A wideband miniaturized 3 dB hybrid coupler for passive beam switching application

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***Abstract*—This paper proposes a wideband miniaturized 3 dB 90˚ hybrid coupler for passive beam switching application. The hybrid coupler is usually employed in an antenna array feed network in a butler matrix. For ease of fabrication and measurement, the operating frequency of the hybrid 90˚ coupler is designed from 700-960 MHz. Hence, an operating bandwidth of around 30% is achieved at the center frequency of 830 MHz. A size reduction of 83% is accomplished along with a fractional bandwidth of 30% by carefully adopting a meander structure with optimized spacing to enhance the capacitance within the structure. The proposed design is fabricated on Rogers 4360 substrate and measured results of the prototype show good agreement with simulated results.**

Keywords— Hybrid coupler; Butler matrix;

I. INTRODUCTION

Due to the rapid increase of cellphone applications and continuous bandwidth demand, network operators have started the deployment of fifth-generation (5G) networks around the world. In this regard, 5G cellphones are shifting to higher frequencies and hence adopting phased array solution to steer the beam. Adaptive phased arrays consume excess power due to high-resolution beamsteering. On the contrary, the switched beam systems (SBS) produce discrete narrow beams that could be switched to select different beam directions. Hence, SBS uses Butler matrix as a passive feeding network that produces multiple orthogonal beams to enable beamsteering.

With phased array implementation in handheld devices, SBS can be a solution for lesser complex and low power beamsteering application. At the heart of this is the 3 dB hybrid 90˚ coupler. The conventional coupler size is not suitable for handheld devices. It suffers from reduced bandwidth i.e., around 10% and larger size [1]. The size is not an issue at higher frequencies, but handheld devices require more compact feed network components when using multiple antennas. At the same time, it is also important to achieve high bandwidth and the required characteristics when the device is miniaturized.

The work in [2] have used folded structure, in [3] fractal construction, stepped impedance resonators [4] and artificial transmission lines [5] for size reduction of the hybrid couplers. To enhance the bandwidth of hybrid coupler techniques employed include defect ground structure (DGS) [6], slot line [7] and multilayer AMC based design [8]. The existing techniques either focus on miniaturization or bandwidth improvement and/or both in some cases. In the proposed work we have achieved both higher miniaturization and at the same time wider operating bandwidth targeted for small factor devices.

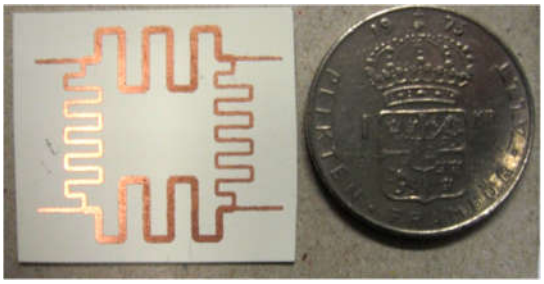

Fig. 1. Fabricated prototype of the proposed 90 couplers

II. HYBRID COUPLER DESIGN

The proposed 90˚ hybrid coupler is modelled and simulated using CST MWS 2019. Figure 1 shows the fabricated prototype of the proposed coupler. The coupler is designed on a 0.305 mm Rogers 4360 dielectric substrate with permittivity $\varepsilon_r = 6.15$ and $\tan\delta = 0.0038$. The choice of a higher dielectric constant and thinner substrate would be an obvious choice for handheld devices to attain compactness in circuits.

The conventional quarter-wavelength arms of the hybrid coupler at the center frequency of 860 MHz is calculated to be 42.5 mm. As the hybrid coupler has 50 Ω impedance in the horizontal arms and 75 Ω in vertical arms, the trace width using Rogers 4360 is calculated to be 0.45 mm and 0.2 mm. As seen in Figure 1, the vertical arm is meandered with a spacing of 1 mm while the spacing optimized in the horizontal arm is about 1.8 mm. Hence the total vertical arm length is reduced to 23 mm. The horizontal arm is decreased to around 20 mm. The proposed volume reduction can be seen in Table 1.

III. RESULT AND DISCUSSION

Both the simulated and measured reflection coefficient (S_{11}) and isolation (S_{41}) are plotted in Figure 3. It can be seen that both (S_{11}) and (S_{14}) are well below -10 dB in the entire operating bandwidth with a maximum of -40 dB at the center frequency of 830 MHz. Due to symmetry of structure results of other ports are not shown.

Table 1: Comparison of the size of the proposed vs conventional coupler

	Dimension (mm)	Volume (mm^2)
Conventional	51.5×51	2601
Proposed	20×23	460

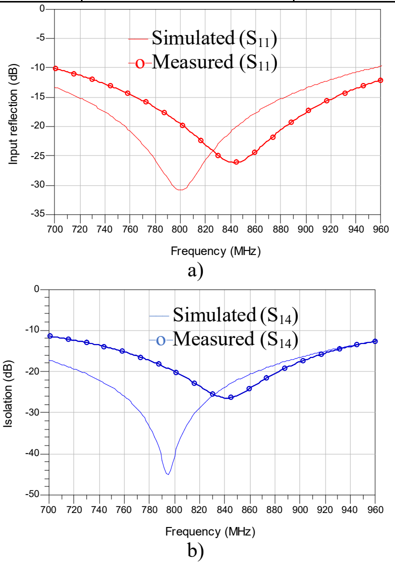

Fig. 2. Simulated and measured (a) Input reflection at port 1 and (b) Isolation

The forward transmission (S_{21}) & (S_{31}) and measured phase response at the output port 2&3 can be seen in Figure 3. An insertion loss of 1 dB is observed at port 3 while same can be seen for port 2 which increases more at frequency below 800 MHz.

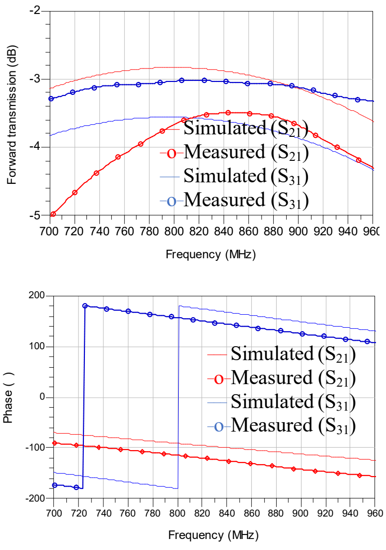

Fig. 3. Simulated and measured : (a) Forward transmission at port 2 and port 3 and and b) Phase betwateen port 2 and port 3

The amplitude imbalance and the phase imbalance is separately calculated and plotted in Figure 4 which is around 1 dB and less than 5˚ and seems suitable for any beamsteering application.

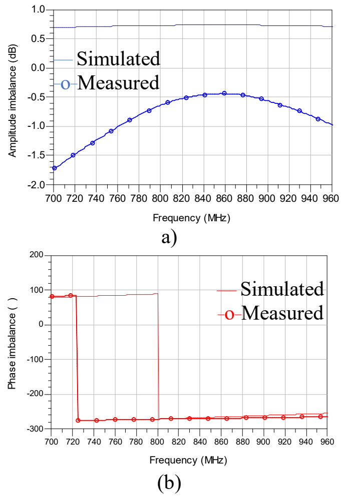

Fig. 4. Simulated and measured (b) Amplitude imbalance between at port 2 and port 3 and b) Phase imbalance between port 2 and port 3

IV. CONCLUSION

A wideband miniaturized 3 dB 90˚ hybrid coupler is designed, simulated and fabricated. The proposed coupler has an operating bandwidth of 260 MHz at the center frequency of 860 MHz. The size reduction achieved is around 83% by utilizing a carefully optimized meander structure. The input reflection and isolation between ports is below -10 dB. The average amplitude imbalance among the output ports is around -1 dB while the phase imbalance is less than 10˚. Due to simplicity, symmetry and achieved percentage bandwidth the proposed design is scalable and can be redesigned to work in the millimetre-wave band for 5G cellphone application.

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