마이크로머신 기술로 제작한 자동차 프런트엔드용 초광대역 빔성형 네트워크

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Micromachined ultra-wideband beamforming network for automotive radar front ends

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Abstract - As anti-crash and pre-crash systems in vehicles become more extensively used, the need for high performance short-range radars is playing an increasing role. This paper presents the design of a micromachined, ultra-wideband beamformer centered at 24 GHz for automotive short-range radar systems. This beamformer is a Butler matrix designed using ultra-wideband transmission-line couplers, which consist of a multilayered structure that exhibits wider bandwidth compared to conventional microstrip branch-line couplers. The circuit has been designed on a quartz substrate, and to achieve the desired coupling, lines suspended on BCB layers located at specific parts of the circuit were used, achieving a three metal layered structure in form of wide microstrips, that give low loss and a wideband response. In this paper the design and fabrication procedure of the proposed beamformer are fully described.

1. Introduction

The 24 GHz band is of great importance for short-range radar applications, as it is very close to the resonant wavelength of water vapor (22.2 GHz), where absorption reduces the range of the radar [1]. Anti-crash and pre-crash systems have been suggested to operate at this frequency. The Federal Communications Commission in the USA (FCC), has approved the use of signals in the Ultra Wide Band frequency (UWB) centered at 24 GHz for vehicular short-range radar sensors. The European Commission has as well taken steps towards this direction introducing the Driver Assistance Systems, with radars centered at 24 GHz [2]. In [3] a system is proposed at the band of 24 GHz. This system consists of 4 short-range sensors, and two computers integrated in the test car. In [4] a switching system is described to build a pulsed-radar for vehicles at 24 GHz. And in [5] a radar mixer is described for the same application. Typically, short-range radars consist of; at the transmit side: a wave generator, an antenna array fed by a beamformer and a circulator; and at the receive side: a bandpass filter, a low noise amplifier, a down converter and IF processing [see Figure 1]. A Butler Matrix is a beamformer circuit suitable for these applications. It contains the least number of couplers compared to other beamformer networks [6], hence size reduction is achieved. In this paper, we present an 8-port Butler matrix using transmission-line couplers [7][8], at a center frequency of 24 GHz for automotive radar applications. The device is micro-machined on a glass-quartz substrate, with a permittivity of 3.8 and a thickness of 125μm.

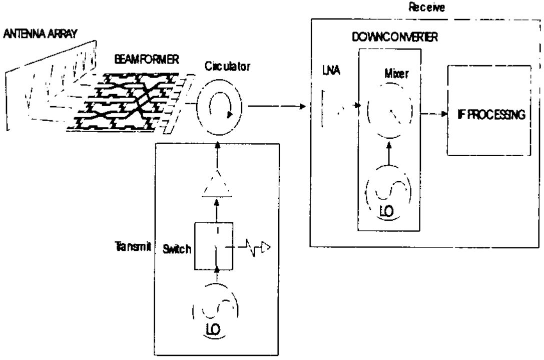

Figure 1. Schematic of pulsed radar with a beamformer network and an antenna array

2. Design

A Butler matrix is a beamformer circuit that gives constant phase shifts at the input of an antenna array, while maintaining the magnitude constant for all. The proposed special arrangement of the couplers avoids line crossovers. The use of Branch line couplers limits the bandwidth of the Butler matrix to approximately 15%, for a coupling unbalance of +/-0.2dB, for this reason, we propose the use of transmission-line couplers, which increases the frequency bandwidth to about 50% with +/-0.3dB. A transmission-line coupler consists of two parallel quarter-wavelength coupled lines. To achieve the required coupling of 3dB, one of the lines has been suspended over the other one as shown in Figure 2. All the layers have been separated for clarity. The top and bottom layers have coupled transmission lines, whereas the middle layer contains the BCB layer. These 3 layers rest on a Quartz substrate. The top line is separated from the bottom line by the 10 μm BCB layer. The total length of the coupler is 2270 μm. The couplers were designed and optimized using a 3D full-wave simulator [9]. If we assume an input signal trough port 1, then port 2 is the isolated port, port 3 is the through port, and port 4 is the coupled port. Figure 3 shows the layout of the proposed

Butler matrix. The bends and phase shifters were simulated and optimized using a planar simulator [10]. The optimum miter of the bends is 56%. The phase shifts between the output ports (5,6,7 and 8) are -45° for input port 1, -135° for input port 2, 45° for input port 3 and 135° for input port 4. A thorough review of the Butler matrix design can be found in [11].

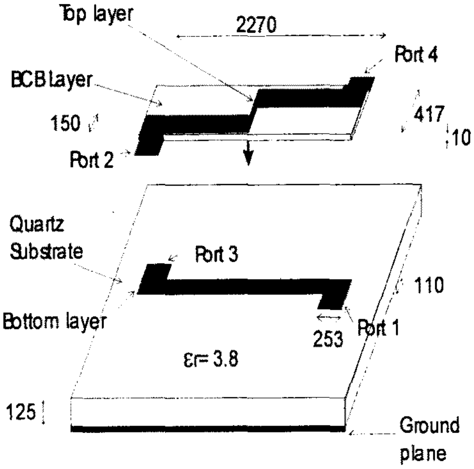

Figure 2. Suspended transmission-line coupler (all distances are given in μm)

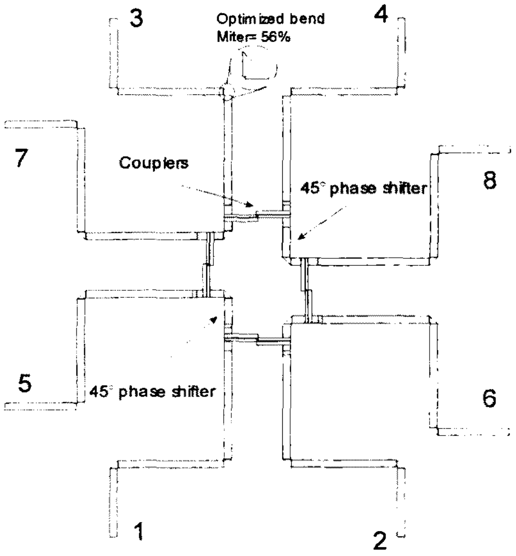

Figure 3. Layout of 8-port Butler matrix

3. Fabrication process

The proposed Butler matrix is fabricated on a 125 μm-thick quartz substrate. A Cr/Au (100/1000 Å) layer is thermally evaporated on the quartz substrate using a thermal evaporator. The mold for the gold electroplating is formed by AZ 4330 photoresist, using *UV photolithography technology. A 3 μm-thick gold* is electroplated to form the signal lines. After mold and seed layer (Cr/Au) removal, Benzo Cyclo Butene (BCB) layers are patterned using UV photolithograpy. BCB is known to be a material with low loss tangent and low permittivity at high frequencies. The patterned BCB is cured at 150 °C, with a thickness of 10 μm. In order to form the suspended transmission lines, a seed layer (Cr/Au) is evaporated, and 3 μm-thick gold is electroplated on the quartz substrate and BCB layers after forming a photoresistive mold. Finally, the photoresistive mold is removed using acetone, and the seed layer (Cr/Au) is removed by a wet etchant.

4. Simulated results

The simulated responses of the Butler matrix are presented in Figure 4 and Figure 5, and show the magnitude response when a signal is input through port 1. Ports 5, 6, 7 and 8 are the output ports (Figure 4), and ports 2 , 3 and 4 are the isolated ports (Figure 5). From Figure 4, it is seen that 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. From Figure 5 it is apparent that the return loss and isolation are better than -20dB for the center frequency, and better than -15dB for a 50% bandwidth. Figure 6 shows the phase response of the matrix when a signal is input through port 1, and Figure 7 shows the response when a signal is input in port 2. For the first case, the phase difference between output ports (5, 6, 7 and 8) is about -45°. For the latter case, the phase difference is about 135° throughout the band. Since the Matrix is symmetrical, the phase difference when a signal is input trough ports 3 and 4 should be 45° and -135° respectively.

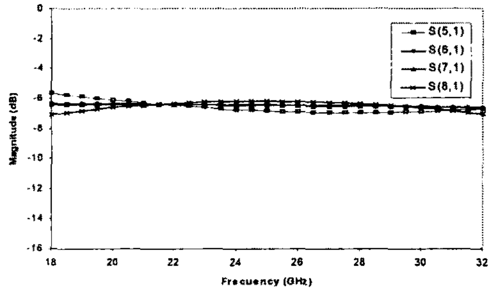

Figure 4: Magnitude simulated response of the Butler matrix. The input port is 1 and the output ports are 5, 6, 7 and 8

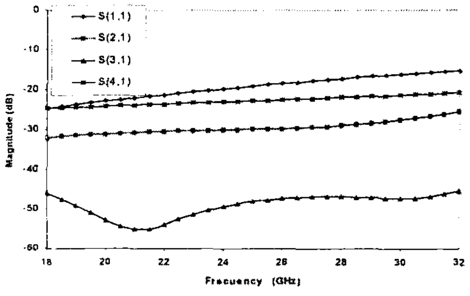

Figure 5. Magnitude simulated response of the Butler matrix. The input port is 1 and the isolated ports are

2, 3 and 4

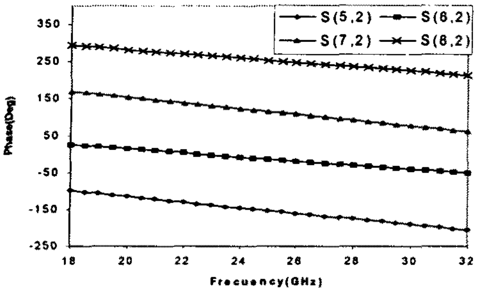

Figure 6. Phase simulated response of the Butler matrix. The input port is 1 and the output ports are 5, 6, 7 and 8

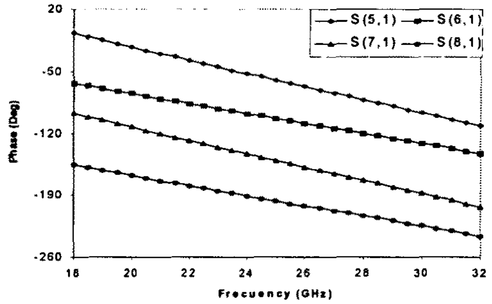

Figure 7. Phase simulated response of the Butler matrix. The input port is 2 and the output ports are 5, 6, 7 and 8

5. Conclusions

In this paper a micromachined 8-port Butler matrix centered at 24 GHz for vehicle front-end radars has been described. This proposed matrix can be constructed using broadband transmission line couplers, that have suspended lines on BCB to achieve the required coupling. Simulated results were presented and the construction method described.

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