ANALYSIS, RECORDING AND MEASUREMENT

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.

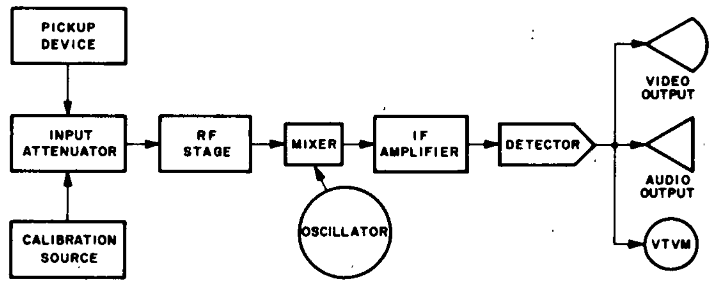

Figure 1. Block Diagram of a Typical Frequency-Selective Voltmeter

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.

Low Frequency Conducted Measurements

"There is more than one way to skin a cat". The evolution of methods of measuring conducted interference illustrates this homely expression in a distorted kind of way. To start with, a propulsion engineer named Alan Watton at Wright Field early in WW II created an artificial line impedance which represented what he had measured on the D. C. buss in a twin-engined aircraft. Watton's work was sponsored by a committee headed by Leonard W. Thomas (then of Buships) with active participation by Dr. Ralph Showers of University of Pennsylvania and others.

So the Line Impedance Stablization Network (LISN) was born. It was a pretty good simulation of that particular aircraft and the electrical systems it included. But then someone arbitrarily decided to use this artificial impedance to represent any power line. This impedance suddenly began appearing in specifications which demanded its use in each ungrounded power line for determining the conducted EMI voltage generated by any kind of a gadget. The resulting test data, it was argued, allowed the government to directly compare measured RFI/EMI voltages from different test samples and different test laboratories. No one was concerned about the fact that filtering devised for suppressing the test sample was based on this artificial impedance in order to pass the requirements, but that the same filter had no relation to reality when used with the test sample in its normal power line connection.

In 1947 Alan Watton, having no connection with the RFI/EMC business, decided to rectify the comedy of errors which had misapplied his original brainchild. He was in a position to place a small R and D contract with Stoddart for the development of two probes; a current measuring probe and a voltage measuring probe. Obviously, he felt that one needed to know at least two parameters for a true understanding of conducted interference. The current probe is not only a measure of EMI current, it is a measure of the magnetic field radiation from the wire or cable under test. This is a more meaningful measure of radiation, particularly at the lower frequencies, since the coupling between power leads at low frequencies is inductive, not capacitive.

Stoddart was successful in developing a current probe based on Watton's suggestions regarding the toroidal transformer approach which is still the primary basis used today. However, the development of the voltage measurement probe suffered for lack of sensitivity. Watton's hope had been to provide a high impedance voltage probe with better sensitivity than was then available for measurement receivers designed for rod antennas and 50 ohm inputs. Since this effort failed and Watton's funds faded out, the program came to a halt.

This meant that the RFI/EMI engineer could either measure EMI voltage across an artificial and meaningless impedance which varied with frequency, or he could measure EMI current flowing through a circuit of unknown R.F. impedance. In spite of the unknown impedance, the military specifications began picking up the idea of measuring EMI current instead of voltage. The test setup was simpler and the current probe was not as limited as the LISN in its ability to cope with large power line currents. And the current probe measurement was also a measurement of magnetic field radiation. The current probe was somewhat better than the LISN for measurements below 150 KHz and above 25 MHz but, even so, the technique was not very sensitive at the lower frequency end of the spectrum.

A Boeing EMI engineer named Frank Beauchamp was the first to apply the current probe to wideband measurements from 30 Hz to 15 KHz. He realized some of the problems in this range so he incorporated the sliding current probe factor into the method of measurement he spelled out in the Minuteman Specification, GM-07-59-2617A. The test method required that the probe factor existing at 20 KHz should be used for obtaining the wideband answer in terms of "per 20 KHz" bandwidth. This meant that the specified limit was not a constant throughout the 20 KHz bandwidth, but was varying as the inverse of the probe factor.

When later EMI specifications extended the need for measurement of EMI currents down to 30 Hz without taking into account the sloping probe factor, the problem of probe sensitivity became critical. Attempts to compensate for the poor current probe response at low frequencies by using active elements suffer from dynamic range difficulties and the possibility of overload.

This led to another way of "skinning the cat", with the aid of the Audio Isolation Transformer already available and in use for susceptibility testing. The technique described in the following paragraphs indicates how to obtain considerably greater measurement sensitivity for conducted narrowband EMI currents and a means for obtaining a flat frequency characteristic without the use of active elements for broadband or "wideband" EMI current measurements.

Basic Concept:

The application described herein has grown out of a suggestion by Sam Shankle of Philco Ford. He first tried this scheme using Wave Analyzers as the associated voltmeter. Other work with the idea has concentrated on conventional EMI meters with 50 ohm inputs. Basically, the test method consists of using the secondary (S) of the Solar Audio Isolation Transformer as the pickup device. The transformer winding normally used as the primary (P) is used as an output winding in this case. The method provides a two-to-one step up to further enhance the sensitivity.

Use of the Transformer

Since the transformer is connected in series with each ungrounded power input lead (sequentially) for performing the audio susceptibility tests, it can be used for two additional purposes while still in the circuit. First, the secondary winding can act as the series inductor suggested for transient injection tests to prevent the transient from being short-circuited by the impedance of the power line. In this application all other windings are left open. (See Figure 2.) Secondly, the transformer can be used for measuring EMI current as described herein. (See Figure 3.) At other times, if it is not needed in the circuit, short circuiting the primary winding will effectively reduce the secondary inductance to a value so low that the transformer acts as if it isn't there.

Achieving Maximum Sensitivity

The basic circuit of Figure 3 provides the most pickup and transfer of energy over the frequency range 30 Hz to 150 KHz. Curve #1 of Figure 4 shows the correction factors required to convert narrowband signals to dB above one microampere. Since the sign of the factor is negative for most of the range, the sensitivity is considerably better than that of conventional current probes. The sensitivity achieved by this technique is better than .05 microamperes at frequencies above 5 KHz when using an EMI meter capable of measuring 1.0 microvolt into 50 ohms. For EMI meters such as the NM-40A and the EMC-10E, the meter sensitivity is a decade better and it is possible to measure EMI currents of .005 microamperes at 5 KHz and above.

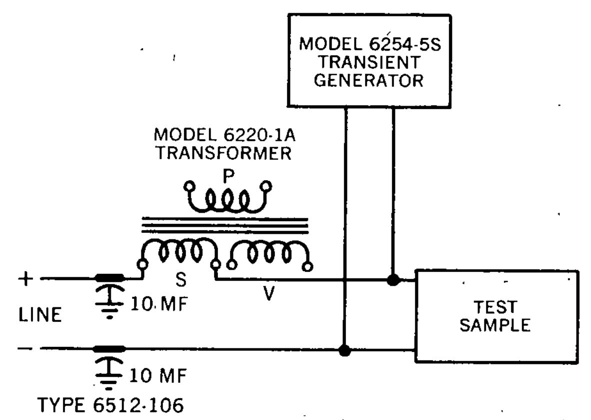

Figure 2 — Transformer Secondary used as Isolating Inductor

Flattening the Response:

At a sacrifice of sensitivity, the upper portion of the frequency vs. correction factor curve can be flattened to provide a constant correction factor from about 1 KHz up to 150 KHz. This is depicted in curve #2 of Figure 4 where a —20 dB correction is suitable over this part of the frequency range. The flattening is obtained by loading the primary with a suitable value of resistance. The resistance value used in this example is 10 ohms. The flattening still allows the measurement of .01 microampere signal when using an EMI meter with 0.1 microvolt sensitivity. An advantage of this response curve is the sloping correction at frequencies below 1 KHz which acts like a high pass filter to remove some of the power line harmonics from wideband measurements.

Like the girdle ads say, you can be firmer and flatter, with a loss in sensitivity, by further reducing the value of the shunt resistor. This is illustrated in curve #4 of Figure 4 where a 0.5 ohm shunt resistor is connected across the transformer primary winding used as an output winding to the EMI meter. The overall flatness is achieved at the sacrifice of considerable sensitivity, but the sensitivity is well under the requirements of existing specifications and the correction network utilizes no active elements.

Limitations of the Method:

When measuring EMI current on D. C. lines, there are no problems, but on A. C. lines there are limitations. The A. C. voltage drop across the winding (S) due to power current flowing to the test sample is the principal problem. This voltage induces twice as much voltage in the output winding (P) at the power frequency. Since we prefer to limit the power dissipation in the 50 ohm input to the EMI meter so that it will not exceed 0.5 watts, the induced voltage must be kept below a safe limit. For 400 Hz lines, the power frequency current must not exceed 16 amperes to avoid too much 400 Hz power dissipation in the input to the EMI meter. Also, the resistance 'R' used across the output winding (P) must be at least a 50 watt rating on 400 Hz lines. This resistor should be noninductive to avoid errors due to inductive reactance.

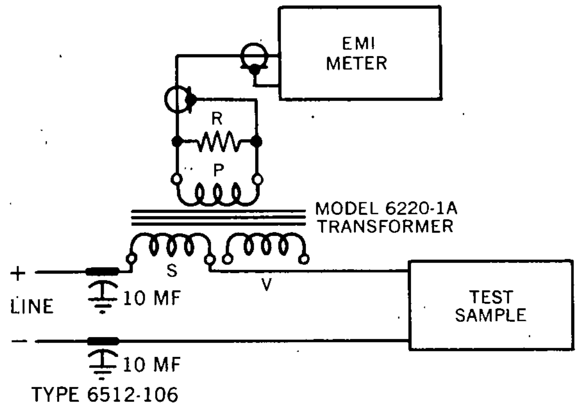

Figure 3 — Test Setup for Measuring Low Frequency, Low Amplitude EMI Current

The 10 mfd feed-thru required by present day specs had appreciable reactance at 30 Hz (≈540 ohms) and acts to reduce the actual EMI current flowing in the circuit. When calibrating the test method described herein, it is wise to short circuit the capacitor. In the case where the input circuit to the EMI meter is reactive, such as the Fairchild EMC-10E, it is necessary to use a minimum loss 'T' pad at the input to the meter. The Stoddart NM-10A and NM-40A units do not require this pad and its loss.

The material on Low Frequency Conducted Measurements was taken with permission from Application Note AN622001, published by Solar Electronics Co. The EMI Prediction Graph was also furnished by Solar Electronics.

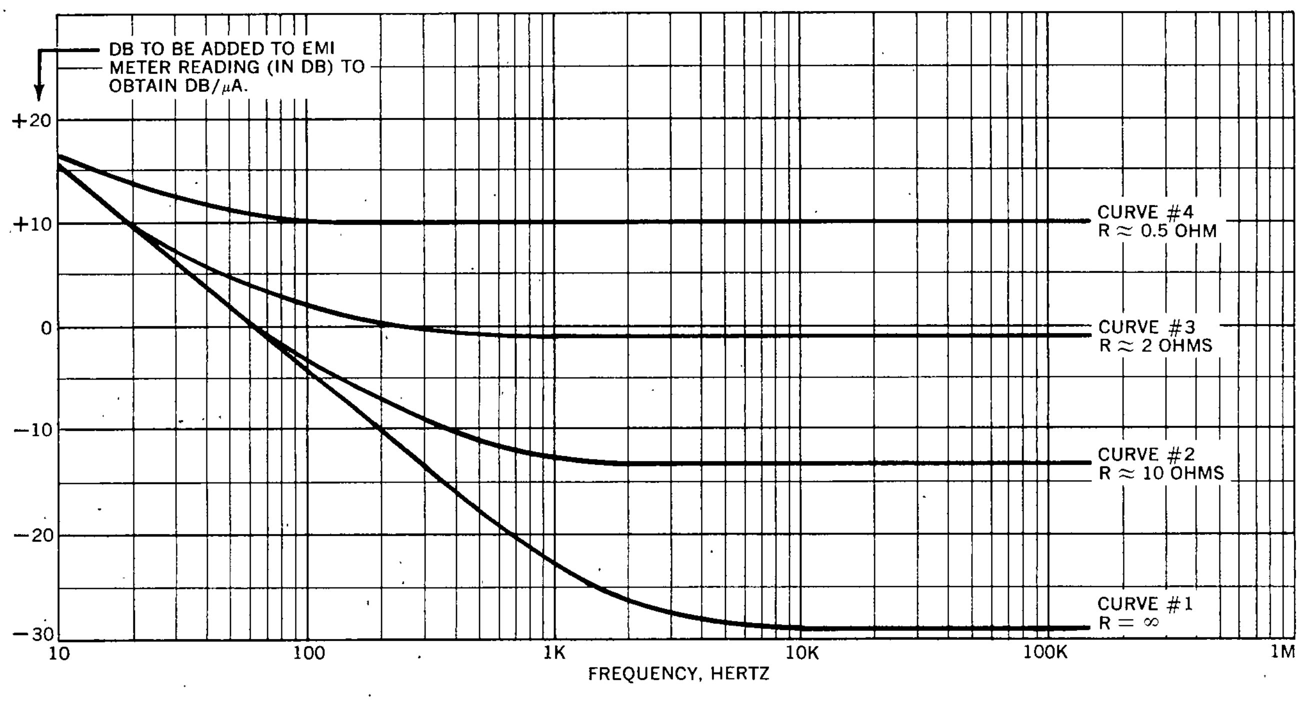

Figure 4 — Typical Correction Data vs. Frequency