NEED FOR A NEW APPROACH IN CONDUCTED RADIO-FREQUENCY EMISSIONS MEASUREMENT

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ABSTRACT

In this paper, the technical problems in the conducted radio-frequency emissions (CE) measurement as per International Standard specifications are discussed and need for a new approach is explained with illustrations and experimental results.

Electromagnetic energy propagated along a power or signal conductor is called conducted interference, if it is undesired. Generally, CE test is conducted over the frequency range 150kHz to 30MHz. However, experience has shown that, below 150kHz, CE comes out from the electrical/electronic system is found to be strong enough to affect the co-existing system's performance. Also, it is generally considered that for frequencies above 30MHz, the disturbing energy is propagated by radiation to the disturbed system. However, if the dimensions of the System Under Test (SUT) are small compared with the wavelengths of operating signals and also, for those particular operating signals, if the in-going and out-going leads (e.g. mains leads) could not behave as passive transmitting antenna networks because they cannot be long enough to operate in resonant mode (i.e. $\lambda/4$, $\lambda/2$ open or folded dipoles), then the disturbing energy is mostly conducted by the mains and other leads of the SUT. It is therefore desirable to define the disturbing capability of SUT as the power it could supply to its leads. Hence it is necessary to quantify such conducted disturbing power signals, below 150kHz and above 30 MHz,, by using a suitable Line Impedance Stabilization Network (LISN) and Absorbing Device respectively. Hence, CE test is to be conducted from 9kHz to 80MHz to measure the system noise frequencies that are conducted by power and other leads of SUT. Accordingly, new specification limits are to be set for the extended frequency range.

INTRODUCTION

Electromagnetic fields exist with any operating electrical circuit. In some instances, the fields generated are strong enough to affect other circuits nearby. This is commonly known as electromagnetic interference (EMI). CE is one of the potential EMI that is directly coupled through conduction (with attenuation) from one system to another. It may be generated inside a system and transferred through power lines, I/O lines, or control leads. Typical sources of CE include switching power supplies, ac motors, and microprocessors. In short, any electrical and electronic system, operating with the rate of change of voltage and current, has the potential to generate CE. Usually, CE is measured as the RF noise voltage injected back in to the mains supply by the SUT. Measurement is made on both the live and neutral lines over the frequency range 150kHz to 30MHz. The noise voltage must be below the limit set by the standard.

BACKGROUND

CE is encountered when electrical systems share wiring such as a common ground or active. For instance, if a common supply bus is used to power a number of systems, a finite voltage drop will be generated when current is drawn from one system. This voltage drop could then interfere with other systems, either at low or high frequency. Common ground return paths are equivalent to shared power leads. An example is that of a hum generated by an electric motor through audio circuits, or the re-setting of a device when transient loads are applied on a power bus. Also, CE may originate from the coupling of ambient radiated interference or may be capacitively, inductively or galvanically induced in the cable by an emitting source. The impedance presented by power cables, cable screens, etc. is generally low and this type of EMI will be readily propagated. CE can be classified according to whether it is incoming or outgoing, and whether it is coupled via the mains port or via signal ports. The vast majority of CISPR-and IEC-based International EMC test standards require testing of all phenomena on the mains port. There are two types of conducted noises produced on AC mains terminal, differential-mode (DM) and common-mode (CM) noises.

DM Noise or Interference

This type of CE is propagated out one wire and returned to the other. This noise is generated by clock signals or switching waveforms power supplies. DM noise amplitudes are usually minimal above 2 MHz because line-to-line and line-to-ground capacitance and wiring inductance tend to filter this type noise.

CM Noise or Interference

This type of CE travels in the same direction in both wires and returns through the ground plane or structure. In power and signal systems that have a single reference to ground or single-point ground, CM noise is capacitively coupled to the ground plane or structure. Because of the capacitive coupling, CM noises are generally high frequency (above approximately 2 MHz). High rates of *dv/dt* and parasitic capacitors to the ground are the reasons for CM interferences. The CM circuit is closed across parasitic capacitors (C_p) to the earth ground and the connecting lines.

CE Measurement with a LISN

Fig. 1 shows the layout for CE measurement. A LISN allows CE test to be made on the mains connections of a SUT. LISN isolates the SUT from interference on the mains supply and provides known RF impedance for coupling to a measuring instrument. CISPR 16 includes a design of LISN intended primarily for use up to 30 MHz.

CE Measurement with a Absorbing Clamp and Current Probe

Fig. 2 shows the ferrite-absorbing clamp.(FAC) The FAC is intended to allow the measurement of the interference power present on the mains cable of SUT. The FAC is moved along the cable until the maximum indication at each test frequency is found between a position adjacent to the SUT and a distance of about a half-wave length from it. This type of measurement is primarily to small apparatus connected only by a mains cable to measure the interference power present on the mains lead. This method has the advantage of not needing a large open area for the tests, but it should be done inside a fairly large screened room. CISPR16-1 specifies the construction, calibration and use of FAC. There is considerable interest in using FAC as a replacement for many radiated emissions (RE) tests, especially in situations such as with small SUTs where the emissions are substantially due to the cables. However, the measurement of the terminal voltage on non-re-wirable leads longer than 2 meters and shorter than 10 meters shall be started at a frequency (in MHz) according to the following formula

$$F\ (\text{start}) = 60/L \qquad (1)$$

where, L is the length of the connecting lead between the SUT and the auxiliary apparatus, in meters. Also, RF current probe could be used for measuring CE. The current probe is essentially the same as the absorbing clamp except that it does not have the absorbers. It is simply a clamp-on, calibrated wideband current transformer. Because the current probe does not have an associated absorber, the RF common mode termination impedance of the line of SUT should be defined by a LISN, which must be transparent to the signals being carried on the line. Both the FAC and the current probe have the great advantage that no direct connection is needed to the cable under test, and disturbance to the circuit is minimal below 30MHz since the probe effect is no more than a slight increase in common mode impedance. However, at higher frequencies, the effect of the common mode coupling capacitance between probe and cable becomes significant. Above 30MHz, it is normal practice to use FAC to measure emissions.

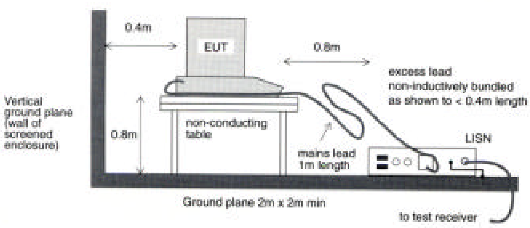

Fig. 1. The layout for CE measurement

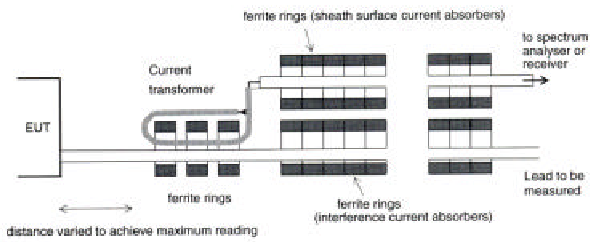

Fig.2. The ferrite–absorbing clamp

THEORETICAL ANALYSIS

Fig.3 shows the basic equivalent circuit for CE testing on the mains port. The mains connection is represented by the LISN giving a defined RF impedance between line and earth and between neutral and earth. The EUT contains both DM and CM sources between line and neutral and between both line and neutral with respect to earth respectively. Note that the connection to the mains is made via an one meter length of cable that should also be included in the model for best accuracy, but is not included in this Fig.3. DM sources appear between line and neutral connections without reference to the earth connection is shown in Fig.4. Now days, most of the modern electronic systems are incorporated with switch-mode power supplies, due to its high efficiency, low volume, low weight etc. However, in circuits with switch-mode power supplies or other power switching circuits the RF emissions are dominated by interference developed across the DC link to the switching devices. Although there will normally be a reservoir capacitor, the high *di/dt* through this capacitor will generate voltages at the harmonics of the switching frequency across its equivalent series impedance. Switching diodes noise, if it is significant, will also appear in DM. Fig. 5 shows the CM sources. The CM voltage appears between both line and neutral with respect to earth. Since the mains input is normally isolated from earth, it is usual for CM coupling to be capacitive in most cases. The coupling is dominated by the interwinding capacitance of the isolating transformer and the stray capacitances of noise sources, both in the power supply (e.g. from heat sinks) and the operating circuit. These capacitances are referred to earth, either directly or via the enclosure if this is conductive. Other impedances may appear in the coupling path: for instance the leakage inductance of the isolating transformer is in series with its interwinding capacitance and may give a series resonant peak in the MHz range.

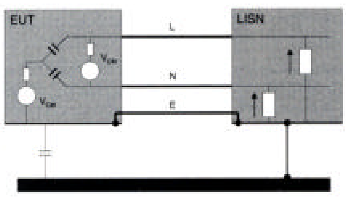

Fig.3. Basic equivalent circuit for CE

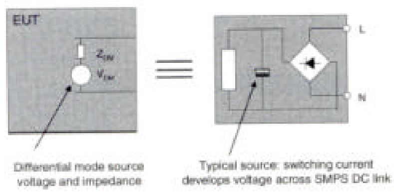

Fig. 4. Differential mode sources

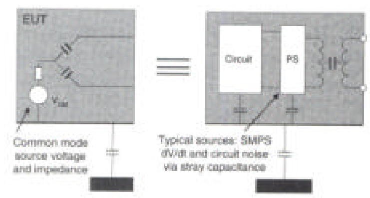

Fig.5. Common mode sources

EXPERIMENTAL ANALYSIS & RESULTS

CE measurement is conducted inside the Shielded Anechoic Chamber (SAC) to avoid the influence of unpredictable time-variant electromagnetic ambient fields (e.g. emissions from the electronic ignition and wireless communication systems) over the measurement. Fig.6 shows the CE noise spectrum from the mains terminal (neutral) of SUT (a typical information technology equipment) over the frequency range 150kHz to 30MHz, measured as per CISPR 22, 2003-04 in quasi-peak and average detection modes with a resolution bandwidth (RBW) 9kHz. It is shown that CE comes out from the SUT is below the quasi-peak and average limit lines. Fig. 7 shows the radiated emissions (RE) noise spectrum from SUT, measured at a 3-meter distance from the receive antenna, kept inside a shielded anechoic chamber over the frequency range 30MHz to 80MHz in quasi-peak detection mode with RBW 120kHz. Except at a spot frequency 33.9MHz (level: 51.4 dBμV/m), the RE from SUT is below the quasi-peak limit line over the frequency range 30MHz to 80MHz. The CE noise spectrum, due to the switching frequency and its harmonics fall over the frequency range 9kHz to 150kHz, is measured with RBW 200 Hz in quasi-peak detection mode using the measurement set-up as shown in Fig.1.The conducted RF power (CRFP) is measured with RBW 120 kHz in quasi-peak detection mode over the frequency range 30MHz to 80MHz using the FAC as shown in Fig.2. Figs.8 &9, show the CE noise spectrum measured from the mains terminal (neutral) of SUT in quasi-peak detection mode, over the frequency ranges 30MHz to 80MHz and 9kHz to 150kHz respectively. By comparison of Figs.7&8, the difference between the noise levels is due to (i) control of RE from a PCB, by reducing the track length and loop areas, so that RE is converted into CE over the lower RE test frequency range, (ii) the receive antenna used in RE measurement is not tuned to the resonant length for frequencies below 80 MHz, (iii) EMI filters, designed to cover the frequency range 150kHz to 30MHz and (iv) the shift-technique used by the EMC design engineers to shift the resonant noise peaks to the outside of the standard CE test frequency range 150kHz to 30MHz. Hence, CE noise spectrum is observed below 150 kHz and above 30 MHz. Table-1 shows the comparison data for noise levels measured from RE (at 3 meter measurement distance) and CRFP tests at some spot frequencies. The difference shown in Table-1 is calculated by the conversion formula

$$\mathrm{dB(pW)} = \mathrm{dB}(\mu\mathrm{V}) - 17 \qquad (2)$$

From the experimental results, it is confirmed that the CE noise spectrum comes out from the mains terminal of the SUT is strong enough to disturb the function of the co-existing electric/electronic systems operating over the frequency ranges 30 MHz to 80 MHz and 9 kHz to 150 kHz, that is not covered in the International EMC Standards.

Table-1: comparison data for noise levels measured from RE and CRFP tests

Frequency MHz	Measured Noise Levels		Difference dB
	RE dB(µV/m)	CRFP dB(pW)	
30.50	47.60	78.00	47.40
31.85	49.10	77.20	45.10
33.00	49.70	77.10	44.40
33.90	51.40	75.90	41.50
36.30	48.80	74.30	42.50
38.45	45.90	76.70	47.80
39.70	43.80	77.50	50.70
42.15	44.40	77.20	49.80
43.85	45.90	78.00	49.10
45.10	46.60	74.70	45.10
48.90	41.80	70.10	45.30
51.95	40.10	69.40	46.30

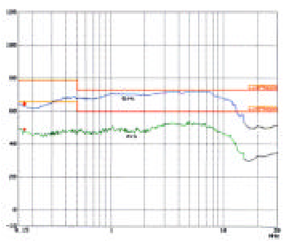
Fig.6 CE (150kHz to 30MHz)

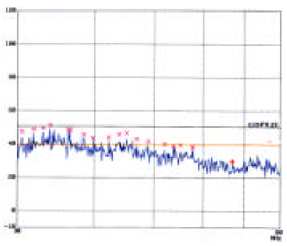
Fig.7 RE (30 to 80MHz)

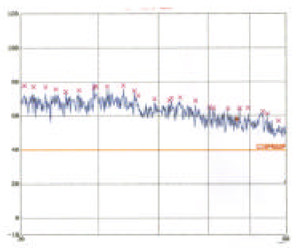
Fig.8 CRFP (30 to 80MHz)

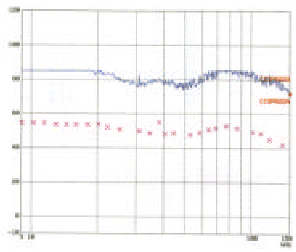
Fig.9 CE (9kHz to 150kHz)

CONCLUSION

At audio and lower radio frequencies, EMI is primarily caused by conduction. CE easily affects audio products operate over the frequency range 9kHz to 150kHz and electronic devices that operate at lower radio frequencies. Hence it is necessary to measure CE from 9kHz onwards. Note that the lower frequency extends to 9kHz for some systems such as lighting equipment (CISPR 15, 1996) and induction cooking appliances (CISPR 11, 2003-03) and the same could be applied to others also. It is important to measure the RE converted into CE by modern technology PCB's design over the frequency range 30MHz to 80MHz. It is well known fact that EMI/EMC testing is designed to ensure that electrical/electronic equipment will perform properly in its expected electromagnetic environment, thus maintaining an acceptable degree of electromagnetic compatibility (EMC). Hence, it is need for a new approach in CE measurement and extends the measurement frequency range from 9kHz to 80MHz. It is also noticeable that as per IEC 61000-4-6, standard for immunity to conducted disturbances induced by radio-frequency fields, it is required to measure the effect of conducted disturbing signals induced by electromagnetic radiation over the frequency range 150 kHz to 80 MHz. Therefore, it is equally important to quantify conducted disturbing signals come out from the SUT over the frequency range 9 kHz to 80 MHz. The new approach in CE measurement becomes inevitable in view of the proliferation of digital electronics, wireless communication and automotive electronics, covering a wide frequency range. Also, the new approach become important since FCC, USA has stipulated, for new CE requirements for products being manufactured after July 11th 2005 to demonstrate compliance with European Standards, based on well-known CISPR limits.

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