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1 Introduction

Signal- and power supply cables carrying conducted noise act as antennas and consequently cause radiated emissions.
Henry Ott and Clayton Paul outlined a method to convert RF current probe measurements into electric field strength radiated from cables carrying RF currents. It is a derivation/simplification of the full treatment outlined in “Antenna Theory – Analysis and Design” (C. Balanis).
This application note is based on an excellent article on the website of Andy Eadie from EMC FASTPASS. The application note explains how this method can be applied, using Tekbox EMCview software. It automatically creates a graph of radiated emissions, converting a common mode current conducted noise measurement carried out with a RF current probe and a spectrum analyzer.
Andy Eadie´s article can be found here:
https://emcfastpass.com/current-probe-e-field-emi-testing/

2 A bit of mathematics

“The Formula”

$$E = \frac{4\pi \cdot 10^{-7}(f \cdot I \cdot L) sin\theta}{r}$$

E = electric field strength [V/m]
f = frequency [Hz]
I = CM current [A]
L = cable length [m]
r = measurement distance [m]
ϴ = π/2

According to Andy Eadie’s article, this formula delivers a very accurate result up until approximately 200 MHz with a 1m cable.
Since we have radiation limits given in dBµV/m and measure RF currents with a spectrum analyzer, we have to convert the formula into a more practical form.

Substituting field strength and RF current by its logarithmic equivalents:

$$E\left[{}^{V}/_{m}\right] = 10^{(E\left[{}^{dB\mu V}/_{m}\right]-120)/20}$$

$$I\,[A] = 10^{(I\,[dB\mu A]-120)/20}$$

Inserting it into the formula:

$$10^{(E\left[{}^{dB\mu V}/_{m}\right]-120)/20} = \frac{4\pi \cdot 10^{-7}(f \cdot L)\cdot 1}{r} \cdot 10^{(I\,[dB\mu A]-120)/20}$$

Applying the logarithm to the formula:

$$\log(10^{(E\left[{}^{dB\mu V}/_{m}\right]-120)/20}) = \log\left(\frac{4\pi \cdot 10^{-7}(f \cdot L)\cdot 1}{r}\right) + \log(10^{(I\,[dB\mu A]-120)/20})$$

Applying logarithmic rules:

$$E\left[{}^{dB\mu V}/_{m}\right] = I[dB\mu A] + 20\log\left(\frac{4\pi \cdot 10^{-7}(f \cdot L)}{r}\right)$$

Substituting I with U being the output voltage of the RF current probe and Z the trans-impedance of the current probe:

$$E\left[{}^{dB\mu V}/_{m}\right] = U[dB\mu V] - Z[dB\Omega] + 20\log\left(\frac{4\pi \cdot 10^{-7}(f \cdot L)}{r}\right)$$

3 Using EMCview to measure cable current and display radiated emissions

The formula was converted into a sum of three logarithmic terms, which now can be processed easily by EMCview:

U [dBµV] is the RF current probe output voltage, measured by the spectrum analyzer

Z [dBΩ] is the trans-impedance versus frequency file of the current probe

$20\log\left(\frac{4\pi\cdot 10^{-7}(f\cdot L)}{r}\right)$ is the "cable current to radiated field strength conversion coefficient"
Calculate it for a series of frequency points and the desired values for cable length and measurement distance using Excel. Next convert it into a cable current to radiated emission conversion file in text format, same as any other conversion / correction file used for EMCview.

Trans-impedance file and the cable current to radiated emission conversion file can be loaded as either LISN file, amplitude correction file or cable correction file, since any of those files simply contain coefficients versus frequency which will be added or subtracted to the measurement values read from the spectrum analyzer.

4 Example

The conversion coefficient shall be calculated for a cable length of 1m and a measurement distance of 3m. The frequency span shall cover 150 kHz to 200 MHz. The table below shows the results of the Excel calculation:

Common Mode Conducted Noise Current to Radiated Emissions Conversion				
Cable length [m]	Measurement distance [m]	Frequency [MHz]	Wavelength/2 [m]	Conversion coefficient [dB]
1.00	3.00	0.15	999.33	-24.04
		0.25	599.60	-19.60
		0.50	299.80	-13.58
		0.75	199.87	-10.06
		1.00	149.90	-7.56
		1.50	99.93	-4.04
		2.00	74.95	-1.54
		2.50	59.96	0.40
		3.00	49.97	1.98
		4.00	37.48	4.48
		5.00	29.98	6.42
		7.50	19.99	9.94
		10.00	14.99	12.44
		12.50	11.99	14.38
		15.00	9.99	15.96
		17.50	8.57	17.30
		20.00	7.50	18.46
		30.00	5.00	21.98
		40.00	3.75	24.48
		50.00	3.00	26.42
		75.00	2.00	29.94
		100.00	1.50	32.44
		125.00	1.20	34.38
		150.00	1.00	35.96
		175.00	0.86	37.30
		200.00	0.75	38.46

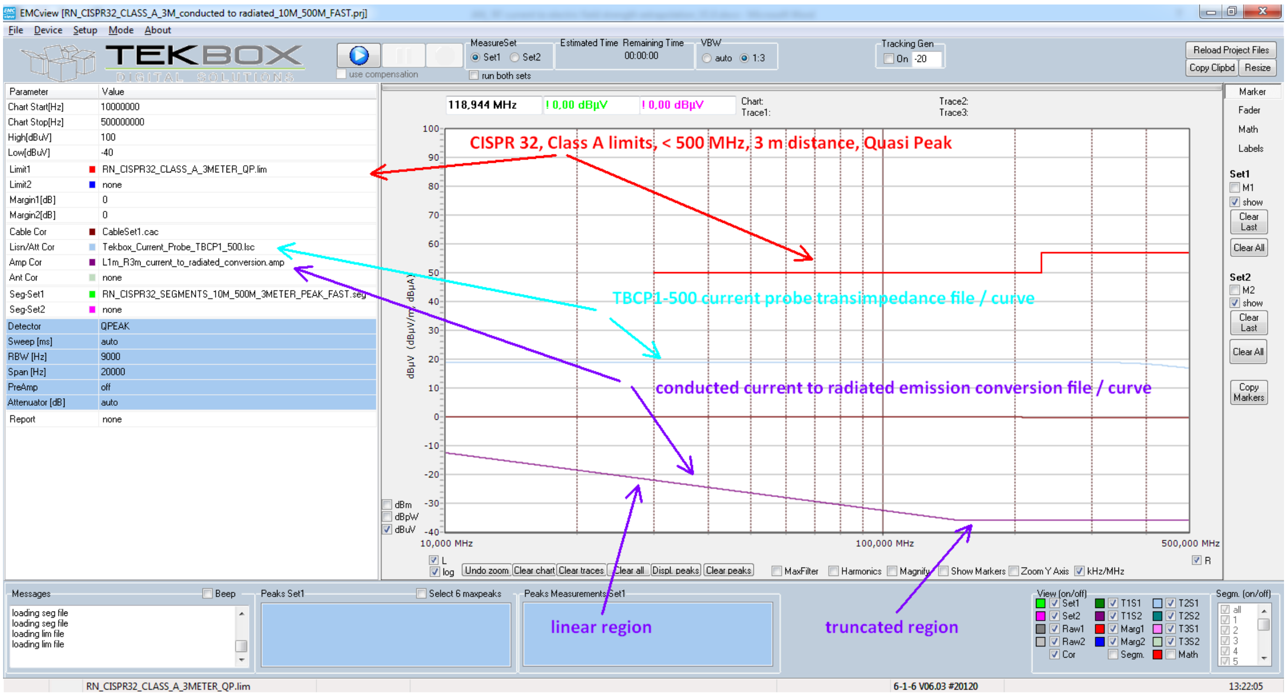
The conversion coefficients need to be entered into a conversion file for EMCview. Andy Edie's article refers to a paper, which recommends to truncate the conversion factor at the maximum cable length of λ/2 in order to increase the accuracy of the conversion. Consequently, the conversion value will be truncated at a value of 35.96 dB above 150 MHz when creating the EMCview conversion file.

The conversion factors are now entered into a gain file for EMCview using a plain text editor and saved as *L1m_R3m_current_to_radiated_conversion.amp*
Since gain will always be subtracted from the measurement result, the sign of the conversion factor needs to be reversed in order to be added.

```
[Application]
Software=TekBox RP-W32-D7
Version=Release
Date=23.06.2020 17:55:55
[General]
Name=L1m_R3m_current_to_radiated_conversion
Freq_Interplot_Mode=log
Level_Interplot_Mode=log
[Data]
Freq1=150000
Lev1=24.04
Freq2=250000
Lev2=19.6
Freq3=500000
Lev3=13.58
Freq4=750000
Lev4=10.06
Freq5=1000000
Lev5=7.56
Freq6=1500000
Lev6=4.04
Freq7=2000000
Lev7=1.54
Freq8=2500000
Lev8=-0.4
Freq9=3000000
Lev9=-1.98
Freq10=4000000
Lev10=-4.48
Freq11=5000000
Lev11=-6.42
Freq12=7500000
Lev12=-9.94
Freq13=10000000
Lev13=-12.44
Freq14=12500000
Lev14=-14.38
Freq15=15000000
Lev15=-15.96
Freq16=17500000
Lev16=-17.3
Freq17=20000000
Lev17=-18.46
Freq18=30000000
Lev18=-21.98
Freq19=40000000
Lev19=-24.48
Freq20=50000000
Lev20=-26.42
Freq21=75000000
Lev21=-29.94
Freq22=100000000
Lev22=-32.44
Freq23=125000000
Lev23=-34.38
Freq24=150000000
Lev24=-35.96
Freq25=175000000
Lev25=-35.96
Freq26=200000000
Lev26=-35.96
Freq27=500000000
Lev27=-35.96
```

The conversion file is extended to 500 MHz in order to use it for a fast pre-test project for CISPR 32 radiated noise tests, which makes a fast scan from 10 MHz to 500 MHz using peak detector. Any spurious with high levels, can then be re-measured using the Quasi Peak detector. The conversion term is linear and in its logarithmic form also results in a straight line within a logarithmic grid. Consequently it would not be

necessary to involve so many frequency points. In fact, a conversion file with 3 frequency points would be sufficient, as will be shown below.
The screenshot of EMCview shows the corresponding project, designed to carry out a fast peak scan as mentioned above.



For an example measurement of the radiated emissions of a Laptop power supply cable, following files were used and can be downloaded from our website:

<u>EMCview configuration files:</u>

Project file: *RN_CISPR32_CLASS_A_3M_conducted to radiated_10M_500M_FAST.prj*
Segment file: *RN_CISPR32_SEGMENTS_10M_500M_3METER_PEAK_FAST.seg*
Limit file: *RN_CISPR32_CLASS_A_3METER_QP.lim*

<u>Measurement equipment specific files:</u>

TBCP1-500 trans-impedance file: *Tekbox_Current_Probe_TBCP1_500.lsc*
Coaxial cable loss file: *CableSet1.cac*

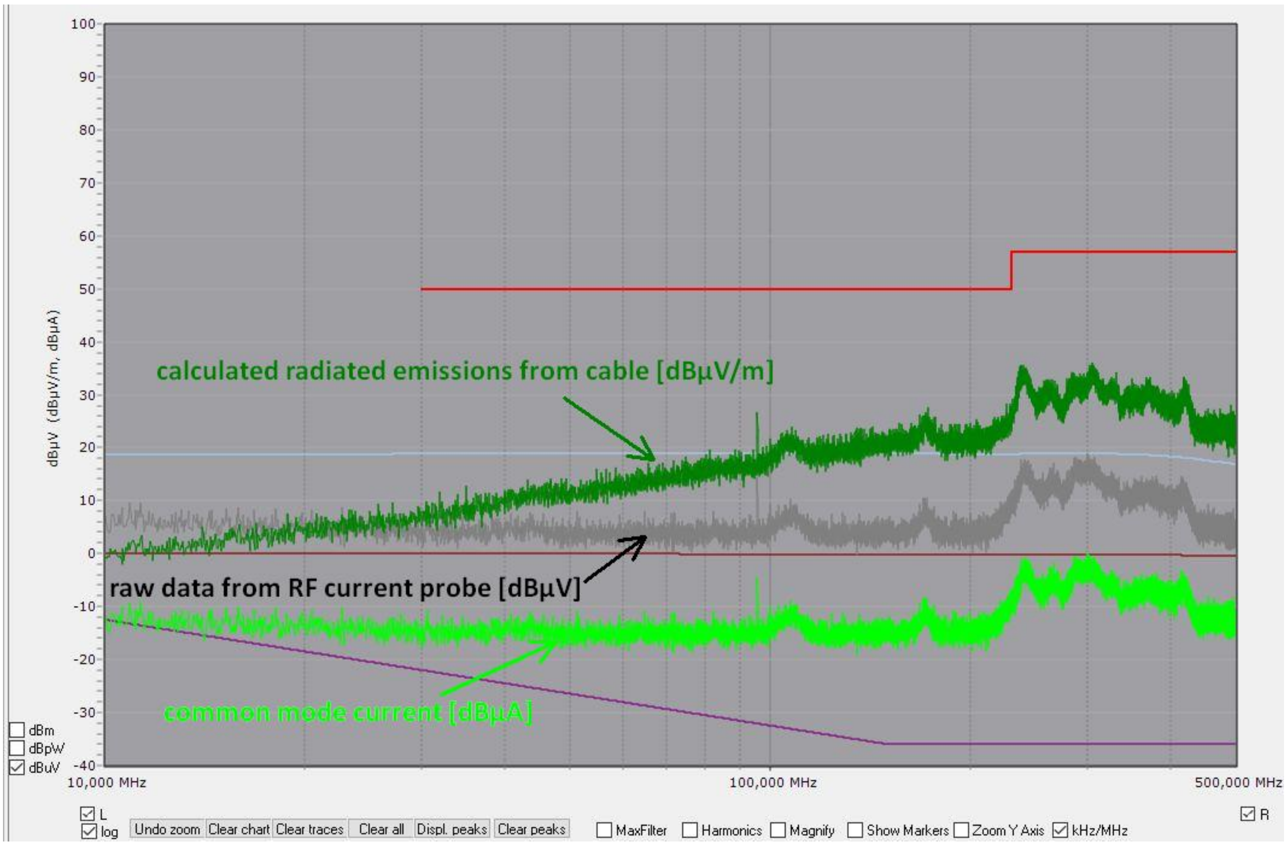
<u>Common mode current to radiated emission conversion file:</u>

1 meter cable length / 3m measuring distance: *L1m_R3m_current_to_radiated_conversion.amp*

<u>Excel file for the calculation of the conversion coefficients:</u>

CM_current_to_radiated_emission_conversion.xlsx

The screenshot on the following page shows the graphs of the example measurement:



5 Simplified solution introduced with EMCview REV 6.07

With SW REV 6.07, the calculation was directly implemented in EMCview. In order to use the feature, the current probe trans-impedance file needs to be modified. Paste following text into the trans-impedance file of the current probe, as shown in red color below:

[Application]
Software=TekBox RP-W32-D7
Version=Demo
Date=18.01.2017 10:05:55
[General]
Name=Tekbox_Current_Probe TBCP1_500_I2E.lsc
Freq_Interplot_Mode=lin
Level_Interplot_Mode=lin
[Option I2E]
Length=1
Distance=3
[Data]
Freq1=30.000
Lev1=-2.34
Freq2=40.000
Lev2=0.07
Freq3=50.000
Lev3=1.93
……..

Where *Length* is the cable length in [m] and *Distance* is the measurement distance in [m]. EMCview will then display the calculated radiated emissions of the cable instead of the RF current. You can permanently leave the text block in the trans-impedance file. In order to de-activate the calculation and show RF current as usual, set the *Length* and *Distance* parameters to 0.

6 History

Version	Date	Author	Changes
V 1.0	23.06.2020	Mayerhofer	Creation of the document
V 1.1	10.07.2020	Mayerhofer	Chapter 5 added