1$$

$$\text{where } K_1 = \frac{7.55 \text{ kHz}}{6.9 \text{ kHz}} = 1.093$$

$$\text{Random noise BW in Khz} = 6 \text{ db BW} \times K_2$$

$$\text{where } K_2 = \frac{5.128 \text{ khz}}{6.9 \text{ khz}} = 743$$

Quite often only "effective random noise bandwidth" data is supplied with RI-FI equipment. The impulse bandwidth can be obtained by multiplying by a similar factor, as in the above example:

$$\frac{\text{Impulse BW}}{\text{Random Noise BW}} = \frac{7.55 \text{ khz}}{5.128 \text{ khz}} = 1.47$$

Bandwidth ratios can vary considerably with different types of circuits and equipments. Even small changes occur between two models of the same equipment or at the extremes in the tunable frequency range of the same model. As the voltage response curve changes toward steeper skirts and a flatter top, the various bandwidths approach each other in value.

Due to the variation in gain with frequency, the usual interference receiver must be calibrated at each measurement frequency. This is usually accomplished in one of two ways. Either an internal source is used in conjunction with a gain control to set a reference level (with the input attenuator being depended on for translation to other levels), or the receiver is used simply as a transfer device with each measured signal being matched exactly by a signal from an external source. The methods are similar in that each one requires a known source. In the case of the reference being set only on one setting of the input attenuator, only a single-level signal is required; in contrast, a wide range of levels, as from a standard signal generator, is required for the substitution method.

Calibration sources include CW, random noise, and impulse noise sources. The CW source is analagous to the standard signal generator. The random noise source provides a wideband repeatable signal, which must be initially calibrated against a CW source. The impulse method is also a wideband repeatable source, but has been more highly developed than the random noise source. The impulse generator usually operates by generating an extremely short (5×10^{-10} second, for example) dc pulse, which has a flat frequency spectrum over a wide range of frequencies. This pulse may be generated by charging and discharging a short (a fraction of a centimeter) length of transmission line. The dependability of the spectral output will then be only a function of the dc charging voltage and of the physical condition of the transmission line and its charge-discharge mechanism.

The impulse method of calibration is widespread and is used over all frequency ranges. Many interference receivers have internal impulse generators with widely variable outputs that can be used either for precalibration or for substitution measurements. It should be noted that to use impulse calibration for CW measurements requires either information about the instrument bandwidths or comparison with a CW source at the desired frequency. Normally, sufficient information is furnished with the receiver to allow complete calibration with an impulse generator.

For more on test equipment, see Singer Instrumentation on page 1.

The information on bandwidths has been provided through the courtesy of Singer Instrumentation.

Figure 2. Voltage Response Curve (Circuit Bandwidth)

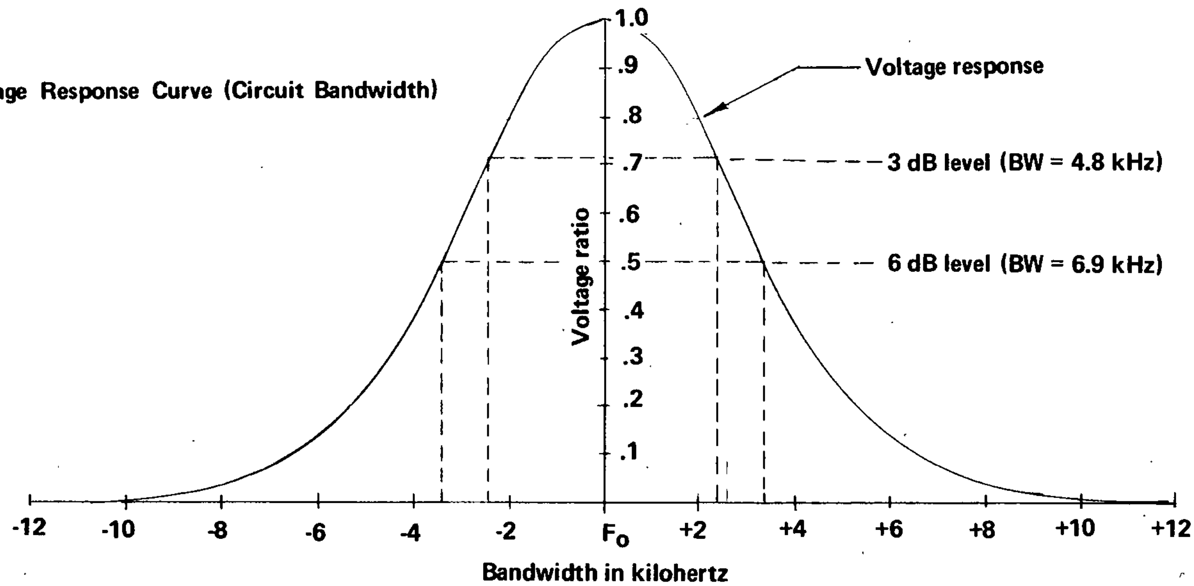


Figure 3. Voltage and Power Response Curve (Effective Random Noise Bandwidth)

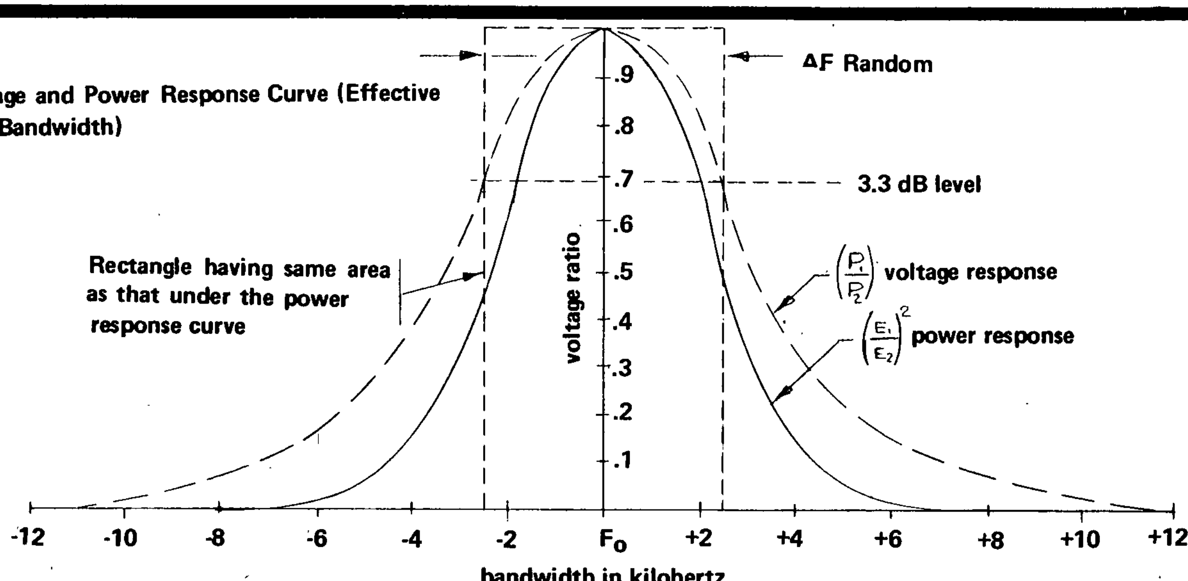
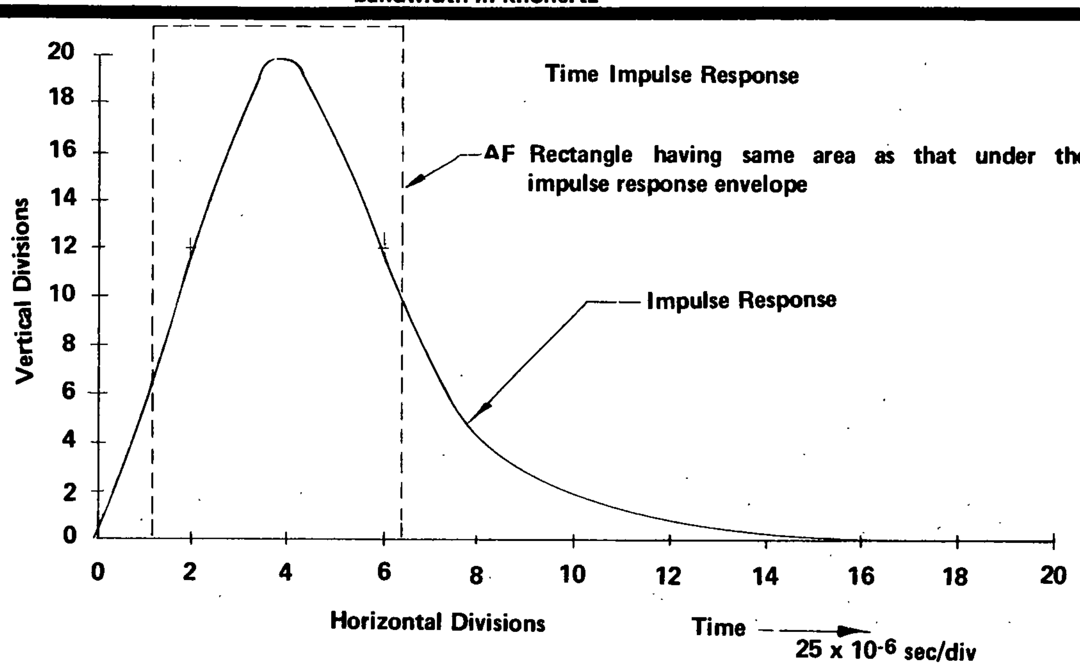


Figure 4. Envelope of Impulse Response.



Using a spectrum analyzer will enable the engineer to expand his measurement capability and save him invaluable time. EMC engineers can often be frustrated by radiated emission specifications and procedures because these often specify that the antenna position, polarization, instrument mode, etc. be adjusted for maximum reading. This is very time-consuming if you are looking at each frequency individually. Furthermore, there is always the chance that signals may be overlooked. With a specific antenna orientation and instrument control setting, an instrument may appear to be clean; but significant signals could be detected by changing conditions slightly. However, with spectrum analyzer displaying a wide frequency range, monitoring the effects of continuous adjustment of device controls, antenna position, and reflective devices in the room is very feasible. Although changing test conditions in a searching fashion may not lead to completely repeatable results, there is a greater probability that all significant emissions will be observed. These emissions can then be measured. It is no longer sufficient to just measure "by the book"; a thorough and fast investigation is necessary if the goal of EMC is to be realized.

The spectrum analyzer is a superheterodyne receiver, as are conventional field intensity meters, but the analyzer has two main differences—the input is swept and the response is constant with frequency. A block diagram of a typical spectrum analyzer appears in Figure 5.

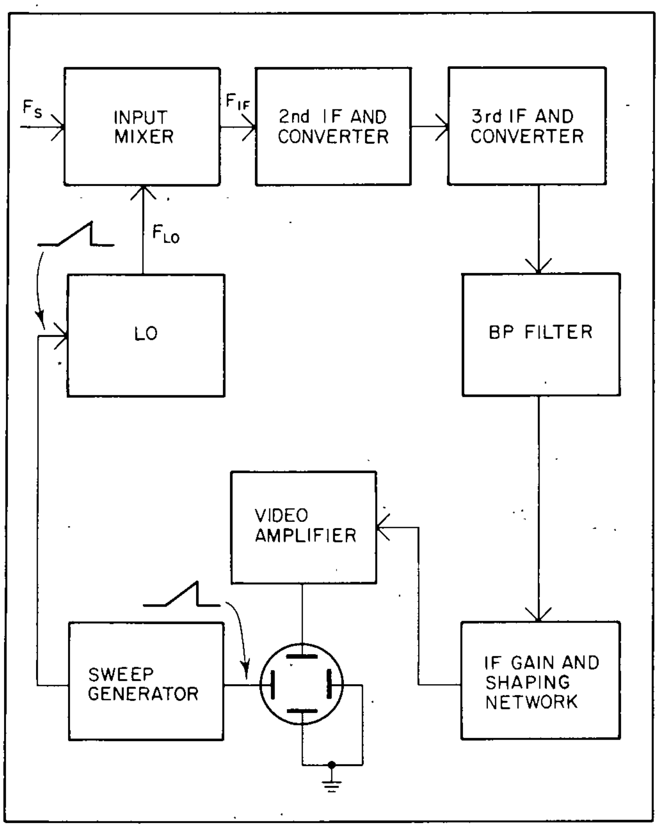


Figure 5. Functional Block Diagram

The input signal is combined with local oscillator power in a mixer. The mixer is a nonlinear device and produces outputs at the sum and difference frequencies of the two input signals. When the mixer is driven hard enough by the local oscillator, harmonics of this signal are generated. These harmonics are also added with the signal, and sum and difference frequencies are present at the mixer output. The IF amplifier is tuned so that it responds to only one frequency, f_{IF}. Usually the equation describing the output of an IF amplifier is:

$$f_S = nf_{LO} \pm f_{IF}$$

where

f_S = signal frequency

n = harmonic number

f_{LO} = local oscillator frequency (variable)

f_{IF} = intermediate frequency.

As f_{LO} is varied, the input band f_s is scanned. The analyzer bandwith can be determined by the bandpass filters, since these filters have the smallest bandwidth in the signal path. These filters are important for they determine the noise bandwidth and therefore the analyzer's ultimate sensitivity. The impulse bandwidth is also determined by the shape of these filters.

The flat response of a good spectrum analyzers means that amplitude and frequency are essentially the CRT display coordinates. At present, antennas and current probes have the only frequency-dependent transfer functions, but it is a relatively simple matter to incorporate these and the specification limit into a single line on the analyzer display. Recording data with a spectrum analyzer CRT photograph eliminates manual data plotting, since the photograph records signal amplitude versus frequency directly.

Calibration

The spectrum analyzer can be calibrated for both narrowband (dBμV) and broadband (dBμV/MHz) measurements. Since the analyzer response is flat throughout each frequency band, calibration need only be performed once for each band. Calibration of the spectrum analyzer consists of recording the response to a known signal level from a CW signal generator and assigning a calibration factor, C, to the instrument.

The input voltage to the analyzer at any particular frequency is

$$V\ (\text{dB}\mu\text{V}) = a - G - L + C$$

where

V = input signal level

a = input attenuator setting in dB

G = IF gain setting in dB

L = absolute magnitude of the signal peak read off the display in dB

C = the narrow band calibration factor for the spectrum analyzer. This is found by recording the response to a known signal level, V, and solving the above equation for C.

An additional calibration factor must be used when measuring broadband signals. This calibration factor, C', can be derived from measurement of the impulse bandwidth BW as:

$$C' = 20 \log (\text{BW}/1\ \text{MHz}).$$

C' is subtracted from the measured signal level V at the input of the analyzer to give spectral intensity A required:

$$A\ (\text{dB}\mu\text{V/MHz}) = V\ (\text{dB}\mu\text{V}) - C'\ (\text{dB MHz})$$

Measurement of the impulse bandwidth to find the factor C' involves the use of a precisely known pulse train or an impulse generator with a calibrated output. The bandwidth factor C' is dependent only on the IF bandwidth and need be measured only once per bandwidth used; i.e., neither frequency bands nor broadband preamplifiers have an effect on C'. In situations allowing reduced amplitude accuracy in the order of 1 or 2 dB, the 6-dB bandwidth can be used as an approximation of the impulse bandwidth. This can be measured from the display of a CW signal.