A Metamaterial T-Junction Power Divider

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***Abstract*--A metamaterial based compact microstrip T-junction power divider working at 10 GHz is proposed. The metamaterial unit cell consists of microstrip gaps and via holes whose behavior is equivalent to the combination of series capacitors and shunt inductors respectively, that is, a dual TL (high-pass) configuration. By adjusting the parameters of these structures, the characteristics of the Metamaterial-medium can be set to achieve a desired phase shift. To validate the design, a T-junction power divider is fabricated and measured. A 70% reduction of the length of the impedance transformer, without significant performance degradation, has been achieved.**

***Index Terms*—Left-Handed (LH) Components, Power Divider Metamaterials, Microstrip technology.**

I. INTRODUCTION

Metamaterials (MTMs) are artificial structures which exhibit properties that can not be found in nature. Among them, MTMs with simultaneously negative permittivity and permeability have received considerable attention during the last years [1]-[3]. These materials were named as left-handed media (LHM), since the vectors $\vec{E}$, $\vec{H}$ and $\vec{k}$ form a left-handed triplet [4].

Originally, media that exhibit simultaneously negative permittivity and permeability were created using split ring resonators and wires [1]-[2]. However, for microwave applications, the size and method of construction of this approach makes them impractical. For these applications a solution was introduced based on dual transmission lines. In this case, a conventional transmission line was loaded with lumped series capacitances and shunt inductors. This type of line has been used to experimentally demonstrate negative refraction [3] and focusing not limited by diffraction [5]. Based on these configurations very compact delay lines were proposed [6] which allows to reduce the size of different microwave components.

However, when frequency increases solutions based on lumped elements are difficult to implement. Planar distributed 2D periodic structures of microstrip-line and strip lines which support left-handed waves have been proposed in [7] by using distributed structures based on Sievenpiper's mushroom structure [8].

If the MTM is intended to be used to create microstrip circuitry a 1D approach can be used. In this respect, a unit cell was presented in [9], which used interdigital capacitors and stub inductors to generate the left-handed behavior. However, capacitor fingers become difficult to manufacture and the parasitic effects tend to dominate its response when frequency increases.

Another simpler LH unit cell has been proposed in [10] for leaky wave antenna applications which was suitable for higher frequencies, since the vias are substituted by virtual ground capacitors and does not make use of interdigital capacitors. In this paper, the mushroom structure is used as a 1D LHM unit cell implemented in microstrip technology. With this unit cell it is possible to achieve LH behavior at frequencies higher than 10GHz.

Based on it, a new T-junction power divider at 10 GHz is proposed using this combination of regular microstrip and LH lines. This power divider exhibits similar power splitting characteristics as the "conventional" ones but it leads to a significant size reduction of the dimensions of the splitter.

II. THE NEW METAMATERIAL UNIT CELL

The MTM unit cell structure proposed in [5]-[6] consists of a host Transmission Line (TL) medium with distributed parameters per unit length L and C, loaded with discrete lumped element components, L_0 and C_0.

The two media must be matched, that is:

$$Z_0 = \sqrt{\frac{L_0}{C_0}} = \sqrt{\frac{L}{C}} \qquad (1)$$

Under this condition, it can be shown that the total phase shift simplifies to (2) [9]. This expression can be interpreted as the sum of the phase shifts of the host TL and a uniform backward wave L-C line.

$$|\phi_0| = \beta_{eff} \cdot d = \phi_{TL} + \frac{-1}{\omega\sqrt{L_0 C_0}} \qquad (2)$$

Thus, (1) and (2) can be used to determine unique values for L_0 and C_0 for any phase shift ϕ_0, given a TL section with intrinsic phase shift ϕ_{TL} and characteristic impedance Z_0.

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In microstrip technology, at low frequencies (1 GHz), these circuits can be fabricated by welding the discrete elements, inductors and capacitors. However, at higher frequencies (X-band, even Ku band) this solution is not practical. In this paper it is proposed to replace these lumped elements by structures with similar behavior, i.e., a series microstrip gap for the series capacitor, and a via hole for the shunt inductor.

The proposed unit cell, shown in the insert Fig. 1, is easy to fabricate and its integration in a TL is straightforward since it is based on a TL, allowing a high degree of compactness. Furthermore, it is possible to work at higher frequencies, but with the fabrication limits of the minimum gap between lines.

An example of the behavior of this unit cell is presented in Fig. 1. The substrate used for simulation and manufacturing is Roger RO31010 material characterized by ε_r = 10.2 and thickness h = 1.27mm and the design frequency was f_r=10GHz. The microstrip TLs were designed with Z_0 = 50Ω at f_r and a total length of 5mm (166° at fr). The radius of the via hole was fixed to r = 0.2mm, and afterwards, the gap was adjusted to obtain the best matching (*gap* = 150µm).

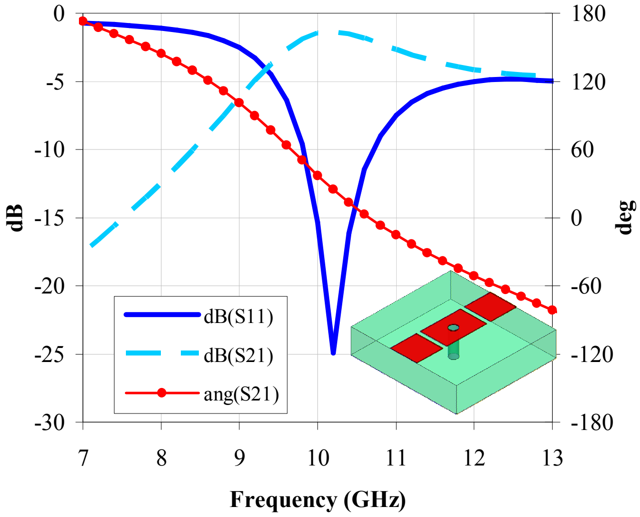


Fig.1. Frequency response of the simulated unit cell.

In the figure, it is observed that the phase-delay of the circuit is around +35° at 10GHz, therefore it can be concluded that the "L-C" structure has introduced a phase of +200° at 10GHz. Furthermore, the matching is satisfactory but with an operational BW_{-10dB} of approximately 1 GHz (10%). The insertion losses are around 1.4 dB.

The dispersion relation and equivalent circuit [5] of the selected unit cell are depicted in Fig. 2. As shown, a left handed band is obtained from 7 to 11 GHz, which means a 45% fractional bandwidth. As a result, a phase compensation is produced at the design frequency proving the correct operation of the unit cell.

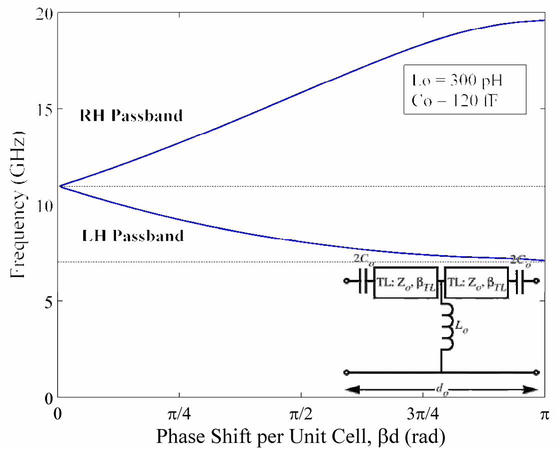


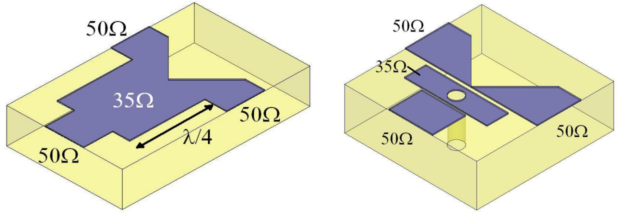
Fig.2. Dispersion relation for periodically L-C loaded LHM.

III. T-JUNCTION METAMATERIAL EXAMPLE

The T-junction power divider is a simple three-port network that can be used for power division or power combining, and can be implemented in any type of transmission line media.

In microstrip technology and for a 50Ω input line, a 3dB (equal split) power divider can be made by using two 100Ω output lines. Quarter-wave transformers must be used to bring the output line impedances back to the desired levels. If the output lines are matched, the input line will be also matched.

Another option is based on converting the input impedance from 50Ω into 25Ω by a λ/4 impedance converter, keeping the 50Ω output lines. This way, a unique impedance transformer is needed. The λ/4 transformer is already matched with the two outputs, which have an input impedance of 25Ω (50Ω||50Ω) (see Fig.3 (a)). A 45° chaffered bend has been designed to improve the matching.



(a) (b)

Fig. 3. (a) "Conventional" and (b) proposed T-junction power divider.

A detailed comparison between the performances of the conventional design vs the one based on the MTM unit cell is presented. The goal is to reduce the length of the λ/4 impedance converter while keeping its main properties.

The parameters used to adjust the response of the MTM transformer are the radius of the via hole, the length of the TL between the gaps and the gaps. After optimization, the width of the 50Ω and the 35Ω TLs were 2.5mm and 1.325mm respectively. To present the same capacitance in both gaps, the wider gap was determined to be double of the narrower one. The radius of the via hole was r= 0.2 mm to achieve a good matching at the design frequency.

The MTM transformer was finally formed by a TL of length 650µm and a gap of 70µm (the wider gap was 140µm long), leading to a total length of 860µm. That means a reduction in size to 33% of its original size (2.6mm).

IV. EXPERIMENTAL RESULTS

The experimental characterization was performed using an Agilent 8722 ES Network Analyzer. Fig. 4 shows both fabricated circuits.

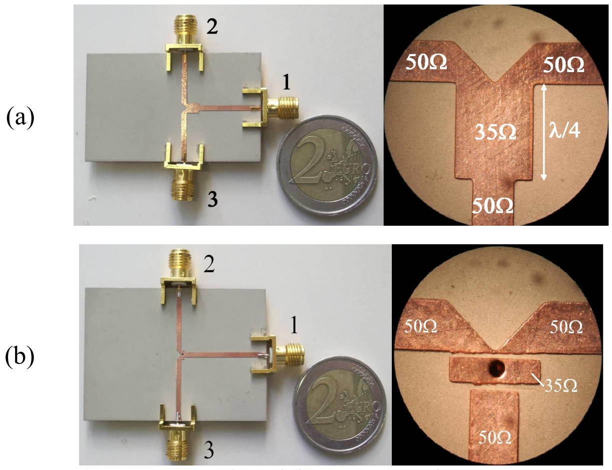


Fig. 4. (a) "Conventional" and (b)"Metamaterial" T-Junction circuits

In Fig. 5 the measured responses of both circuits are depicted. The results agree quite well except for the frequency deviation around the design frequency.

For the conventional circuit (S_{ij}_conv), the frequency has slightly changed, from 10GHz to 10.2GHz, due to a small reduction in the length of the printed impedance transformer. The matching is -45dB and the power at the outputs agrees with the expected one (-3.1dB). The bandwidth at -10dB return loss is 0.25GHz, i.e., a fractional bandwidth of 2.5%.

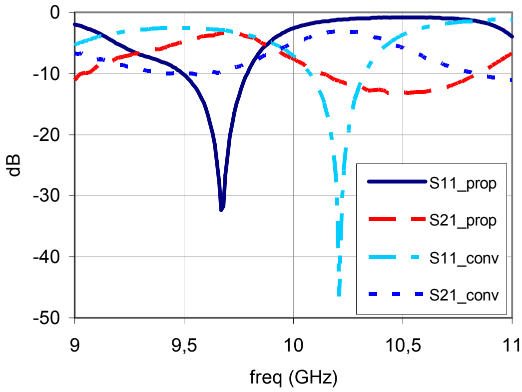


Fig. 5. Measured responses of proposed and conventional T-junction circuits.

For the MTM T-Junction, the frequency has moved from 10GHz to 9.67GHz. This is due to errors in the fabrication process. The via hole is not perfectly in the centre of the TL and the first gap (the one placed below) is wider in one side than in the other. All these errors can be checked in Fig. 4. The matching is good (-33dB) but the transmitted power deviates from -3 dB (it is -3.5dB). The bandwidth at -10dB return loss is 0.29GHz (fractional bandwidth of 3%).

It can be concluded from these results that the matching in both circuits is similar, and the losses introduced in the MTM circuit due to the resistive parts of the via hole and the gaps are quite low (0.4dB). However, the size of the impedance transformer has been reduced to 33% of the original size, and the bandwidth has been improved from 2.5% to 3%.

V. CONCLUSION

A novel implementation of a MTM unit cell has been proposed, which allows extending its use to frequencies above 10 GHz by avoiding any soldering and reducing the size of microstrip components. The maximum operational frequency will be limited by the fabrication techniques able to provide the gaps and via holes required.

Due to the unit cell configuration, it lends itself easily toward integration within components and devices in microstrip or in CPWG technology. It is therefore ideal for reducing long sections of TLs in devices like hybrids and couplers or phase shifters for antenna arrays.

A new type of T-junction power divider has been introduced which possesses a comparable functionality to its conventional counterpart but with a significant size reduction. Good matching and medium losses at the design frequency have been achieved with this novel configuration.

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