COAXIAL RF CURRENT MONITORING PROBES

1 Construction of loop antennas for EMC testing applications

Tekbox coaxial RF current monitoring probes are ideal transducers for active and passive magnetic loop antennas. Combining the transducer with a corrugated coaxial cable forms a magnetic loop antenna. Below examples of a 60 cm and 30 cm passive loop antenna:

The shield of the coaxial cable provides shielding from electric fields. As the shield would create a shorted winding in parallel to the center conductor, the shield has to be slotted and stiffened with a sleeve:

When used for active loop antennas, the TBCCP1_3K100 can easily be attached on top of the pre amplifier by means of a N-Male to N-Male coaxial adapter.

2 Antenna factor

Radiated emission measurements in the frequency range of 9 kHz to 30 MHz are primarily carried out using shielded loop antennas. A coaxial cable connected to a coaxial RF current monitoring probe forms a shorted loop. The short circuit current induced in such a loop is a frequency independent measure of the magnetic field strength.
The connected spectrum analyzer or measurement receiver will typically display measured power in dBm or voltage in dBµV.

The antenna factor AF is a antenna and frequency dependent parameter, which is required to convert the measured voltage into the corresponding electric or magnetic field strength.
For magnetic field strength:

$$H[dB\mu A/m] = V[dB\mu V] + AF_H[dBS/m] \quad (1)$$

Where AF_H is the magnetic antenna factor in dB(Siemens/m) or dB($\Omega^{-1}m^{-1}$)
In the far field, the free space impedance Z_0 = 377 Ω links electric field strength with magnetic field strength.

$$AF_E[dB/m] = AF_H[dBS/m] + Z_0[dB\Omega]$$
$$AF_E[dB/m] = AF_H[dBS/m] + 51.5\ dB\Omega \quad (2)$$

Solving the Biot-Savat law for a shorted current loop in vacuum results in:

$$B = \mu_0 * I/2r \quad (3)$$

Where:

2r [m] loop antenna diameter
I [A] loop current.

Substituting B with the magnetic field strength H:

$$H = B/\mu_0$$
$$H = I/2r\ [A/m] \quad (4)$$

Applying logarithmic laws on *(4)* :

$$H[dB\mu A/m] = I[dB\mu A] - 20\log(2r[m]) \quad (5)$$

Involving current probe transimpedance Z_T:

$$Z_T = Vprobe[V] / Iprobe[A] \quad (6)$$

Applying logarithmic laws on *(6)*:

$$Iprobe[dB\mu A] = Vprobe[dB\mu V] - Z_T[dB\Omega] \quad (7)$$

Substituting I in *(5)*:

$$H[dB\mu A/m] = Vprobe[dB\mu V] - Z_T[dB\Omega] - 20\log(2r[m]) \quad (8)$$

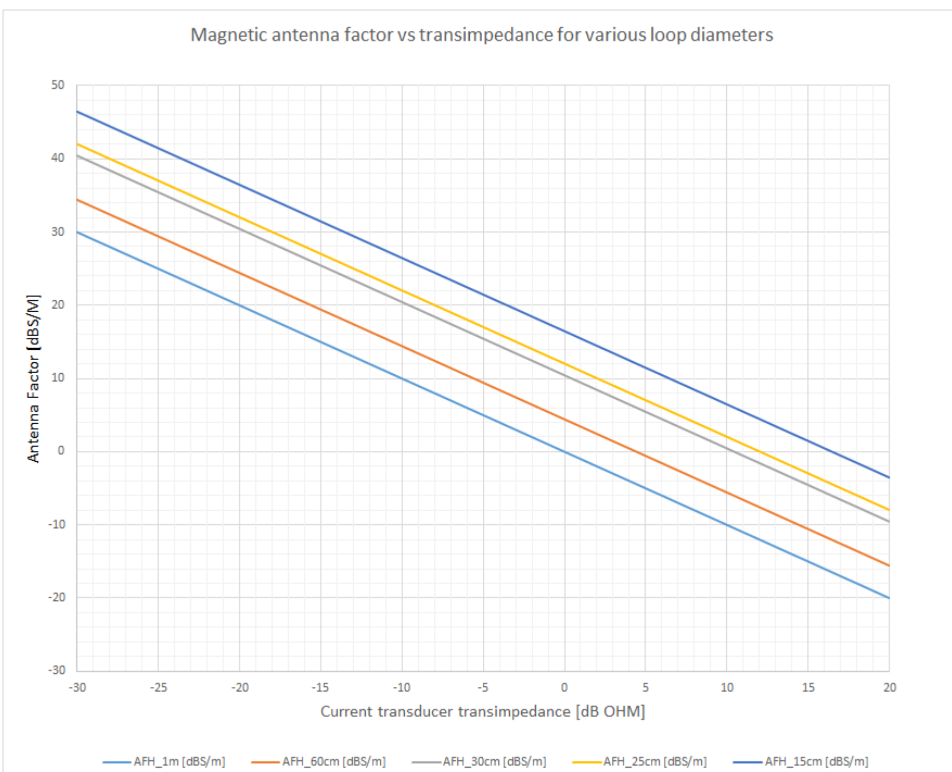
Substituting H in *(1)*:

$$\mathbf{AF_H[dBS/m] = - Z_T[dB\Omega] - 20\log(2r[m])} \quad (9)$$

Where:
$Z_T[dB\Omega]$ transimpedance of the loop antenna current transducer
2r [m] loop antenna diameter
Note that the calculation of (9) is an approximation, ignoring parasitic effects such as wire resistance, skin effect and parasitic capacitance of the loop.

3 Magnetic antenna factor versus current transducer transimpedance

Loop diameter	20log(2r[m]
1 m	0 dB
60 cm	-4.43 dB
30 cm	-10.45 dB
25 cm	-12.04 dB



4 Sensitivity considerations

The conversion formula

$$H[dB\mu A/m] = V[dB\mu V] + AF_H[dBS/m]$$

shows that the lower the magnetic antenna factor, the higher the sensitivity of the measurement set up. The sensitivity of a radiated emission measurement set up is determined by the base noise level of the spectrum analyzer or measurement receiver and the transimpedance of the current transducer.

Noise Floor

The noise floor of the magnetic field strength is determined by the noise floor of the spectrum analyzers at 200 Hz and 9 kHz resolution bandwidth and on the magnitude of the magnetic antenna factor.
In order to figure out the requirements for a loop antenna, the toughest CISPR xx radiated emission specification for the frequency range 9kHz – 30 MHz needs to be looked at:
Taking a Siglent SSA3021X-PLUS analyzer as an example:

Peak detector, 200 Hz RBW, Att=0dB, Preamp=ON:

Frequency	**Noise floor**
9 kHz	17 dBµV
150 kHz	-14 dBµV

Peak detector, 9 kHz RBW, Att=0dB, Preamp=ON:

Frequency	**Noise floor**
150 kHz	4 dBµV
1MHz	-10 dBµV
30MHz	-10 dBµV

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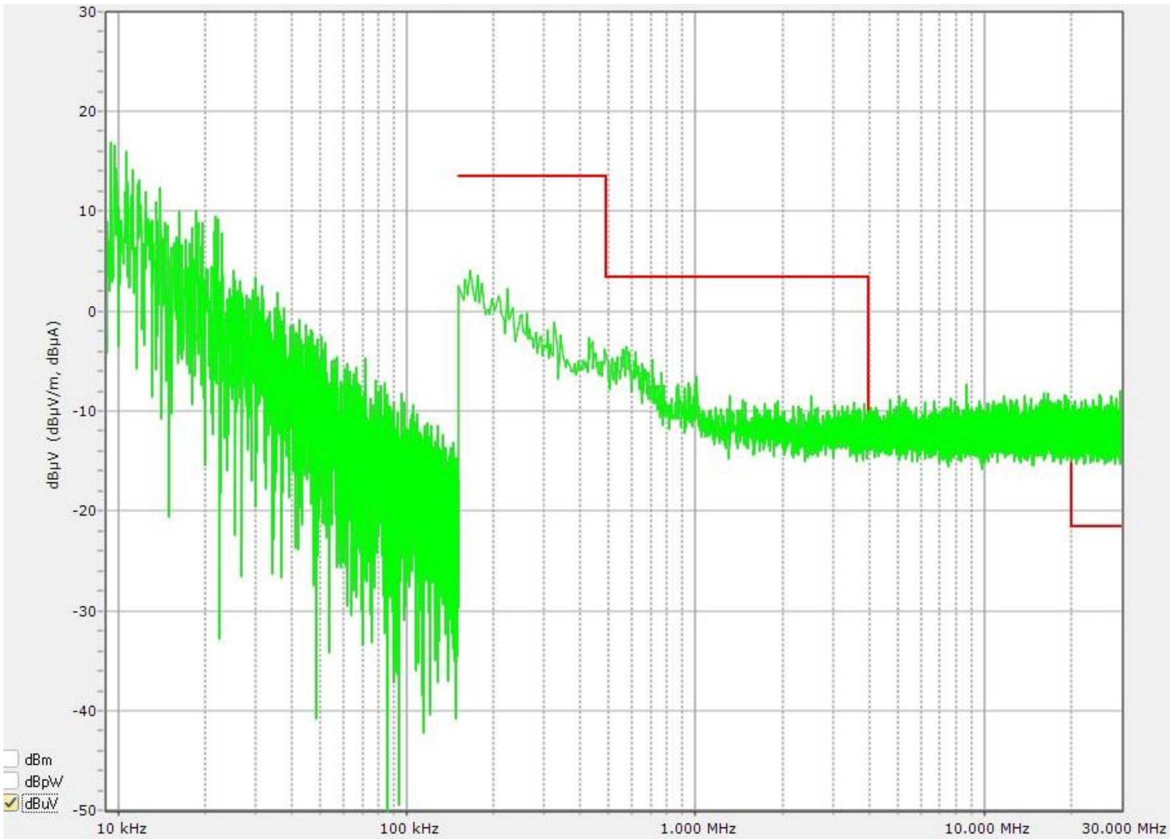


Noise floor of SSA3021X-PLUS with limits of CISPR11 Class A Group 1 in situ; SA input terminated with 50 Ohm

Limits for CISPR11 Class A / Group 1 measured in situ:

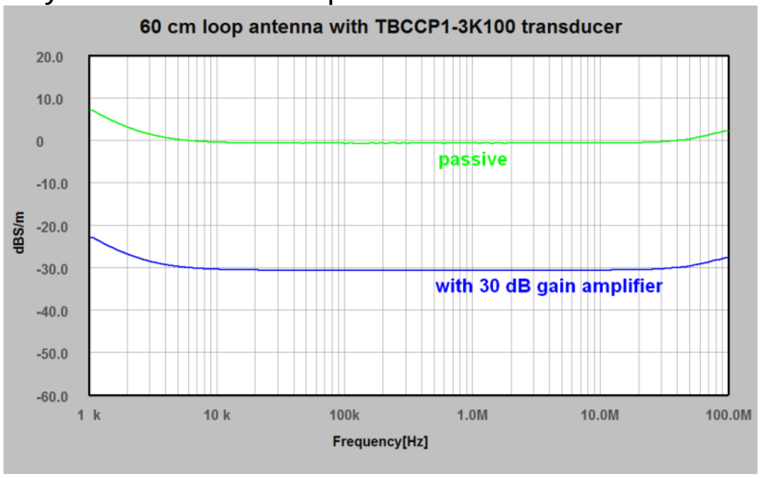
Frequency range [MHz]	RBW [kHz]	Detector	30 m distance	
			Electric field [dBµV/m]	Magnetic field [dBµA/m]
0.15 – 0.49	9	Quasi Peak	-	13.5
0.49 – 3.95			-	3.5
3.95 – 20			-	-11.5
20 – 30			-	-21.5
30 - 230	120		30	-
230 - 1000			37	-

The minimum requirement for a measurement set up according CISPR-16 is a margin of 6 dB between noise floor and limit lines.

For the example above, the necessary magnetic antenna factor is approximately (-21.5 – 6dB) +10 dBµV = -17 dBS/m or better.

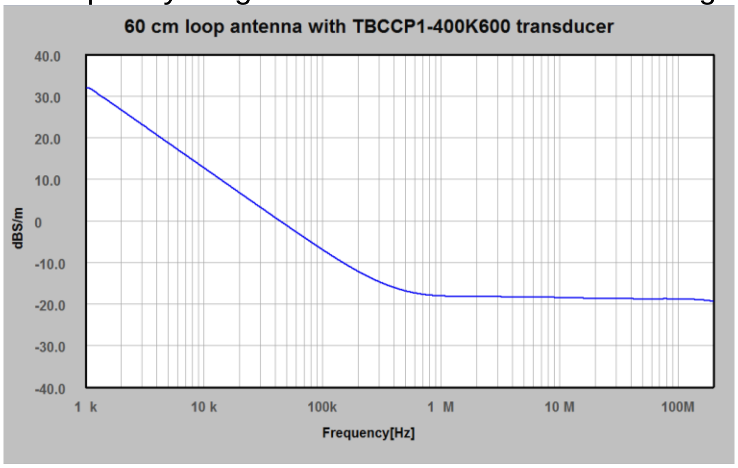
5 Active versus passive magnetic loop antennas

Achieving a flat antenna factor in the frequency range 9 kHz to 30 MHz comes at the cost of a lower transimpedance of the involved RF current transducer. The resulting antenna factor is higher and the sensitivity of the measurement set up is lower. Consequently, such transducers are typically combined with amplifiers in order to decrease the antenna factor.



Example: loop antenna based on TBCCP1-3K100 transducer with and without amplifier

Passive Loop antennas typically don´t have a flat antenna factor over the entire frequency range. These antennas are based on current transducers with a higher transimpedance at the cost of less sensitivity at lower frequencies. The disadvantage of lower sensitivity at lower frequencies is compensated by less stringent limit values in the corresponding frequency range. These RF transducers typically have their transimpedance increasing with 20 dB/decade in the lower frequency range and flatten out in the MHz range.



Example: passive loop antenna based on TBCCP1-400K600 transducer

6 History

Version	Date	Author	Changes
V 1.0	6.5.2022	Mayerhofer	Creation of the preliminary document

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