Development of a programmable small capacitance standard at LNE

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***Abstract* — A programmable small capacitance standard consisting of several capacitors connected to a 20 channels multiplexer has been developed at LNE. This programmable standard is capable of producing decadic capacitances from 10 aF to at least 10 fF. This paper presents the first phase of the measurements which were performed in order to evaluate the errors introduced by the stray and cross capacitances.**

***Index Terms* — Capacitance measurements, multiplexer, small capacitance standard, capacitance bridge.**

I. Introduction

For the growing need of traceable capacitance measurements of very small values in the micro and nano-electronic industry, the LNE is developing capacitance standards in sub-pF range. The aim of this work is to be able to calibrate the measuring systems connected on devices such as probers or functionalized atomic force microscopes with a target uncertainty of 1% for the lowest capacitance of 10 aF at 1 kHz.

In order to achieve this objective and to extend the range of traceable capacitance measurements to very small values, several capacitance standards were developed using different techniques, namely *Zickner air capacitors* and *lithographied capacitors*. A digitally programmable capacitance standard was also developed, which incorporates these capacitors together with a coaxial *multiplexer (MUX)*, generating a set of predefined values ranging from 10 aF to at least 10 fF. This paper describes the design and the construction of these devices together with the preliminary results.

II. Design and Fabrication

A. Zickner air capacitors

The Zickner air capacitors are made by interposing a screen having a small predefined aperture between its active electrodes [1] (see Fig.1.a). The aperture in the screen controls the amount of electric flux between these electrodes, thus defining the value of the capacitance standard. It could have either a cylindrical or a plane geometry.

At LNE, Zickner air capacitors are developed with a plane geometry. Physical dimensions and diameter of the aperture are determined by finite element modelling. A micrometric screw (see Fig.1.b) is also integrated on one of the electrodes in order to have a fine adjustment of the nominal value of the capacitor. Finally, capacitors of values 10 aF, 100 aF, 1 fF, 10 fF and 100 fF are fabricated.

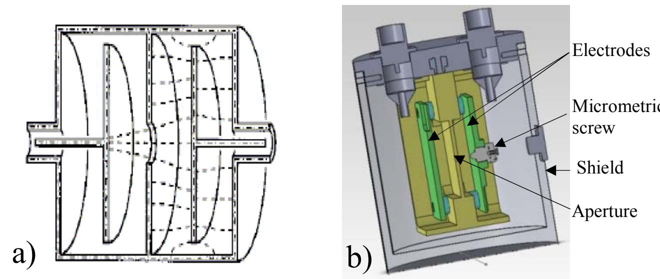

Fig.1. a) Schematic of a Zickner capacitor [1]; b) CAD of LNE's Zickner air capacitor.

B. Lithographied capacitors

Capacitance standards of relatively smaller sizes, facilitating their integration to decades, have been developed by optical lithography. These capacitors have been fabricated on a fused silica substrate where the patterns of the electrodes and a part of the electrical screens have been deposited by gold pulverisation on each face of the substrate (see Fig.2.a). The substrate is then enclosed in a copper shield (see Fig.2.b). The geometry of these capacitors is also determined by finite element modelling. Several capacitors of values 10 aF, 20 aF, 50 aF, 100 aF, 200 aF, 500 aF, 1 fF, 2 fF, and 5 fF have been developed and put together in forms of decades (see Fig.2.c).

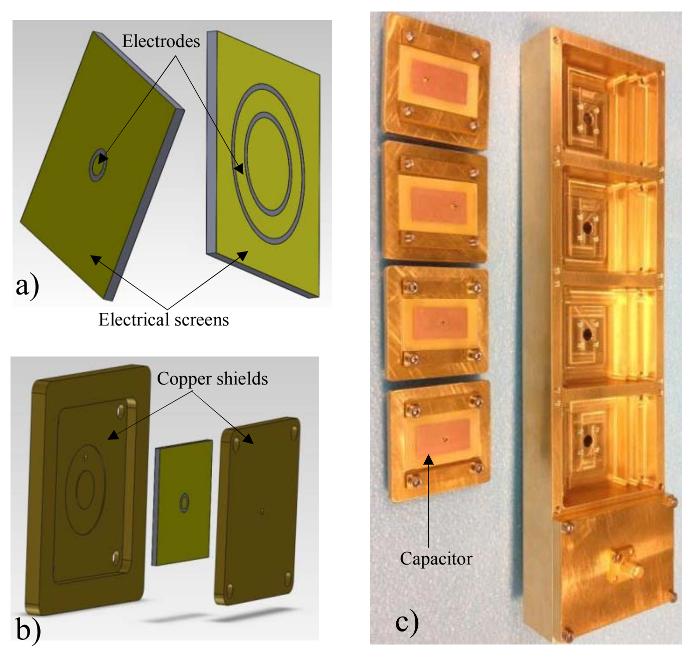

Fig.2. a) Top and bottom faces of the capacitor; b) Capacitor before encapsulation; c) Capacitors ready to be put in decades.

C. Programmable capacitance standard

To produce decadic capacitance values from 10 aF to 10 fF a programmable capacitance standard is developed which incorporates the capacitors described in previous sections together with a 20-channels multiplexer (see Fig.3). The system of multiplexing consists of multi-layered printed circuit boards (PCB) and *National Instrument*™ (NI) relay driver modules PXI-2567.

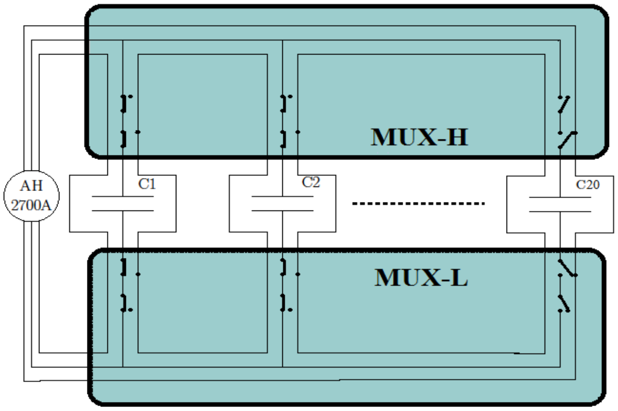

Fig.3. Schematic of programmable capacitance standard where C1 and C2 are connected in parallel to AH2700A bridge.

Special care has been taken in the designing of the MUX, in order to reduce the leakage and cross capacitances. Firstly, high (H) and low (L) terminals are separated. Secondly, the multi-layer construction of the PCB and the shielded relays allows keeping a coaxial geometry as far as possible. Furthermore, the relays used are of latching type. So, once the commutation is done, the circuit piloting the relays is shortened and connected to the ground in order to limit the leakage current [2] and to avoid further perturbations during the measurements. The capacitors not solicited in the measurement are omitted from the system by the configuration of the relays shown in the Fig.3 (for C20), so as not to load the measuring bridge with unnecessary charge.

The MUX is piloted and powered by PXI relay driver modules. The channels can be selected on an interface developed in *LabVIEW*™, which rends the programmable capacitance standard a complete "plug and play" device.

III. Results

A commercial capacitance bridge (AH2700A [3]) is used in order to evaluate the functioning of the MUX by studying the leakage capacitances and the cross capacitances introduced by it. The measurements have been carried out in the frequency range of 1 kHz to 20 kHz and the offset generated by the MUX is corrected each time.

At first, each capacitor has been measured individually with and without the MUX. The difference obtained is lower than 0.5 aF at 1 kHz and could go up to 2.3 aF at 20 kHz, which is negligible in comparison to the specifications of the bridge [3].

Later, the additivity of six of the capacitors (see values in Fig.4) connected to the first six channels of the MUX has been tested until now. A certain number of capacitors are measured in parallel configuration. The result obtained is compared to the sum of capacitances measured individually and the difference is established. The same measurement is repeated with different combinations (different capacitors connected to different channels) and the deviation from the mean of this difference has been studied. It is found to be lower than 1 aF in most of the cases (see Fig.4) and is independent of the number of capacitances and their values. These results are to be confirmed for the rest of channels connected.

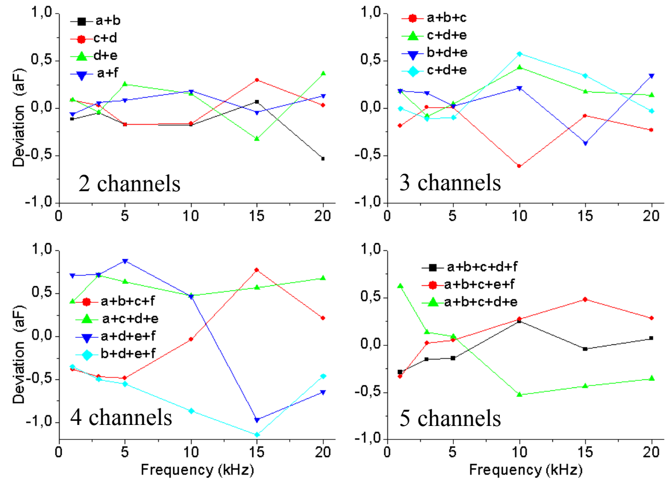

Fig.4. Deviation from the mean of the additivity difference of capacitances. Each graph represents the same number of capacitors and each curve represents different combination of capacitances (a=1 fF; b=2 fF; c=50 aF; d=20 aF; e=10 aF; f=5 fF).

IV. Conclusion

Several very small capacitance standards together with a 20 channels coaxial multiplexer have been developed at LNE, which finally resulted into a digitally programmable capacitance standard. The first measurements that were carried out until now show reproducible errors introduced by the MUX. Further studies are going on and all the results will be discussed in detail during the conference.

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