A novel wide-band Butler matrix for vehicle radars at 24GHz

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Abstract

There is a great scientific and commercial interest in car radars for anti-crash and pre-crash systems, for which beamformer networks with antenna arrays are becoming the norm. In this paper a novel Butler matrix at 24GHz using a new type of micromachined suspended transmission-line couplers is presented. This configuration arranges all the couplers in the center so that no line crossovers are needed. This circuit has been micromachined on a glass-quartz substrate and BCB layers have been used to suspend the transmission lines of the coupler. In this paper the fabrication method will be fully described, simulated and preliminary experimental results are presented.

1. Introduction

The 24GHz band is being widely used for short range anti collision vehicle radars. In [1] a system consisting of 4 short-range sensors and two computers integrated in the test car is proposed. In [2] a switching system is described to build a pulsed-radar for vehicles at 24GHz. And in [3] a radar mixer is described for the same application.

Generally, automotive radars for anti crash systems integrate a beamformer network and an antenna array having the capability of scanning the generated beam by a simple switching of the input.

A Butler Matrix is a beamformer that contains the least number of couplers compared to other beamformer networks [4].

In this paper, we present a novel 4x4 Butler matrix using a new type of suspended transmission- line couplers [5,6] at a center frequency of 24 GHz. This device is micromachined on a glass-quartz substrate with a permittivity of er=3.8 and thickness of h=125mm. BCB is used to suspend the transmission lines of the directional couplers..

2. Circuit design

A Butler matrix is a beamformer circuit with N input ports and N output ports. It offers different constant phase shifts at its output ports depending on the chosen input, hence, when connected to an antenna array a beam-scanning capability is achieved.

Normally, Butler matrices have a great number of line crossovers [4]. For a 4X4 configuration 2 crossovers are needed, however by re-arranging the layout it is possible to eliminate them as shown in Figure 1(a). The phase shifts between the output ports (5,6,7 and 8) are -45o for input port 1, -135o for input port 2, 45o for input port 3 and 135o for input port 4. For further reading on the Butler matrix design refer to [7].

In this paper a 4x4 matrix is proposed using a novel type of suspended transmission-line couplers. These novel couplers have a wide frequency bandwidth of about 50% with a coupling un-balance of +/-0.3dB, while the conventional Branch line couplers have a bandwidth of approximately 15% for the same coupling unbalance. Transmission-line couplers consist of two parallel l/4-coupled lines. One of the main limitations of these directional couplers is the difficulty of manufacturing very close gaps for tight couplings (such as 3dB). In this paper we suggest a new type in which one of the lines is suspended over the other one with an air gap of 10mm as shown in Figure 1(b). The total length of the coupler is 2270mm. The couplers were designed using a full-wave simulator [8].

All the bends of the transmission lines were also optimized for best performance to a miter of 56%. Figure 1(a) shows a picture of the final layout of the matrix and of a single transmission-line coupler.

3. Fabrication

The single coupler and the Butler matrix were fabricated on a 125mm thick quartz substrate. A Cr/Au layer is thermally evaporated on the quartz substrate. The die for the gold electroplating is formed with photo resist

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using UV photolithography. A 3mm thick gold layer is electroplated to form the signal lines. After that, the mold and seed layers are removed and a 10mm layer of BCB is patterned using UV photolithography and cured at 150oC. To form the suspended transmission lines, a seed layer is evaporated and a 3mm thick gold layer is electroplated on the quartz substrate and BCB layers after forming a photo resistive cast. At last, the photoresistive cast is removed using acetone and the seed layer is removed by a wet etchant.

4. Simulated and experimental results

The branch line couplers were simulated using a full wave simulator and these results were then imported into [9] for the final matrix simulation including the interconnecting transmission lines and phase shifters.

The simulated magnitude response for the through and coupled ports of the coupler is -3dB and -3.4dB respectively at the center frequency. For a 50% bandwidth, the coupling is -3dB with a coupling unbalance of about +/-0.4dB. The phase difference between the coupled and through ports is about 90o throughout the band. The experimental measurements of the coupler are shown in Figure 2. At 24 GHz the through port value is -3.9dB and the coupled port is -4.2dB. The return loss and isolation are better than -15dB throughout the band. The phase response shows an 86o phase shift at around 25GHz [10].

The simulated response of the Butler matrix is presented in Figure 3(a). which shows the magnitude assuming a signal is input at port one. As it can be seen, the magnitude responses at the center frequency are -6.7dB for S(5,1), -6.4dB for S(6,1), -6.47dB for S(7,1) and -6.2dB for S(8,1), hence there is an unbalance of about +/- 0.2dB. For the 50% bandwidth this unbalance is about +/- 0.7dB. Figure 3(b). depicts the phase response of the matrix when a signal is input through port 1. In this case the phase difference between output ports (5, 6, 7 and 8) is about -45o throughout the band.

5. Conclusion

In this paper an 8-port wide-band Butler matrix at 24GHz for vehicle front-end radars has been successfully built using micromachined techniques. This matrix was designed using a new type of suspended transmission line couplers. Experimental results of the transmission-line coupler were presented and the construction method has been fully described. Also simulated responses of the whole Butler matrix were presented

6. References

[1] M. Skutek, et. al. "A precrash system based on radar for automotive applications", *IEEE Proceedings of Intelligent Vehicles Symposium*, pp:37 - 41, June 2003.

[2] I. Gresham, A Jenkins. "A fast switching, high isolation absorptive SPST SiGe switch for 24 GHz automotive applications" Presented on the *33rd European Microwave Conference*, vol. 3 , pp. 903-906, Oct. 2003.

[3] I. Gresham, A Jenkins. "A low-noise broadband SiGe mixer for 24GHz ultra-wideband automotive applications". *Proceedings of RAWCON '03*, pp:361-364, Aug. 2003.

[4] A. Corona. M.J. Lancaster. "A high-temperature superconducting Butler matrix". *IEEE Trans. on Applied Superconductivity*, vol. 13 , Issue. 4 , pp 3867-3872, Dec. 2003.

[5] G. Matthaei, L. Young and E.M Jones. "Microwave filters, impedance matching networks, and coupling structures". *Artech House Inc*. 1980.

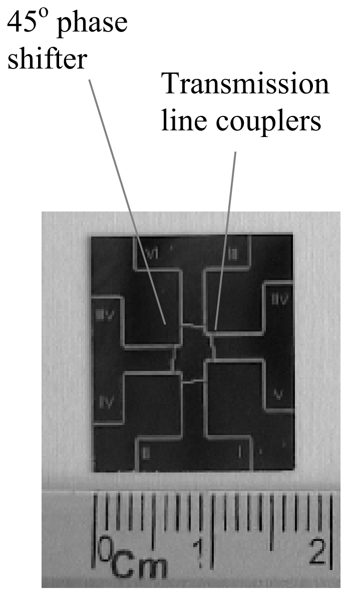
[6] Hong-Teuk kim, et. al. "CPW MMIC coupler based in offset broadside air-gap coupling fabricated by standard air bridge processes". *Electronics Letters*. Vol. 37, No. 6, pp 358,359, March 2001.

[7] H. Moody. "The systematic design of the Butler matrix". *IEEE Trans. on Antennas and Propagation,* pp. 786-788, November 1967

[8] HFSS version 9.1. Ansoft Corporation

[9] Sonnet v.10. Sonnet USA Inc.

[10] Alonso Corona-Chavez, Ignacio Llamas-Garro, Jung-Mu Kim, Yong-Kweon Kim, "Novel Suspended-Line Microstrip Coupler Using BCB as Supporting Layer", *Microwave and Optical Technology Letters*, Vol. 49, No. 8, August 2007, pp 1813-1814



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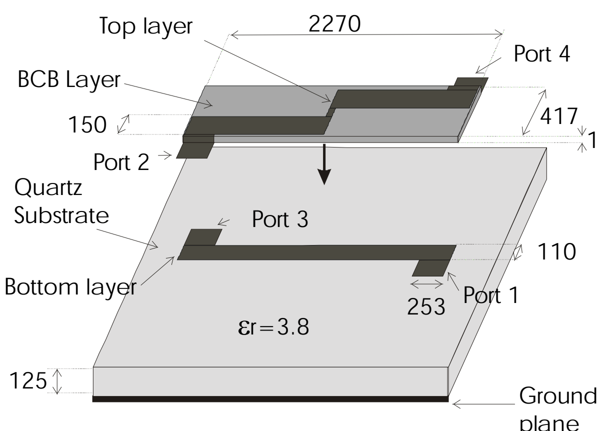
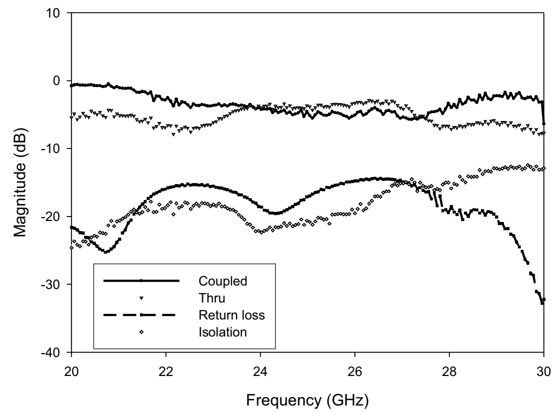


(b)

Figure 1. (a) Micromachined Butler matrix without line crossovers. (b) Proposed suspended transmission-line coupler on a quartz substrate showing the top conductor, the BCB layer and the bottom layer



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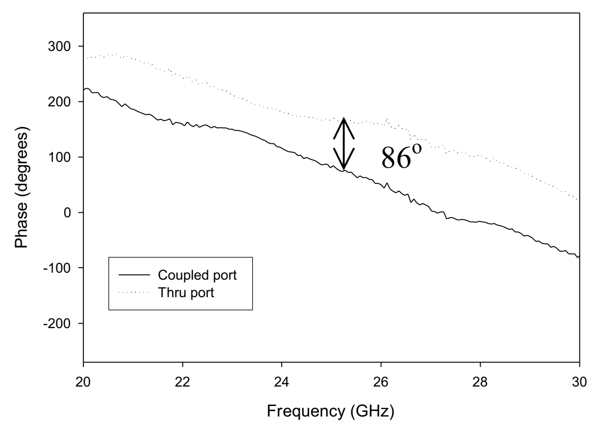
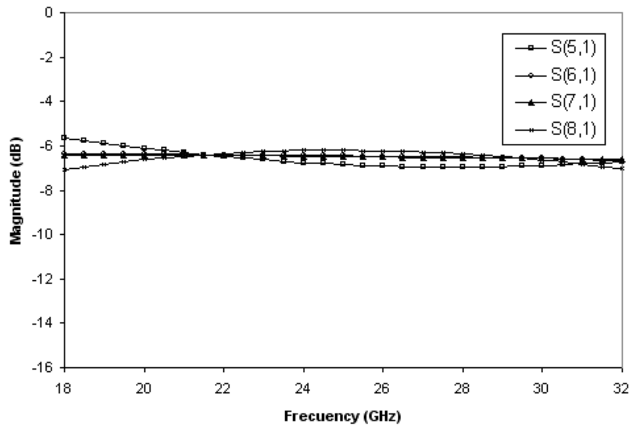


(b)

Figure 2. (a) Experimental magnitude response of transmission-line coupler. (b) Experimental phase response of transmission line coupler



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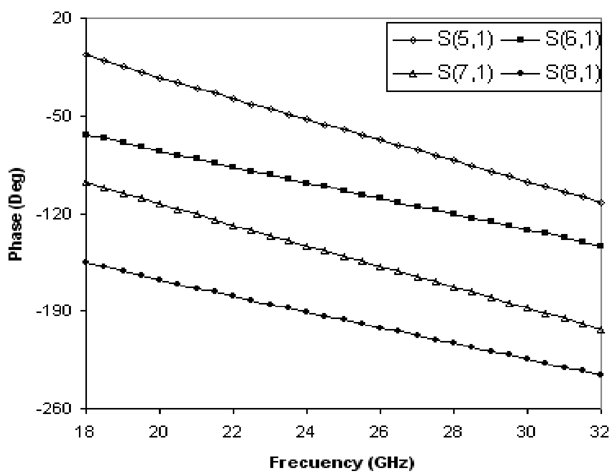

(b)

Figure 3. (a) Simulated response of the Butler matrix. The input is considered to be port 1 and the outputs are ports 5 to 8. The center frequency is 24GHz and for 50% bandwidth the coupling unbalance is about +/-0.7dB. (b) Simulated phase response of the Butler matrix. The input is considered to be port 1 and the outputs are ports 5 to 8. The phase difference is about 45o at the center frequency