Development of a broadband Wilkinson Power Combiner on Liquid Crystal Polymer

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***Abstract*—We present the development of a broadband multi-section Wilkinson power combiner on Liquid Crystal Polymer (LCP) with integrated thin film resistors. The designed frequency of operation is from 2-18 GHz. The measured VSWR is better than 1.6:1, the measured excess insertion loss is less than 1.1dB, and 11dB of isolation is measured across the full band. This work presents the highest performance Wilkinson combiner with the widest bandwidth ratio of 9:1 reported in literature.**

***Index Terms*—Multichip Module, Wilkinson power divider, power combiners, power dividers.**

I. INTRODUCTION

POWER combining and dividing techniques are readily found in many of today's cutting edge technology. With the introduction of GaN devices, broadband power combing to achieve high output powers is very attractive [1]. It is also useful in many RF receiver architectures to divide the in-phase and quadrature channels [2]. Many state-of-the-art microwave hybrid designs are complex with multi-layers. System integration is critical and much research work has been done to show that LCP is an ideal candidate for the integrated millimeter wave needs for the future. The benefit of LCP includes its low moisture absorption that can provide near hermetic packaging [3] in addition to the ability to have multiple layers on a homogeneous substrate. Customarily multi-layer boards need an intermediate adhesion layer which makes the substrate media no longer homogeneous. LCP, however, is self adhesive, allowing for a homogenous substrate media, simplifying microwave designs.

The Wilkinson power divider/combiner was first conceived by Wilkinson [4] and later broadband characterization was done by Cohn [5]. In recent works, researchers have fabricated a single stage Wilkinson combiner on LCP in the V-band and W-band [6]. Their designs are broadband by default because of the high fractional bandwidth associated with a high center frequency. Many applications, such as UWB (3.1-10.6 GHz) require wide bandwidth, but at a much lower center frequency, a more difficult task. This can only be done by cascading sections, as described by Cohn. In this paper, a state-of-the-art broadband Wilkinson power combiner with integrated resistors is presented. The designed combiner can be seen in Fig. 1.

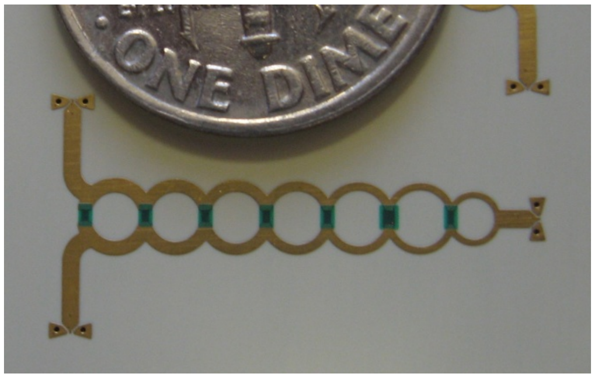

Fig. 1. Photographs of the designed 2-18 GHz Wilkinson power combiner on LCP.

II. DESIGN CONSIDERATIONS

In Cohn's original paper, bandwidth is enhanced by cascading quarter wavelength transmission lines optimized by using the Chebyshev polynomial. The Chebyshev multisection matching transformer optimizes the bandwidth at the cost of ripples in the passband. In this work, a Binomial multisection matching transformer is used to ensure a maximally flat passband and also to simply calculations. As shown in Fig. 2, the cascading of quarter wavelength sections can increase the bandwidth dramatically. A 7-stage Wilkinson was chosen for this work.

Values for the resistors affect both the isolation between output ports and the output return loss. Network theory can be applied to solving for appropriate values for the resistors. For values of N=2, an analytical approach can be taken, but greater than that, an iterative approach is necessary. For this work, the optimization function in Agilent's Advanced Design System (ADS) was used to solve for the value of the resistors to optimize the output return loss. Equally, optimization of the isolation between output ports could also be applied. Table I. shows calculated values for each cascading section and the optimized values for the resistors used.

Test structures for resistor characterization were also manufactured. The primary goal for the resistor test structures

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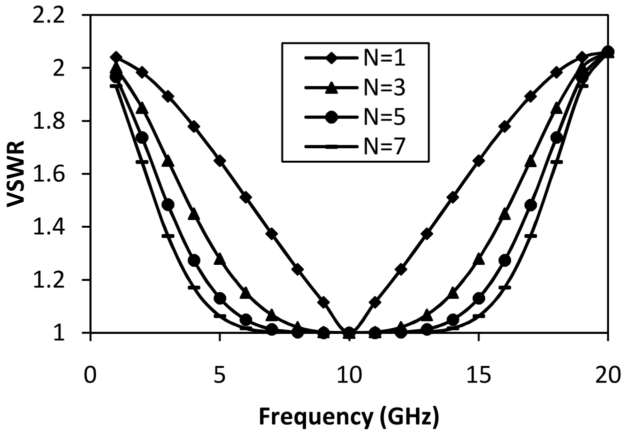


Fig. 2. Comparison of VSWR for differing number of cascading sections across frequency of interest.

was to measure and insure broadband response of the thin film resistors. The measured response of a 100 Ohm test resistor is shown in Fig. 3 and confirms a broadband response and shows no more than a 1% deviation from the design value throughout the frequency band.

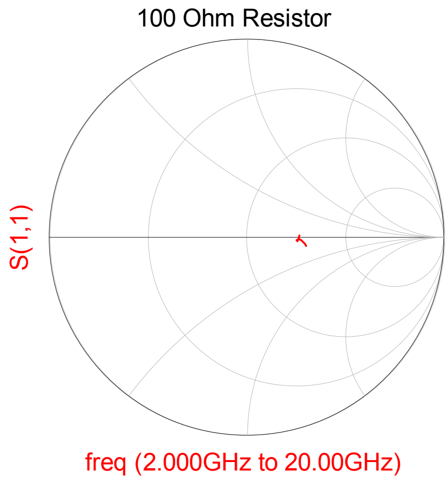


Fig. 3. Measured frequency response of thin film 100 Ohm resistor

III. Circuit Design

In the frequency band of 2-18 GHz, a quarter wavelength transmission line at the center frequency of 10 GHz is 30 mm. Clearly size reduction becomes an important issue. Using a traditional linear architecture such as in [6], the parasitics involved with connecting the common mode resistors can become problematic. Techniques have been suggested in [7] to overcome the transmission line effects of the resistor. Rather, circular sections as suggested in [8] are utilized. To the authors knowledge this is the first implementation using a cascaded topology on microstrip with integrated thin film resistors.

TABLE I
Power Combiner Parameters

Z_1	50.26 Ω	Z_5	85.46 Ω
Z_2	52.21 Ω	Z_6	95.76 Ω
Z_3	58.50 Ω	Z_7	99.46 Ω
R_1	440 Ω	R_5	220 Ω
R_2	615 Ω	R_6	130 Ω
R_3	450 Ω	R_7	150 Ω
R_4	320 Ω		

Integrated thin film resistors can also be beneficial for microwave and millimeter wave designs. Surface mount components can add unexpected parasitic from both the packaging and the solder necessary to mount the devices. If a high sheet resistance is chosen for the thin film resistors, the size of the resistors can be kept to a minimum. In this design a 100 Ω/ NiCr resistor from Ticer Technologies was used. Fig. 1 shows the photographs of the manufactured power combiners.

IV. Results and Discussion

The designed Wilkinson power combiner was manufactured on a 12mil thick LCP substrate with 0.5-oz. copper. Since the device is a 3-port network, either a 4-port network analyzer can be used, or the 3rd port needs to be terminated with a broadband 50 Ω load, the latter of which was used. Fig. 4 shows the physical test setup used to make measurements. A SOLT calibration was used in conjunction with an Agilent E8361A Vector Network Analyzer for all measurements. Simulation results for loss, input and output return loss, and isolation were done using Sonnet EM software and Ansoft HFSS. The measured results from the 2-18 GHz Wilkinson power combiner are shown in Fig. 5.

As can be seen, the designed Wilkinson combiner has a broadband response. The measured input and output return loss all exhibit broadband characteristics having a VSWR of better than 1.6:1. The measured excess insertion loss never exceeds 1.1dB across the full band. The isolation is also better than -14dB, however, suffers some deviation from simulation. This is due to the variability of resistors values when the feature sizes approach the minimum line widths that

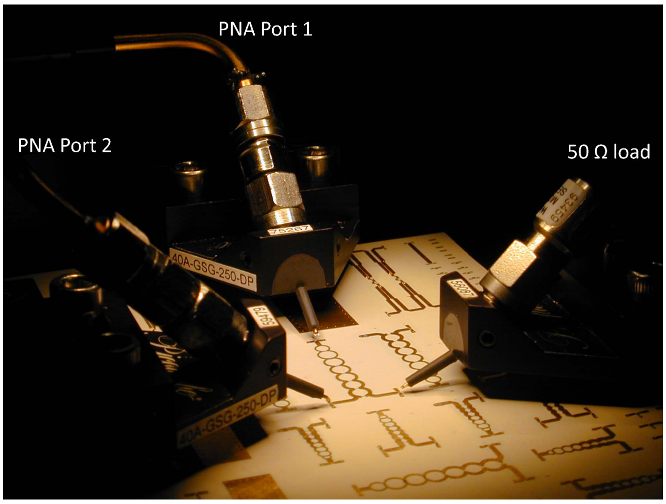
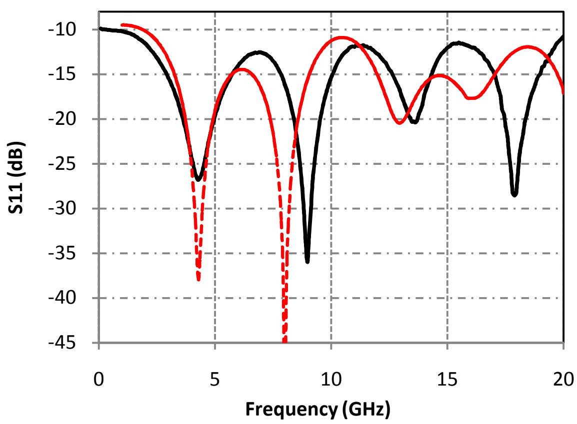


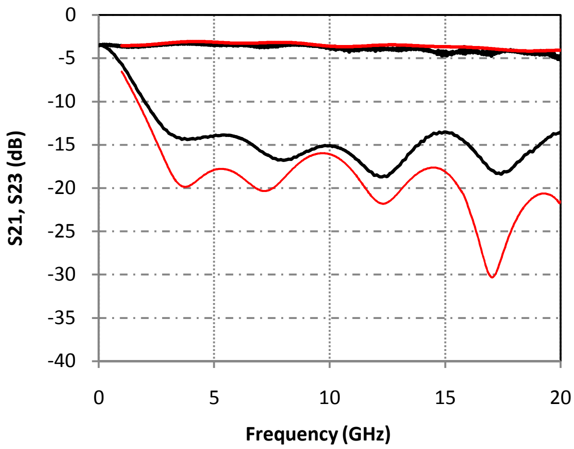
Fig. 4. Photograph of physical test setup used to make measurements.

a manufacture can etch. A simple solution would be to constrain resistor sizes to double that value to ensure consistent resistor values. The measured magnitude imbalance was better than 0.46 dB across the entire bandwidth of interest, from 2-18 GHz.

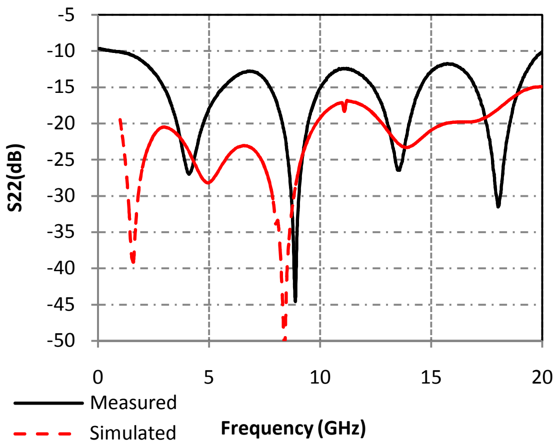
Finally a 1-4-1 back to back structure was measured to confirm functionality and demonstrate the capability of a corporate combiner as shown in Fig. 6. The measured insertion loss of the back to back structure is shown in Fig. 7. and corresponds with the measured insertion loss of the individual test structure. This type of corporate combining structure is a very common method used in high power amplifier design. This particular structure finds applications in very broadband and high power amplifier combining schemes. The limiting factor in this design would be the power handling capability of the thin film resistors used.



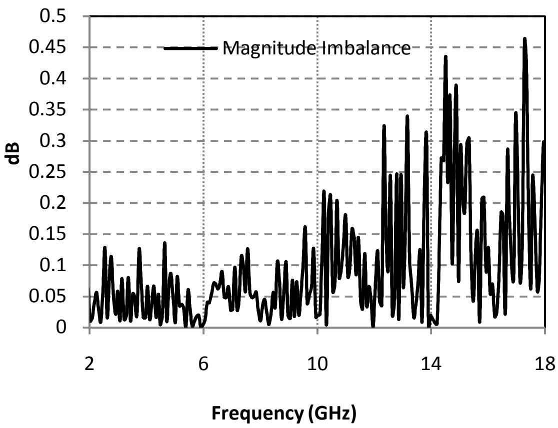
(a)



(b)



(c)



(d)

Fig. 5. Simulation and measurement results for S11. (b) S21, S23. (c) S22. (d) Measured magnitude imbalance between output ports.

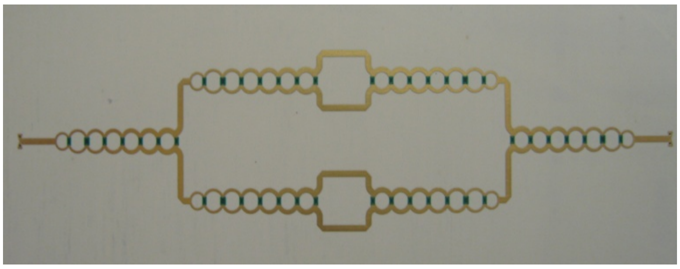


Fig. 6. 1-4-1 Back to back test structure

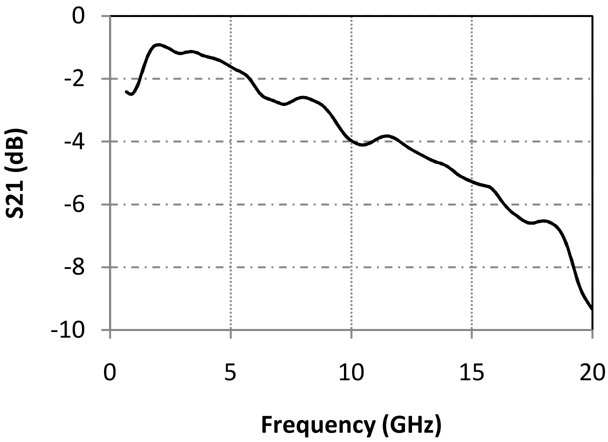


Fig. 7. Measured insertion loss of the back to back test structure

V. Conclusion

A broadband multi-sectioned Wilkinson power combiner on LCP with integrated thin film resistors is presented in this work. A multiple way broadband combiner structure was also fabricated and measured. The designed Wilkinson combiner, to the authors' knowledge, represents the highest performance and most broadband combiner reported to date. The measured VSWR is better than 1.6:1, the excess insertion loss is less than 1.1dB, and 11dB of isolation is achieved across the full band.

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