A Bridge for High-frequency Capacitance Scaling

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Abstract- A bridge, suitable for 1:1 and 10:1 ratio measurements of four terminal-pair impedances to frequencies up to 5 MHz, has been constructed and is presently under testing. The purpose of the bridge is to extend the Italian national standard of capacitance toward higher frequencies; however, the bridge will be employed for resistance comparisons also. Expected best uncertainty is in the order of a few parts in 10^{-5} for 10 nF - 1 nF ratio measurements, at 1 MHz.

I. Introduction

The measurement capabilities of commercial electronic impedance meters have been extended, in recent years, by increasing the frequency range allowed, well into the MHz range. The calibration of such instrument require appropriate sets of impedance standards (typically four terminal-pair resistors and capacitors) provided with certificates reporting the complex impedance up to such high frequencies. The Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN) is working toward the realization and dissemination of impedance unit in the MHz range to satisfy these needs.

A calibration technique for gas-dielectric capacitance standard (typically, 1 pF - 1 nF) based on an automatic network analyzer (ANA) has been set up recently [1]. However, the extension to higher capacitance values (10 nF - 1 μF), i.e. solid-dielectric capacitors, and to resistors, requires a scaling bridge.
Highest accuracy bridges in the audio frequency range are based on inductive voltage dividers (IVD) as ratio arms; therefore, the most natural approach is to extend IVD bridge techniques to higher frequencies [2]; however, setups for high-frequency IVD calibrations become necessary [3]. Hence, we decided to build an all-impedance ratio bridge, suitable for like impedance comparisons in the 10:1 ratio, and with a working frequency range up to several MHz, which is here presented.

II. Bridge schematics

The bridge schematics is shown in Fig. 1.

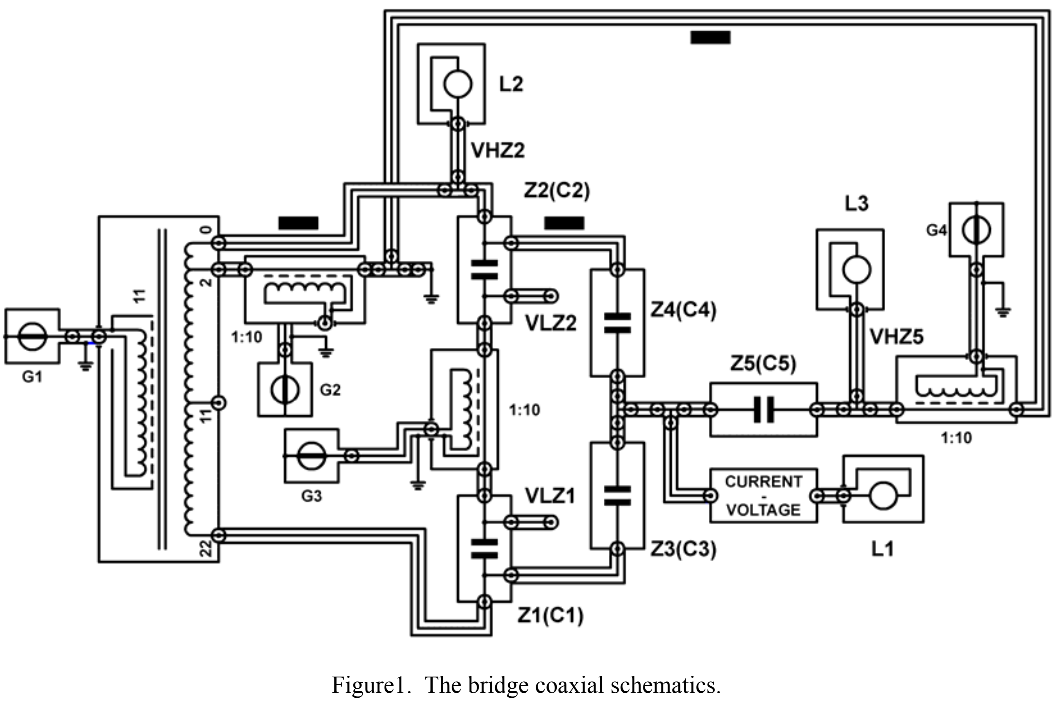

Figure1. The bridge coaxial schematics.

The bridge consists of:

- a main arm, composed of the impedances under comparison Z_1 and Z_2, put in series and defined as four terminal-pair standards;
- a ratio arm, impedances Z_3 and Z_4 , defined as two terminal-pair (2TP) standards;
- main generator G_1, and isolation/ratio transformer, which feeds Z_1 and Z_2 with the measuring current;
- generators G_2, G_3 and injection transformers, to supply voltages necessary to achieve the four terminal-pair condition $V_{LZ1} = V_{LZ2} = 0$ of Z_1 and Z_2;
- Detector L_2 and L_3 to verify $V_{LZ1} = V_{LZ2} = 0$.
- a current balance arm composed of generator G_4, impedance Z_5 which act as current injector, and a current detector (a current to voltage converter, and detector L_1) to verify balance.

When the equilibrium is reached the ratio between Z_1, Z_2 can be calculated from the known values of Z_3, Z_4, Z_5 and measured values of V_{HZ2} and V_{HZ5} by Eq. 1.

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}\left(1 + \frac{Z_4}{Z_5}\frac{V_{HZ5}}{V_{HZ2}}\right) \tag{1}$$

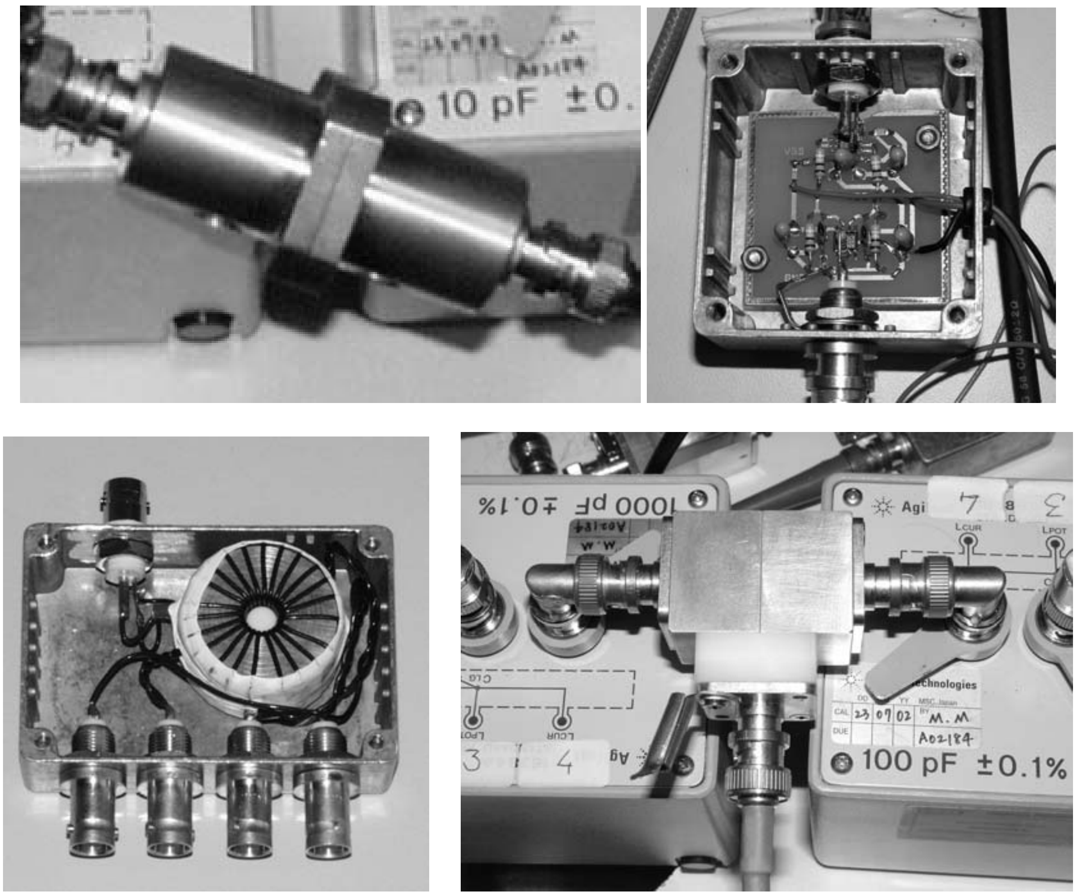

Figure 2. Some components specifically developed for the bridge. (upper left) Zickner injection capacitance; (upper right) current to voltage converter, part of main current detector; (lower left) the main transformer; (lower right) injection transformer inserted in series with impedances Z_1 and Z_2 (now Agilent 16383A 100 pF and 16384A 1000 pF capacitance standards).

III. Implementation details

Generators $G_{1\text{-}4}$ are Agilent 33250A arbitrary generators, configured for sinewave output; $G_{2\text{-}4}$ are frequency-locked to G_1 Depending on the standards and the working frequencies, $G_{2\text{-}4}$ outputs can be reduced by resistive attenuators to mantain a good amplitude resolution. $L_{1\text{-}3}$ is actually a single high frequency lock-in amplifier (Stanford SR844) provided with a differential input head (input capacitance 2 pF) manually switched between different measurement points. Z_5 is a gas-dielectric Zickner capacitor (12 fF) calibrated with the ANA technique as a 2TP impedance. Z_3 and Z_4 are Agilent 16381A (1 pF) and 16382A (10 pF) gas-dielectric capacitors; $Z_{3\text{-}5}$ are calibrated at 1 kHz by a precision capacitance bridge (Andeen-Haegerling AH2500A) and the ANA technique, as 2TP impedances defined at the end of their connecting cables. All transformers are constructed around Vacuumschmelze Vitrovac 2025 small size cores; main transformer is capable of 1:1 or 10:1 ratios, injection transformers have a 10:1 reduction ratio. Coaxial equalizers are commercial clip-on ferrite cores. Some components are shown in Fig. 2.

The instrument is computer controlled via GP-IB interfacing and a LabWindows/CVI control program, whose main purpose is to achieve main balance and definition conditions in an automated way. This is obtained by an implementation of a new, efficient algorithm for multi-detector bridge balancing [see Ref. 4 for an exhaustive description]; the algorithm search for a zero of detector L_1, L_2 and L_3 readings by changing amplitude and phase of $G_{2\text{-}4}$. After a few (typically between 10 and 20) adjustments, zero reading (below 1 μV) of all detectors is reached.

A photo of the bridge is shown in Fig. 3.

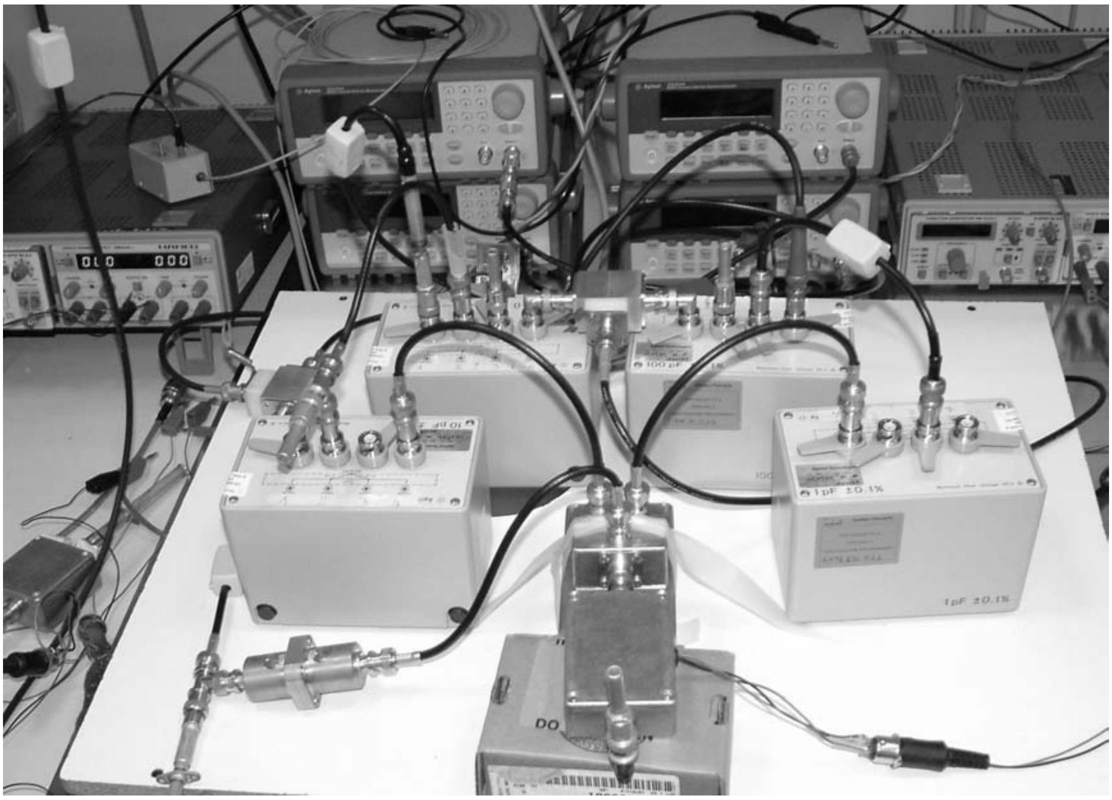

Figure 3. A photo of the complete bridge.

III. Performance

The bridge is now under extensive investigation, to test its performance and investigate the possible presence of systematic errors. Up to now, we operated the bridge for the following comparisons:

a) 1 nF versus 100 pF, frequency range 100 kHz - 5 MHz.
b) 10 nF versus 1 nF, frequency range 100 kHz - 1 MHz;
c) 100 nF versus 10 nF, spot frequency of 100 kHz;
d) 10 kΩ versus 1 kΩ, frequency range 100 kHz - 1 MHz.

Up to now, no uncertainty evaluation has been carried out, but an uncertainty of a few parts in 10^{-5} at 100 kHz and better than 10^{-4} at 1 MHz for case (b) is expected. For the special case (a) of comparisons between gas-dielectric capacitors, it is possible to check capacitance ratios obtained with the bridge with those given by the ANA technique [1]. Fig. 3 shows the result of both techniques for case (a) comparison, and in particular between an Agilent 16383A (100 pF) and 16384A (1000 pF) standards, in the frequency range 100 kHz - 1 MHz, which shows that the two measurements are in in good agreement (better than 50 ppm).

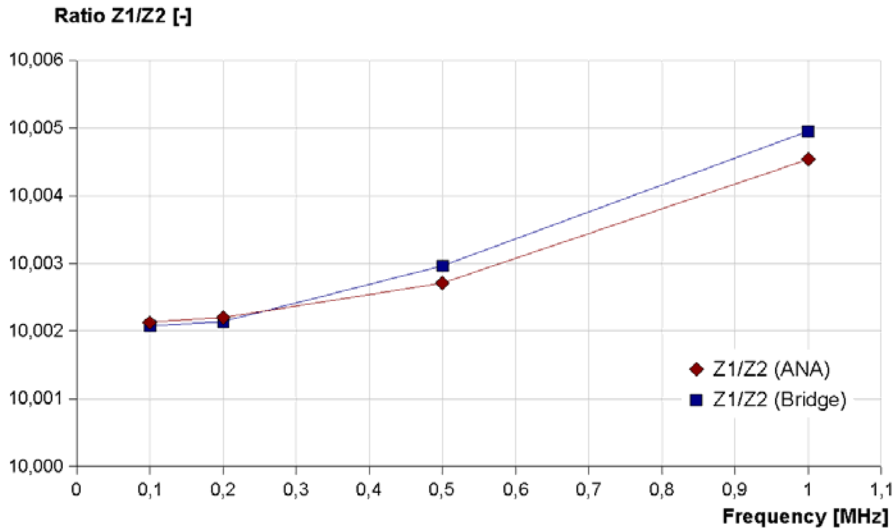

Figure 3. Comparison between the results given by the ANA method and the developed bridge.

IV. Conclusions

A Wheatstone-like coaxial bridge working in a frequency range extending toward the MHz range has been constructed, and the feasibility of sensitive measurements has been demonstrated for a significant impedance range. After a torough uncertainty evaluation, a validation of the performances with an international intercomparison will be organized. The bridge can be used for resistance scaling also, but a reliable calculable 4TP resistance standard in the MHz range is still missing. Attempts to extend the three-voltmeter method [5] of unlike impedance comparison to perform resistance calibration with capacitance reference standards will be attempted in the near future.

References

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