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► To cite this version:

A.-L Perrier, Philippe Ferrari, J.-M Duchamp, D Vincent. A Varactor Tunable Impedance Transformer. Mediterranean Microwave Symposium, Jun 2004, Marseille, France. hal-01816033

HAL Id: hal-01816033

<https://hal.science/hal-01816033>

Submitted on 18 Jun 2018

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A Varactor Tunable Impedance Transformer

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Abstract

We have conceived and realised a microwave tunable transformer. The tunability is obtained by loading a transmission line by reverse biased Schottky diodes eaching as voltage variable capacitances. Only two diode's pairs are necessary to obtain impedance tunability better than $\pm 100\%$ around $50\ \Omega$ with an operating frequency varying of more than $\pm 10\%$. The length of the impedance transformer lies between 0.32 and 0.38 of the wavelength.

1. 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 for a large bandwidth (more than $\pm 15\%$) purpose. Impedance transformers can also be used to realize tunable power dividers, that could be used in the field of beam steering antenna arrays.

In this paper, we present an original topology for a tunable impedance transformer. It is realized by loading a transmission line by variable capacitors. Variable capacitors are obtained with reverse biased Schottky diodes. This approach can be seen as similar to nonlinear transmission lines used for pulse compression or frequency multiplication [3], [4]. However, in the case of impedance transformers, we deal with linear devices. Then 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 at a 2.25 GHz working frequency. The principle was to use quarter-wave impedance transformers 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 necessary (two pairs for a CPW technology), and the device length is around $\lambda/3$, leading to smaller insertion losses. Moreover the bandwidth is not limited by quarter wavelength transformers.

Simulations and measurements of our tunable impedance transformer using a coplanar waveguide topology (CPW) are shown. Two different simulations are presented, one to work at 5 GHz on a FR4 substrate and another to work at 10 GHz on a RT Duroïd substrate. In these two cases the device length is about 35 % of the guided wavelength.

2. Principle

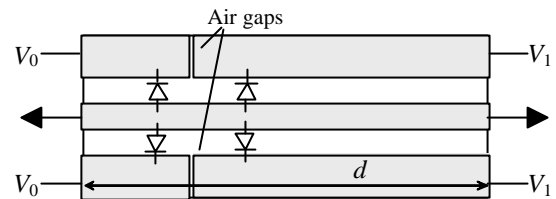


Figure 1 : Topology of the tunable device.

Figure 1 shows the topology of the 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. The CPW technology is used for an easy soldering of the surface mounted Schottky diodes. The two diode's pairs are independently biased (V_0 and V_1), leading to a much more efficient tunability compared to a single bias. Two airgaps are realized in the ground plane to allow for different biases.

3. Tunable impedance transformer results

3.1. First prototype

First measurements have been carried out with less efficient Schottky diodes (Philips BAT62-03W) on a FR4 substrate ($\epsilon_r = 4$; $h = 1.6$ mm). Characteristics of these diodes are as follows : 350 fF to 220 fF tunable capacitance for a 0 - 40 V reverse bias, a $6.6\ \Omega$ series resistance, and case parasitics 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 line impedance is about $118\ \Omega$. The CPW was realized with a mechanical machining, leading to $160\ \mu\text{m}$ airgaps. To minimize insertion losses, CMS capacitances have been soldered on the airgaps, as shown in Figure 1. However, residual insertion losses due to the airgaps lie between 1 and 2 dB.

In Figure 2 we simulate the impedance tunability for a fixed 5 GHz operating frequency. We show a transformation range of 5Ω to 376Ω from a 50Ω source. On this range of impedance the modulus of the input return loss is better than -20 dB. The insertion losses of this impedance transformer are important because of the substrate losses and the diodes series resistance. We will see in the next section that they can be lower than 0.5 dB if we use a more efficient substrate and other diodes.

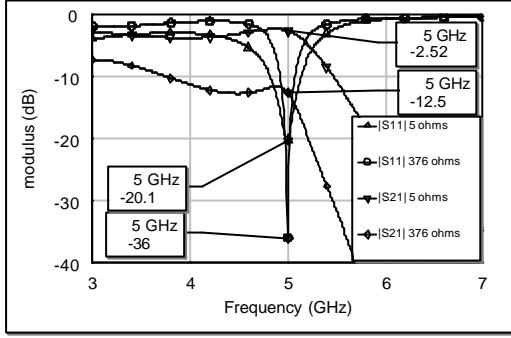


Figure 2 : Simulated $|S_{11}|$ and $|S_{21}|$.

Figure 3 shows simulations (a) and measurements (b) when the impedance transformer is loaded by 50Ω . The extremes 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 $V_0 = V_1 = V_{\min} = 0$ V and $V_0 = V_1 = V_{\max} = 40$ V for measurements.

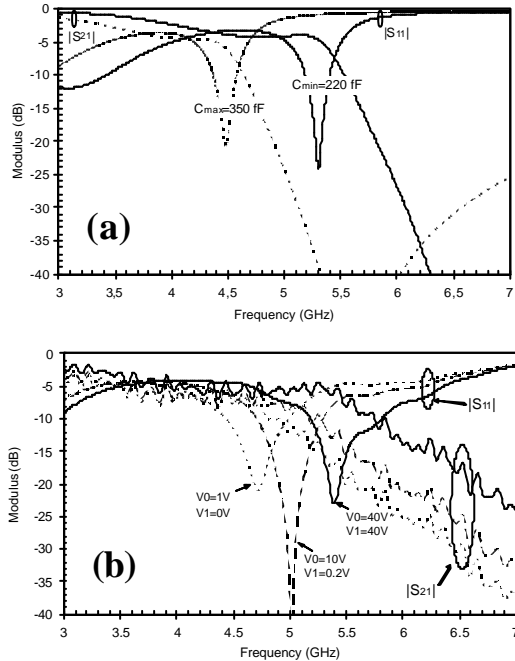


Figure 3 : Measurement and simulation of $|S_{11}|$ and $|S_{21}|$.

The tuning bandwidth, calculated for a return loss better than 20 dB, is about $\pm 7\%$ around 5 GHz for simulations and measurements.

A frequency shift can be noted between simulations and measurement 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. Measurements for a mean value of the frequency (5 GHz) have been reported in Figure 3(b) 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	$F_{\min} = 4.48$	-20.6	-6
	$F_{\max} = 5.3$	-24	-4.7
Measurements	$F_{\min} = 4.73$	-21	-7.5
	$F_{\max} = 5.46$	-22.8	-5.5

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

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 airgaps that were not taken into account in the simulations.

Load (Ω)	5	10	25	50	100	300
$ S_{11} $ (dB)	-19.3	-19.3	-24	-20.6	-20.8	-24.6
F_{\min} (GHz)	4.44	4.44	4.5	4.49	4.5	4.52
$ S_{11} $ (dB)	-15.1	-15.3	-17.6	-24.1	-18	-15.3
F_{\max} (GHz)	5.05	5.04	5.32	5.3	5.32	5.32

Table 2 : Tunable bandwidth simulated for a load varying from 5Ω to 300Ω .

To go further, Table 2 shows the tunable bandwidth simulated for a load varying from 5Ω to 300Ω . The tuning bandwidth, calculated for a return loss better than 15 dB, is about $\pm 8.3\%$ around 4.9 GHz for a 25Ω load, about $\pm 8.8\%$ around 4.9 GHz for a 50Ω load and about $\pm 8.3\%$ around 4.9 GHz for a 100Ω load. The impedance tunability of this impedance transformer is better than $\pm 100\%$ around 50Ω with an operating frequency varying of more than $\pm 8\%$ around 4.9 GHz.

3.2. Second prototype

The first prototype has been realized and measured to show the feasibility of 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 ($\epsilon_r = 2.2$; $h = 1.5$ mm), and high quality factor Agilent Schottky diodes (HSC-5314) have been used. The model given by Agilent for these diodes leads to a 130 fF to 50 fF tunable capacitance for a 0-4 V reverse bias, a 2.8Ω series resistance, and case parasitics capacitance $C_p = 20$ fF and inductance $L_p = 100$ fF. The transformer conceived with these diodes to work at 10 GHz is 6.06 mm length, i.e. 32 % of the wavelength. The line impedance of this device is about 203Ω . Figure 4 shows the simulation results.

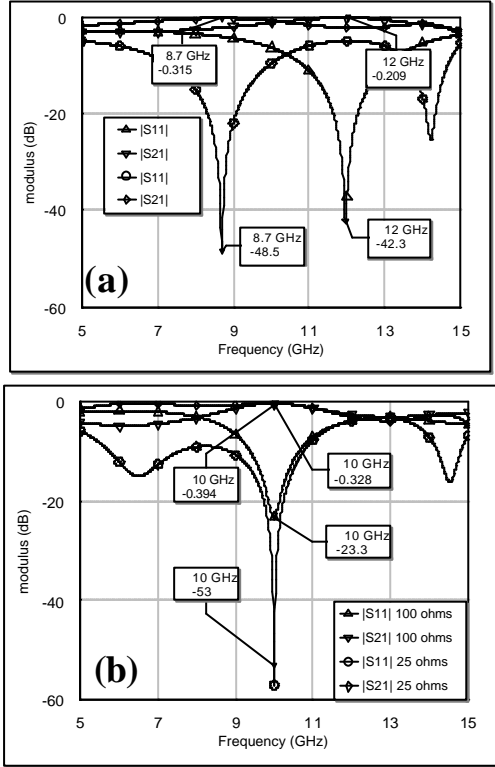


Figure 4 : Simulated $|S_{11}|$ and $|S_{21}|$.

In Figure 4(a), we study the tunable bandwidth obtained for a fixed 50 Ω load. It reaches ± 15 % around 10 GHz for a minimum 20dB return loss. Insertion losses are lower than 0.5 dB.

In Figure 4(b), we study the impedance tunability for a fixed 10 GHz operating frequency. Simulations are shown for a 25 Ω and a 100 Ω load. Insertion losses are better than 0.5 dB.

Table 2 summaries the tunable bandwidth simulated for a load varying from 25 Ω to 100 Ω . The tuning bandwidth, calculated for a return loss better than 20 dB, is about ± 8.7 % around 10.8 GHz for a 25 Ω load, about ± 15.9 % around 10.3 GHz for a 50 Ω load and about ± 10.5 % around 10.1 GHz for a 100 Ω load. The impedance tunability of this impedance transformer is

about ± 100 % around 50 Ω with an operating frequency varying of more than ± 8.7 % around 10 GHz. For this impedance transformer the insertion losses are better than 0.5 dB on all the tunable range.

Load (Ω)	25	50	100
$ S_{11} $ (dB)	-50.4	-48.5	-20.3
$ S_{21} $ (dB)	-0.4	-0.3	-0.45
F_{\min} (GHz)	9.91	8.7	9.06
$ S_{11} $ (dB)	-20.2	-42.3	-20.8
$ S_{21} $ (dB)	-0.4	-0.2	-0.25
F_{\max} (GHz)	10.86	10.35	10.13

Table 3 : Tunable bandwidth simulated for a load varying from 25 Ω to 100 Ω .

An experimental validation with these diodes and this substrate has not been carried out yet. We hope to show the experimental results at the conference.

4. Conclusion

We have simulated and realized a tunable impedance transformer. The tunability is available for a large impedance of loads and broad bandwidth. Losses can be reduced to less than 0.5 dB by using high quality factor diodes on low dielectric losses substrate.

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