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Design and Fabrication of Unequal Amplitude Branch-line Coupler Radar Wind Profiler Applications

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Abstract

In this article, a branch-line coupler with unequal amplitudes with 90^0 phase difference for P-Band 430MHz is proposed. By changing the impedances of the opposite arms in a branch-line coupler, unequal power division can be achieved. There is a good agreement between the theoretical, simulated and measured results. The amplitude weights are selected based on taylors 1-parameter method for side lobe level -17dB. The fabricated coupler is best suited for shared aperture antenna feeding network using branch-line coupler for 430MHz Radar applications. A prototype of unequal power branch-line coupler is fabricated. The measured results show that the Return loss is larger than 23dB. The output power couplings S_{21}& S_{31} is -4.381dB and -3.172dB and the output phase difference is 88.8^0 at the resonant frequency.

1. INTRODUCTION

Radar Wind Profilers are used to probe the atmosphere from the earth surface. Operates UHF/P with required power aperture product . Antenna array consists of microstrip patch elements arranged as planar array of 2X2, 4X4, 8X8, system based on beam width requirement and directivity. Each array element is fed Unequal Power based on different antenna synthesis techniques. The major subsystems in Radar wind profilers are phased array antenna, T/R module, Feeder network, beam forming unit, RF system, digital receiver, radar controller, BITE, radar signal processing, data archive and real time data display system. The feeding of RF power to the antenna is through a coaxial cable like RG214.The cable length is typically of the order of 1-2 meters. The feeder network consists of coaxial cables, optical fibers with modulator and demodulator, power combiners / dividers. Here the feeder network with unequal amplitude equal phase power splitter is used to reduce the side lobe levels -17dB down from the main lobe based on antenna synthesis technique taylors one-parameter method. The RF drive signal is brought to the TRMs through a chain of 1:8 and 1:16 branch-line couplers [1].

In this article, an unequal power branch-line coupler is used to feed a linear array antenna. The main advantage of using such a feed technique is to ensure a non-uniform current distribution of the patches and to get side lobe levels 0f -17dB down from the main beam for amplitude control. The beam forming network, shared aperture antenna ad unequal power branch-line coupler studied in Section 2, and the design equations of coupler measurements and return loss , phase and power coupling are compared with simulations in Section 3.

2. THEORY

2.1. Beam forming network

Beam forming network, which is used in radar systems, is a key factor in a multi-beam antenna system. One key issue in designing any beamforming network is to achieve desired amplitude and phase distribution at the N outputs of the RF network. In order to do so, power splitters/ combiners and phase shifters need to be included. Phase shifters can be implemented by inserting different lengths of the transmission lines between the power splitters and combiners for fixed beam pattern. For a direct radiating array, the phase is mainly used to direct the beam, and the amplitude is used for side lobe control. The simplest way to work with the beam forming is to only adjust the phase of signals from different elements to point the beam in a desired direction. The amplitude and phase applied to each array element is a complex quantity and throughout this work it is referred to as the excitation coefficient. If there is only one element, there is no way to change the pattern of an antenna even if the excitation changes. With two elements, however, changing the excitation coefficient of one element relative to the other will change the pattern. In order to generate multi-beams and shape the beam pattern, beam sharing technology is employed[4].

2.2. Shared aperture antenna

Shared aperture antennas are a new class of phased arrays antennas that combine the functionality several antennas in to one aperture using wideband multiple beam technology. Multi functionality of the antenna system is a key issue in the case of mobile plat forms performing simultaneous multiple tasks, such as communication, remote sensing, electronic warfare etc. By sharing the same antenna aperture, the overall size and weight of the array can be reduced. Microstrip antenna is usually selected for its low profile and simplicity of fabrication. The trend in wind profiling radars is to perform simultaneous measurements at different frequencies, preferably with dual polarization capability. The wind profiling radars for example operating at VHF, UHF/P, L, S & C-band with dual linear polarization at each frequency, but these two antennas did not share a common aperture. Future systems require comparable capabilities, but with reduced mass and reduced size, driving a need for dual frequency dual polarization antennas using a shared aperture. In addition beam scanning in one/two planes, over a few beam widths may be required. This presents the antenna designer with a challenging problem, as the following considerations are critical.[5][6][7].

a. The avoidance of grating lobes(particularly if scanning is required) places an upper limit on element spacing at each band, while maximum element spacings are preferred to minimize the cost..

b. Operating frequencies are widely separated (typically some combination of P,L,S & C-bands), requiring different array element spacings to avoid grating lobes. This implies that an interleaved arrangement of elements at each band is optimum.

c. Combining the functionality of several antennas in to one shared aperture presents several technical challenges. An aperture can be shared between systems in various ways. One way is to simply time-multiplex the use of aperture. Radar operation, for example, includes periodic, scheduled transmissions and receptions therefore, when the radar is not transmitting or receiving, the aperture should be used for other functions, time permitting. The configuration of shared aperture antenna is shown in figure 1

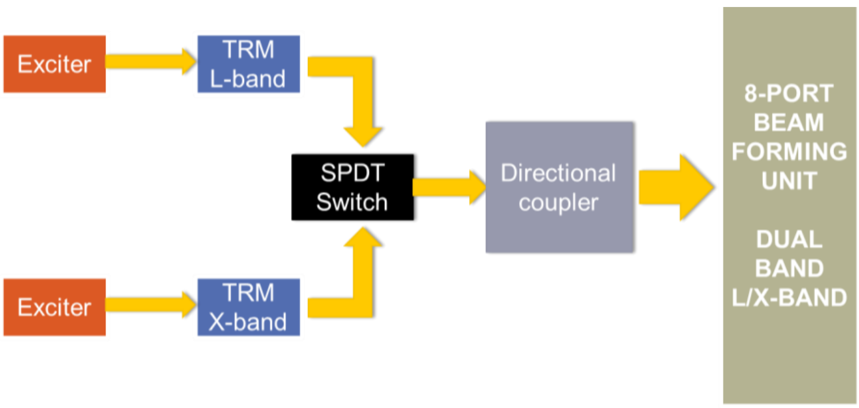


Figure 1. Configuration of the Shared Aperture Radar System

2.3. Unequal Power Branch-line Coupler

In Radar systems, various characteristics such as compact size, broadband, and multi band operation are required for passive circuit design. Therefore, the unequal branch-line coupler [2] is an important passive component needs to be enhanced. A new method to design the unequal microstrip branch-line coupler has been proposed and implemented. With the change in impedances in opposite arms to the conventional branch-line coupler introduced in, the coupler with unequal amplitude can be easily obtained. Analysis and design equations for the proposed coupler are described. It consists, as shown in Figure 2, of a main line that is coupled to a secondary line by two quarter-wavelength long sections spaced one quarter wavelength apart, thus creating a square approximately one wavelength in circumference. When a signal is introduced at port-1, the signals at the two output arms (2,3) are unequal in amplitude but have a 90^0 phase difference between each other. The port located on the same side as the input port is isolated since there is no power reaching it. Z01 and Z02 denote the characteristic impedances of the series and shunt lines respectively. The power applied at a port is evenly distributed between the ports located on the opposite side of the coupler. There is a 90^0phase difference between these two ports, the port closer to the input port is leading in phase by 90^0. The port located on the same side as the input port is isolated since there is no power reaching it.

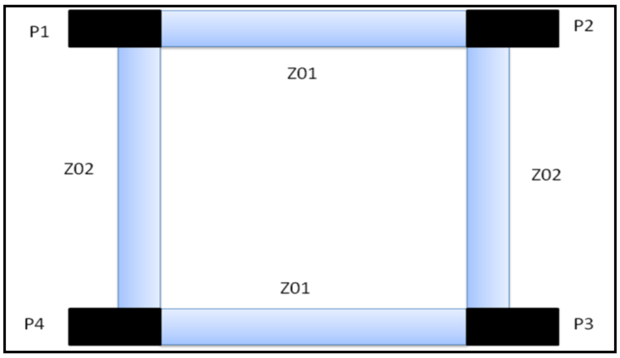


Figure 2. Schematic of branch-line coupler

3. DESIGN EQUATIONS

The microstrip transmission line impedances can be calculated by using the following design equations [1&2] shown below.

$$Z_{01} = Z_0 \left[\frac{\frac{P1}{P2}}{1+\frac{P1}{P2}} \right]^{0.5} = Z_0 \left[\frac{K}{K+1} \right]^{0.5} \text{..........[1]}$$

$$\frac{P1}{P2} = K$$

$$Z_{02} = Z_0 \left[\frac{P1}{P2} \right]^{0.5} = Z_0 [K]^{0.5} \text{..........................[2]}$$

Where P1 & P2 are power divisions at port-2 and port-3

The widths and lengths of series/shunt arm of the branch-line couplers for the above impedances can be calculated by using design equations [1&2].One key issue in designing any beam forming network is to achieve desired amplitude and phase distribution at the N outputs of the RF network. In order to do so, an unequal amplitude quadrature branch-line coupler is used. Phase shifters can be implemented by inserting different lengths of the transmission lines between the branch-line couplers for fixed beam pattern. For a direct radiating array, the phase is mainly used to direct the beam, and the amplitude is used for side lobe control. The simplest way to work with the beam forming is to only adjust the phase of signals from different elements to point the beam in a desired direction but in this proposed work to adjust the amplitude of the signals from different elements to reduce the side lobe levels according to our requirement. The power levels at port 2 and port 3 and impedances, lengths and widths are given in table-1&2 and substrate information in table-3.

TABLE-1 Power at different ports

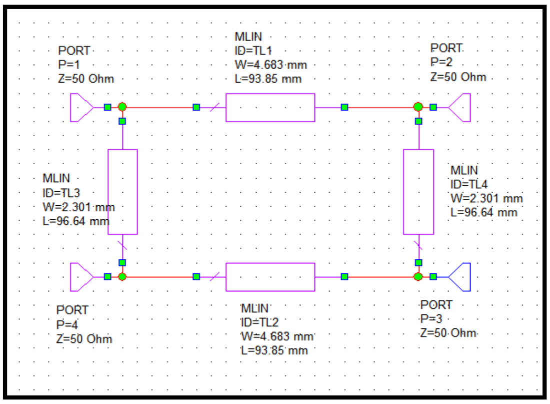
Parameter	Impedances[Ω]	Length [mm]	Width [mm]
Z0	50	95.56	3.06
Z01	38.104	93.85	4.683
Z02	58.84	96.64	2.301

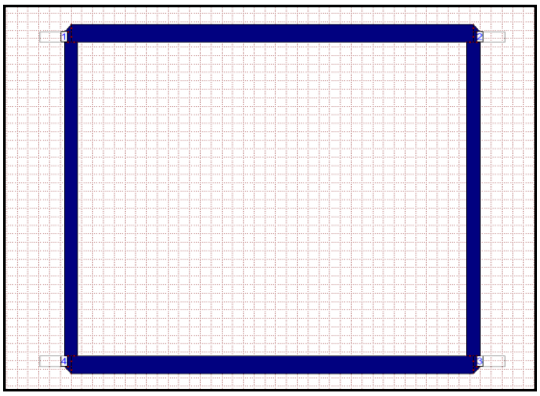
TABLE-2 Impedances, lengths and widths

Parameter	Value
P total	0.73408 watts
P1	0.42631 watts
P2	0.30777 watts
K	1.38515

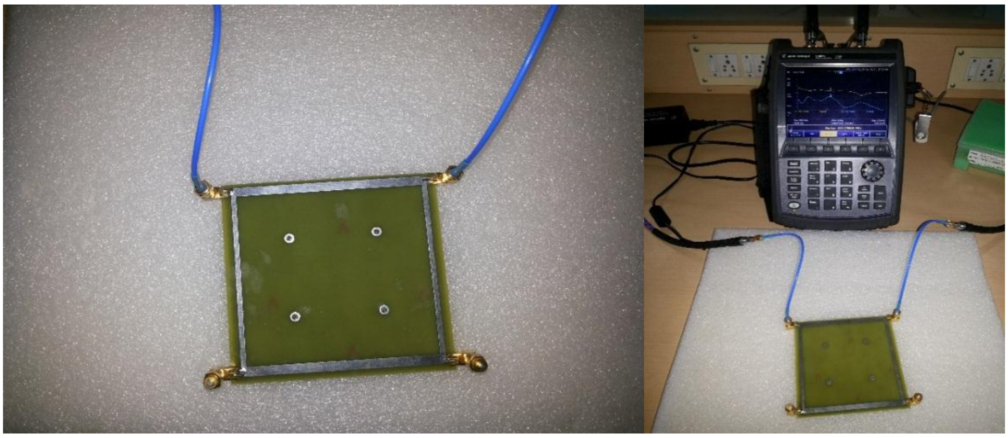
TABLE-3 Substrate information

Parameter	Value
Frequency [MHz]	430
Substrate	FR4 Glass Epoxy
Relative permittivity[εr]	4.4
Loss tangent[tanδ]	0.02
Substrate height[mm]	1.6
Wavelength[m]	0.6976
Electrical length[degrees]	90^0



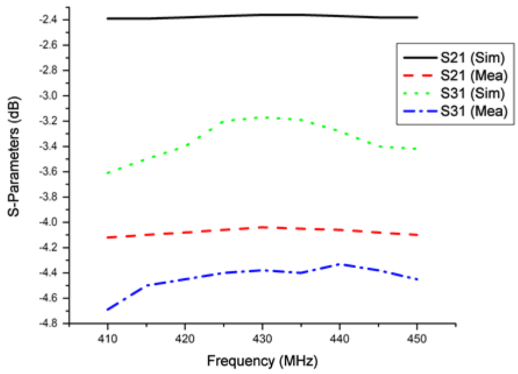


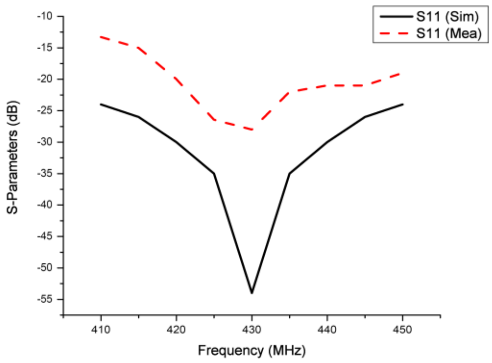
(a) **(b)**



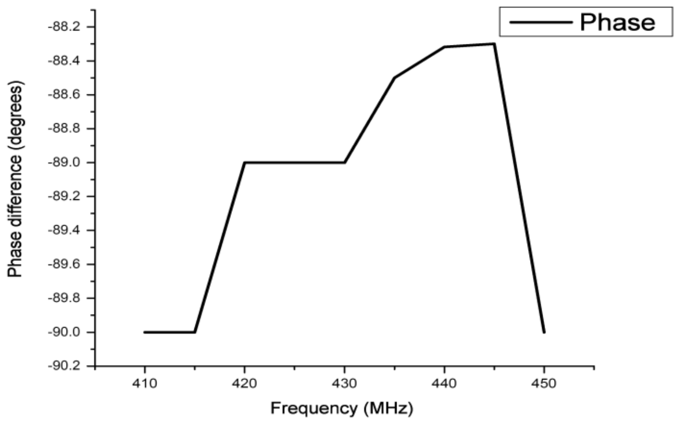
(c)

Figure 3. (a) Schematic design (b) Layout of branch-line coupler design (c) Fabricated unequal branch-line coupler with VNA setup





(a) (b)



(c)

Figure 4. (a)│S_{21}│, │S_{31}│ Simulated & Measured, (b) │S_{11}│ Simulated & Measured, (c) phase difference of the proposed out of phase branch-line coupler

4. MEASUREMENT RESULTS

The proposed unequal power branch-line coupler has been fabricated on a FR-4 substrate with thickness of 1.6mm relative dielectric constant of 4.4. The unequal branch-line coupler has been designed with operating frequency of 430MHz. According to equations 1 & 2 , the line impedance values are Z_0=50Ω, Z_{01}=38.104 & Z_{02}=58.84Ω. based on these impedance values the lengths and widths of corresponding impedances can be calculated Z_0=50Ω (L=95.65mm, W=3.06mm) Z_{01}=38.104 (L=93.85mm, W=4.68mm) & Z_{02}=58.84Ω (L=96.64mm, W=2.301mm). Figure (4) shows the photo of the fabricated unequal power branch-line coupler. The measured S-parameter data collected from Network Analyser N9918A (30KHz-26.5GHz) Agilent make along with simulated results using IE3D are presented in figure(4). There is a good agreement between the simulated and measured results with the unequal power division and good impedance matching at 430MHz for all ports. The Return loss is -62dB and -51dB at both the output port and coupled port. The simulated couplings S21 and S31 are -4.381dB and -3.172dB. the measured return loss at port-1 [S11] is -32.5 dB and return loss at port-2 [S22] is -26.4 dB and the measured S21 and S31 are -4.381 dB and -3.172 dB.

CONCLUSION

In this paper, the proposed coupler is easily fabricated on the FR-4 laminate without any lumped element. The agreement between measured, Simulated and Theoretical prediction validated the feasible configuration of the proposed coupler and amplitude weights are designed based on antenna synthesis technique so called taylors 1-

parameter method for side lobe level -17dB down from the main lobe. The fabricated prototype is suited for shared aperture antenna feeding network using branch-line coupler for 430MHz resonant frequency. A prototype of unequal power branch-line coupler is fabricated. The measured results show that the Return loss is larger than 23dB. The output power couplings S_{21}& S_{31} is -4.381dB and -3.172dB and the output phase difference is 88.8^0 at the resonant frequency.

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