A Semi-Lumped Miniaturized Spurious Less Frequency Tunable Three-port Divider\Combiner with 20 dB Isolation Between Output Ports

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***Abstract*— We propose a new topology based on a semi-lumped complex impedance transformer for the design of a frequency tunable three-port power divider. A prototype has been realized in a hybrid technology with commercially available varactor diodes. Our design is based on an impedance transformer in the input branch (with electrical length of 20.4°), and a loop in the output branches (with electrical length of 2x24°). This leads to a miniaturized device, more than two times shorter than a classical Wilkinson power divider. This divider can be tuned over ±30% around 1.35 GHz (from 0.95 GHz to 1.75 GHz) with insertion loss lower than 0.3 dB, return loss better than 20 dB and isolation between the two output ports better than 20 dB. Moreover, the low-pass behavior of the input impedance transformer leads to a good rejection of the second harmonic.**

***Index Terms*—Output isolation, power divider, tunable device, tuner, spurious free, varactors.**

I. Introduction

Tunable miniaturized devices constitute a great challenge in the field of modern RF/microwave telecommunications. In the near future, more and more applications will use multiple operating frequencies, with hard miniaturization constraints for MMIC applications. In this context, some researches are carried out to show the feasibility of various tunable devices that can be embedded in RF/microwave telecommunication systems like phase shifters, impedance transformers, filters, couplers, and power dividers. Several technologies can be used to achieve such tunable devices: ferroelectric materials, ferromagnetic materials, MEMS, piezoelectric devices, optical control and semiconductors.

The technical maturity of the power dividers dates from the sixties when Wilkinson published an article on a *N*-port divider (with *N* even or odd) [1]. One of the properties of this kind of divider is to distribute uniformly the input power *P* into *N* output ports so as to have a *P*/*N* power in phase on each output. Another property is related to a very good isolation between the output ports. This divider is designed with quarter-wave transmission lines.

In general, power dividers can be classified in two groups: three-port and four-port dividers. Since 1960 many researches on the three-port dividers were carried out, (i) to increase the bandwidth by increasing the number of sections [2], (ii) to distribute a no uniform power to each output [3], (iii) to decrease the size of the devices using lumped elements [4], [5], [6] (iv) to eliminate the higher harmonics [7]. All these researches are based on quarter-wave transmission lines, used as impedance transformers to transform a pure resistive load into another resistive load. In parallel, researches were carried out on complex impedance transformers, not based on quarter-wave transmission lines. One principle was shown in 1967 [8].

In this paper we show a new compact topology of power dividers having the same properties as Wilkinson power dividers. They are based on a complex impedance transformation. The output branches make it possible to transform a resistive load into a complex load using a small-length transmission line. This complex load is then transformed to a resistive load thanks to a small-length complex impedance transformer. This new topology leads to miniaturized, spurious free power dividers. The complex impedance transformer is realized by a transmission line loaded by a capacitor, leading to a slow-wave and low-pass behaviour. First, we will describe the principle of the topology, compared to a classical Wilkinson power divider. Then the design, simulation and measurement results obtained on a tunable power divider will be presented.

II. Principle

A classical three-port Wilkinson power divider is constituted by a *T* junction and two output impedance transformers. A resistor between output ports is used to achieve isolation (see Fig.1).

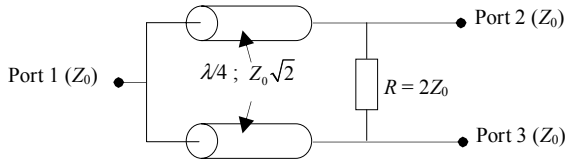


Fig. 1. Wilkinson power divider.

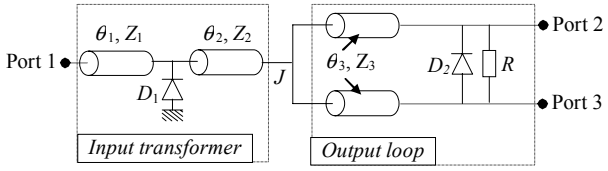


Fig. 2. The proposed power divider topology.

Fig. 2 shows the power divider topology proposed in this

paper. This topology can be divided in two blocs: an input transformer, the "tuning bloc", and an "output loop" necessary to achieve isolation between the two output ports (ports 2 and 3). Compared to the Wilkinson power divider, the impedance transformer is placed in the input port, so the input impedance at the junction point (*J*), looking to ports 2 and 3, can be adjusted, and is not necessary equal to the matching input impedance, ie 50 Ω in general.

The frequency tunability is obtained with the varactor diode D_1. The equivalent capacitance of D_1 can be adjusted by the bias voltage applied to this varactor. So the equivalent electrical length and characteristic impedance of the impedance transformer change. The isolation between the two output ports, for each working frequency, is achieved with the varactor diode D_2 capacitance tuning.

We first detail the tuning bloc, and secondly, we give the principle of the output loop.

The design is carried for a 1.2 GHz working frequency.

A. Tuning bloc :

Fig. 3 shows the electrical equivalent circuit of the tuning bloc. It is realized with a small-size *T* semi-lumped transformer.

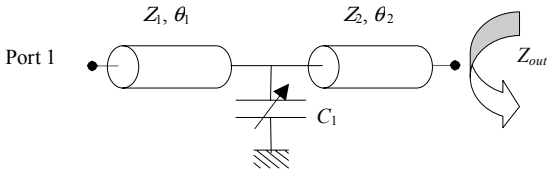


Fig. 3. Input tuning bloc equivalent electrical circuit.

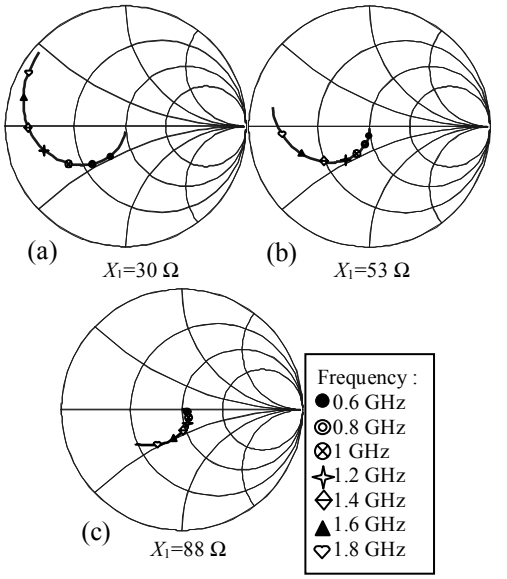


Fig. 4. Impedance seen from the output of the tuning bloc Z_{out}, versus frequency, for different reactance values at the 1.2 GHz central working frequency: minimum (a), mean (b) and maximum (c).

We call Z_{out} the impedance seen from the output of the tuning bloc. Z_{out} has been represented on the Smith chart in Fig. 4, for a typical case with $Z_1=Z_2=120\ \Omega$, $\theta_1=14.4°$, $\theta_2=6°$ and a varactor reactance $X=1/C\omega$ varying from $X_{max}=88\ \Omega$ to $X_{min}=30\ \Omega$ at the center frequency f = 1.2 GHz, ie a C_{max}/C_{min} ratio equal to 3.

Fig. 4 shows that for small length transmission lines ($\theta_1=14.4°$ and $\theta_2=6°$), Z_{out} is always capacitive, and the Z_{out} point can be changed with the varactor tuning.

Finally, this structure could be considered as a low-pass filter [9], leading to a good rejection of the spurious frequencies, especially at twice the working frequency as will be shown in measurement results.

B. Output loop :

The output loop equivalent electrical circuit is given in Fig. 5.

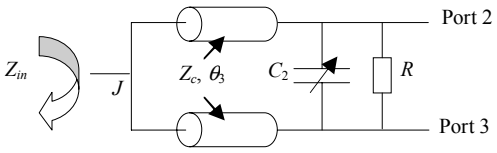


Fig. 5. Output loop equivalent electrical circuit.

We call Z_{in} the impedance seen from the junction input. Z_{in} has been represented on the Smith chart in Fig. 6, for a typical case with $Z_c=120\Omega$ and $\theta_3=24°$ when ports 2 and 3 are loaded by 50 Ω.

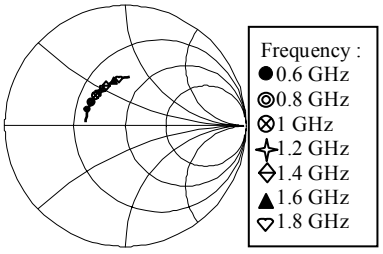


Fig. 6. Impedance seen from the input of the output loop Z_{in}, versus frequency.

For small-length output loop transmission lines, i.e. smaller than a quarter-wave length, Z_{in} is inductive.

C. Blocs matching :

Considering small-length transmission lines for the input tuning and output loop blocs, the points for Z_{out} and Z_{in} are in the lower part (capacitive part) and in the upper part (inductive part) of the Smith Chart, respectively. Then the matching condition $Z_{out}=Z_{in}^*$ can be realized for a large bandwidth.

III. Design and Measurement Results

To illustrate the new concept developed for the design of miniaturized tunable power dividers, a prototype has been realized in a hybrid technology by using surface mounted varactor diodes. For simplicity, the design was done for a 1.2 GHz working center frequency. The characteristic impedance of the input tuning bloc and output loop transmission lines was fixed to 120 Ω. A greater value would lead to much smaller transmission lines, but also increased

insertion loss and manufacturing sensitivity.

The power divider was designed in microstrip on the Rogers™ RO4003 substrate (relative permittivity $\varepsilon_r = 3.38$, dielectric loss $\tan(\delta) = 0.0035$, height $h = 0.813$ mm, and copper thickness $t = 35$ µm). The transmission lines width has been set to 250 µm in order to realize the 120 Ω characteristic impedance.

MA4ST-1240 Macom™ varactor diodes were used. The variable capacitance can be changed between $C_{\min} = 1.5$ pF and $C_{\max} = 8.6$ pF for bias voltages from 0 V to 12 V. The equivalent electrical circuit of the varactor is given in Fig. 9. The parasitic series resistance R_s is 1.6 Ω, the series inductance L_s is 1.2 nH, and the case capacitance C_c is 0.11 pF.

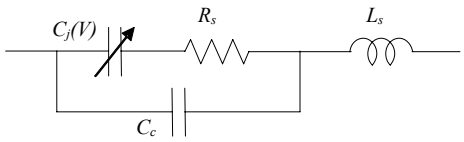


Fig. 9. Macom MA4ST-1240 Varactor equivalent electrical circuit.

Using the complete varactor model, the length of the transmission lines L_1 to L_3, corresponding to θ_1 to θ_3, were optimized with ADS [10] to achieve the largest bandwidth with the matching condition $|S_{11}| < -20$ dB. We obtained $\theta_1 = 14.4°$, $\theta_2 = 6°$, and $\theta_3 = 24°$, leading to a 44.4° long power divider.

Two biasing capacitors are necessary to separate the bias of the varactor diodes D_1 and D_2. Photography of the prototype is shown in Fig. 10.

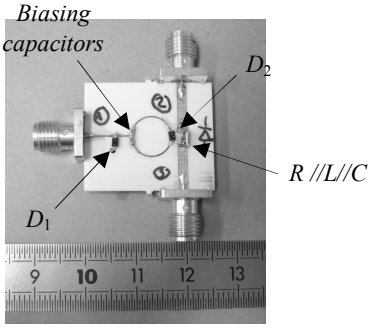


Fig. 10. Photography of the power divider.

Simulations have shown that the capacitance of the varactor D_2 should vary from 0.65 to 4.3 pF. So two different varactors D_1 and D_2 were necessary. In order to use the same varactors, we just had one inductor in parallel with D_2. In this case, the equivalent capacitor is:

$$C_{eq} = L \,//\, C = \left(1 - \left(\frac{\omega}{\omega_0}\right)^2\right) / L\omega^2 \qquad (1)$$

with: $\omega_0 = 1/\sqrt{LC}$.

Measurements were carried out with a WILTRON™ 360 Vector Network Analyzer and a standard SOLT calibration procedure. Simulations were carried out with ADS.

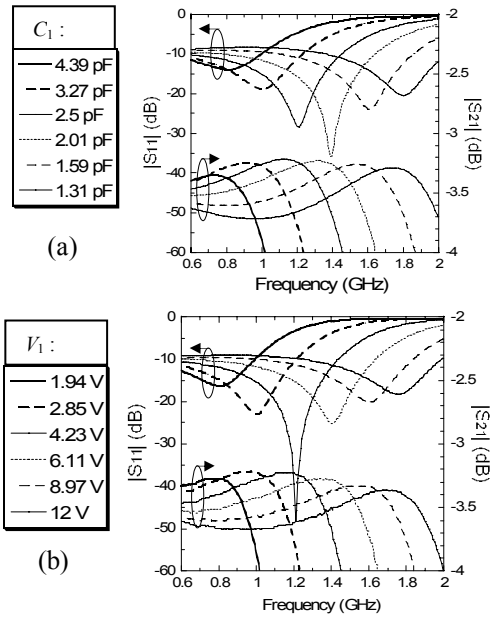


Fig. 11. $|S_{11}|$ and $|S_{21}|$. (a) Simulations. (b) Measurements.

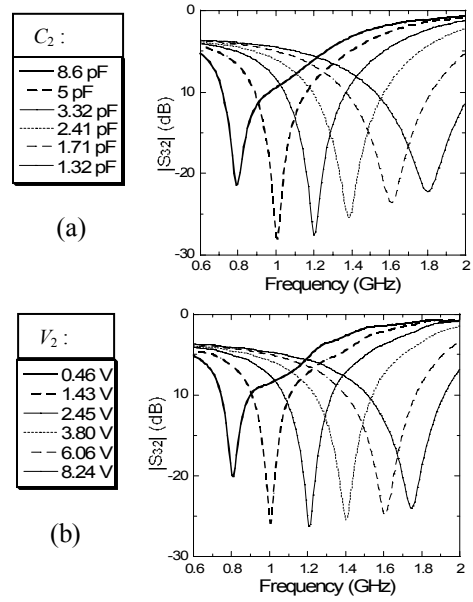


Fig. 12. $|S_{32}|$. (a) Simulations. (b) Measurements.

Fig. 11 (a) and (b) show the simulations and the measurements, respectively, of $|S_{11}|$ and $|S_{21}|$.

The value of the varactor's capacitance and the bias voltage has been indicated in the graphs, for simulations and measurements, respectively. Measurements and simulations show a good agreement, even if some ripples of maximum ± 0.05 dB are present in the measurement results for $|S_{21}|$. If the matching condition $|S_{11}| < -20$ dB is considered, the relative bandwidth reaches ± 30 %, from 0.95 GHz to 1.75 GHz around 1.35 GHz. The insertion losses are limited to 0.3 dB, ie $-3.3 < |S_{21}|_{dB} < -3.2$. These insertion losses are

principally due to the varactor's series resistance.

Fig. 12 (a) and (b) show the simulations and measurements, respectively, of the isolation ($|S_{32}|$) between the two output ports.

Here again, the agreement between simulations and measurements is good. Thanks to the varactor D_2 capacitance tuning, the isolation is better than 20 dB for the whole bandwidth.

Fig. 13 (a) and (b) show the simulations and measurements, respectively, of $|S_{22}|$ and $|S_{12}|$.

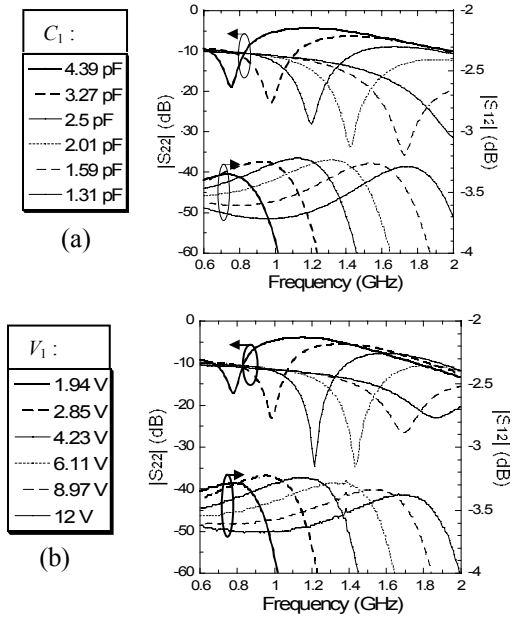


Fig. 13. $|S_{22}|$ and $|S_{12}|$. (a) Simulations. (b) Measurements.

The output ports matching ($|S_{22}|$) is better than 20 dB in the whole bandwidth. The device allows combiner utilization.

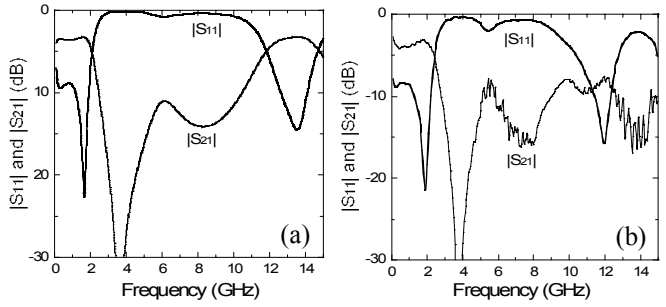


Fig. 14. Rejection of the spurious harmonics. (a) Simulations. (b) Measurments.

Finally, Fig. 14 shows the low-pass behavior of the structure for a 1.68 GHz working frequency, corresponding to $|S_{11}|$ < -20 dB (C_1=1.46 pF). $|S_{21}|$ lies between -3 and -4 dB from DC to about 2 GHz, and rapidly decreases above 2 GHz. The capacitively loaded transmission lines of the input tuning bloc acts as a low pass filter, with a cut-off frequency near the Bragg frequency, as explained in [9]. Moreover the varactor's series inductance leads to a transmission zero at the frequency: $f_0 = 1/\left(2\pi\sqrt{L_s C_1}\right)$, ie f_0 = 3.7 GHz in our case (C_1=1.56 pF and L_s = 1.2 nH).

IV. Conclusion

A new topology for equal three-port power dividers has been proposed. This topology leads to a miniaturized power divider, at mean 50 % smaller than a classical Wilkinson power divider. Due to the use of complex impedance transformer exhibiting a low-pass behavior, spurious are greatly attenuated. Also, the power divider can be completely tuned. A prototype realized with commercially available varactors has shown a good matching and isolation (better than 20 dB) over a tunable bandwidth of 60 % for a C_{max}/C_{min} ratio equal to 3. First harmonic of the working frequency is attenuated by more than 15 dB and spurious are attenuated by more than 9 dB to five times the working frequency. Insertion losses are limited to 0.3 dB. Fixed power dividers can be realized with the proposed approach, leading to spurious free, small-size, small-bandwidth power dividers.

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