APPLICATION NOTE AN622001

USING TYPE 6220-1A TRANSFORMER FOR THE MEASUREMENT OF LOW FREQUENCY EMI CURRENTS

INTRODUCTION

"There is more than one way to skin a cat" your great grandfather and my father used to say. The evolution of methods of measuring conducted interference illustrates this homely expression in a distorted kind of way.

To start with, a clever and versatile propulsion engineer named Alan Watton at Wright Field early in WWII created an artificial line impedance which represented what he had measured on the d.c. buss in a twin-engined aircraft. Probably a DC-3, but memory is dim on this point. 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 Stabilization 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.

At any rate, this impedance suddenly began appearing in specifications which demanded its use in each ungrounded power line for determining the conducted EMI (then known as RFI) 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 might have no relation to reality when used with the test sample in its normal power line connection.

Not until 1947, that is. At that time, this same Alan Watton, a propulsion engineer having no connection with the RFI/EMI 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 magnetic radiation, particularly at the lower frequencies, since the coupling between power leads at low frequencies is inductive, not capacitive.

As it turned out, Stoddart was successful in developing a current probe based on Alan Watton's suggestions regarding the torodial 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 (and probably his interest in the subject) faded out of the picture, the program came to a halt.

This meant that the RFI/EMI engineer could either measure EMI voltage across an artificial impedance which varied with frequency, or he could measure EMI current flowing through a circuit of unknown r.f. impedance. Either way, the whole story is not known. 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 young Boeing EMI engineer named Frank Beauchamp was the first to apply the current probe to wideband measurements from 30 Hz to 20 KHz. He was smart enough to realize 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. A very sensible solution at the time. Regrettably, later specifications did not follow this lead.

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 element 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.

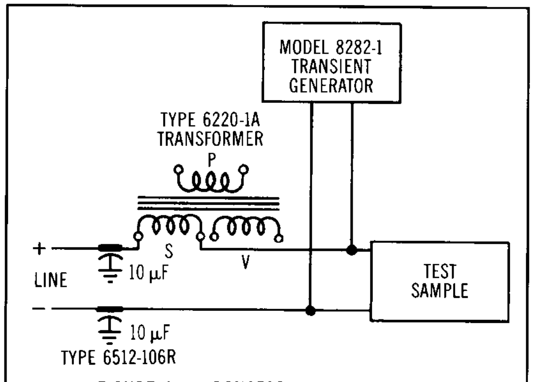

FIGURE 1 — TRANSFORMER SECONDARY USED AS ISOLATING INDUCTOR

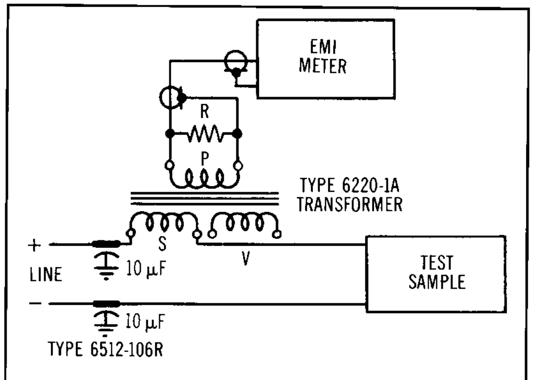

FIGURE 2 — TEST SETUP FOR MEASURING LOW FREQUENCY, LOW AMPLITUDE EMI CURRENT

BASIC CONCEPT

The application described herein has grown out of a suggestion by Sam Shankle of Philco Ford in Palo Alto. He and his capable crew first tried this scheme using H-P Wave Analyzers as the associated voltmeter. Our 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 Type 6220-1A 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 TYPE 6220-1A TRANSFORMER IN GENERAL

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 1. Secondly, the transformer can be used for measuring EMI current as described herein. See Figure 2. At other times, if it is not needed in the circuit, short cicuiting 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 FOR CONDUCTED EMI CURRENT MEASUREMENTS

The basic circuit in Figure 2 provides the most pickup and transfer of energy over the frequency range 30 Hz to 150 KHz. Curve #1 of Figure 3 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-7A 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.

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 3, 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 or resistance. The resistance value used in this example is 10 ohms. The flattening still allows the measurement of a 0.1 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 1KHz which acts like a high pass filter to remove some of the power line harmonics from wideband measurements.

If you are only interested in frequencies above 150 Hz, a 2 ohm resistor is all that is needed. See curve #3.

STILL MORE FLATTENING

Like the girdle ads say, you can 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 3 where a 0.5 ohm shunt resistor (**Solar Type 6920-0.5**) 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.

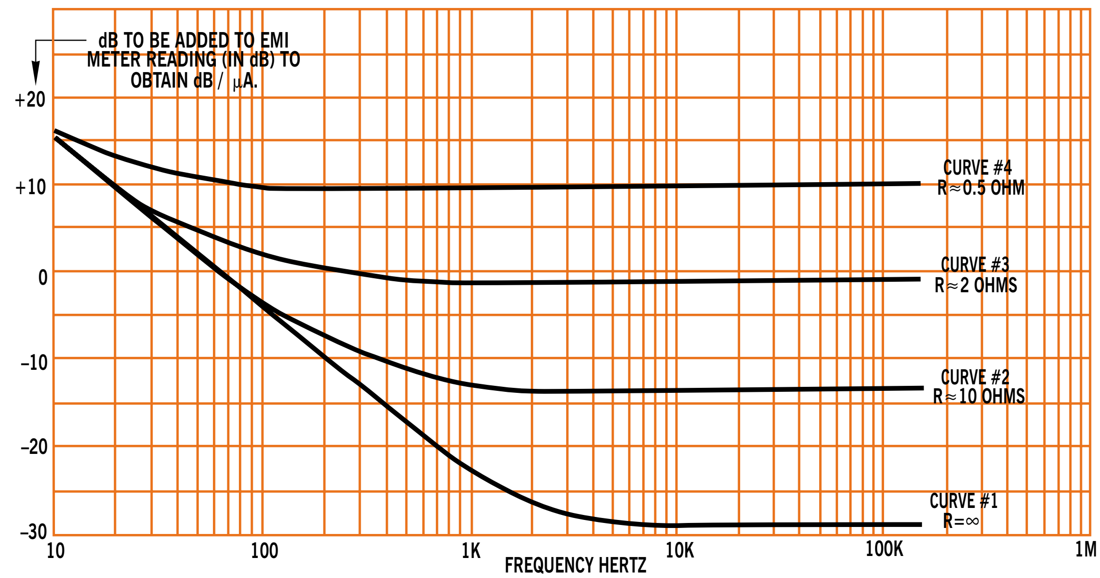

FIGURE 3 – TYPICAL CORRECTION DATA VS. FREQUENCY

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.

THINGS TO BE WARY OF

The 10 µF feed-thru required by present day specs has appreciable reactance at 30 Hz (≈54 ohms) and acts to reduce the actual EMI current flowing in the circuit. This means less trouble in meeting the spec, but 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 EMC-10E, it is necessary to use a minimum loss ‘T’ pad at the input to the meter. The Eaton NM-7A and NM-12/27A units do not require this pad and its loss.

DETERMINING THE NARROWBAND CORRECTION FACTOR

The test setup of Figure 4 describes the simple method of determining either the transfer impedance or the correction curve, whichever is desired. Actually, there is no need to plot the answer as transfer impedance, since the desired end product is the correction factor to be applied to the meter reading to obtain decibels above one microampere. The correction must be obtained for each configuration. In other words, if you want to use the method for maximum sensitivity, the calibration is performed with just a 50 ohm load on the primary winding simulating the EMI meter. If the flattening networks will be used, then they must be connected to the primary winding during the calibration and must be further loaded with 50 ohms to simulate the EMI meter input.

At each test frequency, the output of the audio signal generator is adjusted for a level which delivers the same current to the secondary (S) of the transformer. This is accomplished by setting a constant voltage across the 10 ohm resistor. A convenient level is 0.1 volt across 10 ohms which is 10,000 microamperes (80 dB/uA).

Adjust the gain of the EMI meter to assure a one microvolt meter reading for a one microvolt R.F. input from a standard signal generator. Then connect the 50 ohm input circuit of the EMI meter to the primary of the 6220-1A. If the EMC-10E is used, insert a 10 dB pad in series with the input. If the calibration is for maximum sensitivity, no additional loading is necessary. If the calibration is for the flattened versions discussed above, the appropriate resistance must be connected across the primary of the transformer.

At the frequency of the test, set the output of the signal source to obtain 1.0 volt across the 10 ohm resistor. Carefully tune the EMI meter to the test frequency and note the meter reading on the dB scale. The difference between the meter reading in dB and 80 dB represents the correction necessary to convert the meter reading to dB above one microampere for narrowband measurements. In most cases, the correction will have a negative sign. For example, at 100 Hz the EMI meter may read 88 dB above one microvolt. Since the reference is 80 dB above one microampere, the correction is -8 dB to added algebraically to the meter reading to obtain the correct reading in dB above one microampere.

If the 10 dB pad has been used, this loss must be accounted for in deriving the correction. If the pad will be used in the actual test setups, its loss becomes part of the correction factor. In this case, the meter reading obtained in the foregoing example would be 78 dB above one microvolt and the correction factor would be +2 dB for narrowband measurements.

Repeating this procedure at a number of test frequencies will produce enough data to plot a smooth curve for use when actual tests are being conducted.

DERIVING THE BROADBAND CORRECTION FACTOR

When making broadband measurements as required by MIL-STD-461A in terms of “dB above one microampere per megahertz,” use the average of the narrowband factors over the range 30 Hz to 14 KHz and add a bandwidth correction factor of 37 dB.

In the case of Method CE01 of MIL-STD-461A, use the 20 KHz wideband mode of the EMI meter, determine the average of the narrowband factors over the range 30 Hz to 20 KHz and use this figure as the bandwidth correction factor.

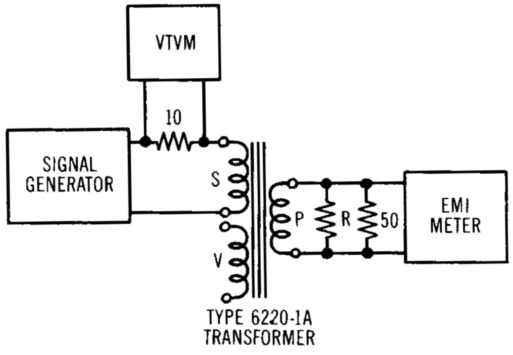

FIGURE 4 – TEST SETUP FOR DETERMINING CORRECTION FACTOR

When using high pass filters at the input to the EMI meter to eliminate the first few harmonics of the power line frequency as allowed by MIL-STD-461A, the range covered will depend upon the cutoff frequency of the filter. For example, on 60 Hz power lines and using **Solar Type 7205-0.35 High Pass Filter** between the 6220-1A Transformer and the EMI meter, obtain the average narrowband correction between 350 Hz and 14 KHz and add the bandwidth correction factor of 37 dB. On 400 Hz lines when using the **Solar Type 7205-2.4 High Pass Filter** between the transformer and the EMI meter, determine the average of the narrowband factors in the range of 2.4 KHz and 14 KHz and add the bandwidth correction factor of 38.5 dB.

SUMMARY

Some of the material given in this Application Note is terse and given without much explanation. If your are confused by this simplification, just call us. Incidentally, the Signal Corps liked this method so well that they included it in Notice #3 to MIL-STD-462 date 9 Feb 71.