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► **To cite this version:**

Eric Rius, Jean-Philippe Coupez, Serge Toutain, Christian Person. Theoretical and experimental study of compensated bridges in coplanar technology : flexibility of the compensation method. Microwave and Optical Technology Letters, 2002, 32 (6), pp.402-408. hal-02359365

HAL Id: hal-02359365

<https://hal.science/hal-02359365>

Submitted on 5 Apr 2022

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THEORETICAL AND EXPERIMENTAL STUDY OF COMPENSATED BRIDGES IN COPLANAR TECHNOLOGY: FLEXIBILITY OF THE COMPENSATION METHOD

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ABSTRACT: *This paper describes a systematic study of compensated bridges in coplanar technology. If bridges are necessary for filtering the parasitic coupled slot-line mode excited by coplanar discontinuities, they modify the electrical characteristics associated with the fundamental even mode. Based on a low-pass filter approach, a very simple technique is used to compensate for this parasitic effect. Here, emphasis is placed on the flexibility of this compensation technique, which allows us to reduce the technological constraints. Several solutions based on this approach are presented in the case of transmission lines, discontinuities such as tee junctions, and classical distributed bandpass filters. This study is valid for air bridges in classical coplanar technology, as well as for integrated dielectric bridges in multilayer coplanar technology. The concepts developed in this paper are illustrated theoretically and experimentally on multilayer devices over the 1–50 GHz frequency band.*

Key words: *coplanar transmission lines; bandpass filters; millimeter-wave circuits*

I. INTRODUCTION

Many studies have shown that the coplanar waveguide can be considered as an alternative to microstrip lines in the millimeter frequency range [1]. Nevertheless, the problems associated with the present shortage of mature equivalent-circuit models and the problems related to the suppression of the

parasitic coupled slot-line mode with bridges are the main drawbacks of this technology. For this last point, additional technological processes are needed to make bridges. Moreover, the bridge excess capacitance can be considered as the dominant performance-limiting factor at millimeter-wave frequencies. So, in order to avoid such a problem, several authors have proposed a very simple compensation technique based on the association of a high-impedance line with the low impedance presented by the bridge [2–5].

The present paper is focused on the flexibility of this compensation techniques. In fact, by taking a classical impedance match approach equivalent to a low-pass filter approach, it is pointed out that the length of the bridges as well as a precise positioning are not critical points.

We illustrate the concepts developed in this paper only in multilayer coplanar technology, but the validity of the compensation technique for air bridges in classical coplanar technology along with integrated dielectric bridges in multilayer coplanar technology has been already demonstrated. Flexibility will be illustrated first by matching bridges of different lengths on 50 Ω coplanar lines. Second, the compensation of tee-junction discontinuities will be considered. The case of cross-junction discontinuities, which we have also studied, although not reported here, give similar results. Finally, theoretical and experimental bandpass filter responses will be compared on considering, first, noncompensated bridges, and then compensated ones.

II. PARASITIC INFLUENCES OF THE DIELECTRIC BRIDGES

Both air and dielectric bridges introduce a shunt capacitance to ground due to the coupling between the CPW center conductor and the bridge span. Obviously, the characteristic impedance and the associated effective dielectric constant of the CPW transmission lines are significantly modified in the bridge region. Taking into account the low dispersive characteristic of the coplanar technology, in a first approximation, these variations can be calculated with a static method like, for instance, the finite-difference method [6]. In the case of an air bridge, Weller et al. [5] have shown that the excess capacitance is about 1.5 times the value expected from a simple parallel-plate approximation. From a numerical point of view, one should note that the presence of a bridge results in a sharp discontinuity for the coplanar waveguide. Fortunately, the overall length of a bridge is usually small. As a result, the influence of one single bridge on the transmitted RF signal remains negligible up to very high frequencies. This frequency depends both on the length of the bridge and on the transverse dimension of the line. However, practical coplanar designs require a large number of bridges, which results in an accumulation of parasitic effects on the circuit and, consequently, deteriorates its electrical performance (Fig. 7).

III. BRIDGE-COMPENSATED APPROACH

A. “Low-Pass Filter” Concept. In terms of technological feasibility, the best way to compensate for the excess capacitance is to introduce a length L of a high-impedance line on either side of the bridge (Fig. 1). Using ideal transmission-line theory for an impedance match, L can be easily calculated. In this way, the bridge capacitance is transformed into a low-pass filter structure ($L-C-L$: T model) with a very high cutoff frequency. The configuration based on the use of two bridges associated with a high-impedance line also can be a

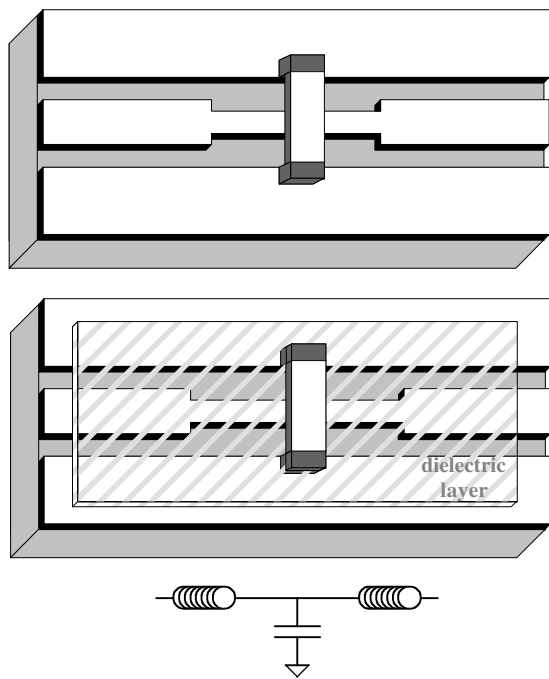


Figure 1 High-impedance compensation in classical and multilayer coplanar technologies

solution: if so, a low-pass structure ($C-L-C$: π model) is implemented.

By comparison with the solution that consists of only reducing the width of the CPW line beneath the bridge in order to offset the decrease in impedance affected by the bridge, the main advantage of the compensation technique lies in the reduction of technological constraints: it requires neither very tiny strips nor a very precise positioning of the bridge.

B. Flexibility of the Compensation Illustration on a 50 Ω Transmission Line. Another advantage of the compensation tech-

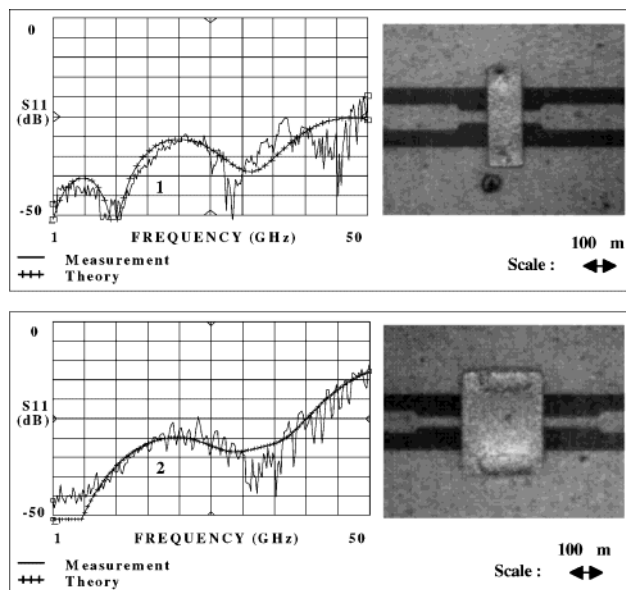


Figure 2 Compensated bridges in multilayer coplanar technology. Experimental results and layouts

nique is its great flexibility. In fact, by using the low-pass approach, this method is valid whatever the bridge length. As the length of the compensation varies with respect to that of the bridge, only the cutoff frequency of the compensation structure is modified. To validate these concepts, we have built two dielectric bridge lengths on 50 Ω coplanar waveguides. The technological parameters for the technology used in this paper are $\epsilon_r = 9.6/h = 635 \mu\text{m}$ for the alumina substrate and $\epsilon_r = 4.3/h = 40 \mu\text{m}$ for the upper dielectric layer. The 50 Ω coplanar waveguide corresponds to a 80 μm strip width and a 55 μm slot width.

The bridge lengths are chosen in order to demonstrate the compensation techniques. The two bridges used have lengths of 135 and 300 μm , respectively (Fig. 2, curves 1 and 2). It is obvious that such lengths will not be used in common prac-

tice. The lengths L of the high-impedance compensations are calculated by using a circuit model coupled with a static analysis. For the two circuits, the experimental return-loss levels obtained at 40 GHz are better than -20 dB; these experimental results are in good agreement with theoretical ones.

IV. COMPENSATED BRIDGES AND JUNCTIONS

A. *Compensated Bridges on Tee Junctions.* The same approach as above is also applied to improve the millimeter-wave performance of tee- and cross-junction discontinuities. The use of bridges to suppress the excitation of the coupled slot-line mode in such geometries is a common practice. Bridges, nevertheless, modify the electrical parameters of the structure, which results in a shift of the resonator frequency

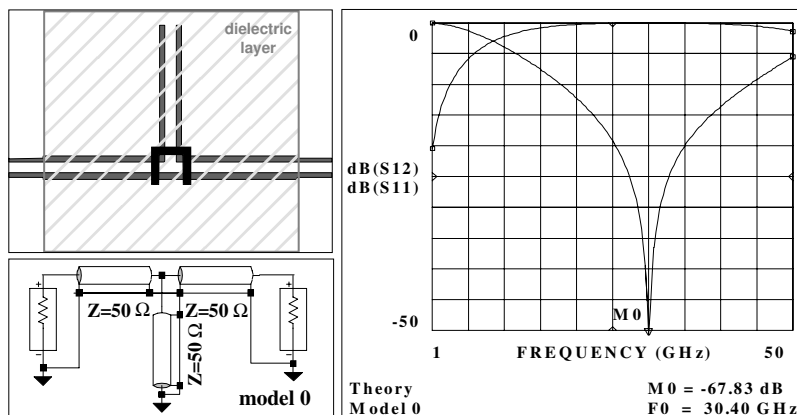


Figure 3 Theoretical multilayer coplanar tee-junction response

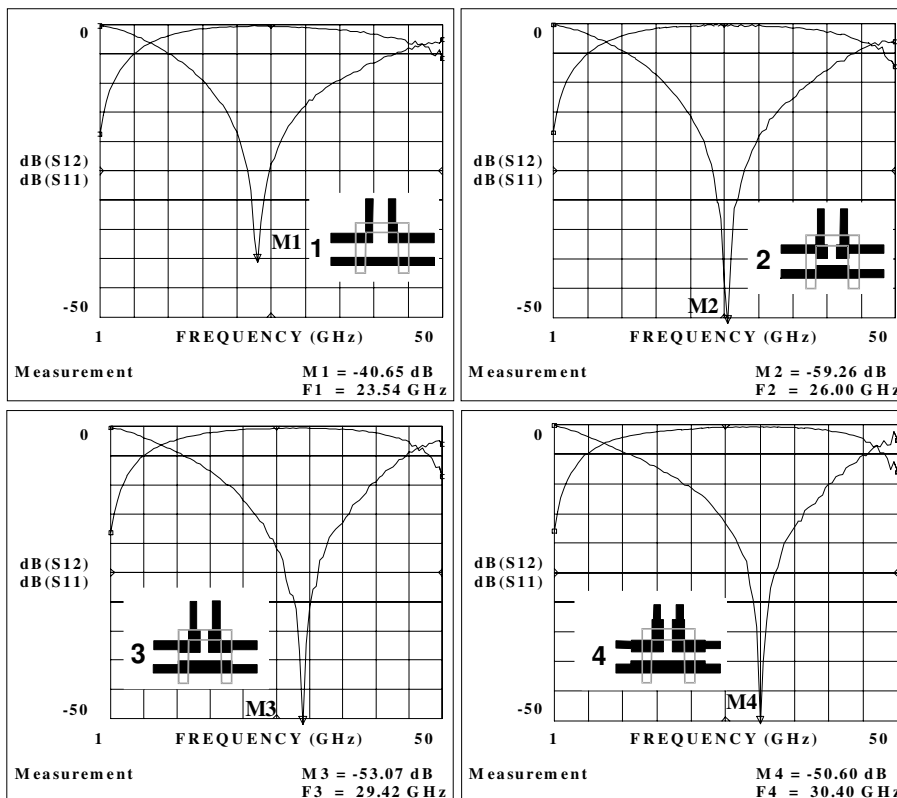


Figure 4 Study of compensated tee junctions. Experimental responses

response. A compensation technique thus allows one to modify the frequency in order to obtain the required value.

We will now deal with tee-junction discontinuities, but the conclusions of this study are also valid for cross-junction discontinuities and bends.

By using a very simple model (model 0), the structure 0 is designed to obtain a resonant frequency equal to 30.4 GHz (Fig. 3). As in the case of a transmission line, the model used is a circuit model coupled with a static analysis. Losses and eventual parasitic modes are not taken into account. On the other hand, according to the classical lumped model, in a first approach, the influence of the junctions is considered by properly defining the reference plane of the different connected lines at the junctions. In the model 0, the bridges are ignored.

A theoretical study and measurement are carried out to examine the behavior of such a structure when the strip width is modified at the junction level. It can be noted that

the presence of the bridges is necessary, and provides a decrease of the resonant frequency (Fig. 4). By modifying the junction geometry, i.e., by reducing the strip width, one can compensate for the bridges, and consequently increase the resonant frequency up to the desired value. Figure 4 also presents experimental results concerning different degrees of the compensation technique at the junction discontinuity. Without any compensation for the dielectric bridges, the measured resonant frequency is 23.54 GHz (structure 1). In structure 2, a first compensation is obtained by modifying the center of the junction with a reduction of the strip width. The frequency value measured is 26 GHz. In structure 3, the strip width is reduced at the junction center and under the bridges: a resonant frequency of 29.42 GHz is measured. The inductive character of the modified junction is noticeable. Finally, structure 4 is characterized by the use of reduced strip-width lines on a correctly chosen length, both on resonators and access lines. In this case, the measured resonant frequency is

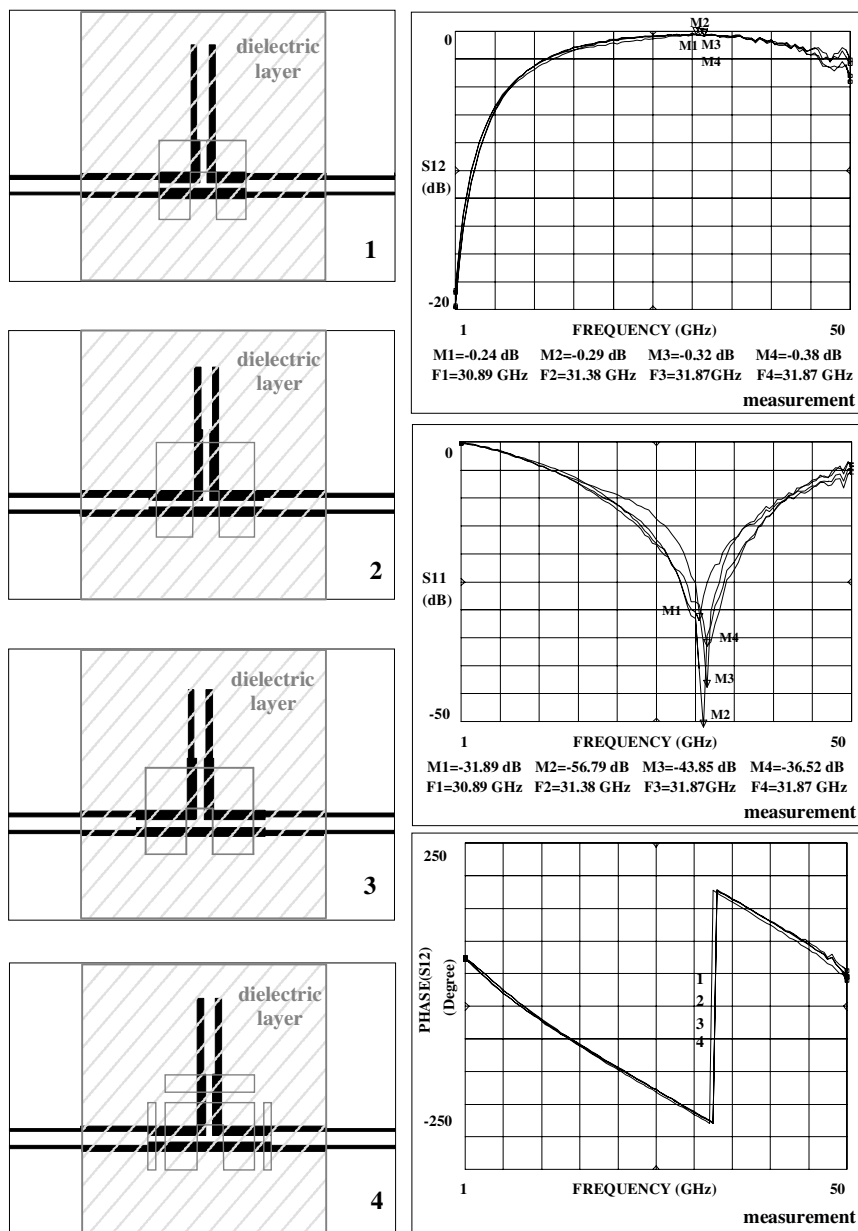


Figure 5 Flexibility of the compensated method. Experimental responses for compensated tee junctions

equal to 30.4 GHz, which is equivalent to the theoretical one given by model 0.

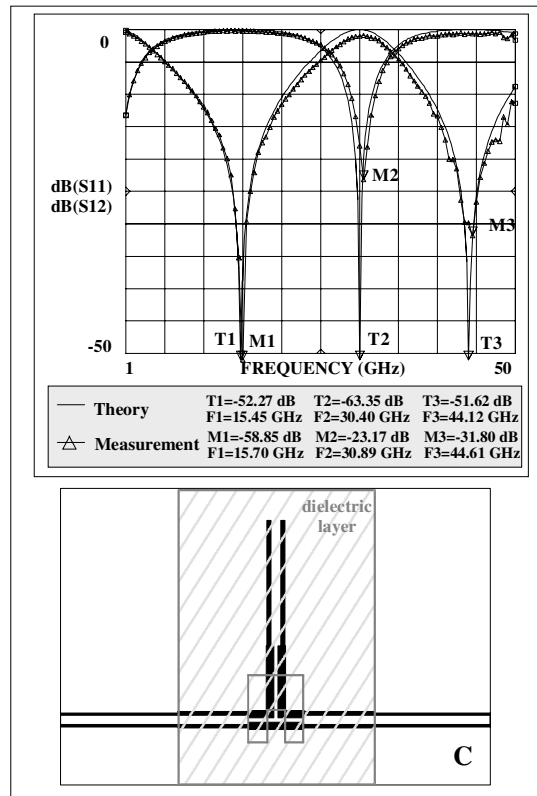
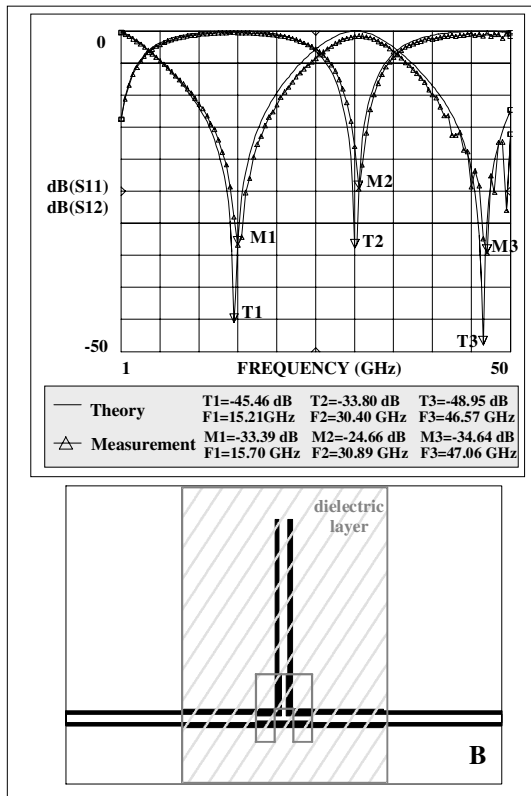
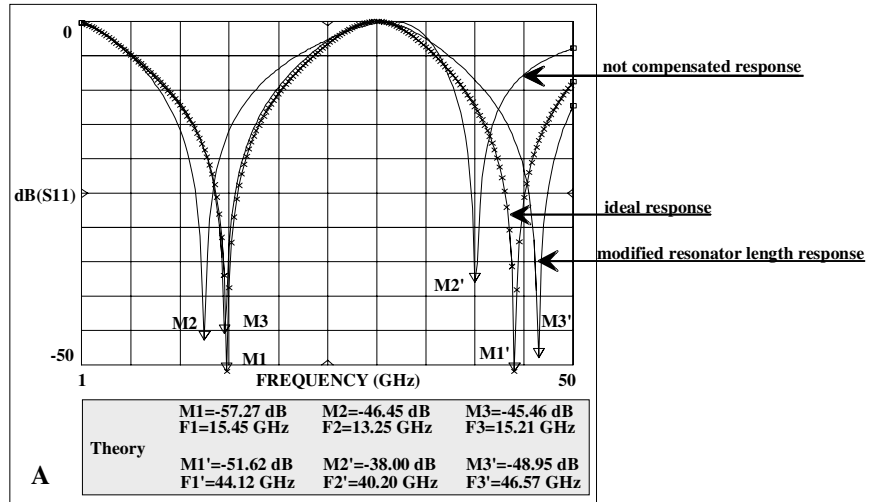
B. Flexibility of the Compensation Method. According to these results, along with the method flexibility, one can thus accurately design a resonator at a fixed frequency. As the compensation technique can be applied to many cases, e.g., for different bridge lengths as well as different numbers of bridges, various topologies of resonators are available for a given response. We have also tested different tee junctions; Figure 5 displays some experimental data. For example, four identical-length resonators with different bridge layouts and compensation techniques have been initially designed to give the same frequency response in both magnitude and phase.

The experimental results obtained with these devices show that the response obtained is the desired one, and that accuracy is good whatever the layout.

In structures 1, the bridges are entirely compensated by the inductive junction center (Fig. 5). In structures 2 and 3, bridge lengths are longer than in the previous case: we thus add compensation. Finally, in structure 4, the single bridge is replaced by dual bridges.

Similar experiments performed on cross junctions and on open resonators gave identical results, and thus confirmed the validity and flexibility of the compensation technique.

C. Broadband Validity of the Compensation Method. As previously illustrated, the presence of bridges on resonators sig-



modified resonator length response

compensated bridge response

Figure 6 Broadband compensation on tee junction

nificantly modifies their resonant frequency. In fact, by simply changing the resonator length, it is easy to obtain the desired resonant frequency. However, since the phase response is modified in this case, it thus differs from the theoretical one.

For instance, for a $\lambda_g/4$ short-circuited resonator, this modification enabled us to adjust the first resonant frequency, but not the other ones that correspond to multiples of $\lambda_g/4$. By correctly using the compensation technique, the response of the compensated resonator will exactly follow the ideal-model response. To illustrate this idea, some experiments are carried out on a 15.5 GHz resonator. Theoretical and experimental data are presented in Figure 6.

Graph A shows that bridges shift the first- and second-zero reflection frequency. By simply modifying the resonator length, only the first-zero reflection frequency is corrected, whereas the use of the compensation technique allows one to obtain the desired theoretical response over the whole frequency band. Experimental and theoretical data obtained with a shortened resonator length are compared (curve B, Fig. 6). Curve C (Fig. 6) illustrates the comparison between experimental and theoretical data when a compensation technique is used. The good results observed validate the proposed technique.

V. APPLICATION TO MILLIMETER-WAVE BANDPASS FILTER

Finally, to validate both the above compensated-bridges concepts and flexibility, we designed a bandpass filter, which consisted of a classical short-circuited stub bandpass filter [7]; it is implemented by using multilayer coplanar technology. This kind of wideband filter is chosen in order to avoid sensitivity problems all over the design. The electrical characteristics of this fifth-order filter are 31.5 GHz central frequency and 61% relative bandwidth. Figure 7 compares the ideal electrical response of this filter with the theoretical

electrical responses of two identical filter configurations designed with 60- and 120- μm -long uncompensated bridges. The responses display strong degradations in the bandwidth. Return losses are greater than -12 dB, and the central frequency is shifted. These simulations illustrate the need to limit the parasitic effects of the bridges by using an appropriate compensation.

In the final prototype, bridges are thus compensated and their lengths chosen in this case to exceed 100 μm . Indeed, the length of the associated compensation is calculated in relation to the bridges one, which explains why the latter is not a critical point. Obviously, technological constraints are drastically reduced.

The experimental response of this filter presented in Figure 8 fits well with the desired response, and thus validates our approach.

VI. CONCLUSION

This work has dealt with the compensation of excess capacitance presented by bridges in coplanar technology. This compensation technique, based on high-impedance association, is a well-known method. Here, we only emphasized the high-flexibility degree of this technique that, finally, allows one to significantly reduce the technological constraints associated with the bridge length and position.

For instance, flexibility enables one to design the same electrical basic function in magnitude and phase, with different bridge lengths, numbers, and configurations. For each configuration, the associated compensation line is correctly modified. Furthermore, such a flexibility allows one to perform broadband compensation.

The concepts exposed here are valid for both air bridges in classical coplanar technology and integrated dielectric bridges for multilayer coplanar technology. They are theoretic-

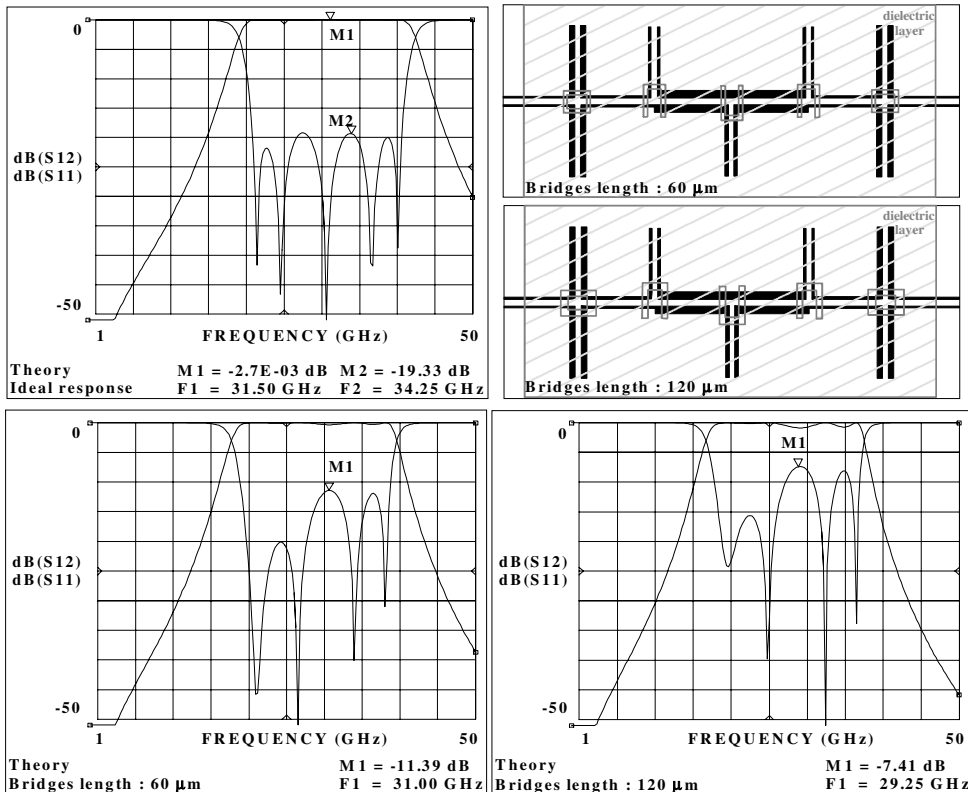


Figure 7 Parasitic influence of uncompensated bridges on a bandpass filter

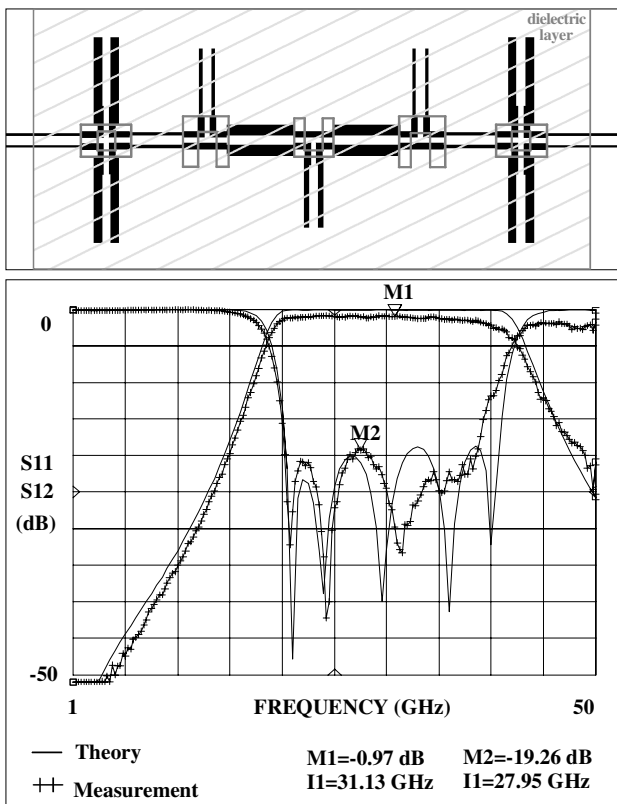


Figure 8 Compensated bridges on a bandpass filter. Experimental and theoretical responses

cally and experimentally validated, in the multilayer case, on transmission lines, tee junctions, and bandpass filter at millimeter frequency. Concerning modeling, because of the low dispersive coplanar technology, the use of a circuit model approach coupled with a static analysis seems to be sufficient up to 50 GHz.

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