

Multilayer Organic X-Band Antenna Arrays Using Wilkinson Power Dividers with Embedded Thin Film Resistors

Introduction

Antenna arrays are used extensively in remote sensing applications where a highly directed beam is desired to scan a particular area on the surface of the Earth. Compact size, lightweight, and flexibility are essential characteristics for such applications that require portability and surface conformance. Multilayer Organic (MLO) System on a Package (SOP) technology offers a low cost solution for this type of applications while providing excellent RF performance. Microstrip antenna phased arrays utilizing a substrate of Liquid Crystal Polymer (LCP) and RT/Duroid dielectric layers, and with integrated SiGe LNAs and phase-shifters, have been demonstrated in [1]. The radiating elements on these arrays were uniformly fed in parallel using an embedded microstrip feed network with reactive power dividers. This paper presents a different approach to the feed network, using Wilkinson power dividers with embedded thin film resistors; which will provide better performance in terms of isolation between output ports.

The use of Wilkinson power dividers prevents mismatches and reflected signals on one output port from propagating elsewhere in the system. Wilkinson couplers have been successfully used in [2] for the power distribution of a phased array front-end; however, the isolating resistors used are not embedded. Since the antenna array feed network in this study is embedded, the resistors needed for the Wilkinson dividers must also be embedded. Having the resistors in the substrate as opposed to surface-mounted is advantageous because parasitic effects are reduced, and because the size of the resistor can be scaled as needed by the circuit layout. The feed network proposed in this paper was implemented in multilayer antenna arrays of 4 and 64 elements centered at 9.5 GHz. S-parameter results from ADS/Momentum simulations are presented for the two arrays.

Wilkinson Divider Design

The schematic of a Wilkinson power divider with equal power splits is shown in Figure 1. All ports have matched impedance, and the two output ports are isolated through the resistor R . When implemented in planar form, a common problem found designing the Wilkinson divider is separating the quarter-wave transformers to avoid mutual coupling, while keeping them close enough to place a resistor between them [3]. Figure 2 shows the layout of the Wilkinson divider designed for the feed network of the antenna arrays discussed in the next section.

The width of the microstrip lines depends on the desired impedance and the substrate height. A thin substrate is desired for the feed network to minimize undesired radiation and coupling and to decrease the line widths, making it easier to achieve a layout conducive to good RF performance. However, a thin substrate also adds to the conductor loss. In this study, a 4-mil thick LCP substrate was chosen for the embedded feed network to minimize the conductor loss while also achieving a practical layout [3]. Since the system characteristic impedance (Z_0) is 50 Ω , the quarter-wave transformer arms should have an impedance of 70.7 Ω . The width of the 50- Ω lines is 253 μm , and the width of the quarter-wave transformer arms is 138.5 μm . The length of the microstrip lines depends on the effective wavelength at the operating frequency of 9.5 GHz; the length of the quarter-wave transformer arms is 5200 μm . As seen in Figure 2, the quarter-wave transformers are wrapped around the resistor using a bend radius as large as possible [3].

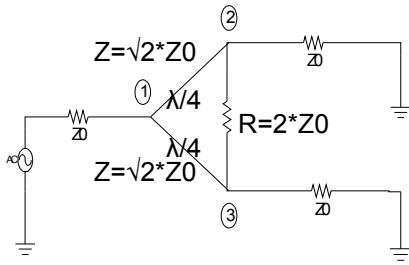


Fig. 1. Schematic of Wilkinson power divider with equal power splits.

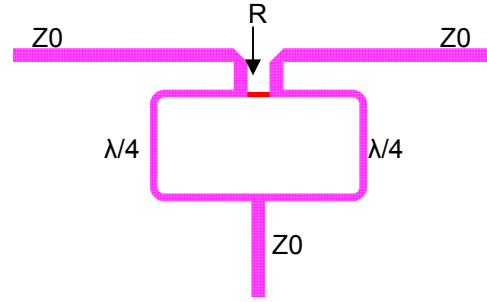


Fig. 2. Layout of Wilkinson divider used in feed network.

The resistor is realized with a commercially available resistive foil laminated to the LCP, which provides a low cost manufacturing solution. Resistors are formed using an etching process after lamination. Since the resistance value is highly dependent on the physical dimensions, uniformity needs to be tightly controlled. Using the embedded foil eliminates the need to control the thickness of the lines, leaving only the length and width to be defined by the etching process. More accurate resistance values can be obtained with larger length and width of the resistors [3]. Using a $25\Omega/\square$ resistive foil, the 100Ω resistor R has length of $400\mu\text{m}$ and width of $100\mu\text{m}$.

Microstrip Antenna Arrays

Multilayer aperture-coupled rectangular patch antenna arrays were designed using the stack-up shown in Figure 3. A 50-mil thick Rogers RT/Duroid 5880 LZ layer was used for the radiating elements, while 4-mil and 2-mil thick Rogers LCP 3850 layers were used for the feed networks. Two 1-mil thick bond ply layers were used to complete the multilayer stack-up. The RF distribution network was built on an embedded layer to allow room for integrated SiGe active devices such as LNAs, and phase-shifters on the bottom layer [1]. The antenna arrays were designed at a center frequency of 9.5 GHz with a bandwidth of 500 MHz.

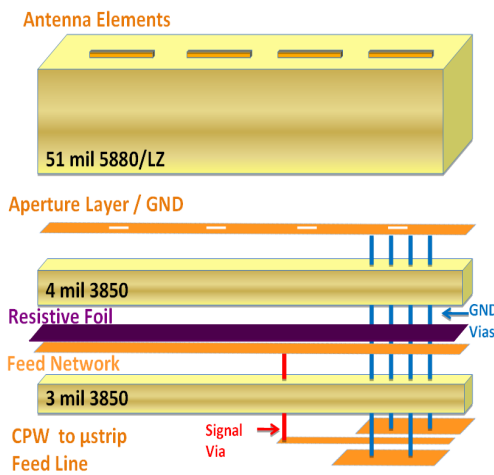


Fig. 3. Stack-up of antenna arrays, shown here for a 4x1 array.

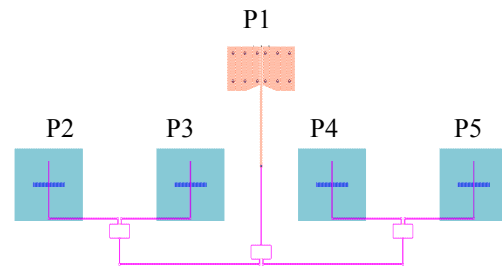


Fig. 4. Layout of 4x1 antenna array using Wilkinson power dividers.

Figure 4 shows the layout of a 4x1 array. The length and width of each patch are 9658 mm and 12979 mm respectively; the length and width of the apertures are 6140 mm and 614 mm

respectively. The distance between patches is 2.7 cm. The gain of the 4x1 array is 9.7 dB. Figure 5 shows the S-parameter results from the 4x1 array Momentum simulation. The return loss is about 20 dB in the desired frequency band. The S23 and S45 traces indicate that the isolation between the output ports of the feed network is greater than 30 dB; whereas the isolation between output ports of a feed network using reactive T-junctions is considerably lower as can be observed on the plot in Figure 6.

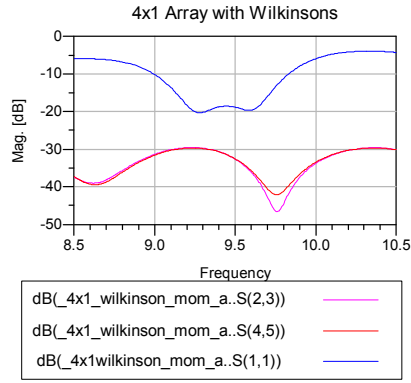


Fig. 5. Simulated S-parameters of 4x1 array with Wilkinson dividers.

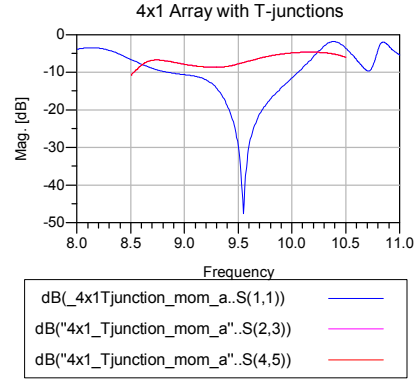


Fig. 6. Simulated S-parameters of 4x1 array with reactive dividers.

The 4x1 array using Wilkinson dividers was used as the building block to create larger arrays. A planar 8x8 array shown in Figure 7 was modeled and optimized using Momentum. The distance between patches in the vertical direction is 2.0 cm, and 3 dB reactive power dividers were used on the bottom layer to feed each row of antennas in parallel. Figure 8 shows a simulated return loss for the 8x8 array greater than 20 dB in the desired frequency band. The simulated 3D radiation pattern of the 8x8 array is shown in Figure 9; the gain is 21.3 dB.

The next step in achieving a working phased array will be to integrate a SiGe LNA and phase-shifter to each 8x1 row of the array. These active devices will be wire-bonded to the bottom layer of the MLO substrate. Figure 10 shows the measured return loss obtained from a fabricated 8x2 array with integrated LNAs and phase-shifters [1]. Similar performance is expected from the fabricated 8x8 array with Wilkinson dividers. Measured data from fabricated 4x1 and 8x8 arrays with Wilkinson dividers will be available during the presentation of this paper.

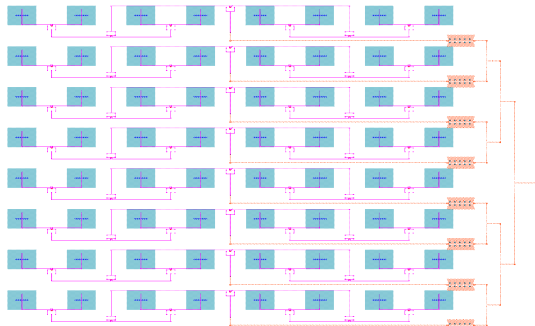


Fig. 7. Layout of 8x8 antenna array using Wilkinson power dividers.

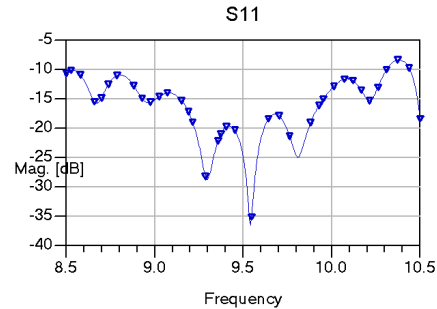


Fig. 8. Simulated return loss of 8x8 array with Wilkinson dividers.

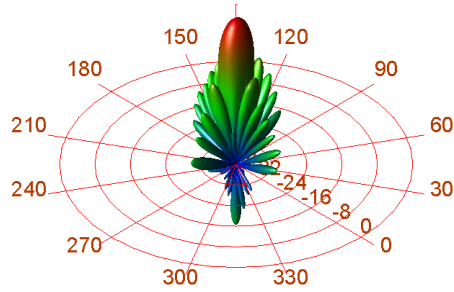


Fig. 9. Simulated radiation pattern of 8x8 array with Wilkinson dividers.

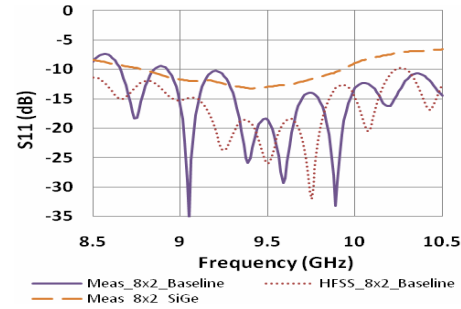


Fig. 10. Return loss of 8x2 array with reactive dividers.

Fabrication

The etching process for forming the embedded resistors for the Wilkinson power divider design is depicted in Figure 11. In Figure 11a, the sample is shown with the resistor foil bonded to the LCP. After defining a pattern with a photoresist mask, the copper and thin film resistor underneath the copper are etched in a single bath as seen in Figure 11b. A second photoresist mask followed by a selective copper etch exposes the thin film resistors and completes the formation of the layer as shown in Figure 11c. The resistor layer thus defined will be embedded in the multilayer antenna design shown in Figure 3.

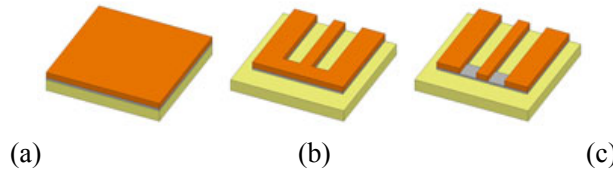


Fig. 11. Process for fabricating embedded resistor for Wilkinson power divider; (a) laminated resistor on LCP, (b) patterned Cu and resistor, (c) resistor with copper terminal pads.

Conclusions

Wilkinson power dividers using embedded resistors were implemented in the feed networks of X-band microstrip antenna arrays of different sizes, and realized on a multilayer organic substrate. A thin film resistive foil is used to fabricate the resistors needed for the embedded Wilkinson dividers. Momentum simulation results show very good isolation between the output ports of the dividers.

References

- [1] Patterson, C.E.; Thirvikraman, T.K.; Yepes A.M; Begley S.M.; Bhattacharya S.K.; Cressler J.D.; Papapolymerou, J., "A Lightweight Organic X-Band Phased Array with Integrated SiGe Amplifiers and Phase Shifters," submitted to the *IEEE Transactions on Antennas & Propagation*, 2010
- [2] Kwang-Jin Koh; Rebeiz, G.M., "A Q-band phased-array front-end with integrated Wilkinson couplers for linear power combining in SiGe BiCMOS," *Bipolar/BiCMOS Circuits and Technology Meeting, 2008. BCTM 2008. IEEE*, vol., no., pp.190-193, 13-15 Oct. 2008
- [3] Horst, S.; Bhattacharya, S.; Tentzeris, M.; Papapolymerou, J., "Monolithic Low Cost Ka-Band Wilkinson Power Dividers on Flexible Organic Substrates," *Electronic Components and Technology Conference, 2007. ECTC '07 Proceedings. 57th*, vol., no., pp.1851-1854, May 29 2007-June 1 2007