

OPEN TEM CELLS FOR EMC PRE-COMPLIANCE TESTING

1 Introduction

Radiated emission tests are typically carried out in anechoic chambers, using antennas to pick up the radiated signals. Due to bandwidth limitations, several antennas are required to cover the complete frequency range. Furthermore, it requires much space and the cost of the equipment for a standard conformant setup is immense.

An engineer of a small or medium size enterprise usually has to rely on his experience and on best practice methods in order to design an EMC compliant product. Nevertheless, it is estimated that > 50% of products fail testing first time around. Anytime an engineer sends a new product for compliance testing, it is a shot in the dark. Failing is very expensive. Not only that re-testing costs are high, but also the project schedule and market introduction gets delayed.

What is needed is an affordable laboratory set up to measure radiated emissions in the own lab, prior to compliance testing. A TEM cell is the right piece of equipment for desktop testing of radiated emissions. Tekbox developed open TEM cells to cover the complete frequency range up to 2GHz and with usability even at frequencies beyond.

Combined with a spectrum analyzer, products can be tested before and after EMC related design modifications. A set up with a TEM cell will not deliver exactly the same quantitative results as a measurement in a certified test house, however it will give an excellent indication on whether the design suffers from excessive radiated noise or not. The engineer will clearly see, whether his changes improved or deteriorated the EMC performance or whether it remained unchanged. Using TEM cells eliminates the guesswork.

2 TEM cell

A TEM cell is a stripline device for radiated emissions and immunity testing of electronic devices. It is not a replacement, but due to its size and cost it is a convenient alternative to measurements in an anechoic chamber.

A TEM cell consists of a septum, the conductive strip in the centre section and walls which are connected to ground. The geometry is designed to present a 50Ω stripline. The device under test (DUT) is placed in between the bottom wall and the septum.

The TBTC1/2/3 are so called “open TEM cells”, which got no side walls for convenient placement of the DUT. It may pick up RF background noise, which however can be taken into account by doing a measurement of the cell output signal before powering on the DUT.

Tekbox open TEM cells got a better frequency response compared to standard TEM cells of similar size. TEM cells suffer from higher order wave modes which limit the usable bandwidth. A unique design feature of the Tekbox TEM cells implements resistance perpendicular to the desired propagation direction of the wave. Consequently higher order wave modes and resonances are suppressed.

The device is supplied together with a 50Ω/25W RF termination and a DC block to protect the spectrum analyzer or RF receiver input.

Application of TEM cells

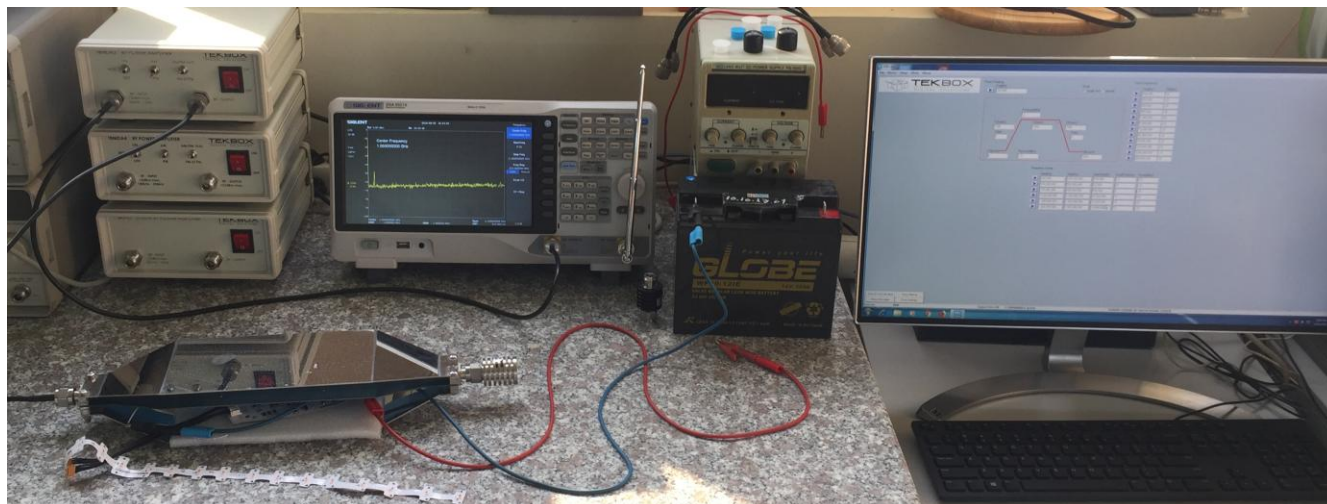
Radiated emission tests:

The septum of the TEM cell picks up radiated noise from the DUT, similar to a broadband antenna, and presents it to the spectrum analyzer or to a receiver input.

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Radiated immunity tests:

The TEM cell will be connected to the output of a swept signal or tracking generator + RF amplifier. The septum radiates the RF signal into the DUT. The RF signal is typically amplitude or pulse modulated.



Picture 1 – radiated immunity test of a LED lamp using the TBTC0 TEM cell, a TBMDA3 modulated amplifier and a Siglent SSA3021X spectrum analyzer controlled by the EMCview software

Complete solutions

Following additional equipment may be used for a complete and low cost setup:

Radiated emission testing: Spectrum analyzers such as the models from RIGOL, SIGLENT, UNI-T, R&S FPC/FPH series. Shielded tents or bags to suppress ambient noise.

RF immunity testing: RF power amplifiers

Tekbox offers a range of modulated driver / power amplifiers which are ideal for a low cost immunity testing set up. These amplifiers have built in modulators to generate the required modulation formats and consequently can be driven by the tracking generator output of spectrum analyzer. Hence, there is no necessity to invest into an RF signal generator. The Tekbox EMCview software controls the tracking generator.

Depending on the chosen modulated driver / power amplifier and on the involved TEM cell, field strengths of up to several hundred Volt can be generated by such a set up.

Refer to the datasheets of the modulated amplifiers for additional information.

Consider that the electric field is oriented orthogonally to the septum. To create a worst case scenario for the DUT, orient it inside the TEM cell, in order to have the PCB traces oriented orthogonally to the Septum in order to expose it to the maximum field gradient.

3 EMC pre-compliance testing with the TBTC0/1/2/3- radiated emissions

Combined with a spectrum analyzer, products can be tested before and after EMC related design modifications. The engineer will clearly see, whether his changes improved or deteriorated the EMC performance or whether it remained unchanged. Tem cells eliminate the guesswork.

OPEN TEM CELLS FOR EMC PRE-COMPLIANCE TESTING

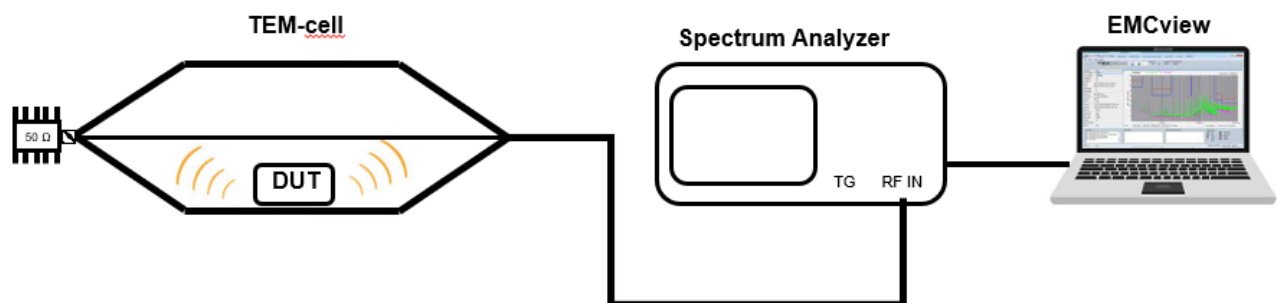
Terminate any of the two ports of the TEM cell with the 50Ω load, connect the DC-Block to the other port and connect it to the input of the spectrum analyzer or test receiver. Place the DUT under the septum and power it on. Reduce the input attenuation of the analyzer to 0dB and if available turn on the pre-amplifier to increase the dynamic range of the measurement. Reduce the resolution bandwidth to 9 kHz or whatever specified in the corresponding standard. Set the trace to max hold and let the analyzer run as many sweeps as may be necessary to catch pulsed or sporadic signals from your DUT.

EMC measurements are typically started by performing scans using a peak detector to find problem areas. Spurious suspected to exceed the limits should then be measured using a quasi-peak detector, if available on your receiver or spectrum analyzer. A quasi peak detector measures the weighted peak value of the envelope of a signal. Signals are weighted according to their duration and repetition rate. Signals that occur less frequently will result in a lower quasi peak value than frequent signals. Due to the nature of this measurement method, quasi peak measurements consume much more time than simple peak measurements and are often carried out with reduced span in frequency regions with high amplitude spurious.

The TEM cell can be very effectively used to identify potential issues that may result in failing the compliance test. As a rule of thumb, given that the PCB is positioned not much higher than 1-2cm above the bottom wall, any spurious with amplitudes higher than 40dμV may be critical. Note that this is just a ballpark figure. It is a common misconception that the RF voltage at the TEM cell output can be converted into field strength corresponding with an antenna measurement in an anechoic chamber. Refer to the TEM cell Q&A document for detailed information.

A quick check to ensure that spurious are not picked up from outside is done by powering off the DUT. Despite its construction, the TEM cell is not very sensitive to signals from outside. However cables connected to the DUT may pick up background noise and guide it into the TEM cell. This signals are usually also present with the DUT powered off and consequently can be easily identified. Take a screenshot of the radiated spectrum, modify your design, and check if it improved. Any reduction of spurious level measured in the TEM cell, will also translate into a reduction of the spurious level measured in the test house. A more convenient method to suppress ambient noise is using shielded tents or bags.

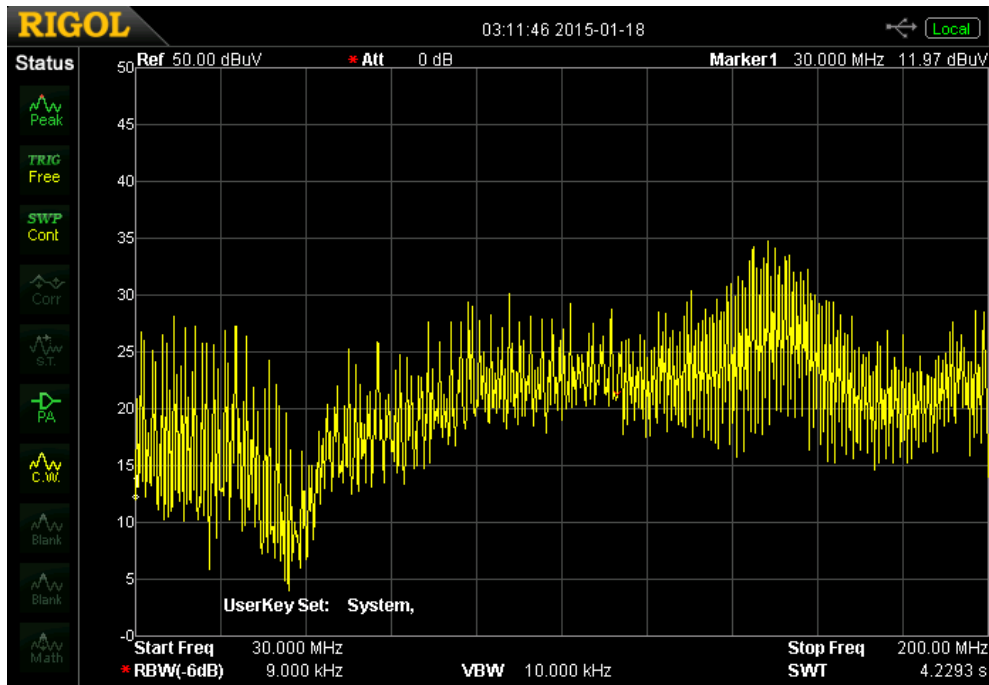
When failing a compliance test, measure it in the TEM cell and save the results before carrying out any modifications. Compare the spurious levels documented in the compliance test report versus the spurious levels measured in the TEM cell. Check how many dB's are missing to pass the test. Modify/improve the device until the spurious level measured inside the TEM cell dropped accordingly.



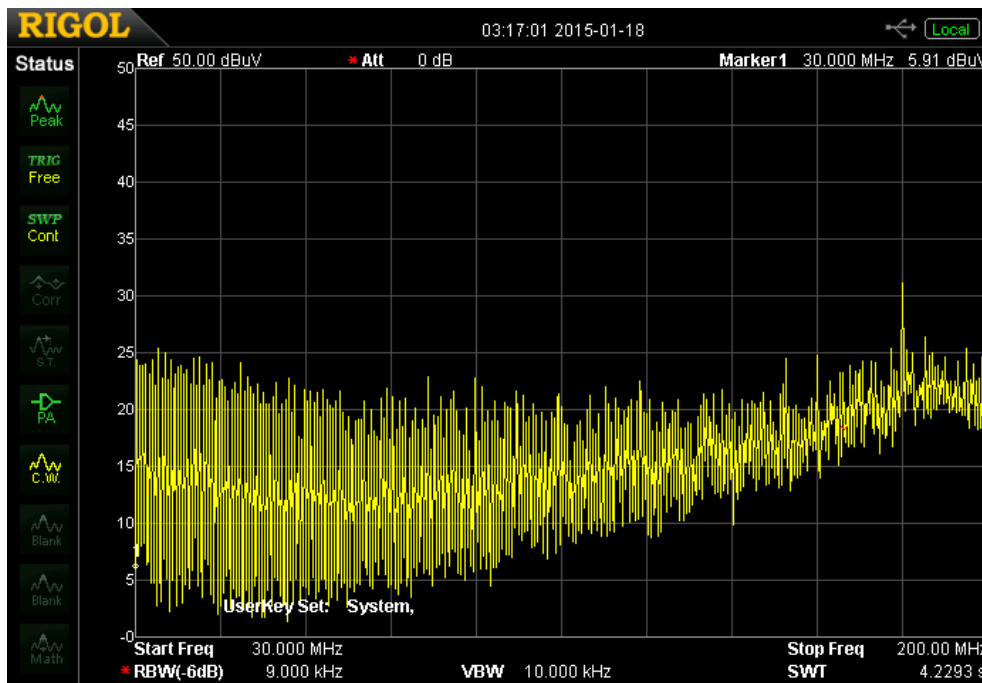
Picture 2 – radiated emission measurement set up

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Example of radiated emission measurements before and after modification



Picture 3 – TBTC1, radiated emissions of a LED lamp prototype



Picture 4 – TBTC1, radiated emissions of a LED lamp prototype after modification. The spurious level in the measured frequency range could be reduced by 10dBuV. The spurious crossing 30dBuV was identified as picked up from outside.

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4 EMC pre-compliance testing with the TBTC1/2/3 - immunity to radiated signals

The E-field (V/m) between septum and lower (upper) wall of the TBTC1 is

$E = V/d$ where V is the RMS voltage of the applied signal and d is the distance between septum and lower (upper) wall. This is based on the simplified assumption that the E field would be perfectly homogenous/evenly distributed.

A more practical formula is $E = V \cdot \text{Cor}/d$ where Cor is a correction factor for the average field strength over the volume of the DUT derived from the analysis of the field distribution over the cross section of the cell.

Assuming the DUT is placed in the center of the cell and in the middle between bottom wall and septum, we can however use the simplified formula with sufficient accuracy.

$$d = 2.8 \text{ cm} \quad E = (\sqrt{P \cdot 50\Omega}) \cdot 35.7$$

$$d = 5 \text{ cm} \quad E = (\sqrt{P \cdot 50\Omega}) \cdot 20$$

$$d = 10 \text{ cm} \quad E = (\sqrt{P \cdot 50\Omega}) \cdot 10$$

$$d = 15 \text{ cm} \quad E = (\sqrt{P \cdot 50\Omega}) \cdot 6.66$$

TBTC0, applied RF power	Maximum field strength between septum and wall
10W (40 dBm)	799 V/m
1 W (30 dBm)	253 V/m
0.1 W (20 dBm)	82 V/m
0.01 W (10dBm)	25 V/m

Table 1 – TBTC0, field strength vs. RF power

TBTC1, applied RF power	Maximum field strength between septum and wall
10W (40 dBm)	447 V/m
1 W (30 dBm)	141 V/m
0.1 W (20 dBm)	44 V/m
0.01 W (10dBm)	14 V/m

Table 2 – TBTC1, field strength vs. RF power

TBTC2, applied RF power	Maximum field strength between septum and wall
10W (40 dBm)	224 V/m
1 W (30 dBm)	71 V/m
0.1 W (20 dBm)	22 V/m
0.01 W (10dBm)	7 V/m

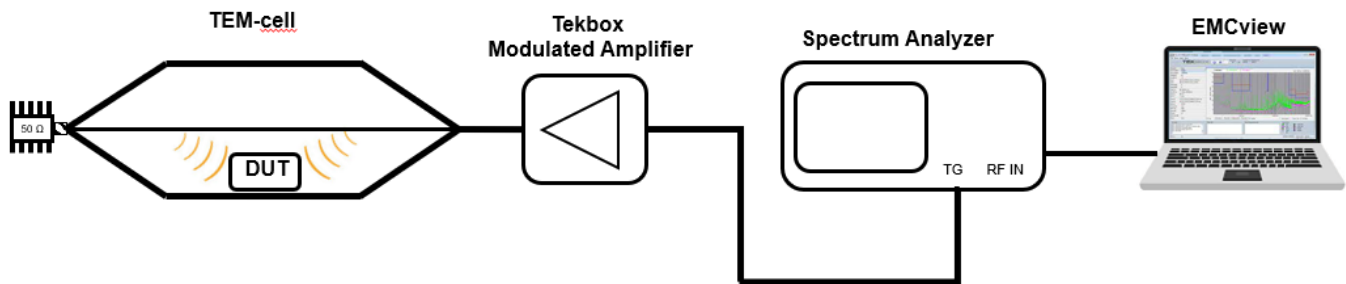
Table 3 – TBTC2, field strength vs. RF power

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TBTC3, applied RF power	Maximum field strength between septum and wall
10W (40 dBm)	148 V/m
1 W (30 dBm)	47 V/m
0.1 W (20 dBm)	14 V/m
0.01 W (10dBm)	5 V/m

Table 4 – TBTC3, field strength vs. RF power

Terminate any of the two ports of the TEM cell with the 50Ω RF-termination, and connect the other port to a swept frequency generator / RF power amplifier. Place the DUT under the septum and power it on. Sweep the frequency and observe the behavior of the DUT. The field decreases with approximately 30dB/m outside the cell, hence it is uncritical to operate it in ordinary facilities.



Picture 5 – RF immunity measurement set up

Picture 5 shows a “minimum set-up” for immunity testing. Test houses would furthermore insert a directional coupler in between the power amplifier and the TEM Cell and monitor forward and reflected power. EMC standards differ largely with respect to the applied field strength. Standards for industrial electronics such as EN61000-6-4 specify 10V/m (prior to the application of modulation) whereas individual standards of automotive manufacturers may specify a field strength as high as 400V/m. The required field strength determines the requirements for the RF power amplifier as listed in tables 1 to 3. Certain standards specify the RF signal to be amplitude modulated, others specify pulse modulation.

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5 Technical data

TEM Cell TBTC0

TEM cell dimensions:

Length: 390 mm Width: 100 mm Height: 62 mm Septum height: 28 mm

Rectangular area under the septum: 19 cm x 7 cm x 2.8 cm

TEM cell connectors: N-female

Nominal cell impedance: 50 Ohm

Wave impedance: 377 Ohm

Maximum RF input power: 10W (limited by supplied 50 Termination)

Input return loss: S11 up to 3.15 GHz < -15dB

Transmission loss: up to 3 GHz < 3 dB, up to 6 GHz < 4dB

TEM Cell TBTC1

TEM cell dimensions:

Length: 390 mm Width: 200 mm Height: 108 mm Septum height: 50 mm

Rectangular area under the septum: 19 cm x 13 cm x 5 cm

TEM cell connectors: N-female

Nominal cell impedance: 50 Ohm

Wave impedance: 377 Ohm

Maximum RF input power: 25W (limited by supplied 50 Termination)

Input return loss: S11 up to 1.2 GHz < -20dB, up to 2.1 GHz < -17dB, up to 3GHz < -14dB

Transmission loss: up to 1.4 GHz < 1 dB, up to 2.1 GHz < 3dB, up to 3 GHz < 6dB

TEM Cell TBTC2

TEM cell dimensions:

Length: 636 mm Width: 300 mm Height: 205mm Septum height: 100 mm

Rectangular area under the septum: 23 cm x 28 cm x 10 cm

TEM cell connectors: N-female

Nominal cell impedance: 50 Ohm

Wave impedance: 377 Ohm

Maximum RF input power: 25W (limited by supplied 50 Termination)

Input return loss: S11 up to 800 MHz < -15dB, up to 1.5 GHz < -10dB, up to 3GHz < -8dB

Transmission loss: up to 800 MHz < 1 dB, up to 1.15 GHz < 3dB

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TEM Cell TBTC3

TEM cell dimensions:

Length: 1038 mm Width: 501 mm Height: 305mm Septum height: 150 mm

Rectangular area under the septum: 36 cm x 48 cm x 15 cm

TEM cell connectors: N-female

Nominal cell impedance: 50 Ohm

Wave impedance: 377 Ohm

Maximum RF input power: 25W (limited by supplied 50 Termination)

Input return loss: up to 700 MHz < -16 dB

Transmission loss: up to 730 MHz < 3dB

DC-Block 50V-6GHz-N

Connectors: N-Male/Female

Nominal impedance: 50 Ohm

Max. continuous RF power: 2W

Max. continuous RF voltage: 50V RMS

Frequency: 500kHz to 6 GHz **VSWR:** ≤ 1.2

Insertion loss:

Frequency [MHz]	0.3	0.7	1	10	100	1000	3000
Insertion loss [dB]	7.5	3	1.5	0.02	0.02	0.06	0.2

Table 1 – DC-Block frequency response

RF-Termination 50Ω-3GHz-25W-N

Connector: N-Male

Nominal impedance: 50 Ohm

Max. continuous RF power: 25W

Frequency: DC to 3 GHz **VSWR:** ≤ 1.2

Third order intermodulation: ≤ 120 dBc

RF-Termination 50Ω-6GHz-10W-N

Connector: N-Male

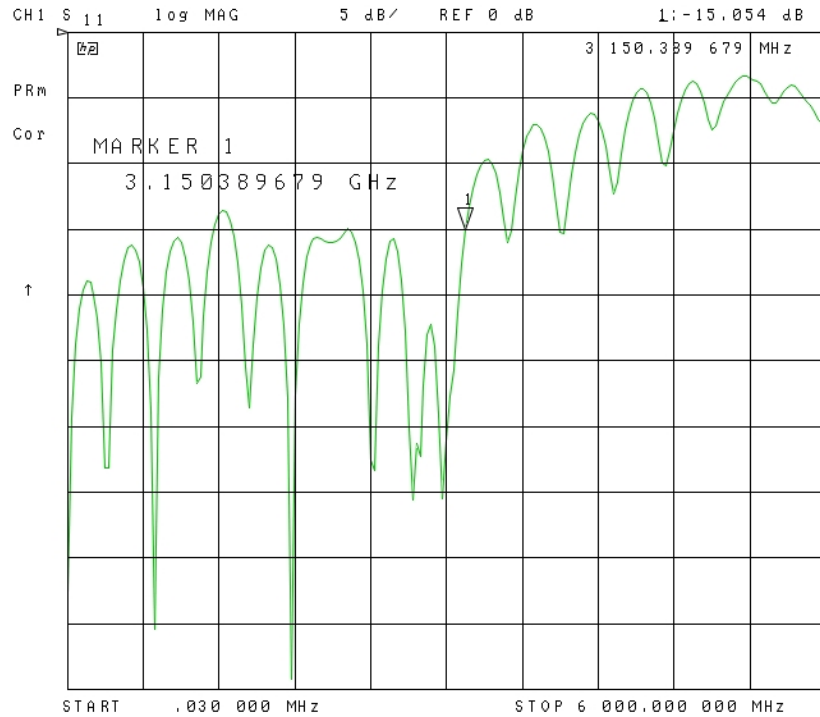
Nominal impedance: 50 Ohm

Max. continuous RF power: 25W

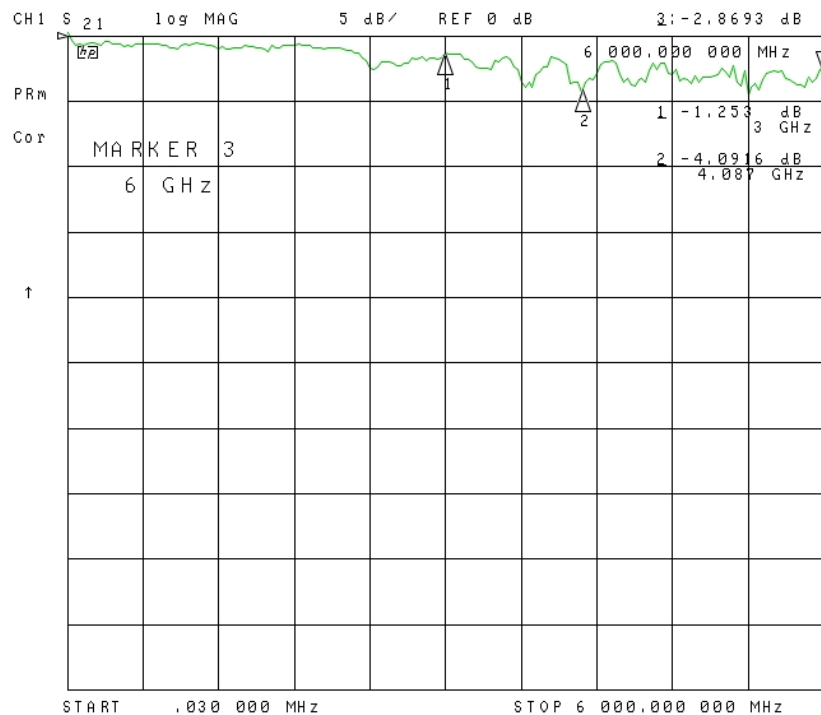
Frequency: DC to 6 GHz **VSWR:** ≤ 1.2

Third order intermodulation: ≤ 120 dBc

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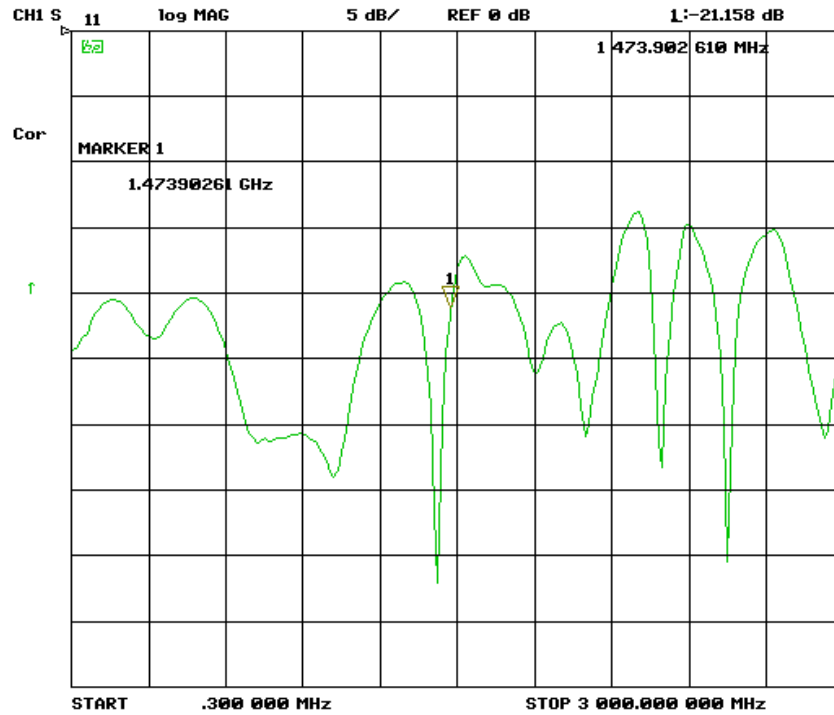


Picture 6 – TBTC0, input return loss

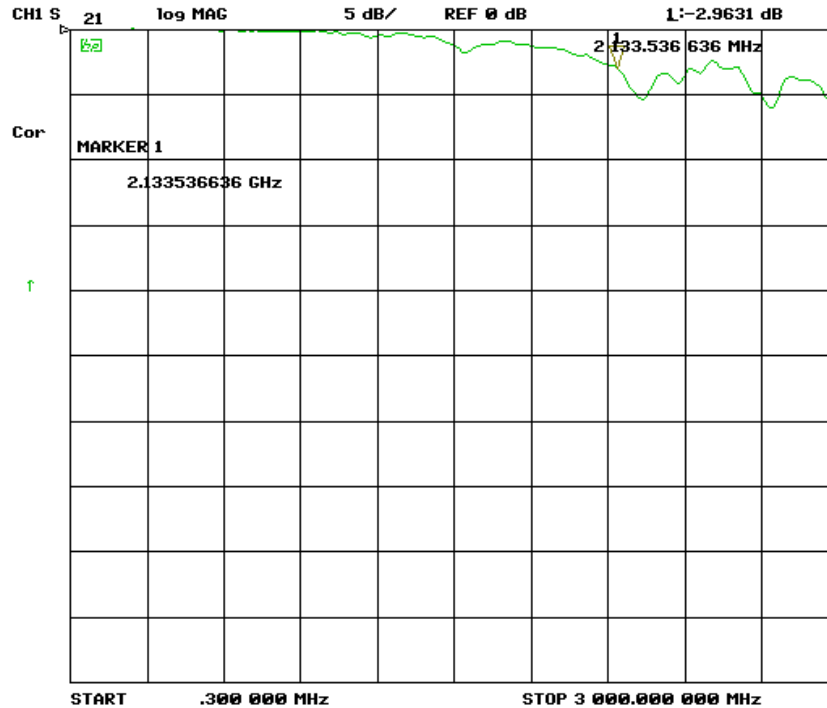


Picture 7 – TBTC0, transmission loss

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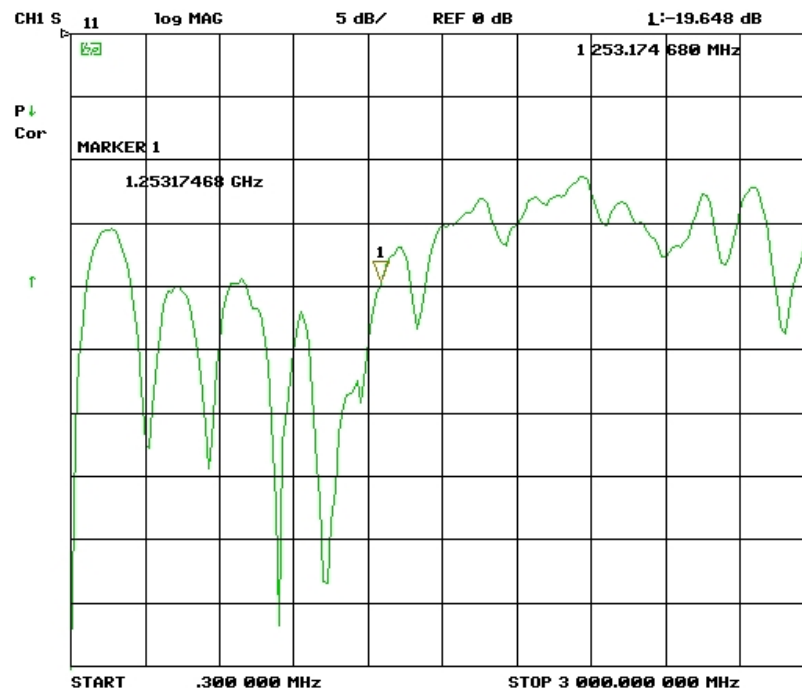


Picture 8 – TBTC1, input return loss

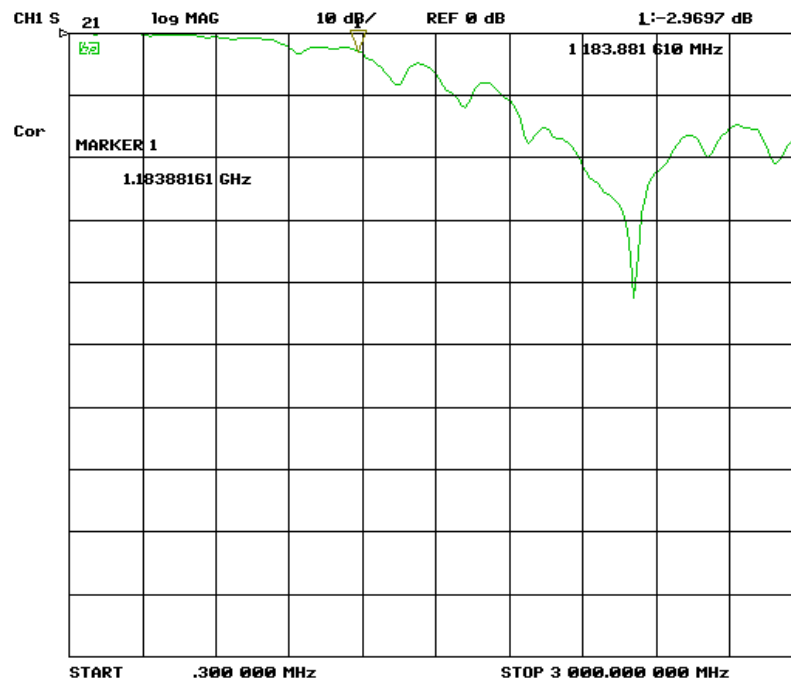


Picture 9 – TBTC1, transmission loss

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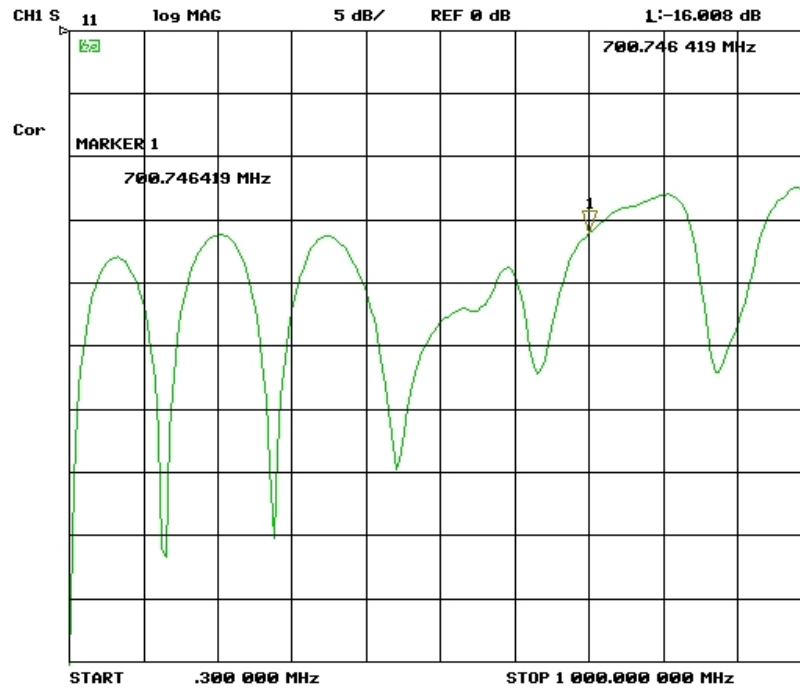


Picture 10 – TBTC2, input return loss

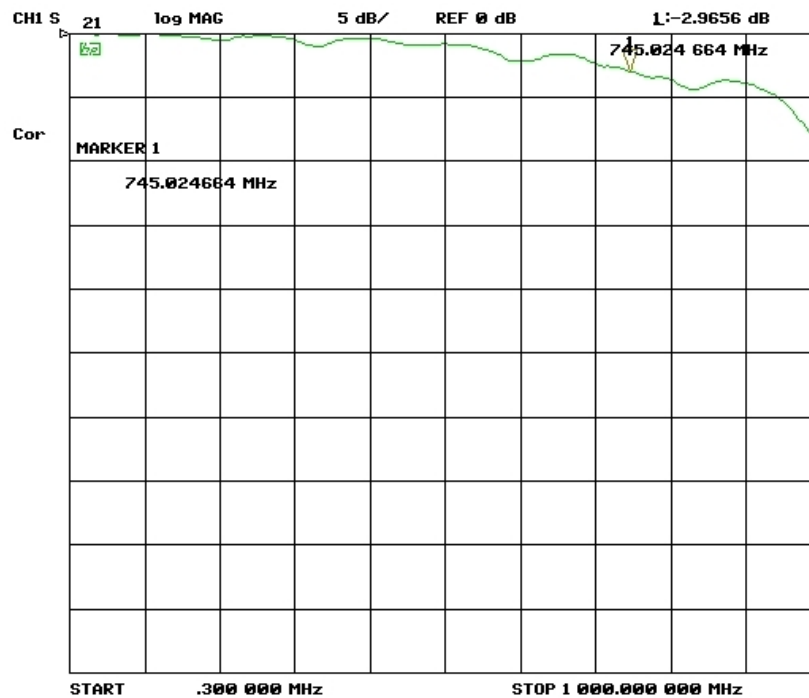


Picture 11 – TBTC2, transmission loss

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Picture 12 – TBTC3, input return loss



Picture 13 – TBTC3, transmission loss

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6 Warning

Keep the DUT insulated from the septum and cell walls. Insert the DC-block to get additional input protection for DC coupled spectrum analyzers or measurement receivers.

7 Ordering Information

Part Number	Description
TBTC0	Open TEM cell, 28mm septum height, Termination 50Ω-6GHz-10W-N, DC-Block 50V-6GHz-N, N-Male to N-Male coaxial cable
TBTC1	Open TEM cell, 50mm septum height, Termination 50Ω-3GHz-25W-N, DC-Block 50V-6GHz-N, N-Male to N-Male coaxial cable
TBTC2	Open TEM cell, 100mm septum height, Termination 50Ω-3GHz-25W-N, DC-Block 50V-6GHz-N, N-Male to N-Male coaxial cable
TBTC3	Open TEM cell, 150mm septum height, Termination 50Ω-3GHz-25W-N, DC-Block 50V-6GHz-N, N-Male to N-Male coaxial cable

Table 2 – Ordering Information

8 History

Version	Date	Author	Changes
V1.0	14.04.2016	Mayerhofer	Creation of the document
V1.1	30.06.2016	Mayerhofer	Update TBTC3
V1.2	12.02.2016	Mayerhofer	Update TBTC0
V1.3	2.06.2018	Mayerhofer	Information concerning amplifiers for immunity testing
V1.4	17.06.2019	Mayerhofer	Chapter 2 and chapter 5 updated
V1.5	9.06.2025	Mayerhofer	Chapter 2 and chapter 3 updated

Table 3 – History