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# A Varactor Tunable Complex Impedance Transformer

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**Abstract** - We have conceived and realized a microwave tunable transformer. The tunability is obtained by loading a transmission line by reverse biased Schottky diodes acting as voltage variable capacitances. Only two diodes pairs are necessary to obtain impedance tunability between  $5 \Omega$  to  $300 \Omega$ , with an operating frequency varying of more than  $\pm 10\%$ . Complex loads can also be matched with a wide covering of the Smith chart, but small bandwidth of about 2%. The device length is around a third of the guided wavelength.

## I INTRODUCTION

Tunable devices are of great interest in the field of microwave telecommunications. Tunable filters allow the use of only one filter for the purpose of emission and reception [1], [2], leading to smaller emitter – receiver systems. In the same manner, a tunable complex impedance transformer is interesting for the matching of transistors with a large bandwidth (more than  $\pm 10\%$ ) purpose. Impedance transformers can also be used to realize tunable power dividers useful in the field of beam steering antenna arrays.

In this paper, we present an original topology for a tunable complex impedance transformer. It is realized by loading a transmission line with variable capacitors. Variable capacitors are obtained with reverse biased Schottky diodes. This approach can be seen as similar to nonlinear transmission lines used as tunable delay lines [3], [4]. However, in our case, the design is very different owing the fact that not only the phase has been tuned, but also the characteristic impedance. The varactors are used in small signal around a tunable DC bias, leading to small signal tunable capacitances.

A tunable impedance transformer was already carried out in 1997 by Sinsky and Westgate [5]. Their device was realized in microstrip technology for a frequency around 2.25GHz. The principle was to use a quarter-wave impedance transformer to achieve a simple tunable ladder network. This conception leads to  $\lambda/2$  length devices and needs at least three varactors. In our approach, only two varactors are required (two pairs for a CPW technology without via). Furthermore the device length is around  $\lambda/3$ , leading to smaller insertion losses. Moreover, another interesting feature is that complex load impedances can be matched and the bandwidth is not limited by quarter wavelength transformers.

We show simulations and measurements of a first prototype of tunable complex impedance transformer

using a coplanar waveguide topology (CPW) on a FR4 substrate. Next simulations of a second design are presented on a RT Duroïd substrate with more efficient varactors at 10 GHz. In these two cases the device length is about 35 % of the guided wavelength.

## II PRINCIPLE

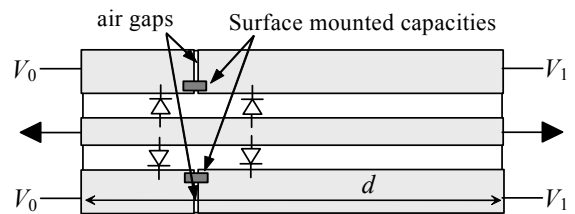


Fig 1. Topology of the tunable device.

Fig. 1 shows the topology of the complex impedance transformer. A CPW transmission line of length  $d$  is loaded by two pairs of diodes, the distance between these two diode's pairs is optimized in term of return loss. With the CPW technology the surface mounted Schottky diodes can be easily soldered. The two diode's pairs are independently biased (voltages  $V_0$  and  $V_1$ ), leading to a much more efficient tunability compared to a single bias. Two air gaps are realized in the ground plane to allow different biases.

Is we take a series LC model to simplify for the varactor, neglecting the series resistance, the effective capacitance can be written as :

$$C_{eff} = \frac{C}{1 - \left( \frac{\omega}{\omega_{cut-off}} \right)^2} \quad (1)$$

where  $\omega_{cut-off} = \frac{1}{\sqrt{LC}}$  is the case cut-off frequency.

So, when L increases the effective capacitance increases leading to a frequency shift to ward low frequencies for the same matching point. Indeed, probably the parasitic inductance is lower in practice than indicated by the manufacturer.

From relation (1) it is also easy to see that the varactor effective capacitance is frequency dependent and

increases with frequency, for  $\omega > \omega_{cut-off}$ , the varactor has an inductance behaviour.

### III RESULTS

#### A. First Prototype

First measurements have been carried out with less efficient Schottky diodes (Philips BAT62-03W) on a FR4 substrate ( $\epsilon_r = 4$ ). Characteristics of these diodes are as follows : 350 fF to 220 fF tunable capacitance for a 0-40V reverse bias, a 6.6  $\Omega$  series resistance, a case parasitic capacitance  $C_p = 100$  fF and inductance  $L_p = 1.8$  nH . The transformer is 15.6 mm long (38% of the wavelength) for a 5 GHz operating frequency. The CPW was realized with a mechanical machining, leading to 160  $\mu$ m air gaps. To minimize insertion losses, surface mounted capacitances have been connected on the air gaps, as shown in Fig. 1.

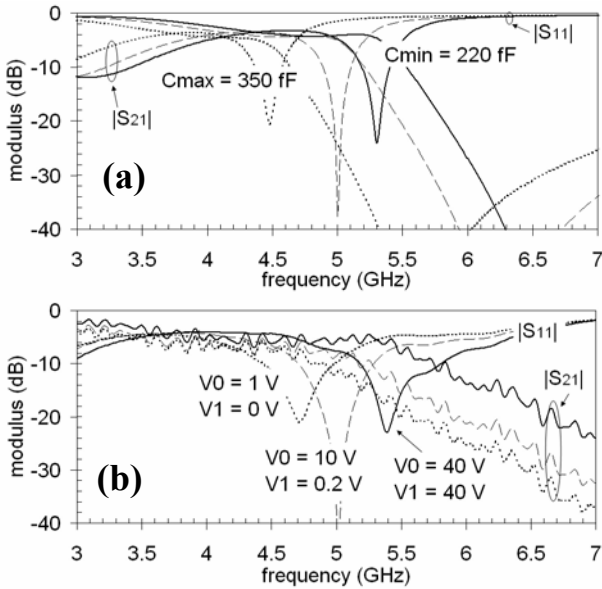


Fig. 2. Measurement and simulation of  $|S_{11}|$  and  $|S_{21}|$ .

Fig. 2 shows simulations (a) and measurements (b) when the impedance transformer is first loaded by 50  $\Omega$ . The extreme matching points leading to a 20 dB return loss have been reported. These points correspond to a variable capacitance of  $C_{max} = 350$  fF and  $C_{min} = 220$  fF for simulations, and biases  $V_0 = V_1 = V_{min} = 0V$  and  $V_0 = V_1 = V_{max} = 40V$  for measurements.

The tuning bandwidth, calculated for a return loss lower than -20 dB, is about  $\pm 7\%$  around 5 GHz for simulations and measurements. The same bandwidth is obtained for load impedances varying from 5  $\Omega$  to 300  $\Omega$ . A frequency shift can be noted between measurement and simulation results, the matching is between 4.49 GHz to 5.3 GHz for

simulations, and 4.73 GHz to 5.46 GHz for measurements. This shift can be due to a bad estimation of the case parasitic inductance given by the manufacturer. The influence of the case parasitic inductance has an important effect on the varactor effective capacitance (1). Measurements for a mean value of the frequency (5 GHz) have been reported in Fig. 2 to show that the return loss can be very small (50 dB in that case).

$S_{11}$  and  $S_{21}$  modulus for the extreme frequencies have been reported in Table 1.

	Frequency (GHz)	$ S_{11} $ (dB)	$ S_{21} $ (dB)
Simulations	$F_{min} = 4.49GHz$	-20.6	-6
	$F_{max} = 5.3GHz$	-24	-4.7
Measurements	$F_{min} = 4.73GHz$	-21	-7.5
	$F_{max} = 5.46GHz$	-22.8	-5.5

Table 1. Summary of  $|S_{11}|$  and  $|S_{21}|$  for the first impedance transformer.

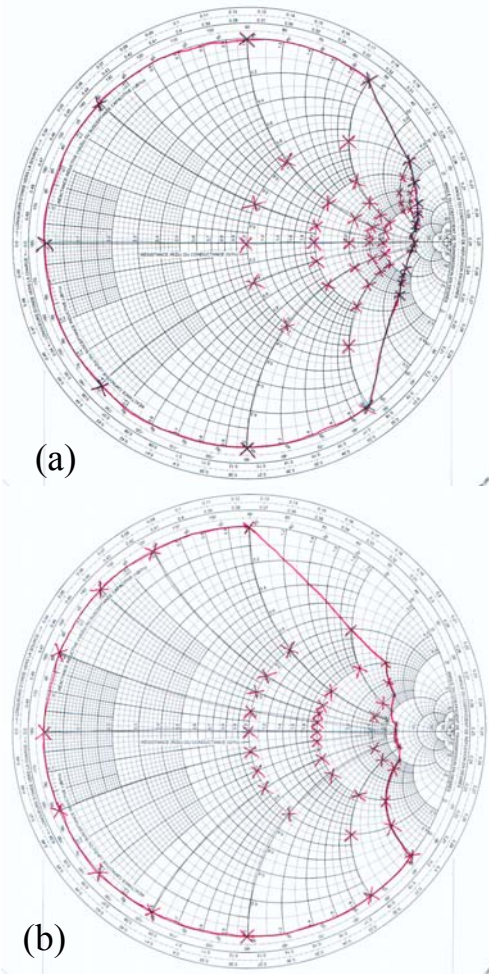


Fig. 3. Smith Chart coverage for complex loads matching.

Simulations and measurements are in good agreement, except the frequency shift mentioned above. Measurement results show more losses than simulations (between 0.8 to 1.5 dB more). This is due to the air gaps with surface mounted capacitor residual losses which were not taken into account in the simulations. Excepted air gap losses which could be minimized with a finer technology, losses are mostly due to the diodes series resistance and substrate losses. We will see in the next section that they can be lower than 0.5 dB if we use more efficient substrate and diodes are used.

Complex loads can also be matched with this impedance transformer. Fig. 3 shows the simulation of the Smith Chart coverage for a return loss better than 20 dB, at 4.8 GHz in (a) and 5 GHz in (b). The coverage is very large. This is very interesting in the field of amplifier design. The complex impedance transformer can be used instead of a quarter-wave transformer associated with stubs in the design of the matching networks. However a large coverage is only obtained for a small bandwidth, about 2 %.

### B Second Prototype

The first prototype has been realized and measured to show the feasibility of complex impedance transformers. It was realized on FR4 with low quality diodes, leading to significant insertion losses. The second prototype shown in this section is realized on a RT Duroid 5880 substrate ( $\epsilon_r = 2.2$ ), with high quality factor Schottky diodes (Agilent HSCH-5314). The model given by Agilent for these diodes leads to a 130 fF to 50 fF tunable capacitance for a 0-4V reverse bias, a 2.8  $\Omega$  series resistance, a case parasitic capacitance  $C_p = 20$  fF and inductance  $L_p = 100$  pH. At 10 GHz the transformer is 6.06 mm length, i.e. 32 % of the wavelength. Figure 4 shows the simulation results.

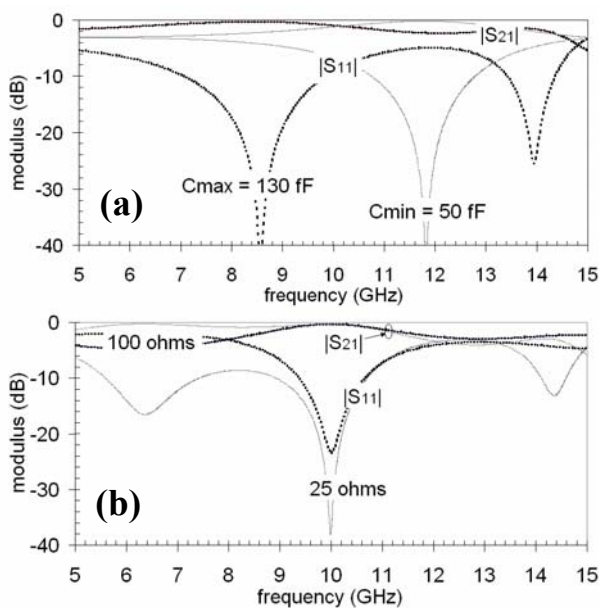


Fig. 4. Simulated  $|S_{11}|$  and  $|S_{21}|$ .

In Fig. 4(a), the tunable bandwidth obtained for a fixed 50  $\Omega$  load is studied. It reaches  $\pm 15\%$  around 10 GHz for a minimum 20 dB return loss. Insertion losses are lower than 0.5 dB.

In Fig. 4(b), the impedance tunability for a fixed 10 GHz operating frequency is studied. Simulations are shown for 25  $\Omega$  and 100  $\Omega$  loads. Insertion losses are better than 0.5 dB.

The tunable bandwidth is always  $\pm 10\%$  for 25  $\Omega$  to 100  $\Omega$  loads.

## IV CONCLUSION

A tunable complex impedance transformer has been designed and measured. The tunability is available for a wide range of complex loads and broad bandwidth. Losses can be reduced to less than 0.5 dB by using high quality factor diodes with a low losses dielectric substrate. The large Smith Chart coverage leads to a device that can be used efficiently instead of a classical quarter-wave transformer associated with stubs for the design of microwave amplifiers matching networks. The wide bandwidth (more than  $\pm 10\%$ ) allows this impedance transformer to be used in the context of wideband amplifiers. Furthermore it could also be used to address the problem of tunable or reconfigurable power dividers.

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