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Technical Note - TN11

MIL-STD 461 / RS105 Material requirement

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Table of contents

1. Introduction

This technical note will comment the specifications and the material required by the standard MIL-STD 461E paragraph RS105. The text of the standard mentions the following devices:

- Transverse electromagnetic (TEM) cell, parallel plate transmission line or equivalent
- Transient pulse generator, monopulse output, plus and minus polarity
- Terminal protection devices
- LISNs
- Storage oscilloscope, 500 MHz, single-shot bandwidth (minimum), variable sampling rate up to 1 gigasample per second (Gsa/s)
- High-voltage probe, 1 GHz bandwidth (minimum)
- D-dot sensor probe
- B-dot sensor probe
- Integrator, time constant ten times the overall pulse width.

The other requirements concerning the test set-up will be reviewed.

2. Transmission line

The transmission line radiates the field on the equipment under test (EUT). The line must be optimised for good waveform fidelity and therefore must have low reflection at the end of the structure formed by a resistive load which impedance is adapted to the generator.

The structure shown in the figure 1 exhibits a vertical electric field. The type of antenna is not clearly explained in the text, except in the appendix (page A-97). The polarisation of the field is intuitively vertical.

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The appendix mentions a bounded wave TEM radiator which leaves a broader choice of radiating structures than the description made in the main part of the text.

After an analysis of the TEM cell mentioned in the standard, we recommend a triangular radiation line which has some advantages. This preferred structure fulfils the appendix of the requirement. See also the technical note TN07-11 (fast rise time pulses: generation and measurement).

The design of the overall shape of the line is a compromise between the low reflection and the compactness.

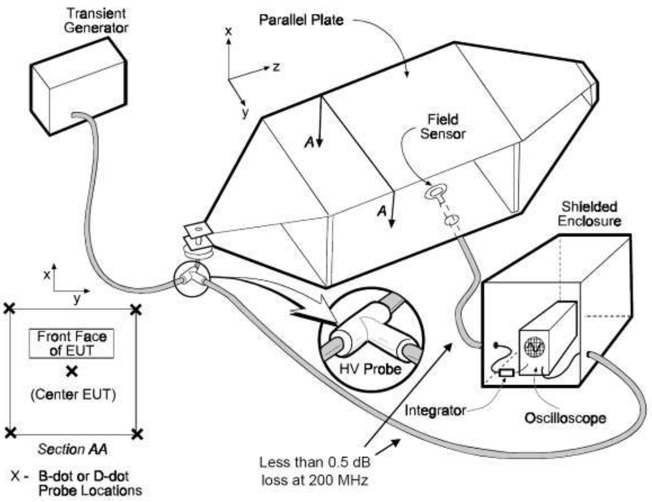
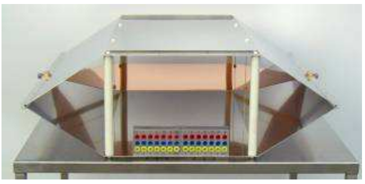
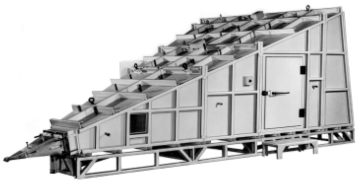


Fig. 1: figure RS105-2 of the standard - typical test set-up for the calibration

For small EUTs a special GTEM cell or a small TEM cell could be used as a radiation device. GTEM cells are expensive and do not exist in a very big size but they have the advantage to not radiate outside the cell.



TEM cell



GTEM cell

Large radiation line

Fig. 2: radiating structures

3. Transient pulse generator

Fig. 3: Marx + peaking 360 kV pulse generator

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Depending on the voltage to produce, different topologies of the generator are possible: Marx, Marx + peaking or direct discharge. The high voltage pulse generator produces a waveform which has to fulfil the waveform shown in figure 2. The following specifications have to be fulfilled:

- The rise time is between 1.8 ns and 2.8 ns. The electric field must be continuously increasing during this part of the pulse.
- The full width half maximum (FWHM) pulse width must be between 18 and 28 ns.

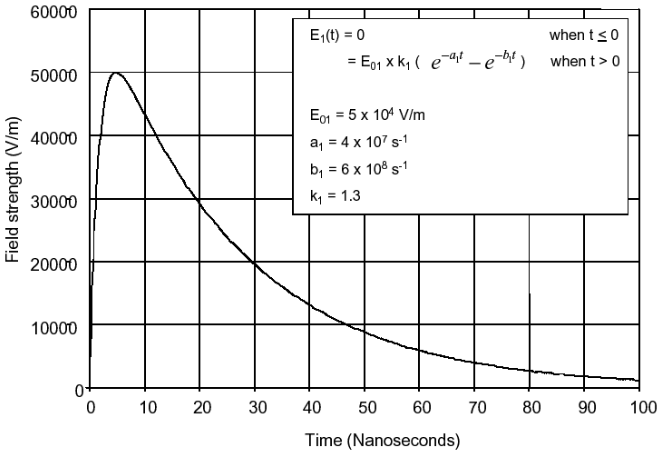

Fig. 4: figure RS105-1 of the standard - waveform of the electric field

Remarks:

1. No cable or connectors are available for middle and high voltage generation. Therefore we provide a direct connection between the generator and the line unlike the example given in the standard (figure 1).
2. Very often only a positive polarity is tested. To be fully compliant with the standard a negative pulse has also to be tested. In that case the option positive and negative pulses must be selected before ordering the generator. In our opinion, the electric field pulse penetrating in the EUT and coupled in the internal cabling will be mainly almost symmetrical because of the high pass effect of the coupling. Therefore the test of the positive and of the negative pulses will exhibit mostly the same results.
3. The Marx type generators produce small pre-pulses which are generated by the internal HV stages. These pre-pulses cannot be avoided but they have no influence because of their reduced amplitude and of their short duration.

4. LISN

The LISN (Line Impedance Stabilisation Network) are used to provide standardised impedance in common mode to the lines connected to the EUT. This allows a better reproducibility of the tests.

Fig. 5: LISN

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5. Terminal protection devices

Fig. 6: TPD

The cabling of the EUT going outside the test installation could drive disturbance at quite long distance. Therefore the installation of the terminal protection devices (TPD) is recommended. This device is intended to block the disturbance. It consists of a filter generally built with a capacitance to ground. The internal construction must be adapted to the type of signal or power to filter.

Remark:
We suggest combined devices which integrate LISNs and TPDs in the same box allowing an easier connection.

6. Storage oscilloscope

The oscilloscope is used to measure the voltage and the field produced by the test installation. The requirement of a minimum 500 MHz bandwidth is well adapted to this type of pulse. But the 1 Gsa/s is absolutely inadequate. We request a minimum of 5 Gsa/s.

Remark:
If a passive integrator is used, a high impedance input is required. The quality of the high impedance input must be carefully analysed before purchasing the oscilloscope. See also paragraph 8 of the technical note TN05-02.

7. High-voltage probe

The high voltage probe is intended to measure the pulse produced at the output of the generator. No resistive voltage probe with sufficient RF performances is available from the market. High speed capacitive dividers are used instead of them. Due to the derivative behaviour of the capacitive dividers an integrator must be used (see further on).

The requirement of a minimum bandwidth of 1 GHz given by the standard is all the more unjustified as the oscilloscope is limited to 500 MHz. Therefore a 500 MHz bandwidth is enough.

8. D-dot sensor

D-dot sensors are derivative electric field sensors. Two types are available:

- Ground plane sensor: they must be placed directly on the metallic ground plane and they measure the field intensity near the ground. Their construction and the connection are quite simple. They can be bolted on the ground plane and the connection can be a coaxial cable.
- Free field sensor: they can be placed everywhere in the space but they are more complicated, more expensive and must be floating. In addition, the connection between the sensor and the measuring equipment disturbs the field. Therefore a fibre optic link must be used instead of a simple coaxial cable.

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An example of a free field sensor is shown in the figure 7.

Fig. 7: example of a free field sensor

The voltage at the output of the electric sensor is given by the following relation:

$$V = R\ A_{eq} \frac{\partial D}{\partial t}$$

where R is the impedance of the sensor
A_{eq} the equivalent surface
D the electric displacement
and with

$D = \varepsilon_0\ E$ in free space

where E is the electric field (in V/m)

Remark:
Because the figure 1 mentions many required positions in the test volume it is assumed that a free field sensor is needed. Actually the electric field waveform is the same in the all test volume, if the radiating TEM structure is well designed. Additionally the distribution of the field can be calculated. Therefore a ground plane sensor could be sufficient for an installation for which the budget is limited.

9. B-dot sensor

B-dot sensors are derivative magnetic field sensors. There are also ground plane and free field type sensors, like the electric field sensors. They must also use an integrator.

The voltage at the output of the magnetic sensor is given by the following relation:

$$V = A_{eq} \frac{\partial B}{\partial t}$$

where A_{eq} is the equivalent surface
B the magnetic induction
and with

$B = \mu_0\ H$ in free space

where H is the magnetic field (in A/m)

Remark:
The magnetic field can be calculated from the electric field by dividing it by the impedance of the vacuum (377 ohm) because the structure propagates in a TEM mode. If the reflection at the end of the line is limited, the waveform of the magnetic field is the same than the waveform of the electric field. Additionally the standard does not require any waveform of the magnetic component. Therefore an electric field sensor could be sufficient for an installation for which the budget is limited.

10. Integrator

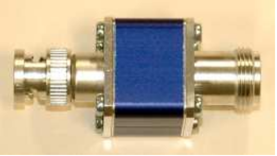

Fig. 8: passive integrator

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The integrator is used to compensate the derivative behaviour of the sensors. The following types can be selected:

Passive integration:
The passive integrators are based on a passive capacitive circuit. They have a very high frequency limit, are robust and have a high dynamic. They need a high impedance measuring system and therefore they must be connected directly to the input of the oscilloscope. In principle, we recommend a passive integration.

Numerical integration:
The disadvantage with the numerical integration is the offset influence. The offset must be corrected otherwise the measured waveform is distorted. The measurement of the rise time is possible and the influence of the offset is low if the settings of the oscilloscope are well adapted. But the measurement of the pulse duration is more difficult and is less precise because the offset is almost impossible to compensate.

The standard requires a time constant of 230 ns (ten times the overall pulse width).
The figure 9 shows an example of the error of the duration measurement induced by a too short time constant of the integrator.

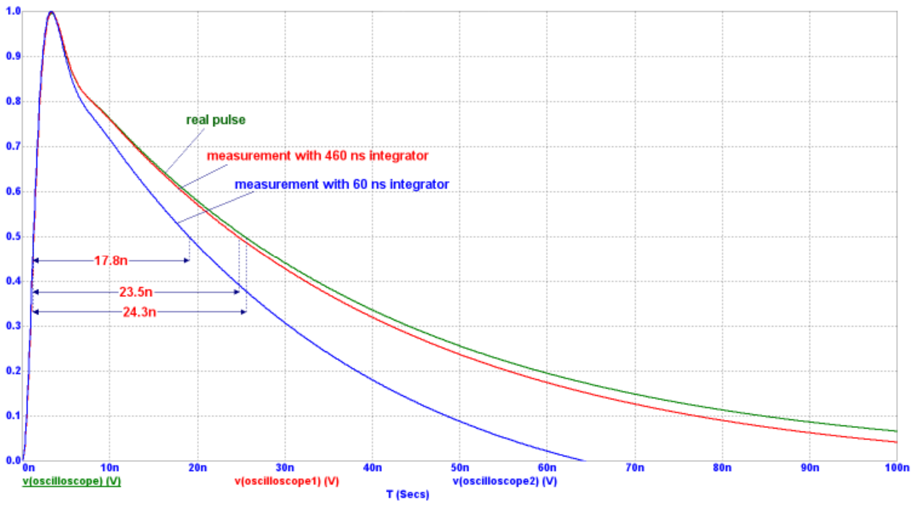

Fig. 9: influence of the time constant

11. Limitation in the test set-up

If metallic walls (or electrical installations, barriers, etc.) are in the vicinity of the installation, reflections of the wave can occur. The reflected waves return to the test zone and are added to the field under the antenna. Depending on the phase of the reflected wave, the distortion of the signal is positive or negative.

The figure below shows the comparison of the measurement of the electric field in 3 different environments: open area test site (OATS) and anechoic chambers no 1 (length 13 m / foam absorbers) and no 2 (length 15 m / ferrite absorbers).

It is important to note that reflections are occurring even if the walls of the chamber are covered with electromagnetic absorbers. The frequency content of the pulse is lower than the low frequency limit of the absorbers. As an example for a 14 x 9 x 6 meter anechoic chamber, the lowest frequency resonance is about 20 MHz. At this frequency the absorbers are completely transparent and the chamber is fully resonant.

In case of a room with metallic structures, electric wiring, etc. could be higher and distortions of the pulse worst!

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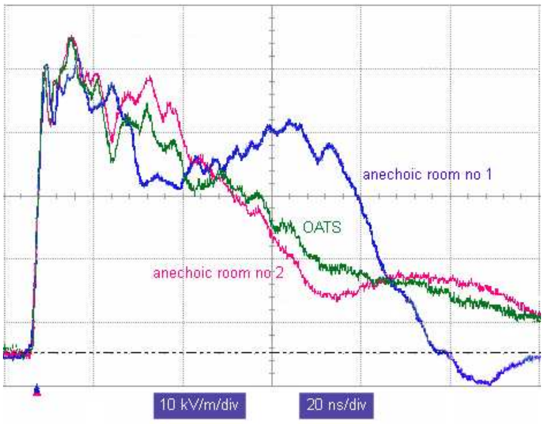

Fig. 10: field produced by a RS105 test installation in 3 different situations

Additionally, the standard MIL-STD-461E / RS105 specify a minimum distance between the line and the ceiling of 2 times the maximum height of the line. This requirement is also motivated by the reduction of the distortions due to reflections but also to avoid a change of the wave impedance of the line. So it is recommended to place the installation away from the walls according to the following diagram in order to avoid the distortions.

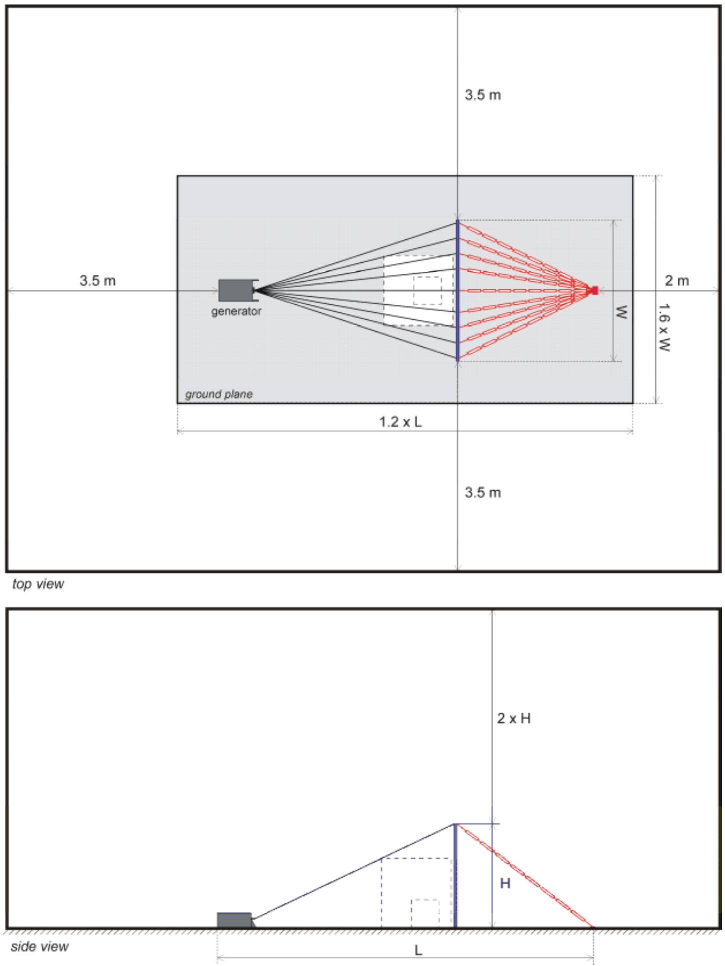

Fig. 11: minimum recommended clearance distances

Another solution to decrease the risk of waveform distortion is to place the installation in a wooden building without metallic structure. The disadvantage of this solution is that the field is radiated outside in the environment.

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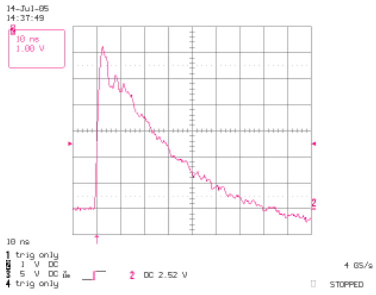
12. Other accessories

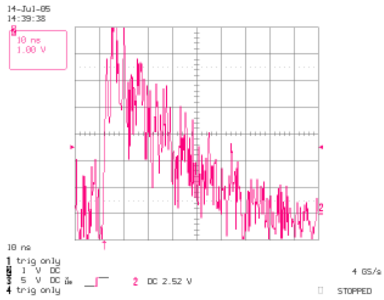
12.1 Shielded box

The measuring equipment (mainly the oscilloscope must be placed in a shielded room or in a small shielded enclosure, like the model SB3G shown in the picture below. The 2 measurements show below a possible disturbance.

Shielded enclosure model SB3G



Measurement carried out with the door closed

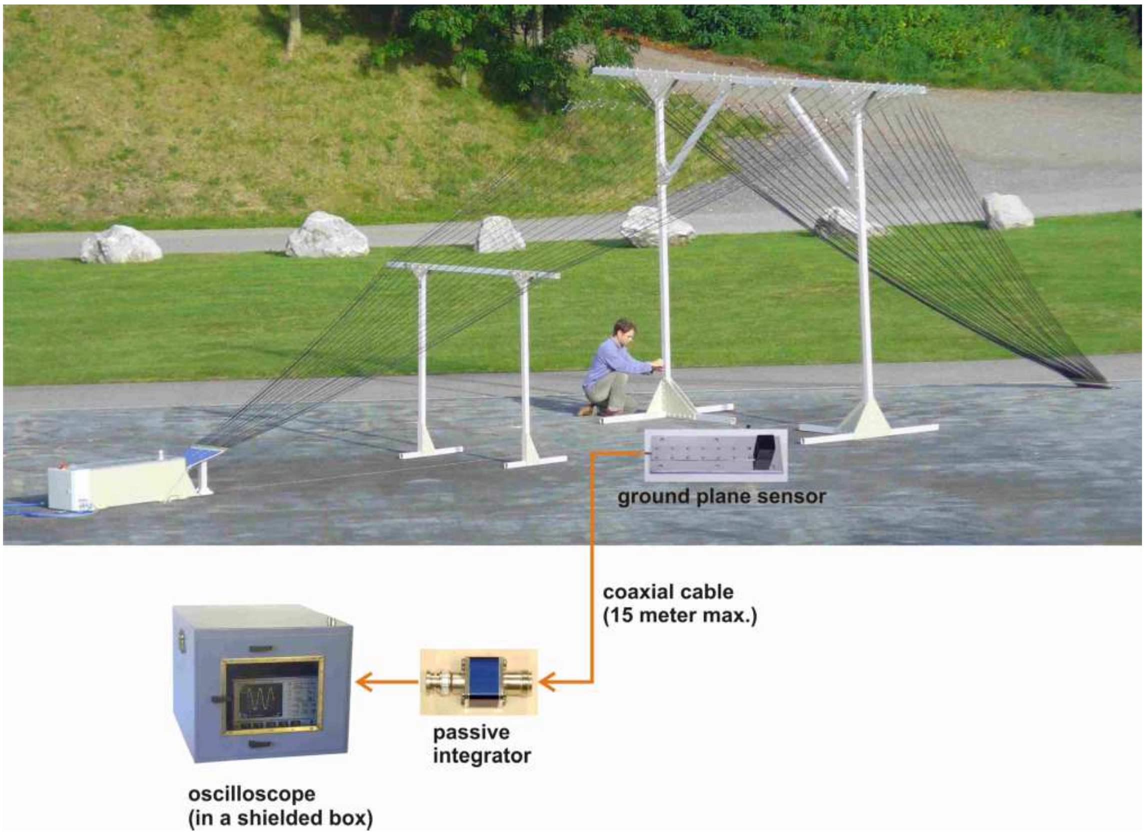


Same measurement but with the door open

Fig. 12: protection of the oscilloscope

12.2 Electromagnetic field probe connection

1. Ground plane sensor - connection through a coaxial cable



Advantages:

- simple and reliable construction
- lower cost

Disadvantage:

- limited length: about 15 meter

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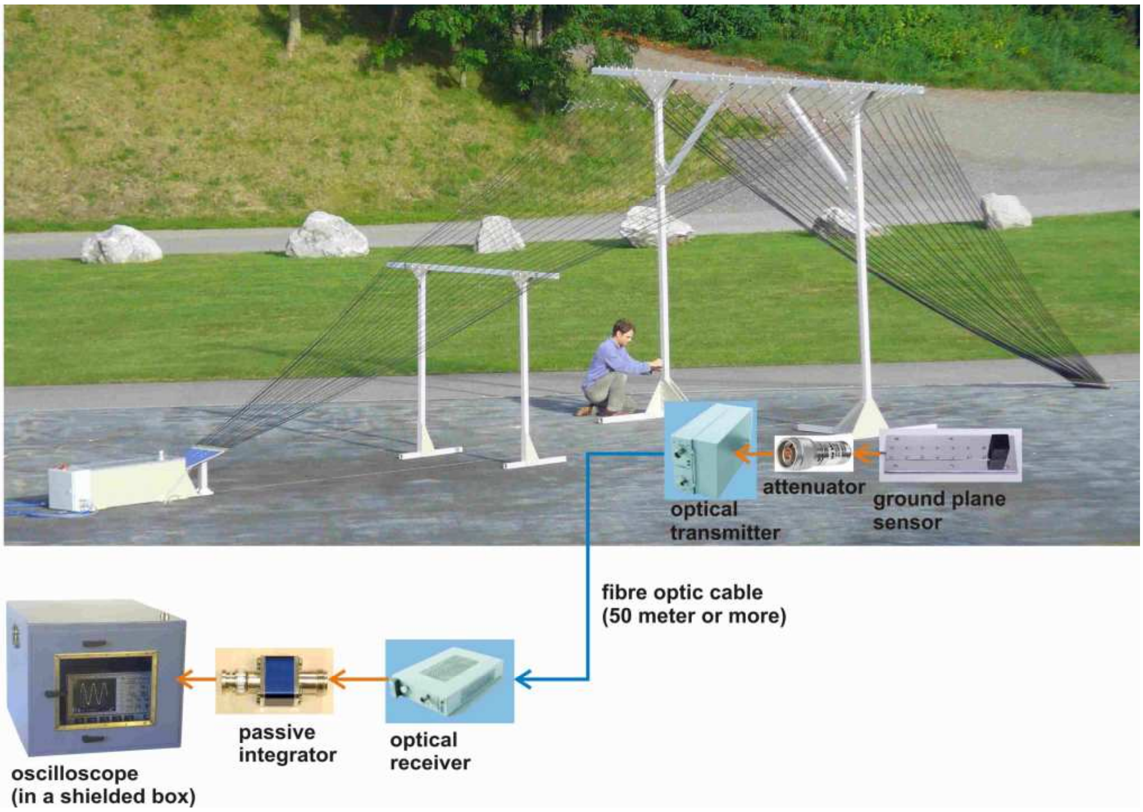
2. Ground plane sensor - connection through a fibre optic cable



Advantages:

- length of the connection almost not limited
- floating connection

Disadvantages:

- fibre optic link expensive

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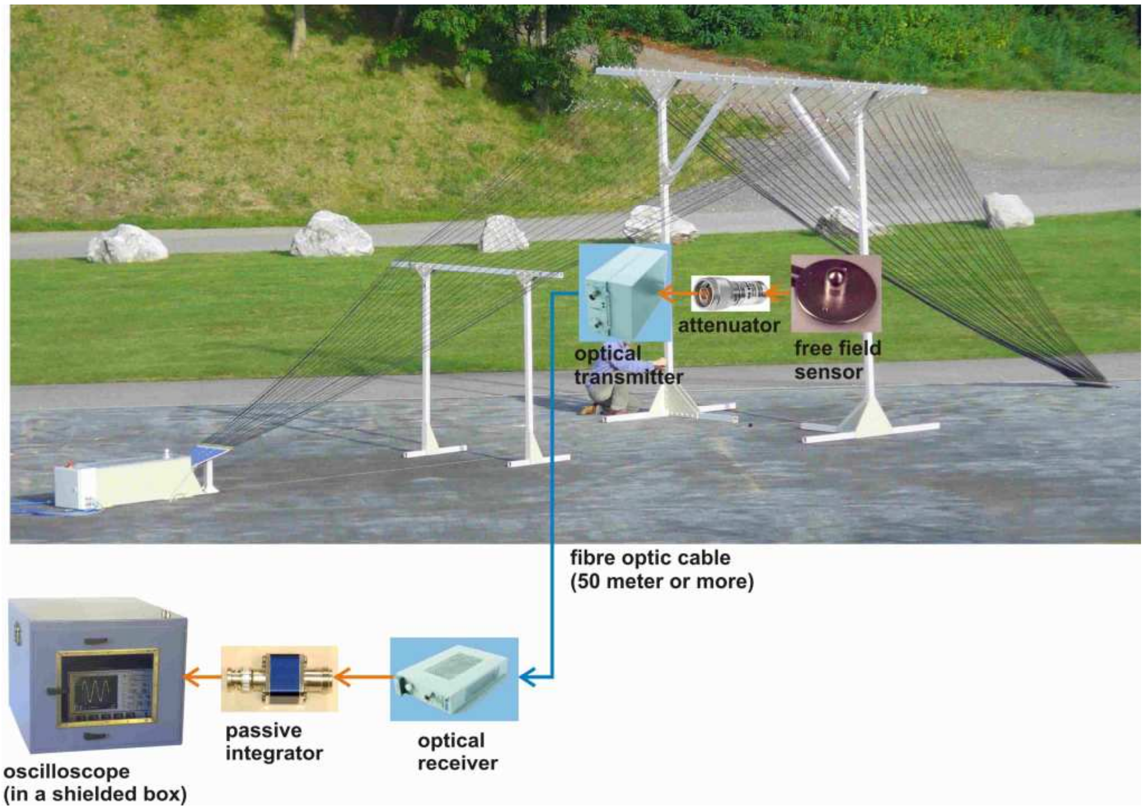
3. Free field sensor - connection through a fibre optic cable



<u>Advantages:</u>

- all purposes solution, allows a measurement everywhere in the test volume
- floating connection

<u>Disadvantages:</u>

- expensive solution
- sensor expensive

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