COUPLING ENHANCEMENT OF PARALLEL TRANSMISSION LINES USING A SLOT SPLIT RING RESONATORS DEFECTED GROUND PLANE

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INTRODUCTION

During the last few years, the use of microstrip lines with Defected Ground Planes (DGPs) has greatly contributed for the size reduction of microwave circuits. DGPs are usually periodically patterned by Electromagnetic/Photonic Band Gap (EBG/PBG) structures [1]. Recently, a novel pattern having dimensions of $\lambda/10$ has been proposed and its use in the DGP of a microstrip line for filter designs has been studied [2, 3]. This element is called Slot Split Ring Resonator (SSRR) and refers to a slot having the shape of a Split Ring Resonator (SRR) [4] made in a conducting plane.

The aim of this paper is to show that the coupling between two parallel microstrip lines can be considerably enhanced by the use of a Slot Split Ring Resonators (SSRRs) defected ground plane. With this method, we have more flexibility in the fabrication process, especially concerning the distance separating the two parallel transmission lines. The most interesting advantage of this technique is the separation of a signal at a desired frequency and the signal outside this frequency on two different accesses, opening the way to new applications.

First of all, two parallel microstrip lines of length $\lambda_g/4$ at 9.7 GHz separated by a gap, $\boldsymbol{s}$ = 0.6 mm, are designed on a RO4003C® having a relative permittivity of 3.38 and a thickness of 0.81 mm. The study is done for 4-16 GHz frequency range for a normal ground plane. Then the ground plane is modified by the milling of the SSRRs whose dimensions have been optimised for a frequency of 9.7 GHz. From the different simulations run on Ansoft's *HFSS* [5] and measurements done on the fabricated prototype, it is noted that the coupling phenomena between the two lines is enhanced around 9.7 GHz in the case of the SSRRs defected ground plane.

The first results obtained from simulation and measurements show the possibility of designing a novel type of compact diplexer or transponder. Such a device can also be very useful in an autonomous system, where the signal recovered from the direct output can be used to bias active components, after being rectified to DC power.

STUDY OF CONVENTIONAL COUPLED MICROSTRIP LINES

The parallel microstrip lines used for this study (Fig. 1) have a length of $\lambda_g/4$ each at 9.7 GHz, which corresponds to the resonance frequency of the SSRR designed for the next section. The gap spacing between the two lines is 0.6 mm and tapers are designed at both ends of each line in order to have a normalized impedance Z of 50 Ω on the four accesses. A 50 Ω line extension is added at the end of each taper for the welding of the SMA connectors used in the experimental tests. The RO4003C® substrate from Rogers of relative permittivity 3.38, tangential loss 0.0027 and thickness 0.81mm is employed for the design of this structure. The ground plane is a normal Perfect Electrical Conductor (PEC) one with a thickness of 0.035 mm. The dimensions of the studied structure are 30×30 mm^2.

The frequency band aimed for this study is the X-band [8.2 GHz ; 12.4 GHz]. However, the different *S*-parameters extracted from simulations and measurements will be displayed for frequencies from 4 GHz to 16 GHz.

Fig. 2 represents the *S*-parameters obtained from simulations run on HFSS. As shown by these results, the coupling is initially weak due to the large gap spacing between the parallel lines. The backward coupling (S_{31}) is less than -13 dB, the isolated signal (S_{41}) is close to -22 dB and the direct transmitted signal (S_{21}) is nearly 0 dB; thus indicating that the signal injected to port 1 is transferred to the direct output (port 2) with very low insertion losses.

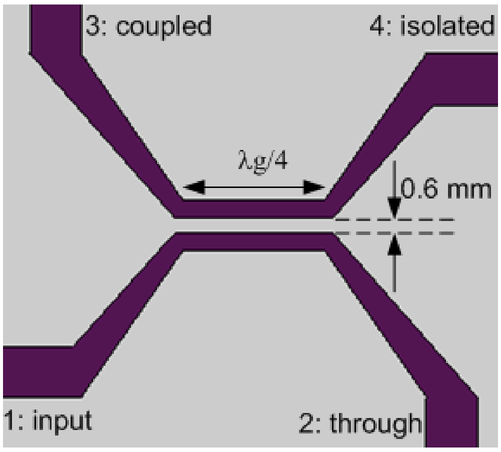

Fig. 1. Coupled lines on a PEC ground plane.

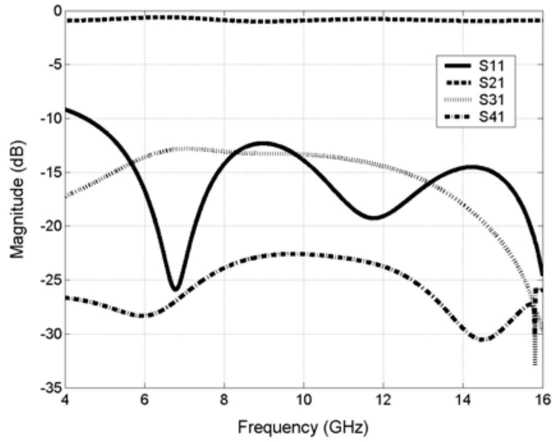

Fig. 2. *S*-parameters extracted from *HFSS*.

Fig. 3 shows the E-field distribution along the microstrip parallel lines and illustrates the results presented on Fig. 2. A weak coupling is present between the two parallel lines since the gap spacing is quite large. In order to increase the coupling between the two lines, a smaller gap spacing is required. Hence, this device cannot be used as a power divider due to its very low coupling coefficient. For example, for a coupling coefficient of 3 dB, a spacing of 0.013 mm is required between the two parallel lines according to simulation results obtained from Agilent's *ADS* [6]. Even in the fabrication process, it is quite difficult to achieve such a low spacing in microstrip technology.

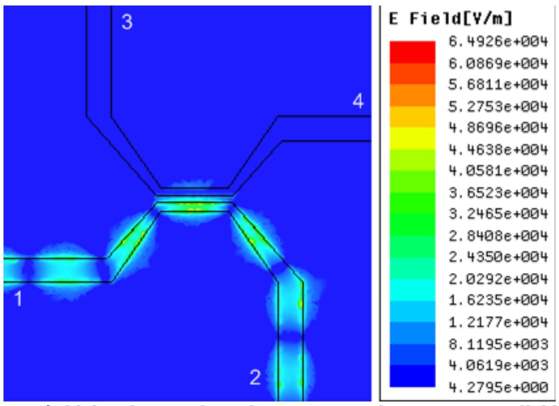

Fig. 3. E-field distribution along the conventional microstrip parallel lines.

STUDY OF COUPLED LINES ON A SSRRs DEFECTED GROUND PLANE

As mentioned earlier, the working frequency of the device under study has been set to 9.7 GHz and the different dimensions of the SSRRs have been optimized to operate at this specified frequency. The optimization procedure has been carried out by placing a 50 Ω microstrip line on a ground plane defected by one unit cell of SSRR [3]. Unlike the polarization used in the case of the SRRs in [4], here we are going to make use of the E-field in order to feed the SSRRs, which are complementary to SRRs.

Effectively, the studies made in [2] and [3] have shown that the SSRRs are excited by the E-field of the line. A band-stop phenomenon has been observed when a microstrip line is placed on a SSRRs defected ground plane. It has also been noted that a very strong capacitive coupling is created between the line and the metallic part of the SSRR. However, a magnetic coupling exists between the two slot rings of the SSRR, but the capacitive one is dominant.

The aim is to use these SSRRs in the ground plane of the coupled parallel microstrip lines and study their influence. So, an array of three SSRRs is first milled in the ground plane in the middle of the $\lambda_g/4$ lines (Fig. 4). The simulated results in Fig. 5 show the SSRRs prevent the transfer of power from port 1 to port 2, that is, the direct coupling at the resonance frequency of the SSRRS (9.7 GHz). At this frequency a band-stop is observed on the S_{21} response (S_{21} = -6.5 dB) and thus, the energy stored in the SSRRs is transferred to the non-excited line, causing the coupling to port 3 with insertion losses of about 4.5 dB. It can be noted that the isolated signal (S_{41}) has a mean attenuation of about 9.5 dB.

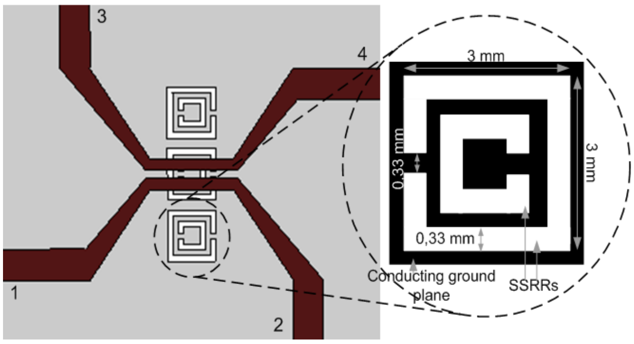

Fig. 4. Coupled lines with a defected ground plane of three SSRRs.

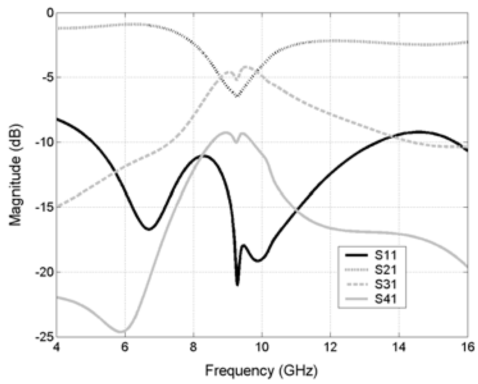

Fig. 5. Simulated S-parameters in the case of the defected ground plane by three SSRRs.

Hence, by collecting the signal at 9.7 GHz on port 3, we can also transfer any signal outside this frequency to port 2. We will refer the signal at the frequency of 9.7 GHz as the main (useful) signal, and the entire signal outside 9.7 GHz as the parasitic signal. Two more SSRRs are milled in the ground plane just below the microstrip transitions going to port 2 and 4 in order to attenuate much more signals arriving on these two tracks at 9.7 GHz (Fig. 6). By attenuating the signal on port 2, a better coupling is expected with the other microstrip line. And, since the signal on port 4 is also attenuated, a higher transmission must be obtained on port 3.

The device has been fabricated by mechanical milling using a LPKF machine. Measurements have been done on an HP8720C network vector analyzer. The different experimental S-parameters are shown in Fig. 7.

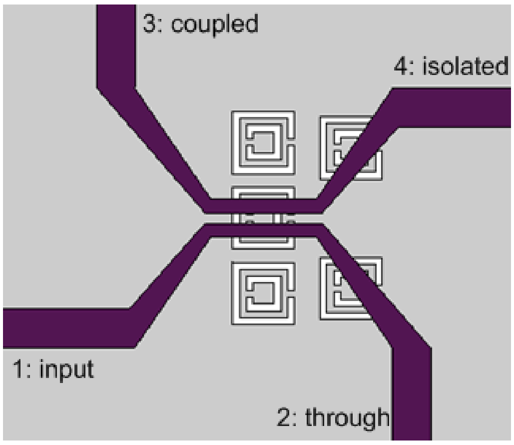

Fig. 6. Coupled lines with a defected ground plane of five SSRRs.

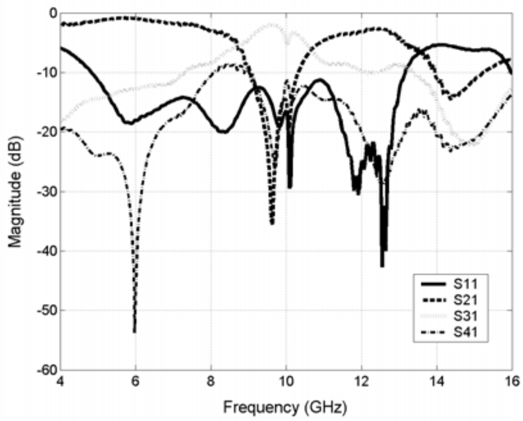

Fig. 7. Measured S-parameters in the case of the defected ground plane by five SSRRs.

The measured results (Fig. 7) show that the main signal at 9.7 GHz is recovered on port 3 with a bandwidth of nearly 1 GHz and insertion losses of about 2 dB. Outside this frequency band and for a maximum frequency of 12.5 GHz, the signal is recovered on port 2. The isolated signal on port 4 presents an attenuation of 26 dB at 9.7 GHz. Hence, the SSRRs added under the transitions have greatly contributed for the enhancement of the coupling between the two parallel lines. Similar results are obtained when only one SSRR is used under the $\lambda_g/4$ parallel lines. The dimensions of both circuits, without DGP (Fig. 1) and with DGP (Fig. 6), are the same but the one with the proposed DGP increases the coupling with moderate gap spacing requirement, relaxing the fabrication constraints.

To better understand how energy is transferred between the two parallel lines, the current distribution of the *HFSS* simulated structure at 5 GHz and 9.7 GHz are shown in Fig. 8 and 9. Fig. 8 shows that the whole signal is transmitted to port 2, which explains why a close value to 0 dB for S_{21}. At 9.7 GHz, the signal is transmitted to port 3 (Fig. 9) due to the band-stop phenomenon related to the SSRRs at this frequency.

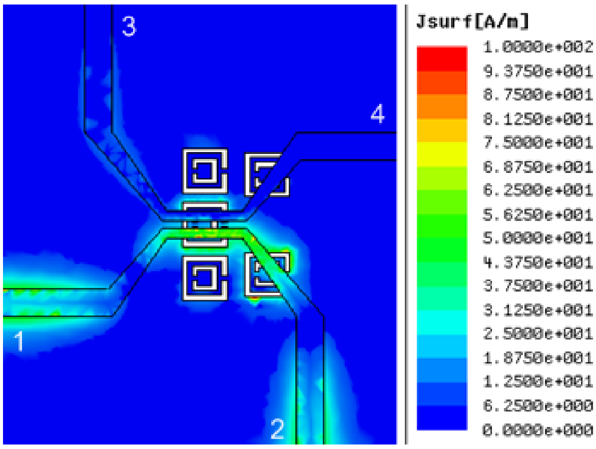

Fig. 8. Simulated current distribution at 5 GHz.

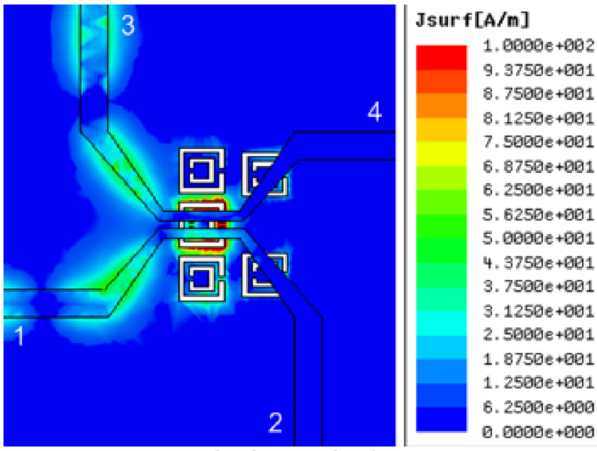

Fig. 9. Simulated current distribution at 9.7 GHz.

This device is very interesting since it separates the main and parasitic signals on two different accesses. Hence, we can imagine the design of a novel type of compact diplexer where the operating frequency can be modified by simply electrically adjusting the different dimensions of the SSRRs. It can also be very useful in an autonomous system where no external DC feeding or battery is required. In this case, the parasitic signal recovered on port 2 can be used, after being rectified to DC power, to bias active components in the system which is fed by the main signal from port 3.

CONCLUSION

This study shows that the coupling between two parallel microstrip lines is enhanced by the use of a Slot Split Ring Resonators (SSRRs) defected ground plane. Since the gap between the two lines is 0.6 mm, this device can be easily designed, thus relaxing the fabrication technology constraints at high frequencies. The first results obtained from simulation and measurements show the possibility of designing novel type compact couplers, diplexers or transponders. Such a device can also be very useful in an autonomous system. The parasitic signal recovered on port 2 can be used, after being rectified to DC power, to bias the active components of a circuit, which is itself, fed by the main signal recovered on port 3 through the coupling. Such a device can be made to operate at any frequency. The only thing to do is to design the SSRR with the appropriate dimensions in order to have the desired resonance frequency.

The use of this technique to broadside coupled microstrip lines is under study.

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