User Guide

EM Field Measurement System

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1. Forewords

Thanks for choosing Kapteos®. We do hope that you will be satisfied with our products, accessories and services. The present document deals with all major functions of our systems. To ensure operational capacity and limitations, please refer to related data sheets on our website (https://en.kapteos.com/documentation). As part on its on-going product improvement, Kapteos® reserves the right to modify the specifications of the product described here without notice.

1.1. Acronyms

To simplify the reading, we are using the acronyms given in Tab. 1.

AF	Antenna Factor	MO	Magneto-Optic
ASA	Automatic Spectrum Analyzer	MRI	Magnetic Resonance Imaging
AWG	Arbitrary Wave Generator	NSD	Noise Spectral Density
BW	Band Width	OEC	Opto-Electronic Converter
CPRR	Cross Polarization Rejection Ratio	OM	Optical Multiplexer
CW	Continuous Wave	PC	Personal Computer
DSO	Digital Sampling Oscilloscope	PRB	Probe
DUT	Device Under Test	RBW	Resolution Band Width
E	Electric	RMS	Root Mean Square
EM	Electro-Magnetic	RX	Receiving
EMF	Electro-Magnetic Field	SNR	Signal-to-Noise Ratio
EMP	Electro-Magnetic Pulse	TEM	Transverse Electro-Magnetic
EO	Electro-Optic	TD	Time Domain
FD	Frequency Domain	TX	Transmitting
H	Magnetic	UWB	Ultra Wide Band
HV	High Voltage	VNA	Vector Network Analyzer
IL	Insertion Loss	[ ]	SI unit indicated in square brackets
LAN	Local Area Network		

Tab. 1 - Glossary of acronyms used in text and schematics

1.2. Safety considerations

Tab. 2 gives the meaning of pictograms used in this document.

	Electrical hazard		General hazard
	Laser hazard		General obligation

Tab. 2 - Meaning of pictograms

All Kapteos® products have been designed and tested in accordance with international standards as listed for each product in its related data sheet (refer to our website: https://en.kapteos.com/documentation). This document contains information and warnings that must be followed in order to ensure safe operation and to maintain the products in safe condition.

1.3. Limitation of liability

It is the liability of the user to have a valid delegation and competencies to operate Kapteos® products presented in this user guide. Malfunction of the product due to lack of competencies or negligence or non-compliance with the rules and procedures laid down in the present document will lead to the loss of warranty claims. In terms of security, all possible means in order to perform the EMF measurements must be deployed by the user under its sole liability.

1.4. After sales service/assistance/support

For any request, you can contact Kapteos® via email at the following address: contact@kapteos.com

1.5. Copyright

The content of this document is protected under copyright law. The user is not allowed to copy the picture(s) and/or text(s) for being published by any means like, but not limited to, website, newsletters, social networks, leaflets, documentations...

If the user of this manual would need to communicate upon current content of this document, prior written authorization from Kapteos® must be required.

1.6. Limited warranty

The limited warranty described in the General Sales Conditions of Kapteos® applies to this document.

2. Basic concepts

Kapteos® products allow the vector measurement (magnitude and phase) of one component of the EMF (either E-field or H-field) both in TD and in FD using a none-interfering optical RX antenna. When using an antenna, you get an output voltage $V_{out}(t)$ or current $I_{out}(t)$, function of time, which is linked to an EMF component $E(t)$ or $H(t)$, respectively. The relationship between these two quantities is given in Tab. 3.

Antenna				
Type	Output	Measured physical parameter	Related relationship	Antenna factor
Electric	$V_{out}(t)$ [V]	$E(t)$ [V/m]	$E(t) = AF \,.\, V_{out}(t)$	AF [m^{-1}]
Magnetic	$I_{out}(t)$ [V]	$H(t)$ [A/m]	$H(t) = AF \,.\, I_{out}(t)$	

Tab. 3 - Relation between antenna output and EMF component of interest

Whatever type of antenna, the component of the EMF of interest is straightforwardly calculated as soon as the AF is known, this latter one being the main feature of an antenna for EMF assessment.

2.1. Comparison between classical and optical RX antennas

Contrary to classical metallic antennas which are bi-directional (classical antennas can be used either as TX antennas or as RX antennas) and which constitute a monobloc unit with a RF output connector, Kapteos® optical antennas are only RX antennas and are composed of two distinctive parts:

- the EO transducer that converts the E field into an optical information (the MO transducer that converts the H field into optical information respectively),
- the OEC that converts the optical information back to a voltage/current function of time (see Fig. 1).

Among these differences, it is also crucial to take the link from the antenna to the digitizer into account as it constitutes a key point in the RF link budget.

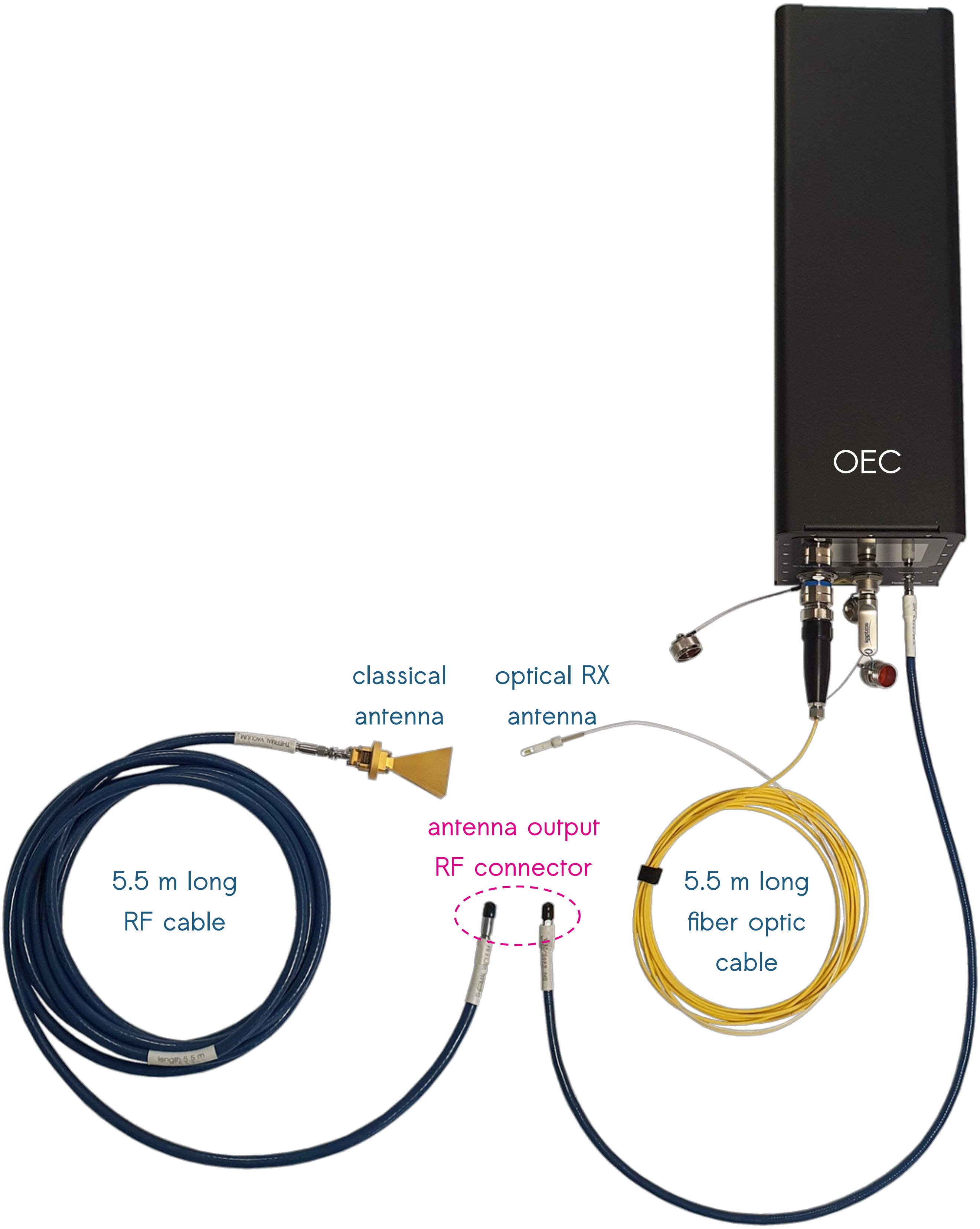

Fig. 1 - Classical (on the left) and Kapteos® optical (on the right) RX antennas for E-field assessment for 26.5-40 GHz frequency range with a 5.5 m long cable (either RF or fiber optic)

Tab. 4 summarizes the main difference between classical antenna and Kapteos® optical RX antenna.

RX antenna type		Classical with G = 10 dBi	Kapteos® optical
Composition		metal	Ultra low tan δ dielectric materials
AF [dB/m]		20 $\log_{10}(9.73 / \lambda\sqrt{G}) + IL_{RF\ cable}$ [dB] (frequency dependent) 5 GHz / 10 GHz / 20 GHz / 40 GHz / 65 GHz 5 m cable: 47 / 57 / 70 / 85 / 99 20 m cable: 85 / 108 / 140 / 185 / 228	frequency independent cable length independent ~100
Size [mm]		≳ λ/2 ≳ 150 @ 1 GHz, ≳ 15 @ 10 GHz	frequency independent Ø 5.5
Measurement voxel [cm^3]		≳ $(\lambda/2)^3$ (forbidden use in near field) ≳ 3000 @ 1 GHz, ≳ 3 @ 10 GHz	frequency independent 0.005
BW [octave]		0.6 (26.5-40 GHz in Fig. 1)	> 33 (10 Hz → 100 GHz for the EO transducer in Fig. 1)
CPRR [dB]		~ 30	> 50
Sensitivity E_{min} [$mV_{RMS}/m\sqrt{Hz}$]		5 GHz / 10 GHz / 20 GHz / 40 GHz / 65 GHz 5 m cable: 0.01 / 0.02 / 0.07 / 0.42 / 2.1 20 m cable: 0.42 / 5.9 / 225 / 39 000 / 5.4 10^6	frequency independent cable length independent ~ 25-40
Damage threshold [kV_{RMS}/m]		~ 10	> 10 000
DC HV withstand [V]		500	> 1 000 000
Cable	Type	RF	fiber optic
	IL [dB/m]	5 GHz / 10 GHz / 20 GHz / 40 GHz / 65 GHz 2.56 / 3.41 / 4.69 / 6.63 / 8.56	frequency independent 0.00015
Use in	near field	NO	YES
	liquids	NO	YES
	plasma	NO	YES
	MRI	YES with some restriction	YES

Tab. 4 - Main differences between classical antennas (RF cable PE-P103, NSD = -140 dBm/Hz) & Kapteos® RX electrical antennas

Except its AF and sensitivity when using short RF cables, Kapteos® optical RX antenna surpasses classical antennas in all points. Indeed, as soon as long RF cables are used, Kapteos® optical RX antennas are even more efficient than classical antennas in terms of AF and sensitivity.

For the calculation of the sensitivity of classical antennas, we have considered the NSD of the ASA on the one hand, and the AF equation given in Tab. 4 on the other hand, thus leading to:

$$E_{min}[V_{RMS}/m\sqrt{Hz}]=7.26\ 10^{\frac{NSD[dBm/Hz]-G[dBi]+IL_{RF\ cable}[dB]}{20}}\ f[GHz] \quad (1)$$

2.2. EM-FIELD PROBE

Kapteos® EMF probes eoProbe™ are optical probes fed by a laser source. Their relative permeability is equal to 1 and their relative effective permittivity is lower than 4 for low κ probes, leading to a negligible interference induced by the probe on the EM-field to be measured.

Under no circumstances, Kapteos® EM-field probe tip shall be exposed to a temperature higher than 50°C or subjected to an impact otherwise it will be irreparably damaged.

In case of serious mechanical damage of EM-field probe tip, do not use it anymore as the intrinsic protection against optical leakage is no longer guaranteed. Then contact Kapteos® after sales service for reparation.

It is strongly recommended to use the probe holder eoPod™ for the positioning of the EM-field probe whatever the environment (high voltage, immersion inside aqueous liquids, plasma, vacuum…).

When dealing with EMF measurements inside vacuum (plasma thruster, intense laser-plasma interaction…), inside high pressure chambers (gas insulating switchgear, spark gap…) or inside liquids (liquid phantom, high voltage transformer…), it is crucial to use the gas-tight and liquid-tight removable feedthrough eoVac™ which has been designed to be used with Kapteos® EMF probes.

2.3. OPTO-ELECTRONIC CONVERTER

Kapteos® OEC eoSense™ have been designed to work with Kapteos® EM-field probes. They permit to cover the major part of the RF spectrum, from 10 Hz up to 100 GHz. A frequency range larger than 30 octaves can be covered with only 3 OEC:

- the LF OEC on the 10 Hz - 50 MHz frequency BW,
- the HF OEC on the 40 MHz - 3.2 GHz frequency BW,
- the SHF-1-18 OEC on the 1 - 18 GHz frequency BW.


Under no circumstances, Kapteos® OEC protective housing shall be removed as it may void the warranty and as it gives access to unprotected live elements and class 3R laser that could result in serious injury or death.

2.4. Optical multiplexer

Contrary to single shot measurements (artificial lightning, partial discharges, dielectric barrier discharges, EMP generated by intense laser-plasma interaction…) where all measurements have to be carried out simultaneously, assessment of different components of the EM-field in different locations can be addressed sequentially when dealing with repetitive signals (either CW or repetitive pulses). When time of measurement doesn't constitute a key issue, Kapteos® OM eoSwitch™ constitutes a cost-effective solution to address a large number of EMF probes with a single or a small number of OEC.

> Under no circumstances, Kapteos® OM protective housing shall be removed as it may void the warranty and as it gives access to high optical power of invisible light that could result in serious injury for the eyes.

2.5. E-field applicator

For the calibration of any EMF probe, a measurement volume much wider than its size with a constant EMF (both in magnitude and direction) is required.

Calibration of E-field probes in air/vacuum at low frequency is straightforward up to few hundred MHz as a plane-parallel capacitor made by two metallic plates separated by a distance *d* much larger than the EMF probe size does perfectly the job as soon as strict design rules are applied. Indeed, the dimension *D* of the plates (of surface *A*) has to be at least twice the distance between them to avoid edge effects. Therefore the capacitance ($C = \varepsilon_0\ \varepsilon_r\ A/d$) of such E-field applicator presents a min value given by:

$$min(C) \simeq 4\,\epsilon_0\,d \qquad (2)$$

The capacitance of a suitable plane-parallel capacitor with a gap of 50 mm is therefore ~ 2 pF, leading to a cutoff frequency of $1/(2\pi\ R_{50\Omega}\ C) \simeq 1.6$ GHz when fed with a 50Ω impedance AWG. This cutoff frequency varies inversely proportional to the capacitor size.

Consequently, to go further, it is necessary to use a specific E-field applicator such as Kapteos® adiabatic TEM cell eoCal™ which has been specifically designed to be used with Kapteos® EMF probes. Such TEM cell allow accurate EMF probe calibration in air/vacuum up to 6 GHz with E-field strength up to 2 kV_{RMS}/m.

2.6. General environmental specifications

Tab. 5 provides the general environmental specifications that Kapteos® products and accessories satisfy. For specific environmental specifications related to a given product or accessory, please refer to the corresponding data sheet on our website (https://en.kapteos.com/documentation).

		Min	Typical	Max	Unit
Temperature	Operating	15		30	°C
	Storage	5		40	°C
Pressure		690		1075	hPa
Relative humidity	Non-condensing			90	%

Tab. 5 - General environmental conditions

2.7. Videos for operating products

More than thousand words, short subtitled videos for operating our products can be seen on Kapteos® website (https://en.kapteos.com/documentation): they give advice on how to use efficiently Kapteos® products and accessories while having the main precautions of use. Regularly new videos presenting new products, new product releases or features are posted on the website. For that purpose, we recommend to visit regularly Kapteos® website.

3. EM-field measurement system

Kapteos® EM-field measurement system is available in various configurations from basic ones to comprehensive test benches either in TD or FD.

3.1. Basic configuration for scalar measurement in FD

As seen in Fig. 2, the most basic configuration is composed of:

- an AWG,
- the DUT,
- a single EMF probe,
- a single OEC,
- an ASA.

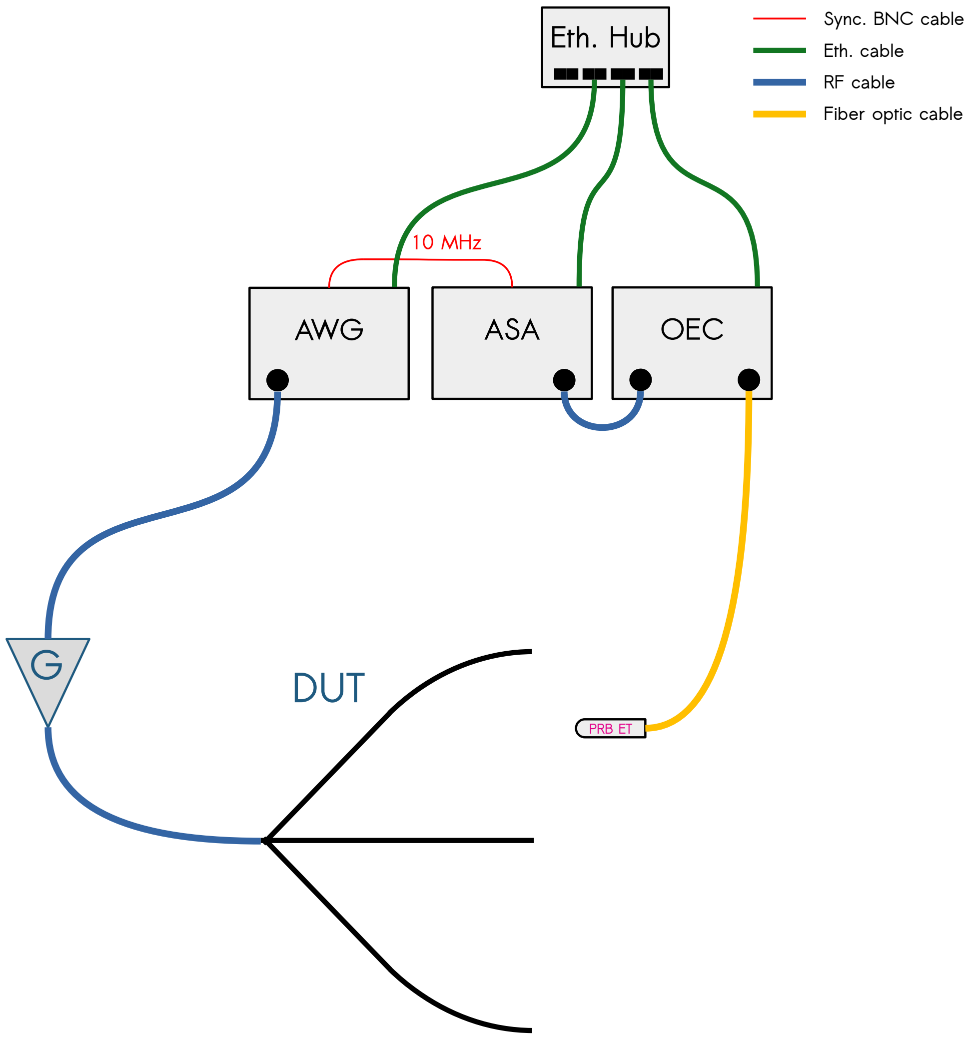

Fig. 2 - Basic test bench for scalar EMF measurements in FD with a LAN

Either way, it is always recommended to use an amplifier to boost the radiated or conducted E-field strength generated by the DUT in order to get a good SNR. Let us remind that a gain of 10 dB in terms of E-field strength (10 times more emitted power) leads to a 10-fold reduction in measurement time for same SNR. It is therefore very efficient to reduce the measurement time and/or to increase the SNR by increasing the power that feeds the DUT.

The synchronization signal @ 10 MHz between AWG and ASA is of key importance when using either -ASA or -AWG+ASA software options on the OEC, these latter ones requiring a LAN in order to operate. In such a case, OEC will directly display the E field strength (see Fig. 3) without need of any calculation on your side using formulas given in Tab. 3.

Fig. 3 - Information displayed by the OEC depending on software option

3.2. How to integrate Kapteos® EMF measurement system in your scalar test bench in FD

To illustrate how to integrate Kapteos® EMF measurement system in your test bench, we are considering here the most comprehensive and complex configuration (see Fig. 4) with several set of 3 E-field probes for sequential assessment of the E-field vector at different locations.

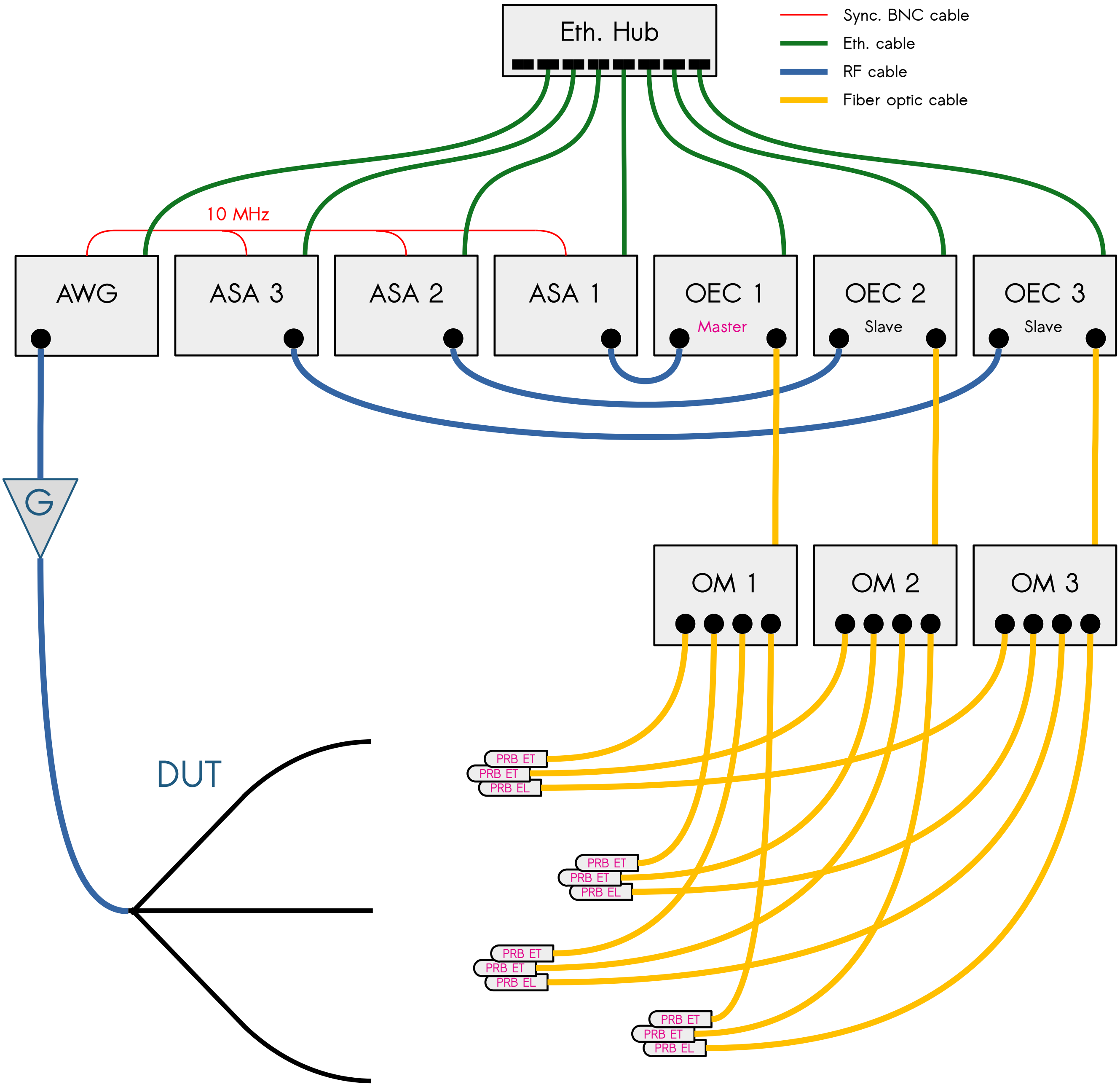

Fig. 4 - Comprehensive test bench for scalar EMF measurements in FD

In that illustration, one need to make scalar measurements of the 3 components of the E-field vector at 4 different positions in front of the DUT. For that purpose, 12 probes are required, bundled by sets of 3 E-field probes, each bundle being constituted of:

- 2 transverse probes ET-type to get the 2 transverse E-field components,
- 1 longitudinal probe EL-type to get the longitudinal E-field component.

With -AWG+ASA software option on each OEC, the complete test bench can be monitored from a single OEC:

- OEC 1 being configured as master,
- OEC 2 and OEC 3 being configured as slaves.

Each OEC is displaying the current E-field strength measured by the related E-field probe and the current OM channel on which the E-field probe in operation is plugged in (see Fig. 5).

OEC 1	OEC 2	OEC 3
Low K Transverse E-field probe #23357 on Ch. 2	Low K Transverse E-field probe #23358 on Ch. 2	Low K Longitudinal E-field probe #23359 on Ch. 2
E = 12.4 V_{RMS}/m @ 21.4 GHz	E = 21.1 V_{RMS}/m @ 21.4 GHz	E = 1.0 V_{RMS}/m @ 21.4 GHz

Fig. 5 - Information displayed by the three optoelectronic converters

With the master OEC, both power and frequency delivered by the AWG can be configured very easily. Once done, the master OEC sets immediately and automatically the corresponding settings on all ASA and slave OEC. If a PC is also connected to the Eth. hub, then you can very easily drive the complete test bench by:

- sending commands from a terminal,
- or much more efficiently by writing a program in the langrage of your choice to carry out as complex measurements as you could imagine.

In order to get all the apparatuses talking efficiently to each other in the test bench of Fig. 4, a hierarchical LAN as shown in Fig. 6 has to be implemented with IP addresses of all the master and slave apparatuses detailed in Tab. 6.

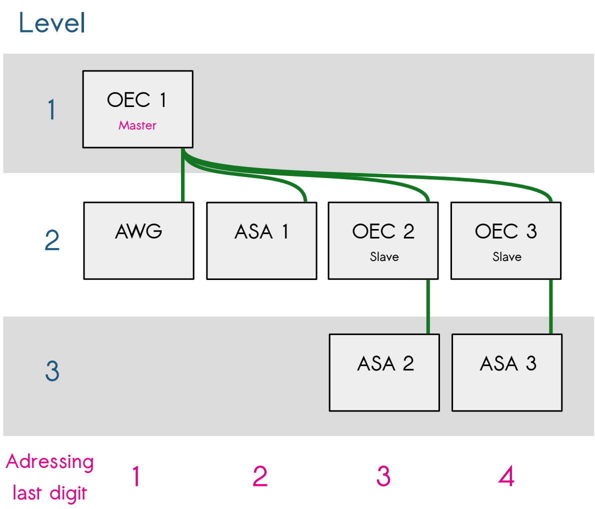

Fig. 6 - Hierarchical LAN with master-slave relationship and easy IP addressing for scalar meas.

Apparatus	IP address	Slave apparatuses to register with their IP address

		1st slave apparatus	2nd slave apparatus	3rd slave apparatus	4th slave apparatus
OEC 1	192.168.150.11	AWG 192.168.150.21	ASA 1 192.168.150.22	OEC 2 192.168.150.23	OEC 3 192.168.150.24
OEC 2	192.168.150.23	ASA 2 192.168.150.33			
OEC 3	192.168.150.24	ASA 3 92.168.150.34			

Tab. 6 - Easy addressing of all apparatuses in the hierarchical LAN for scalar meas.

It is also possible to use an external PC to monitor the complete test bench as shown in Fig. 7.

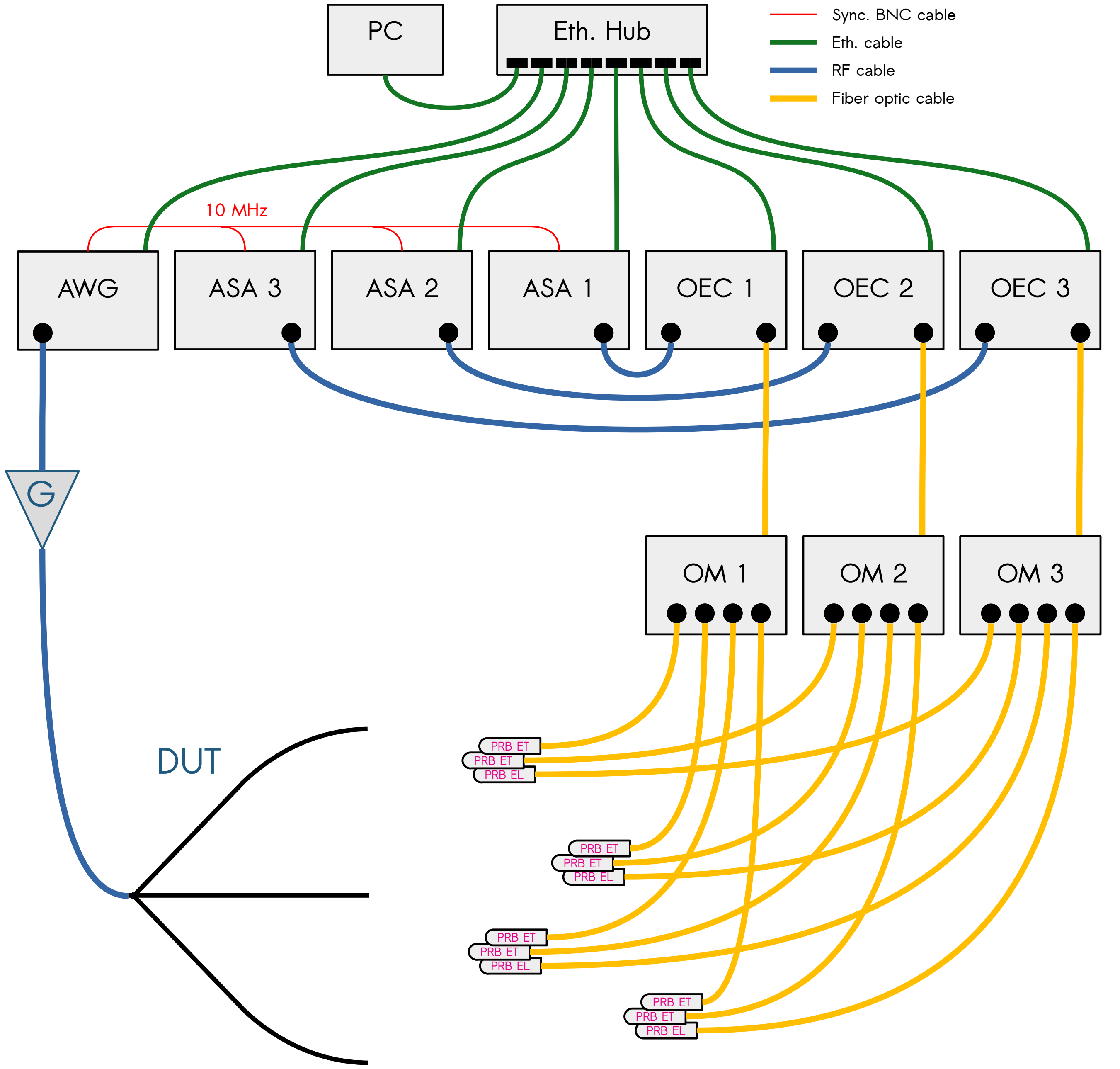

Fig. 7 - Comprehensive test bench for scalar EMF measurements in FD with external PC

In order to get all the apparatuses talking efficiently to each other in the test bench of Fig. 7, a hierarchical LAN as shown in Fig. 8 has to be implemented with IP addresses of all the master and slave apparatuses detailed in Tab. 7.

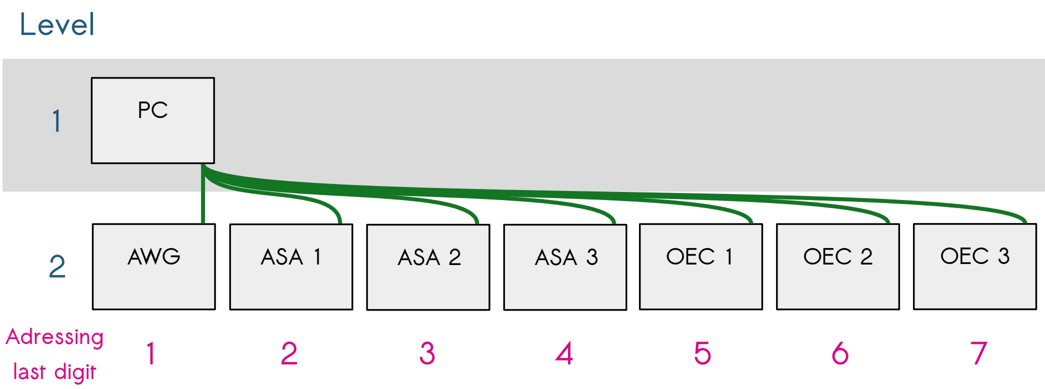

Fig. 8 - Hierarchical LAN with master-slave relationship and easy IP addressing for scalar meas. with external PC

Apparatus	IP address	Slave apparatuses to register with their IP address						
		1st slave apparatus	2nd slave apparatus	3rd slave apparatus	4th slave apparatus	5th slave apparatus	6th slave apparatus	7th slave apparatus
PC	192.168.150.11	AWG 192.168.150.21	ASA 1 192.168.150.22	ASA 2 192.168.150.23	ASA 3 192.168.150.24	OEC 1 192.168.150.25	OEC 2 192.168.150.26	OEC 3 192.168.150.27

Tab. 7 - Easy addressing of all apparatuses in the hierarchical LAN for scalar meas. with ext. PC

3.3. How to integrate Kapteos® EMF measurement system in your vector test bench in FD

Similarly to § 3.2, we are considering here the most comprehensive and complex configuration with several set of 3 E-field probes for sequential assessment of the E-field vector at different locations (see Fig. 9).

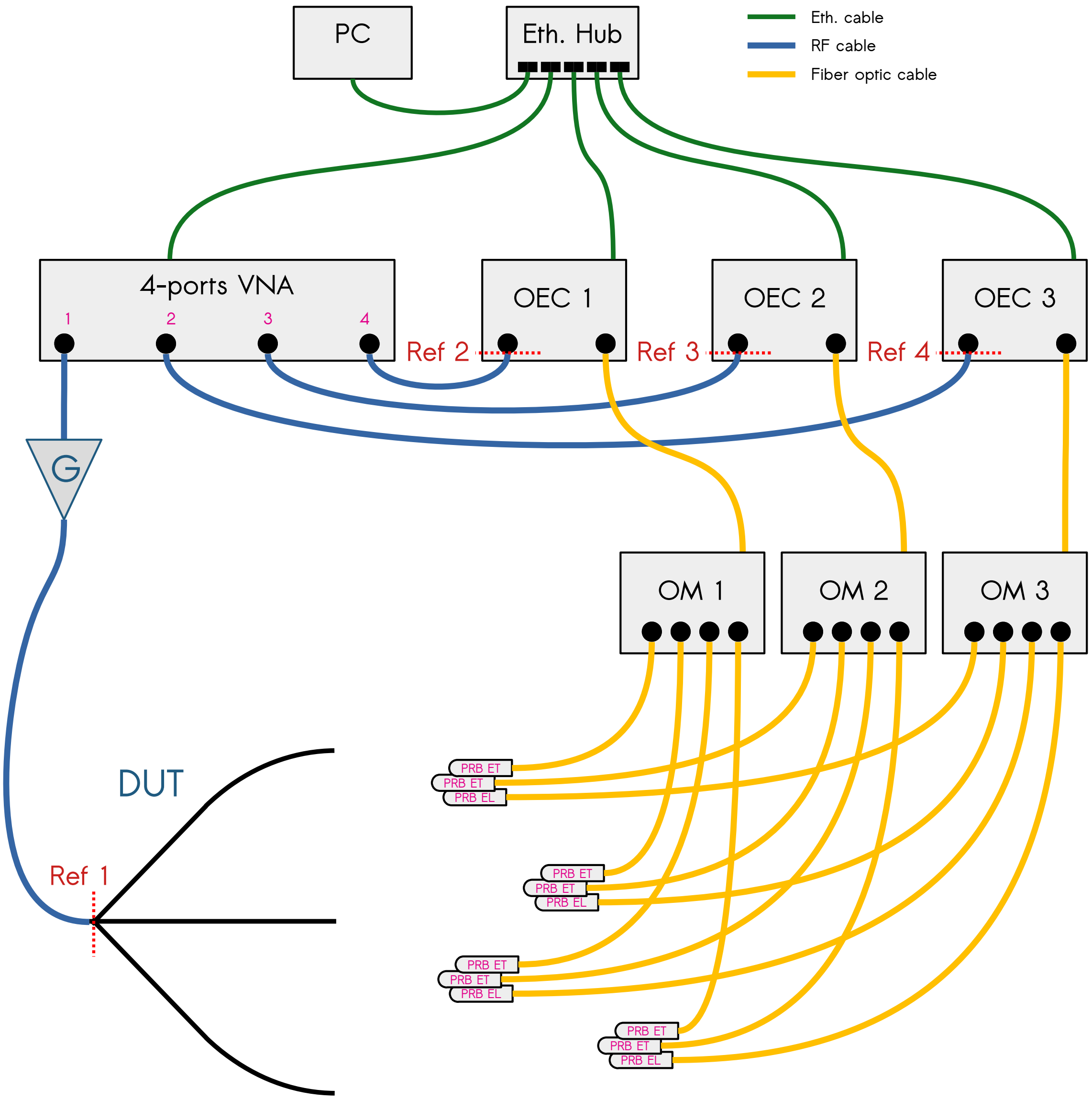

Fig. 9 - Comprehensive test bench for vector EMF measurements in FD with reference planes in red

When using a VNA, prior to any connection to OEC, you have to disable first power emission of all VNA ports that will be connected to OEC outputs, otherwise you can fully destroy the OEC output stages.

In order to get all the apparatuses talking efficiently to each other in the test bench of Fig. 9, a hierarchical LAN as shown in Fig. 10 has to be implemented with IP addresses of all the master and slave apparatuses detailed in Tab 8.

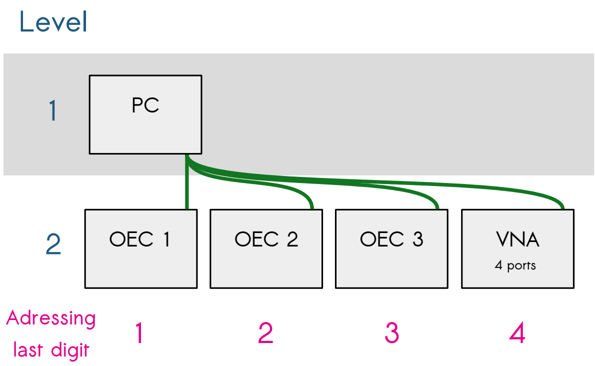

Fig. 10 - Hierarchical LAN with master-slave relationship and easy IP addressing for vector meas.

Apparatus	IP address	Slave apparatuses to register with their IP address			
		1st slave apparatus	2nd slave apparatus	3rd slave apparatus	4th slave apparatus
PC	192.168.150.11	OEC1 192.168.150.21	OEC 2 192.168.150.22	OEC 3 192.168.150.23	VNA 192.168.150.24

Tab. 8 - Easy addressing of all apparatuses in the hierarchical LAN for vector meas.

The recommended reference planes for the VNA calibration are shown in Fig. 9. As for any classical antenna loaded on a 50**Ω** termination, we get for each OEC output:

$$P_{output}[\text{dBm}] = E[\text{dBV}_{RMS}/\text{m}] - AF[\text{dB/m}] + 13.01 \qquad (3)$$

The E field strength generated at the E-field probe location is given by:

$$E[\text{V}_{RMS}/\text{m}] = \sqrt{P_{input}[\text{W}].\, TF_{DUT}[\Omega/\text{m}^2]} \qquad (4)$$

or equivalently:

$$E[\text{dBV}_{RMS}/\text{m}] = 30 + P_{input}[\text{dBm}] + TF_{DUT}[\text{dB}\Omega/\text{m}^2] \qquad (5)$$

where TF_{DUT} [**Ω**/m^2] = E^2 [V_{RMS}/m] / P_{input} [W] is the power transfer function (ratio of the output physical quantity of interest -square of E-field strength- and input physical quantity that feeds the DUT -power-) of the DUT generating a given E-field at the E-field probe location from the RF power injected at its input, its dimension being in **Ω**/m^2 as power surface density $P / S \propto E^2 / Z$.

Using (3) and (5), the transfer function of the DUT is simply given by the following equation:

$$TF_{DUT}[dB\Omega/m^2]=|S_{X1}|[dB]+AF[dB/m]-43.01 \quad (6)$$

where $|S_{X1}|$ is the modulus of the scattering parameter related to the E-field component of interest ($X \in \{2, 3, 4\}$). Eq. (6) can be rewritten as:

$$TF_{DUT}[\Omega/m^2]=50\times 10^{\frac{|S_{X1}|[dB]+AF[dB/m]-60}{10}} \quad (7)$$

Eq. (7) gives a straightforward method to get the transfer function of any DUT used to generate a given E-field strength in a specific quiet zone: it could be a TEM cell, a GTEM cell, a TX antenna...

With the PC driving all apparatuses, the VNA setting parameters have to be defined (start frequency, stop frequency, IF bandwidth...) and the OM channel of interest has to be set. Then the 3 OEC AF which are functions of frequency have to be read from master OEC 1 and saved. Once all scattering parameters $|S_{21}|$, $|S_{31}|$ and $|S_{41}|$ are measured, the transfer function of the DUT can then be calculated using Eq. (7) on the frequency bandwidth of interest.

3.4. How to integrate Kapteos® EMF measurement system in your test bench in TD

Similar to § 3.2, we are considering here the most comprehensive and complex configuration with several set of 3 E-field probes for sequential assessment of the E-field vector at different locations (see Fig. 11).

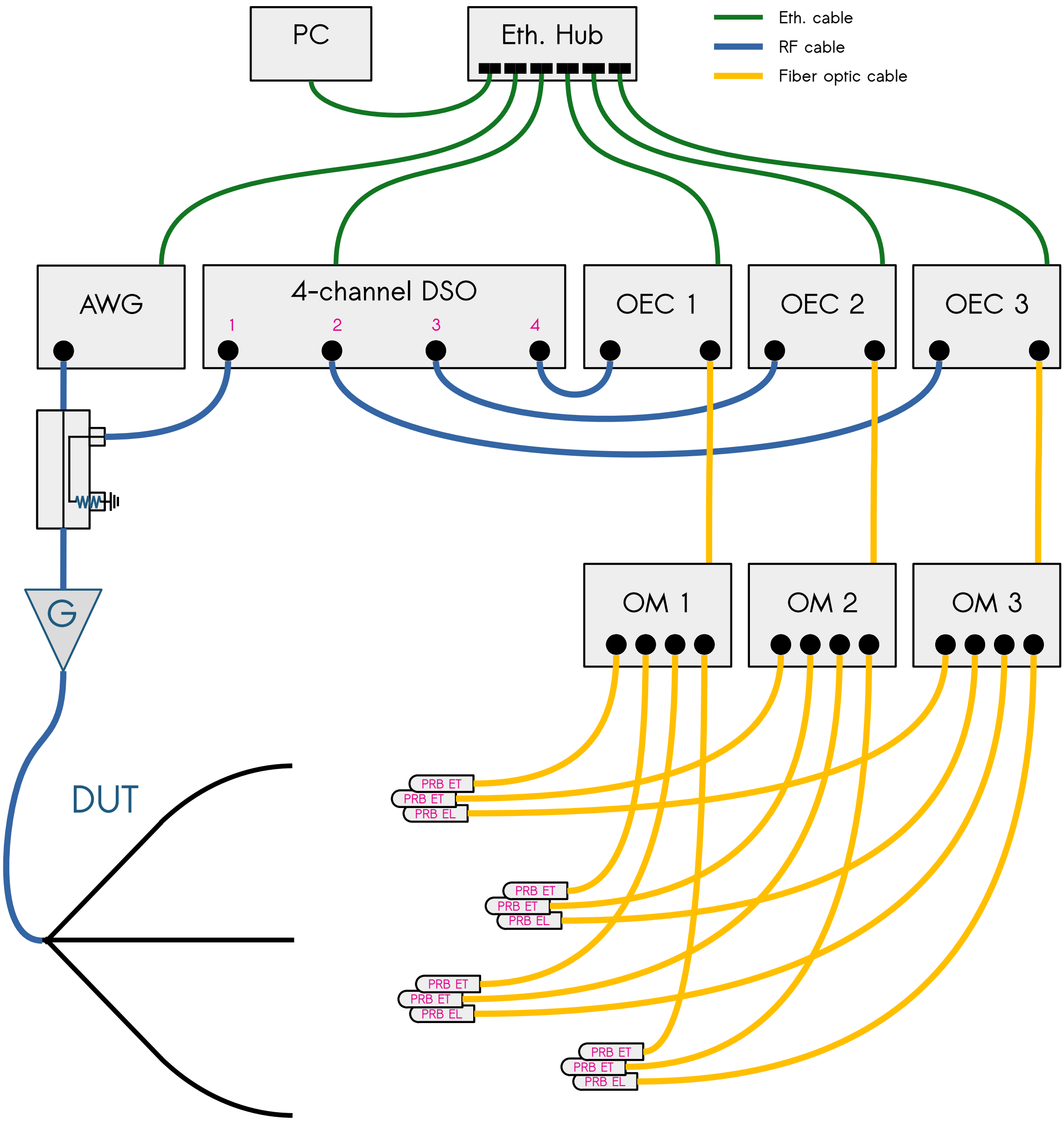

Fig. 11 - Comprehensive test bench for EMF measurements in TD

In order to get all the apparatuses talking efficiently to each other in the test bench of Fig. 11, a hierarchical LAN as shown in Fig. 12 has to be implemented with IP addresses of all the master and slave apparatuses detailed in Tab. 9.

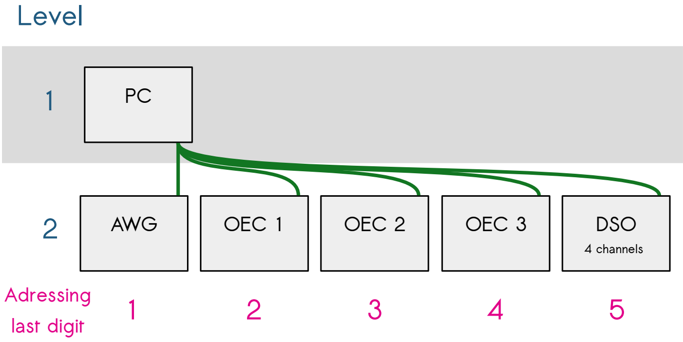

Fig. 12 - Hierarchical LAN with master-slave relationship and easy IP addressing for TD meas.

Apparatus	IP address	Slave apparatuses to register with their IP address				
		1st slave apparatus	2nd slave apparatus	3rd slave apparatus	4th slave apparatus	5th slave apparatus
PC	192.168.150.11	AWG 192.168.150.21	OEC 1 192.168.150.22	OEC 2 192.168.150.23	OEC 3 192.168.150.24	DSO 192.168.150.25

Tab. 9 - Easy addressing of all apparatuses in the hierarchical LAN for TD meas.

In such configuration, an UWB RF coupler is used to get a trigger signal plugged in DSO channel 1 as shown in Fig. 11. Thanks to this trigger signal, measurements of noisy repetitive signals can be carried out even with a very low SNR as explained in this application note.

4. Ethernet interface connection and setup

The communication protocols used by Kapteos® OEC are based on TCP/IP network protocol for remote operation. OEC is set as a server to respond to any request from a client (see illustration on Fig. 13)

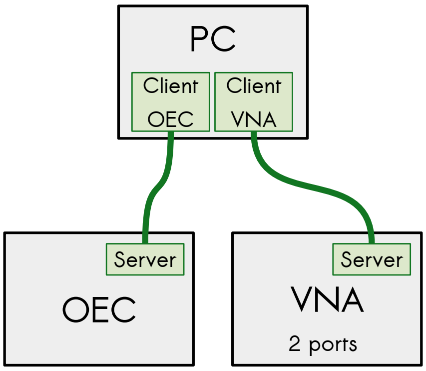

Fig. 13 - Synoptic of a client-server model for a vector measurement in FD using a single OEC

For each client command sent to Kapteos® OEC (see Tab. 10), the EOL sequence must be **"\n"** (line feed LF), otherwise OEC server will not respond.

Example: Send **"*IDN?\n"** to get the OEC identifier.

A configuration example for TCP/IP connection between PC and OEC 1 shown in Fig. 11 is given in Fig. 14.

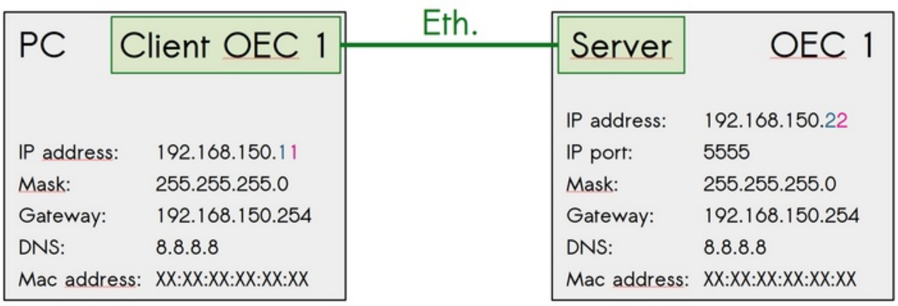

Fig. 14 - Example of configuration for the TCP/IP client-server connection

4.1. List of client requests

The complete list of client requests is given in Tab. 10.

Command	Sub-command	Subject of command /sub-command	Parameters	Format Example of command/response
*IDN?		Get OEC identifier		Manufacturer:Model:Type:Serial number:Manufacture date:Firmware version Kapteos:eoSense:LF:24057:2024-04-03:4.0.9
*STATUS?		Get OEC status		NoProbe | Autocal#[1] | Calibrated | Uncalibrated | Error | Stop
*CLS		Clear error status and restart		
*CAL		Restart auto-calibration procedure		
*STOP		Stop measurement		
PROBE	:NAME?	Get probe type		ET5-LK
	:CAL_LIST?	Get list of recorded calibrations		FactoryCal, EndCustCal
	:INFO?	Get complete information on probe		manufacturer:Kapteos,model:eoProbe,nature:E-field, field axis:Transverse,medium:Low K,s/n:23357,production date:2024-03-21
	:CAL	Set the calibration to use	Cal. to use	PROBE:CAL FactoryCal
	:CAL?	Check the used calibration		FactoryCal | Error: Please set Cal.
	:CAL_INFO?	Get complete information on selected calibration		frequency:Converter BW,rf channel:1,date:2024-05-05,medium:Air,epsilon_r:1,temperature[°C]:22
	:AF?	Get the AF [dB/m]	Frequency [Hz]	PROBE:AF? 1.2e9 99.5 | Error: Please set Cal. | Missing parameter
	:CH_LIST?	Get list of optical multiplexer channels		List with Channel number:Probe type:Probe serial number:Probe alias 0::: | 1:ET5-LK:23357: | 1:ET5-LK:23357:Left Knee, 2:ET5-LK:23357:Right Knee, 4:ET5-LK:23357:Heart
	:CH_REG	Register a probe to a given channel of optical multiplexer eoSwitch™	Channel number, probe alias	PROBE:CH_REG 2,Right Knee
	:CH	Set the optical multiplexer channel	Channel number	PROBE:CH 2
	:CH?	Get the optical multiplexer channel		0::: | 2:ET5-LK:23357:Right Knee

[1] # ∈ {1, 2, 3, 4}, | ≡ XOR

Tab. 10 - List of client requests and examples of commands & responses