# A Class of Novel Uniplanar Series Resonators and Their Implementation in Original Applications

Khelifa Hettak, Nihad Dib, *Member, IEEE,* Abdul-Fattah Sheta, and S. Toutain

***Abstract*— A class of novel millimetric uniplanar series resonators are presented, which can be used in monolithic and hybrid uniplanar microwave integrated circuits (MIC's). The proposed structures are able to demonstrate low radiation and compactness characteristics, which are attractive for passive and active monolithic and hybrid integrated circuits. A principle of achieving these high-quality circuits is described and also confirmed by experimental and theoretical results, which are in good agreement up to 50 GHz. To illustrate the features of the proposed series resonators and demonstrate their effectiveness, two classes of miniature coplanar waveguide (CPW) filters (namely, low-pass and bandpass) are designed using these resonators. The developed low-pass filter has some important advantages such as low insertion loss in passband, very wide stopband, high cutoff rates, small size, low number of elements, and an effective control of spurious signals. On the other hand, the newly developed bandpass filter provides an alternative, yet compact, structure to classical filters. Obviously, many other classes of filters or passive components can also be designed.**

***Index Terms*—Bandpass filters, coplanar waveguides, equivalent circuits, integral equations, low-pass filters, microwave filters.**

## I. Introduction

UNTIL NOW, in microwave integrated circuits (MIC's), the microstrip transmission line has been predominant. Nearly all well-known devices of the conventional microwave circuits can be realized in microstrip, e.g., couplers, power splitters, hybrids, filters, and circulators. However, only a few investigations were made into the capability of making these devices into uniplanar technology [1]–[8]. The recent development of the uniplanar technology has offered microwave designers more flexibility for circuit integration. The association of coplanar and slotline and the use of both parallel and series passive and active solid-state devices considerably facilitate circuit implementation. Among these advantages, the inherent decoupling of adjacent lines offers high flexibility in circuit design and miniaturization without scarifying the performance. In addition, the use of uniplanar technology circumvents the need for via holes to connect the center conductor to ground. However, while the subject of resonators is now very mature, there is relatively little literature on coplanar waveguide (CPW) resonators [9]–[11]. Indeed, resonators form the basic design elements in many microwave components. Using uniplanar technology, sophisticated circuit elements can be designed, which are mostly impossible in conventional microstrip technology. Some basic elements, which have already been proposed by Houdart [12] and Holder [13], are short- or open-ended 90° transmission-line resonators connected in series. In uniplanar technology, resonator elements can be either implemented in the "inner" or "outer" conductor of the CPW. Recently, Weller [14] reported on a compact-series resonator configuration using the microshield line, which are up to 2.5 times smaller than a conventional implementation. These basic circuits can be used in filters, switches, impedance transforming elements, and dc blocking applications.

In this context, considering that all the degrees of freedom linked to uniplanar technology are not yet fully exploited, the objective of this paper, on one hand, is to show that the coexistence of the principal forms of propagation (CPW and slotline) on one substrate leads to new developments in the design of different types of series resonators, which brings a great flexibility for the designer. The other objective is to propose a clever way to create alternative structures to traditional configurations, which is an essential factor in the construction of multifunction circuits. In order to fully explore the inherent advantages of the proposed uniplanar series resonators, a possibility of the usage of such structures in the area of filters is investigated. In the first application, it is shown that the very compact structure of the low-pass filter, using the proposed series resonator, permits the control of the stopband behavior, gives lower insertion loss in passband, very high cutoff rates, and very wide stopband. For the second application, it is illustrated that the joint use of series and parallel elements leads to an original structure of a bandpass filter, which presents good performance and compactness.

## II. Variants of Series Circuit Elements in Uniplanar Technology

Fig. 1 indicates the possibilities for using the uniplanar technology to produce the main types of elements required in millimeter-wave circuitry. The figure also reveals the possibility of simply coupling slotline to coplanar lines in order to form series resonators. It is important to note that the different new forms of uniplanar series resonators, presented above, indicate, firstly, the harmonious coexistence of various propagation modes (slotline and CPW modes) built into a single structure, and, secondly, leads to new challenges in circuit design. Fig. 2 shows the schematic of the tested CPW series

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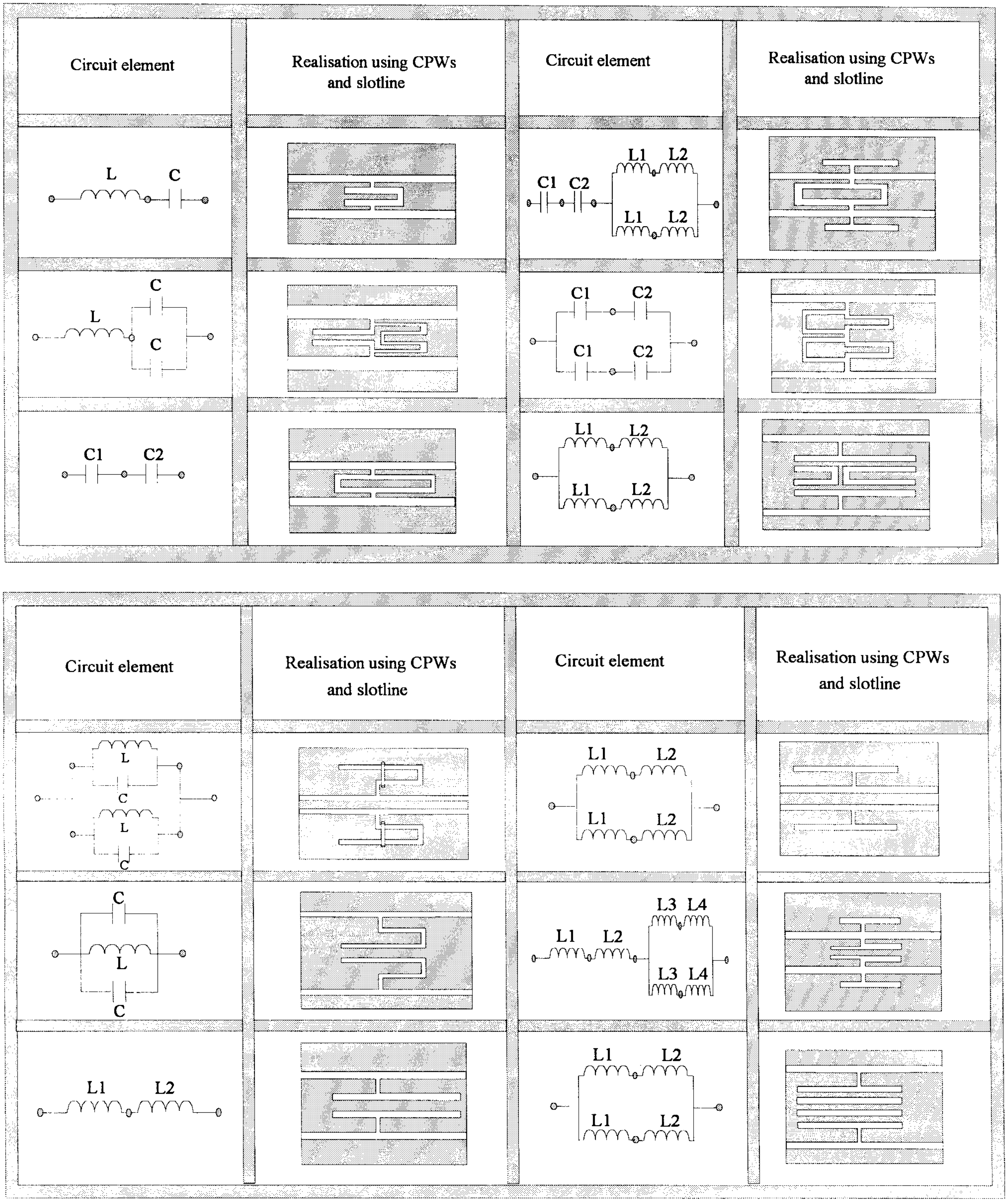


Fig. 1. Series circuit elements in uniplanar technology.

resonators, where simplified models can be considered as a first step for the design of these new structures (i.e., no discontinuity effects, low frequency, and zero electromagnetic interaction). Several variants of these types can be used in practice to achieve specific circuits. In order to understand the electromagnetic behavior of these resonators, it is necessary to study their response as a function of frequency so as to better understand their effect on the performance of filters. Therefore, a rigorous space-domain integral-equation (SDIE) method solved by the method of moments (Galerkin's technique) in conjunction with simple transmission-line theory is applied to analyze the structures shown in Fig. 2. The SDIE approach has been previously

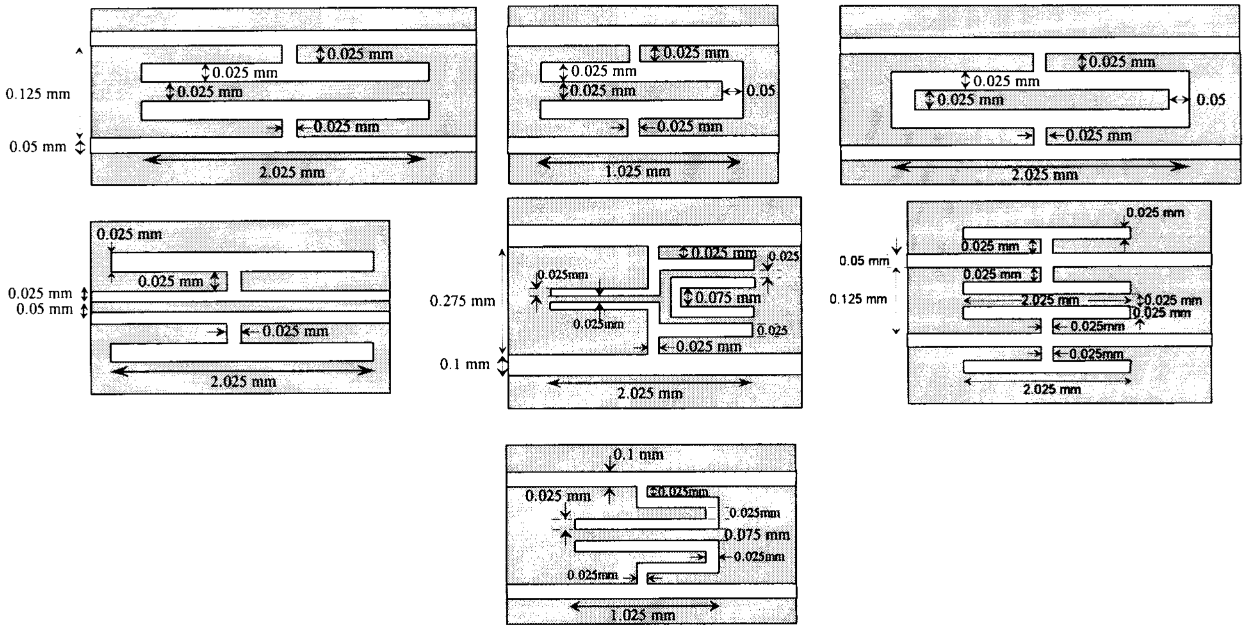

Fig. 2. The top views of the tested CPW series resonators.

applied to study several CPW discontinuities, and has shown very good accuracy and versatility in terms of the geometries it can solve [15], [16]. The details of the SDIE method may be found in [17]. Fig. 3 shows that theoretical and experimental results are in very good agreement, which proves our original concept. It should be noted that such a behavior will not be obtained if an ideal resonator is assumed, which clearly shows the need for full-wave analysis of such structures.

The above results were obtained using circuits fabricated on 0.254-mm-thick $Al_2O_3$ substrates, metallized with approximately 3-$\mu$m-thick gold layers. With this study being performed, the potential of the proposed resonators to be used in the implementation of new filter structures is investigated in Section III.

## III. The Potential of the Presented Resonators for Filter Realization

New systems like communications satellites, and mobile and cellular radio communications, continue to require microwave filters with more stringent passband and stopband control, smaller size, and lighter weight. This requirement has stimulated specially sophisticated advances in insertion loss and group delay, and more practical and compact configurations. To help meet this requirement, this section will present the design of uniplanar filters in a more compact form and with some improvement on their electrical performance. Indeed, the recent progress in the uniplanar technology has stimulated many researchers to be interested in the design of filters using this technology [18]–[32]. It is advisable to note that the possibility to realize series and parallel elements by simple etching of the central conductor or the ground plane suppresses the need to use impedance inverters in cells of filtering. Thereby, a certain number of filters has been realized to demonstrate the efficiency of the design method and the pertinence of the joint utilization of the series and parallel stubs to get satisfactory performance with a low number of elements. This demonstration is going to be made on low-pass and bandpass filters.

### A. A New Miniature Semilumped Low-Pass Elliptical Filter

Previously, literature on different microstrip low-pass elliptical filters have been published, most of which are based upon the use of two modes of resonances at different frequencies in a metallized rectangle on the microstrip substrate, and by properly joining such rectangles together. An example is a seven-pole elliptic-function low-pass filter consisting of only three rectangles and the microstrip terminating lines [33]. However, the problem of the limited width of the stopband makes the design very difficult to apply when very wide stopbands are required. Therefore, an alternative solution is proposed in order to overcome this problem.

As presented in Fig. 4, the series cell, which is composed of an inductance in parallel with a capacitance, is realized through a specific series component integrated into low-impedance line sections simulating parallel capacitances. In addition, these low-impedance line sections can be minimized in length by adding the open-end CPW shunt stubs. This configuration improves the behavior of the filter in the stopband region, resulting in the suppression of spurious responses through a large bandwidth beyond the cutoff frequency of the low-pass filter. This filter represents a new realization of a third-order semi-lumped low-pass elliptic filter in uniplanar configuration with a cutoff frequency of 3 GHz. The elements of the filter are calculated using a standard design procedure [34].

The advantages obtained are size reduction, low insertion loss, and very wide stopband of the distributed prototype, leading to a filter with improved overall characteristics, as demonstrated by the experimental results. The above demonstrates that uniplanar low-pass filter with very wide stopband, low number of elements, and high cutoff rates can be designed and fabricated. This is obtained through the use of a new

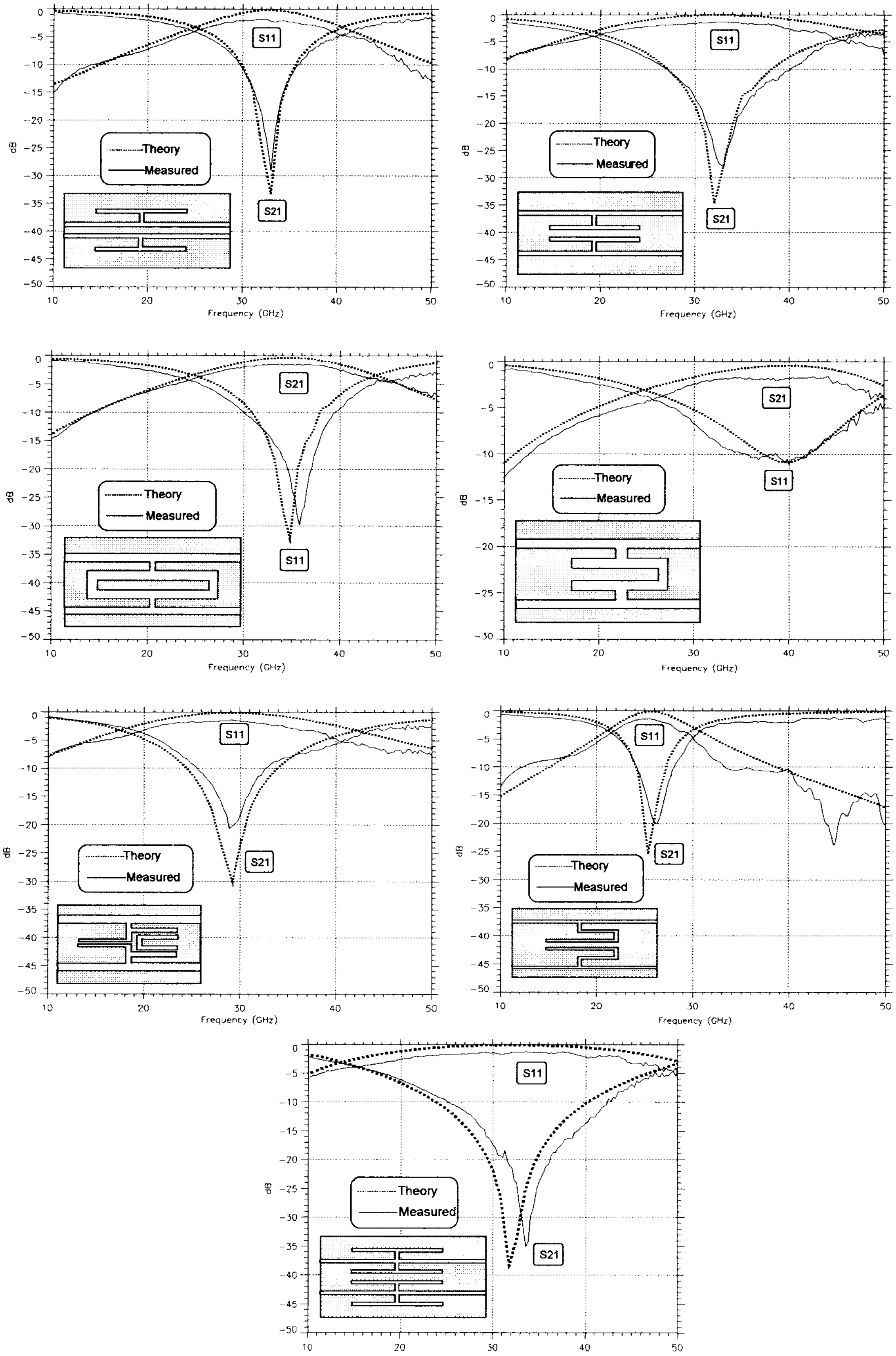


Fig. 3. Experimental and theoretical results for the different uniplanar series resonators.

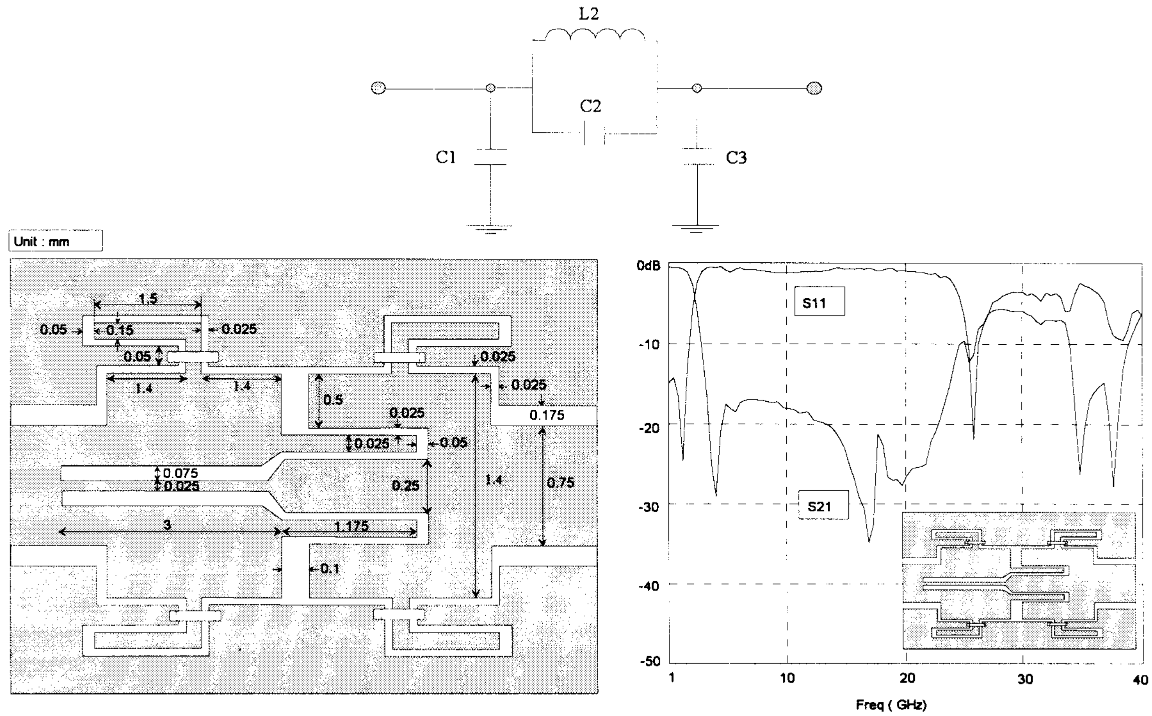


Fig. 4. Layout of a new miniature semilumped low-pass elliptical filter and measured response.

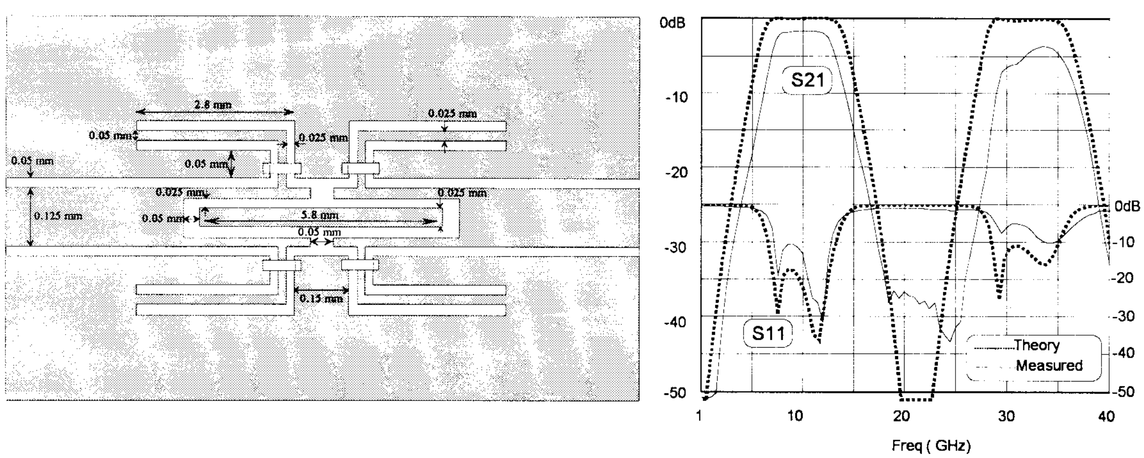


Fig. 5. One possible topology of a multistub bandpass filter and measured response.

specific series stub. The high design flexibility linked to uniplanar technology can also be illustrated on other types of filters. In Section III-B, its use in the design of a bandpass filter is presented.

### *B. A New Miniature Multistub Bandpass Filter*

Very wide-band miniaturized bandpass filters are always in demand for systems requiring broad bandwidth, small size, and light weight. Bandpass structures with multipoles of attenuation at the quater-wave frequency and dc are attractive for miniaturized bandpass filters. Here, it is illustrated that the joint use of series and parallel elements leads to original structures with good performance bandpass filters. It is advisable to note that the design of such filters using a microstrip line requires the utilization of series $\lambda_g/4$ inverters, which considerably increases the number of elements and may cause unacceptable insertion loss in the passband. As suggested in this paper, the interest in the uniplanar technology is linked to the diversity of configurations which it provides for the designer. Indeed, the possibility to realize simple parallel and series resonators necessary for the bandpass-filter design allows one to decrease the dimensions of these filters. Thus, several physical realizations are possible (e.g., configurations with multistubs can be used). One compact bandpass filter is shown in Fig. 5, which consists of two $\lambda_g/4$ open-ended series stubs and two $\lambda_g/4$ shorted parallel stubs with a center frequency of 10 GHz and a bandwidth of 60%. The structure has been designed following the guidelines given in [34]. The experimental results of this filter are plotted in Fig. 5, along with simulated results, which are obtained using the procedure described in [35].

The filter configuration allows a high degree of compactness with very good electrical performance. The agreement between simulated and measured results is relatively reasonable until 40 GHz. This might be due to the weak coupling between the stubs, even though the separation between them here is only 100 $\mu$m. In general, in the whole bandwidth, the return loss is lower than $-10$ dB with the insertion losses (including radiation, dielectric, and metallic loss) not exceeding 2 dB. These losses can be reduced by widening the dimensions of the central conductor of the coplanar line, so as to minimize metallic loss. Besides, the filter provides a very high rejection outside the passband. The design of such a filter would not have been possible using classical microstrip technology. With this compact uniplanar filter example, the validity of the developed models has been confirmed.

## IV. Conclusion

Because of the possibilities that it offers for the realization of series elements, uniplanar technology (contrary to microstrip technology) allows one to realize very compact low-pass filters with good performance. Furthermore, the joint utilization of parallel and series resonators allows one to decrease dimensions of bandpass filters, resulting in a high degree of compactness with very good electrical performance. In this paper, two examples were given which should serve as a proof of the validity of the proposed resonators and their models. To fully benefit from these resonators, it is necessary to have reliable models of each constitutive element of the filtering function. It has been shown that the relative flexibility of the SDIE method makes it an attractive tool for the analysis and design of these complex circuits. Finally, these new resonators will greatly expand the freedom in design, resulting in a major reduction of size and superior performance compared to microstrip technology.

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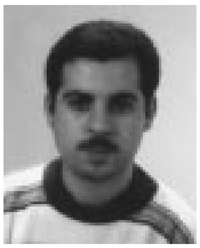

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