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Development of a Standard Measuring System for High-Voltage Nanosecond Pulse Measurements

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Abstract — This paper reports the on-going development of calculable voltage dividers at LNE for the traceable measurements of high voltage nanosecond impulses. The system will be capable of measuring voltage amplitudes up to 0.5 MV and rise time from 1 nanosecond (ns) to few ns with a target uncertainty of 3 % for the amplitude and 1 ns for the temporal parameters.

Index Terms — High pulsed power (HPP), metrology, measurement standards, nanosecond pulse, voltage divider.

I. INTRODUCTION

Since its establishment in 1960s, the High Pulsed Power (HPP) range of technologies has found its applications in various domains and has now become one of the rapidly growing areas of research [1-2]. Historically, the first applications were all military, such as, among others, high frequency transmitters, radars, satellites and space probes, intense electromagnetic interferences; however, after declassification of many of these works, several civil and medical applications have emerged in recent years. Among them, the most important ones are ground penetration radars (GPR), X-ray machines, pasteurization of food and vulnerability testing of electronic equipment, proving the strong potential of innovation which lies behind these technologies. Furthermore, HPP is studied as a new alternative for cancer cells treatment when are exposed to sub nanosecond high electric field pulses. For these applications, nanosecond or sub nanosecond pulsed power need to be controlled with better uncertainty (less than 5 %) in order to achieve efficient results without irradiating the targeted objects.

The associated measurement systems in these technologies are most often developed by the laboratory itself because commercial devices for this level of power could not be found or are very rare in the market. The calibrations of these systems are generally carried out at low levels of amplitude by comparison with existing commercial probes. Therefore, the validity of the measurement is based exclusively on these commercial probes; and the traceability is not then assured. National Metrology Institutes (NMIs) still don't issue calibration of such systems with fast pulses, high voltage and current levels.

In general, the HPP systems consist of three major parts; namely, HPP generator, voltage divider and load. The most

important instrument in the HPP measurement is the divider, as the amplitude of the voltage can vary from tens of kilovolts to hundreds of kilovolts. In addition, the divider should be capable of measuring accurately, not only the amplitude of the signal but also the precise waveform of the signal, without any deformation or loss of information. For this, it is necessary to know the exact division ratio and the bandwidth of the divider should be compatible with the frequencies of the spectrum of the signal. In order to achieve these objectives and to ensure the traceability of nanosecond HPP, a new measurement system is under development at LNE, which is presented in this paper.

II. THE PRINCIPLE OF THE MEASURING SYSTEM

Capacitive Voltage Dividers (CVDs) are widely used to measure the waveform of a HPP signal [3]. They have the advantages of simple principle, fast response, large power and small measuring distortion. Depending upon the applications, CVDs could be of different structure shapes and could be based on slightly different measurement principles. A measurement system of HPP is under development at LNE, it consists of two main elements. The first one is a calculable CVD and the second one is calculable Resistive Voltage Divider (RVD). The system will have a characteristic impedance of 50 ohm in both high voltage arm and low voltage arm. The principle of this system is presented in Fig.1.

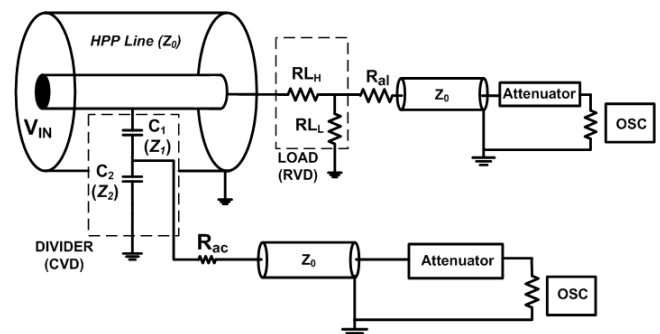


Fig. 1. HPP measurement system at LNE; $R_{ac} = R_{al}$, represent the resistances of impedance adaptation

The calculable CVD presented above is based on a coaxial geometry, which could be directly integrated to the high

voltage coaxial line of a HPP generator and the division ratio (DR) is a function of the characteristic impedances of the coaxial lines present in the divider. It consists of replacing a part of the coaxial line at the output of HPP generator of characteristic impedance of Z_0 by two concentric coaxial lines of characteristic impedances of Z_1 and Z_2 , in such a manner that the sum of their impedances result in the characteristic impedance of the line in which they are present ($Z_0 = Z_1 + Z_2$). In simple terms, the DR of this divider is given by

$$DR = 2 \frac{Z_0}{Z_2} = 2 \frac{C_1 + C_2}{C_1} \quad (1)$$

where C_1 and C_2 represent the capacitances of high voltage and low voltage arms of the divider, respectively.

The DR is chosen to be around 1000:1, in order to have an information rich signal, with high SNR. This signal is again attenuated before it could be read on an oscilloscope (OSC). The most critical part of the CVD is the low voltage arm, as represented by $C_2(Z_2)$ in the Fig.1. It determines not only the DR but also the stability of divider is based on the realization of this component. Even a slightest imperfection could lead to large errors in the high frequency range. It has to be the most homogeneous possible and should be capable of supporting voltage amplitudes up to 500 V. Commonly, dielectrics such as Kapton, alumina and fused silica are used for the low voltage arm but the problem lies in the long term stability of dividers formed with these dielectrics. Kapton is a flexible material, it could be easily integrated in the output line of the HPP generators but before insertion, a conducting film has to be pasted at one of its surfaces, this is usually done by printed circuit board (PCB) techniques [2]. As the time passes, defects arise in the pasted conducting film, which eventually modifies the DR of the divider. On the other hand, a conducting film can be easily deposited on the surfaces of alumina and fused silica substrates. Nonetheless, these latter dielectrics are hard materials, after their insertion in the output line of the HPP generator the coaxial geometry of the line is not assured and the DR cannot be precisely calculated from (1). Different solutions for the geometry and the realization of the low voltage arm of the CVD are under test.

The resistive load presented in the measurement setup, itself is a resistive divider (RVD). It is well known that the resistive dividers are not suited for HPP measurements because of capacitive coupling between various points on the divider that will induce a time constant which could deform the signal [3]. However, with some special care this deformation could be controlled, but with the detriment of the rise time of the signal (upper cut-off frequency). The reason behind this approach is to possess a supplementary validation of the signal at the output of the CVD, in the bandwidth common to these dividers.

III. SIMULATIONS

As a preliminary validation of the approach presented in the previous section, simulations have been performed and the results are presented in the Fig.2.

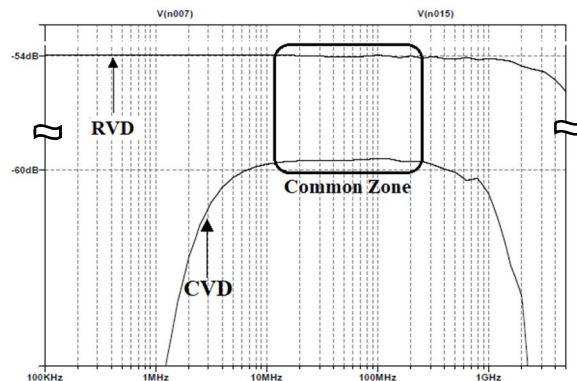


Fig. 2. Bandwidths of CVD and RVD; y-axis not to scale for presentation purpose

It is to be noted that RVD is simulated without parasitic capacitances; it is the reason behind it having a bandwidth of some tens of GHz. Other electromagnetic simulations are in progress in order to optimize the performance and the mechanical designs of both dividers. Once these simulations terminated, the voltage dividers will be fabricated and tested on real HPP systems. Theoretical calculations, simulation results and practical measurements will be then compared together to evaluate errors of the dividers and an uncertainty budget will be presented.

IV. CONCLUSION

In order to respond to the need of traceability of HPP, a measurement system, consisting of a calculable voltage divider standard is under development at LNE. It will be capable of measuring voltage amplitudes up to 0.5 MV with rise times of 1 ns to few ns, with an uncertainty of 3 % for the amplitude and 1 ns for temporal parameters. Electromagnetic simulations are under progress to optimize the performance of these dividers. Structural details together with the simulation results will be given at the conference.

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