ESDI Technical Note on Estimating Maximum RF E-Field Based on RF Current Probe Measurement of Common Mode Current and length of Cable

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Overview of RF Current Probes

The following is summarized from the references given below. It is intended to estimate the magnitude of the maximum radiated E-field in the far field zone (r > wavelength/2π) based on the current in a wire or cable measured using an RF current probe.

An RF current probe is a passive broadband probe designed to clamp on over a cable and calibrated to drive a 50 ohm load via a coaxial cable. Normally, this is connected to a spectrum analyzer which reads the output value in dBuV.

The probe manufacturer provides a calibration of "transfer impedance" Z as a function of frequency over the range of the probe. Since Voltage V = Current I x Impedance Z, the current can be derived from the voltage measurement by dividing by the transfer impedance Z:

$I = V/Z$.

In Logarithmic terms (dB), this is $20Log(I) = 20Log(V) – 20Log(Z)$ or
$I_{dBuA} = V_{dBuV} – Z_{dBOhms}$.

A typical probe may have a $Z_{transfer}$ of 2 to 20 ohms. At 15 ohms transfer impedance, $Z_{dB\Omega}$ is 20 Log(15) = 23.5 dB.

For a probe reading indicated on a spectrum analyzer of 45 dBuV, the current would be 45 - 23.5 = 21.5 dBuA. If -23.5 is added to the path loss table in the spectrum analyzer, one can read dBuV directly.

Each probe comes with a calibration table showing the $Z_{transfer}$ for frequencies within its measurement range. Most probes are limited to a maximum 200 or 500 MHz, but some are available for 1GHz or more. Probes intended for conducted measurements have ranges extending down as low as 9 or 10KHz.

Current distribution on a cable may vary significantly when the cable is no longer "electrically long" compared to the wavelength at the frequency of interest, especially at frequencies of resonance where standing waves occur.

Current probes are typically designed and calibrated to be used with instruments with a 50Ω input.

Estimating Radiated Field Strength

From the references (see below), Henry Ott and Clayton Powell outlined a method for estimating *Maximum* E field strength from a cable carrying RF currents, based on the maximum RF current on it measured by an RF current probe, the frequency, and the length of the cable. It is a simplification based on Antenna Theory and only estimates the maximum, and assumes that the distance is far enough into the far field zone that the near field components of the H and E fields are negligible.

However, it is quite useful in spotting and identifying trouble spots before taking a product to test or to troubleshoot radiating cables. It is stated in the reference to be reasonably accurate to about 200 MHz, for 1M cables, though most useful below ½ wavelength.

The formula from the reference is:

$$E = (4\pi \times 10^{-7} \times (F \times I \times L) \times \sin\text{Ø}) / r$$

Where

E is Max Electric Field Strength in V/m
F is Frequency in Hz
I is current in A/m
L is length of the cable in meters
Ø is $\pi/2$ ($\sin(\pi/2) = 1$) – the maximum
r is the measurement distance in meters

Converting to Logarithmic form and adjusting to uA and uV/m, and F in MHz.

$$E_{dBuV/m} = I_{dBuA} + 20Log((4\pi \times 10^{-1} \times (F_{MHz} \times L) / r)$$
$$= I_{dBuA} + 20Log((F_{MHz} \times L) / r) + 20Log(4\pi \times 10^{-1})$$
$$= I_{dBuA} + 20Log((F_{MHz} \times L) / r) + 1.98$$

Where

$E_{dBuV/m}$ is Max Electric Field Strength in dBuV/m
I_{dBuA} is max measured current on cable in dBuA
F_{MHz} is Frequency in MHz
L is length of the cable in meters
r is the measurement distance in meters

Example

In the EMI test lab, radiated emissions will strongly depend on many factors outside of this estimation and resonances will play a major role. This is a complex issue and unfortunately, very difficult or even impossible to predict.

However, just looking at the current probe / cable question and the cable maximum E field estimation, one can look at the cable length, the frequency of interest, the required radiated E field limit and desired margin.

For example, a 1 meter cable with at a frequency of 100 MHz would require a current of 8 dBuA to fail CISPR32 class B (30 dBuV/m at 10m), less 3 dB for standard Lab Minimum Error, or 5 dB

$$30_{dBuV/m} = 5_{dBuA} + 20Log((100_{MHz} \times 1m) / 10m) + 1.98 + 3_{dBuV}$$

Here are some other examples:

2m cable, 45 MHz, 10m, CISPR32 B

$$30_{dBuV/m} = 6_{dBuA} + 20Log((45_{MHz} \text{ x } 2m) / 10m) + 1.98 + 3_{dBuV}$$

0.9m cable, 140 MHz, 10m, CISPR32 B

$$30_{dBuV/m} = 3_{dBuA} + 20Log((140_{MHz} \text{ x } 0.9m) / 10m) + 1.98 + 3_{dBuV}$$

Note that the measurements in the lab are done first by Peak and then after identifying highest level frequencies, QP (Quasi Peak) measurements are made. To compare the current probe levels, similar measuring methodology should be used (e.g., Peak vs Peak, QP vs QP, etc.). For pulsing signals, this can be problematic and highly depend on spectrum analyzer and setup used.

Use in the Time Domain

RF Current probes can also be very useful in the time domain – using an oscilloscope rather than a spectrum analyzer to display the current. A high bandwidth scope is needed but 200 MHz is enough for many measurements. Scopes have high impedance inputs with an input capacitance intended to work with compensated scope probes. RF current probes are calibrated for 50Ω inputs, so a Tee and 50Ω terminator may be needed for a given scope input.

It is not easy to get calibrated measurements since the transfer impedance is a function of frequency. Set the scope to 1X probe mode and have the calibration data handy. To convert from the displayed voltage to current, get the transfer impedance at the measured frequency (if it can be identified) and do the conversions.

Time domain measurements allow using a switching source as trigger on one channel and viewing the RF current response (e.g., ringing) at and after the trigger point.

References:

Electromagnetic Compatibility, Clayton Paul, Wiley
Noise Reduction in Electronic Systems, Henry Ott, Wiley
"Using RF Current Probe to Extrapolate Radiated E-Field Strength", Tekbox App Note