High power microwave measurement techniques at CEA-Gramat

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Abstract: *High power microwave (HPM) measurement remains a challenging application since it requires accurate sensors with high power handling. Electromagnetic (EM) fields can reach dramatically high magnitudes such as MV per meter. If no particular attention is paid when designing a sensor for HPM measurements, electrical breakdowns may appear. This leads to irreversible damages and non-accurate results. Through the HPM developments achieved at CEA-Gramat various techniques have raised for the diagnostic of EM fields patterns and microwave power levels delivered by relativistic sources. Three are here introduced: EM field measurement with in-situ calibration; a waveguide integrated coupler to determine output powers of microwave sources; a photothermal film to observe the EM field.*

Keywords: High power microwave measurement; power diagnostic; directional coupler; photothermal film; in-situ calibration.

Introduction

High power microwave measurement remains a challenging application since it requires accurate sensors with compatible power handling. Moreover there are different physic effects that need to be monitored in order to evaluate the HPM elements performances (guided microwave power magnitude; radiated EM field levels; hot test radiation patterns of used high power antennas; …). Through the developments of relativistic sources and high power antennas at CEA-Gramat, different HPM measurement methods have been developed. They are here introduced regarding to data that one needs to evaluate.

Horn antennas [1-2] or waveguide couplers [3] are relevant solutions to evaluate EM field magnitudes emitted by an HPM system. They usually offer accurate results and can be optimized for high power handling. The output power delivered by a microwave source can be then computed if the gain of the antenna is known. However the latter is usually evaluated in anechoic chamber in perfect absorbing conditions. It is well known that the realized gain can dramatically vary depending on the reflecting conditions of the scene illuminated by the antenna. First presented method takes advantage of in-situ calibration that takes into account overall electromagnetic contributions, inside (waveguide losses; sensors transmission coefficients; attenuator magnitudes; …) and around (electromagnetic reflections of the environment) the evaluated HPM system. No particular anechoic environment is thus required to define the output power of a microwave source calculated from the realized gain of the antenna.

Directional couplers are of great interest for the diagnostic of guided microwave power delivered by power sources [4]. They are low intrusive and offer good accuracy. The second measurement technique here detailed is illustrated by a directional coupler employed to evaluate the microwave source output power and the input reflection coefficient during a pulse.

HPM radiation parameters can be for instance evaluated thanks to few sensors positioned within the emitted microwave beam [5]. The resulting resolution can be low and the radiation pattern is finally deducted from the simulation results combined with measured values. The last method exploited at CEA-Gramat for HPM radiation measurement is based on a photothermal film that converts the EM energy into thermic energy.

EM field measurement with *In-situ* calibration

This first technique is employed to evaluate the output power of a relativistic source from the magnitude of the radiated electromagnetic fields. Two waveguide probes loaded with absorbing foam are positioned within the microwave beam to monitor both vertical and horizontal polarizations. The microwave source power is computed by applying an attenuation factor to the measured EM field.

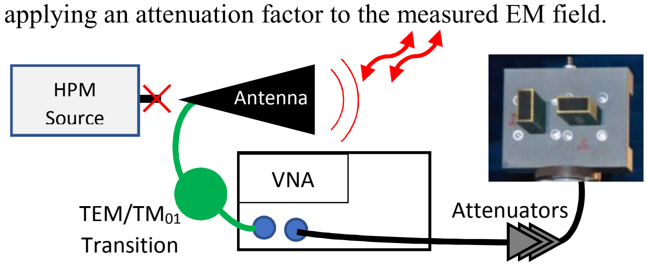

Figure 1. *In-situ* calibration to determine microwave source output power (Red arrows are EM perturbations)

This factor is deducted from *in-situ* calibration that takes into account all electromagnetic perturbations like reflections (red arrows on figure 1) and losses or transmission coefficient of EM mode transition (if used). This method offers the great advantage of knowing precisely the resulting realized gain (impacted by the reflections of the illuminated scene) of the antenna and thus a better diagnostic of the microwave source power.

Directional coupler for guided power diagnostic

Maximizing the diagnostic accuracy means limiting the uncertainty of the measurement. One relevant solution is to locate the measurement probe as close as possible to the physic parameter to evaluate. Waveguide integrated couplers offer the advantage of being situated at the output of the microwave source. What is more the directional feature allows monitoring both the incident (from the source) and the reflected power (from the antenna input). Probe measurement attenuation and isolation are illustrated by the figure 2. It depicts the simulated and realized S-parameters of a coupler used at CEA-Gramat to diagnostic the output microwave magnitude of power relativistic sources.

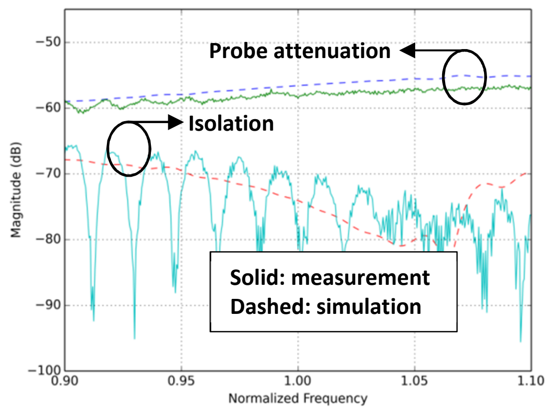

Figure 2. Incident and reflected S-parameters of a directional coupler for HPM measurement

The coupler has been designed to lower the observed signal with 60 dB attenuation. It can be first concluded that simulated and measured probe attenuation are close. Measured isolation is not identical to simulated one, oscillations can indeed be spotted. They are induced by the impedance mismatch between the coupler output and the antenna input that only exists in measurement, since the coupler is loaded with matched impedance in simulation. The isolation is at least 10 dB (up to 18 dB) on a frequency range of 10% making it also compatible with frequency tunable sources diagnostics (with corresponding 10% bandwidth agility).

Photothermal film for HPM radiation pattern measurement

A lot of challenges motivate HPM sources researches such as efficiency, compactness, frequency agility and many others. However the antenna that converts guided microwaves into radiated waves is also of first importance since it dictates the radiation behavior. Antennas are usually characterized in anechoic chamber that offers great accuracy but hot test evaluation is also of interest to state either if the radiating element handles the input power or not. Power breakdown can be for instance illustrated by a gain drop during the hot test. A photothermal film developed by ONERA and CEA-Gramat allows observing qualitatively if the device under test is operating nominally. This is a helpful notification for the HPM source or antenna designer especially during the system setup process. When passing through the film, the microwave energy is converted into thermic energy that can be observed with an infrared camera (examples are showed on figure 3).

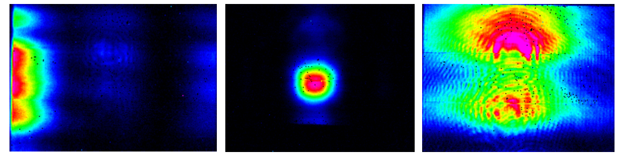

Figure 3. Examples of HPM radiation patterns observed on the photothermal film.

Post processing calculation finally reveals the microwave radiation pattern. The photothermal film is heated linearly as function to the deposited energy. Radiation parameters are consequently directly derived from the infrared print. The post processing computation also permits to evaluate the magnitude of the incident radiated power thus the equivalent isotropic radiated power.

Conclusion

Three techniques developed for HPM measurement at the CEA-Gramat are here summarized. They can be chosen according to the physic parameter to evaluate. EM field measurement using *in-situ* calibration that takes consideration of the EM environment allows determining the microwave source output power with good accuracy. The power delivered by a source is measured as close as possible to its output with a directional coupler. With the last method an infrared camera takes a picture of a photothermal film heated by the HPM. The radiation pattern and EM field magnitude are extracted from the electromagnetic print.

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