Linear Dielectric Resonator Array Fed by N-Way Bow-Tie Shaped Dielectric Resonator Power Divider

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Abstract**–**The concept of using high order modes of a bow-tie shaped dielectric resonator in the design of N-way power divider is presented in this paper. The design of 6-way power divider operating at X-band frequency range is illustrated, simulated and tested for concept validation. The combination of probe type excitation and microstrip technology is used to excite an H-polarized resonating mode around 10 GHz. Both input matching and in phase tapered power distribution are experimentally maintained within 150 MHz frequency band around the resonant frequency. Measured scattering parameters magnitude and phase of the proposed 7-port structure are shown to verify the expected simulation results. Also, the proposed power divider is used to excite an antenna array of six rectangular dielectric resonators using narrow slots coupled to the power divider output through microstrip lines. Good agreement between simulated and measured results is obtained for application validation.

Index Terms**–**Antenna array feed, bow-tie shaped dielectric resonators, higher-order modes, power divider, and X-band.

I. INTRODUCTION

Dielectric resonators (DRs) have been used in the design of microwave components such as microwave filters and stabilized oscillators [1-3]. These ceramic resonators are made of low loss, temperature-stable and of high dielectric constant materials [4-5]. However, for antenna applications, such dielectric resonators can be of low radiation Q-factor. Hence, high radiation efficiency device characteristics are obtained [6-8]. All these properties made them suitable for multi- functional applications as either radiator and/or resonator for microwave circuits [9-12].

High-order mode dielectric resonators were studies for several years due to their desirable properties in the design of microwave and millimeter devices. They have been used for measurements of dielectric loss tangent and for sensing applications in the microwave and millimeter wave regions due to their high Q-factor and strong field concentration in the surrounding area of the dielectric boundaries [13-14]. Among such high-order modes are the so-called dielectric resonator whispering-gallery modes (WGMs), which are usually travelling along the dielectric resonator's boundary with oscillating field distributed between the outer boundary and the inner caustic of the resonator.

These high-order modes have practical use in many optical, millimeter and even sub-millimeter electronic systems [15]. Recent research work was devoted in the use of such H-polarized WGM in the design of N-way microwave power divider with equal in-phase and out-of-phase power distribution [16-17]. The objective of this work is to investigate the availability of exciting an H-polarized high order mode with high radial index to be used in the design of microwave tapered power divider.

In this paper, an extension to [18] for a bow-tie shaped dielectric resonator operating in the H-polarized high-order radial field variation mode is presented. The bow-tie shaped dielectric resonator is enclosed by cylindrical cavity to obtain an N-ports microwave power divider. The resonator is placed on top of a rectangular ground plane and excited by microstrip feeding network to be

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printed on a microwave substrate and coupled to the dielectric resonator through conducting probes penetrating inside the resonator at certain designed positions with fixed heights. An early stage of fabricating the physical layout for the proposed structure is shown in Fig. 1 for 6-way power divider. The proposed design is assumed to produce in-phase tapered power distribution at the output ports while the spacing distance between the adjacent output ports are kept to be half wavelength apart to feed linear antenna array.

A brief description of the proposed geometry and the design procedure using ANSYS HFSS commercial software [19] are provided in section II. In section III, simulated results are compared with the measured results for further concept validation in addition to demonstrating the advantages of using shielded cavity resonator to suppress radiation losses and enhance the coupling to the resonating mode. In section IV, the design of 6-elements linear rectangular dielectric resonator antenna array is described.

II. DESCRIPTION OF PROPOSED POWER DIVIDER

The proposed X-band power divider geometry is shown in Fig. 2. The bottom layer is sketched in solid lines while the top layer is in dashed lines to have a better understanding of the designed configuration. The proposed power divider consists of a bow-tie shaped dielectric resonator with 24 mm sector radius, 5 mm height, and 23^o sector angle placed on top of a rectangular RT/duroid 6010LM dielectric substrate with dielectric constant 10.2 and 0.625 mm thickness. The resonator is exposed to the grounded side of the microstrip feeding network.

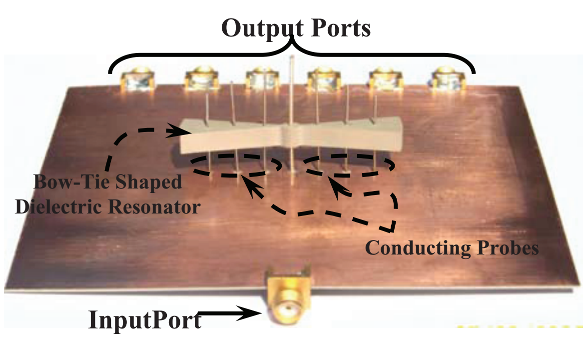


Fig. 1. Early fabrication stage for the proposed X-band 6-way power divider using bow-tie shaped dielectric resonator (side view).

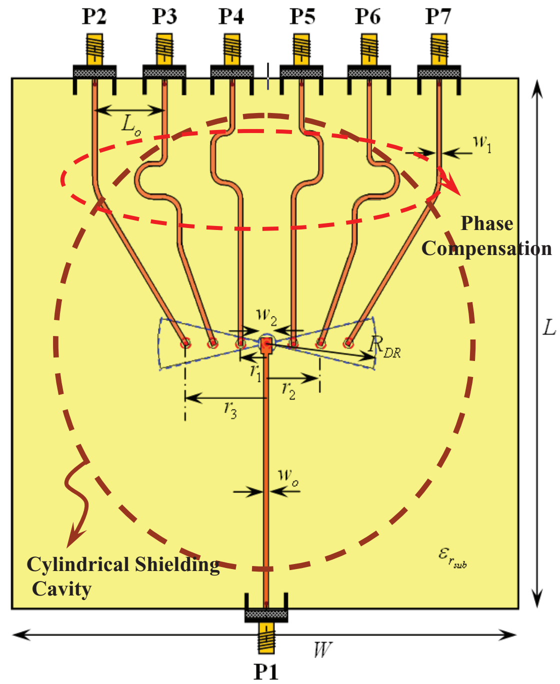


Fig. 2. Bottom view of the proposed X-band 6-way tapered higher order dielectric resonator power divider.

The design procedure was done in two successive phases. The first phase focused on the design of the dielectric resonator and compromises its shape to meet the desired specifications. The second phase involved the design of the microstrip feeding network that is printed on the other side of the dielectric substrate. In phase and symmetrical tapered power distribution are obtained at the different output ports while acceptable impedance matching at the input port is achieved as shown in Fig. 2. This power divider is more compact in size compared to other traditional power dividers. The design is not restricted to 2^n-output ports.

It is important to understand the electrical nature of the excited higher order mode to help in choosing the dielectric resonator's shape and the appropriate excitation or coupling technique. A sector-shaped dielectric resonator is designed and excited through coaxial probe at the center. Thus, higher-order transverse magnetic mode with three radial magnetic loops on each side of the probe and of different field strength are recognized around 10 GHz.

For transverse magnetic modes with larger radial mode index, the magnetic field lines are circularly oriented with successive out of phase field loops (in y-axis). The number of these loops is equal to the radial index of the excited mode, which are three in this case. Due to the fact that symmetrical tapering scheme is required, a bow-tie shaped resonator is suggested as shown in Fig. 1. The magnetic field distribution inside the bow-tie shaped dielectric resonator at the resonant frequency of the excited mode is shown in Fig. 3, where out-of-phase magnetic field loops are observed while exciting the resonator from port 1 and terminating the other ports with matched loads.

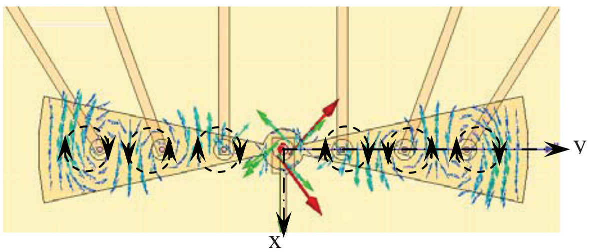


Fig. 3. Magnetic field representation of the excited high-order dielectric resonator mode inside the bow-tie shaped resonator at 10 GHz.

An easy method to couple with the H-polarized high-order mode is by using coaxial probes as reported in [16]. Conducting probes are inserted inside the dielectric resonator at the center of each magnetic loop. Parametric studies were conducted at the beginning to obtain the proper positioning and height of the six conducting probes for acceptable coupling to the resonating mode while maintaining the probe radius to be 0.27 mm. The conducting probes were placed at distances of 6, 12, and 18 mm away from the center of the resonator as shown in Figs. 1, and 3. It was found that the optimum length of the conducting probes to penetrate inside the resonator, ***Hp***, is 1 mm for appropriate coupling to the desired mode. The design of the non-radiating microstrip feeding network on the bottom side of the dielectric substrate was modeled. Conducting "vias" were used to connect between the inserted probes and the open ended terminals of the non-radiating microstrip lines.

The output ports were connected to three pairs of symmetrical microstrip lines around the x-axis from the other side of the dielectric substrate with 50 Ω SMA connectors as shown in Fig. 2. The input port was also connected to a microstrip pad of width w_2. In-phase power distribution at the output ports was obtained by introducing different sections of meandering lines as part of the feeding network design. The spacing distance, L_o, between the successive adjacent ports is kept to be half a wavelength around 10 GHz for the antenna array application. Table I lists all the design parameters that have been used in Fig. 2. Since it was stated in previous work [16-17] that radiation losses from the bow-tie shaped dielectric resonator are significant, a cylindrical conducting cavity of 45 mm radius and 10 mm height was used to shield the resonator and prevent any radiation losses as shown in Fig. 4. The cavity design parameters were chosen while maintaining acceptable impedance matching at the input port while reducing any disturbance to the excited mode due to the designed shielding cavity.

Table I: The proposed 6-way power divider design parameters.

Design Parameter	Parameter Value (mm)	Design Parameter	Parameter Value (mm)
W	110	w_o	0.6
L	110	w_1	1
L_o	15	w_2	2.2
r_1	6	r_3	18
r_2	12	R_{DR}	24

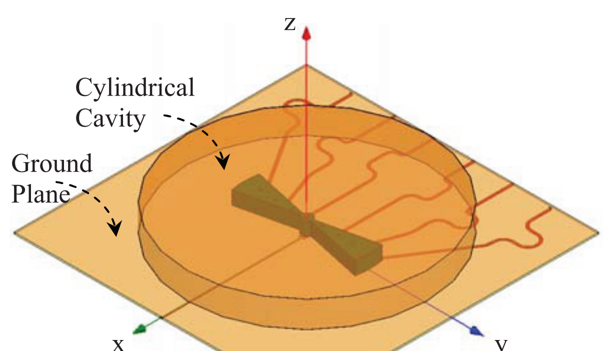


Fig. 4. Illustration of simulated 6-way power divider with the proposed cylindrical shielding cavity to suppress the radiation losses of the bow-tie dielectric resonator.

III. POWER DIVIDER RESULTS

A homemade bow-tie shaped dielectric resonator was machined according to the selected design parameters listed in Table I. The resonator was machined to have three holes of 0.27mm radius at each side of the resonator while the middle hole was of 1 mm radius to host the input probe. Measurements were conducted on the fabricated design for verification.

Figure 5 illustrates the simulated and measured scattering parameters of the power divider. It can be noticed that tapering in the coupled power is achieved within the range of 2dB between the different output ports. The concept of using the bow-tie resonator was intended to achieve tapering for the power. However, the measured tapering level was smaller than anticipated. It could be controlled further by changing the probes' lengths, but this will add to the practical difficulty of adjusting the probe's length with our in house limited facilities.

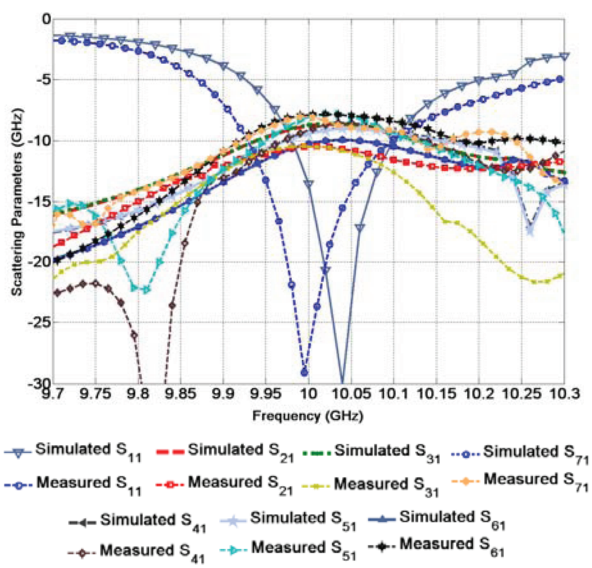


Fig. 5. Measured and simulated reflection and coupling coefficients for the shielded 7-port X-band in-phase power divider.

The advantages of the resonant-type power divider are the high efficiency of the power distribution and the assurance that the output signals are exactly in-phaseor out-of-phase with respect to each other before entering the microstrip lines feeding network. Assuming that the input source andthe output ports are properly matched, the efficiency of the power divider can be obtained as,

$$\eta = \frac{\sum_{i=2}^{7} |S_{1i}|^2}{1 - |S_{11}|^2}. \quad (1)$$

By using the measured values of the scattering parameters shown in Fig. 5, the efficiency at 10 GHz comes out to be 62 %. It is believed that a significant portion of the losses occurs in the microstrip feeding network. In addition, phase measurements were also done for the different ports with respect to the input port and compared with the simulated results as shown in Fig. 6. Differences between the simulated and measured results can be noticed, which could be attributed to the fabrication tolerances.

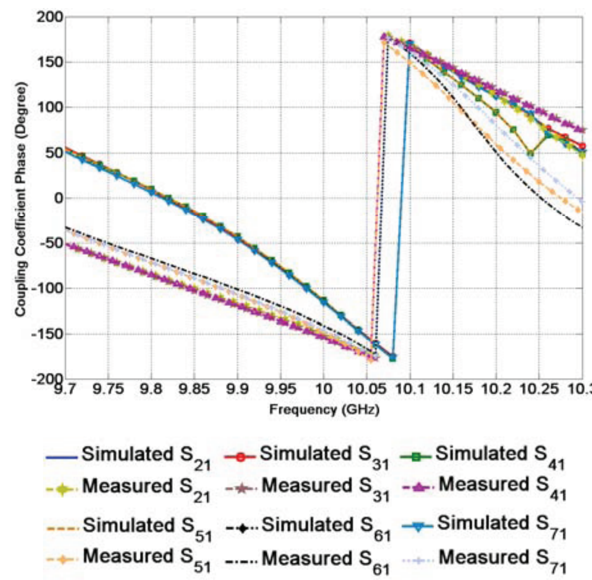


Fig. 6. Comparison between the measured and simulated coupling coefficients phase with respect to the input ports.

IV. ANTENNA ARRAY RESULTS

A rectangular dielectric resonator with length, L_{DR}, width, W_{DR}, and height, H_{DR} is placed on a rectangular ground plane and excited with rectangular narrow slot to resonate at 10 GHz. The slot is of length L_s and width W_s and is excited by a microstrip line that is terminated by an open stub of length L_t beyond the middle of the narrow slot as shown in Fig. 7. The proposed power divider is used as a feeder for the modeled linear rectangular DRA array. The spacing between the elements is maintained to be half a wavelength at 10 GHz.

The reflection coefficient of a single element is shown in Fig. 8 (a), and the radiation pattern of a single element over a finite ground plane is shown in Fig. 8 (b). All the dimensions are listed in Table II.

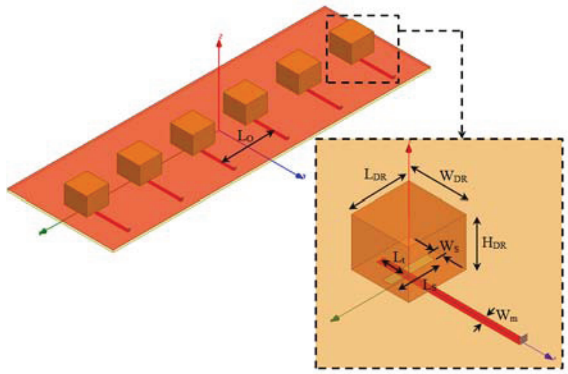
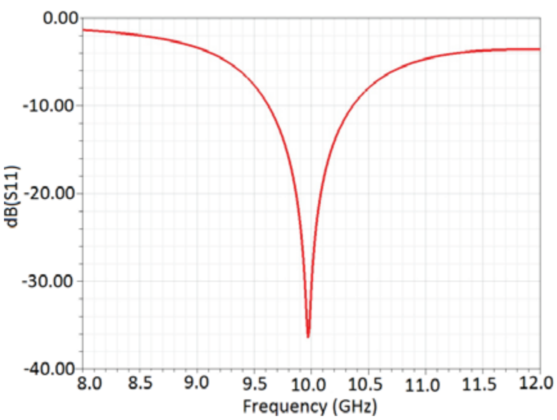
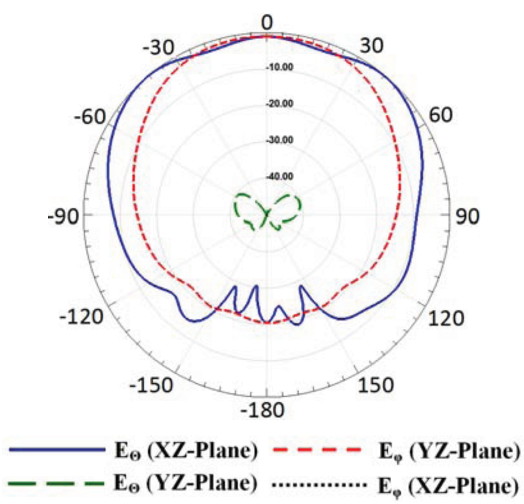


Fig. 7. Proposed rectangular dielectric resonator antenna array excited with narrow slots and coupled to microstrip feeding network.



(a)



(b)

Fig. 8. Simulated results for a single rectangular DRA element excited by a narrow slot: (a) antenna reflection coefficient and (b) far filed radiation patterns.

Table II: Dimensions of single element DRA.

Design Parameter Symbol	Parameter Value (mm)	Design Parameter Symbol	Parameter Value (mm)
L	151.25	L_S	4.6
W	165	W_S	0.9
L_{DR}	6.3	L_t	6.375
W_{DR}	6.3	W_m	0.8
H_{DR}	5	D	14.73
R_{Cavity}	45	H_{Cavity}	10

Finally, Fig. 9 illustrates the complete design configuration simulated using ANSYS HFSS commercial software [19]. The physical layout of the antenna array with the proposed power divider in its final presentation is shown in Fig. 10 from both top and bottom views.

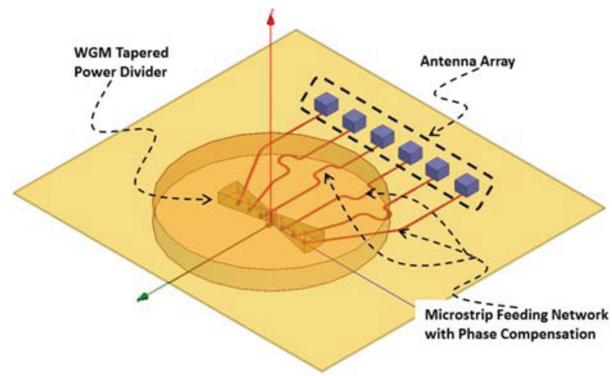


Fig. 9. Simulated rectangular DRA array fed by the proposed X-band power divider based on bow-tie shaped dielectric resonator.

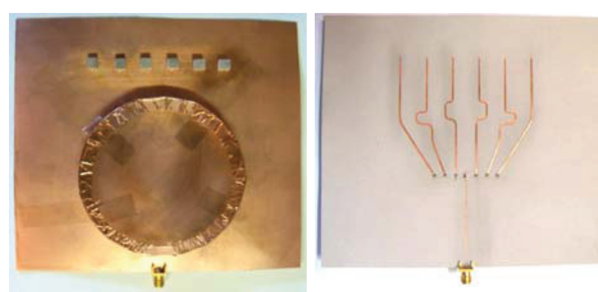


Fig. 10. Top and bottom views of the array and the power divider.

Figure 11 shows the measured and simulated reflection coefficients of the final proposed design configuration shown in Fig. 10. Acceptable matching to input impedance with 100 MHz impedance bandwidth around the designed resonant frequency is achieved. In addition, simulated and measured far field radiation patterns at 10 GHz for the designed array fed with the proposed power divider are shown in Fig. 12.

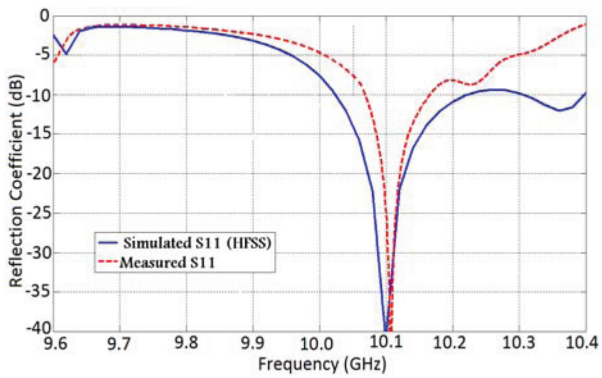


Fig. 11. Measured and simulated input reflection coefficient of the proposed rectangular DRA array fed by the 7-way power divider.

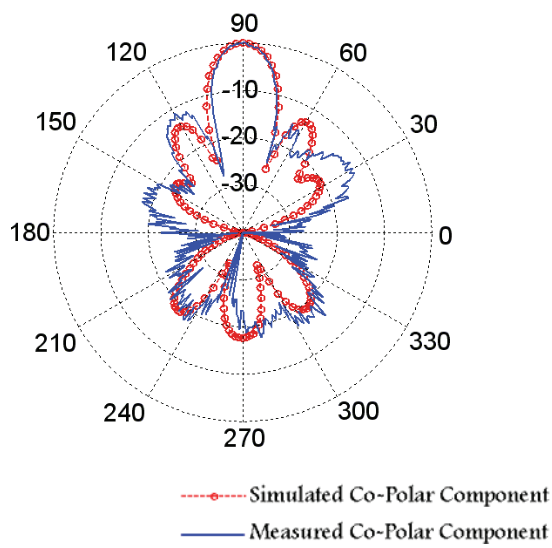


Fig. 12. Measured and simulated far field radiation patterns of the proposed antenna array.

Broadside type of radiation pattern with 12 dB side lobe level is achieved as shown in Fig. 12. Based on HFSS results, the computed directivity is 11.6 dB and the gain is 11.5 dB indicating very high radiation efficiency. As mentioned before, the tapering level can be controlled by the probe lengths or by the radial position of the probes from the center of the bow-tie resonator. These are possible techniques that can be investigated in the future.

V. CONCLUSION

An X-band high-order bow-tie shaped dielectric resonator enclosed by a cylindrical cavity was designed, built, and tested to perform as a 7-way tapered power divider. The excitation of the transverse magnetic mode was carried out by using microstrip feeding technology integrated with probe coupling technique. The amplitudes of both reflection and transmission coefficients were measured and compared with the simulated results. In addition, phase measurements were also done for the transmission coefficients. Finally, the application of the proposed power divider was demonstrated in feeding 6-element rectangular dielectric resonator antenna array. Antenna array reflection coefficient and far field radiation patterns were obtained and compared with measured data.

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