Array of Coaxial Periodic Leaky Wave Antennas in Parallel Configuration for Restricted Volume Applications

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***Abstract*—This paper studies a unique approach to combine coaxial periodic leaky wave (CPLW) antennas in parallel array configuration for restricted volume application. An improved gain and mitigated stopband attenuation are observed when up to four 200 mm long CPLW semi-rigid cables are simultaneously fed, forming a narrow beam pattern suitable for use in a confined volume due to the reduced size. The proposed antenna array exhibits a gain of greater than 10 dB from 8.0 to 10.5 GHz. The sidelobe levels are less than -10 dB at broadside frequency 9.8 GHz. The beam width of the CPLWA array is approximately 9° with a scanning range of greater than 25°over the operated frequency band. The array of CPLW antenna called parallel CPLWA array is discussed, fabricated and measured showing good agreement with simulations.**

I. INTRODUCTION

Coaxial leaky-wave antennas are the type of travelling wave antenna capable of receive and transmit RF signals because of the slots in their outer ground conductor which make them radiate. Most coaxial leaky-wave antennas operate at microwave frequencies or higher due to the shorter cable length and fewer ground slots required relative to the wavelength of operation. The antenna gain significantly reduces at broadside direction due to the bandgap region that manifests as a result of the high attenuation value (α) in the propagation constant. Researchers have introduced various techniques to eliminate the stopband attenuation which causes the poor return loss and gain reduction at the broadside frequency [1] including the use of open matching stubs [2] which suppresses the open bandstop region. Due to the periodic slots etched at guided wavelength separation, the required cable length for a single coaxial leaky-wave antenna with wide beam scanning at lower frequencies is challenging to realise, particularly at RF frequencies below a few GHz, by α/k0 = 0.18*λ/L where L is the length of the antenna, k0 is the wave number. For ground penetrating radar applications, where an antenna is to be deployed in a small diameter borehole and manual positioning of the antennas are required, the CPLW antenna is a good choice because of its beam scanning radiation pattern making it possible to acquire images of the subsurface without the need of positioning of the antennas into the borehole.

As a proof-of-concept, we investigate combining multiple shorter slotted CPLW antennas to form a leaky-wave antenna array. Four coaxial cables each with periodic slots in the outer ground conductor over their entire length, are configured in parallel array so that the cables are excited simultaneously and radiate in a constructive manner producing a radiation pattern with an overall gain greater than 10 dB from 8.0 GHz to 10.5 GHz. The pencil beam radiation pattern is obtained and verified experimentally. The proposed approach reduces the stopband attenuation at broadside frequency and makes the CPLWA length realisable for confined space .

II. ANTENNA DESIGN

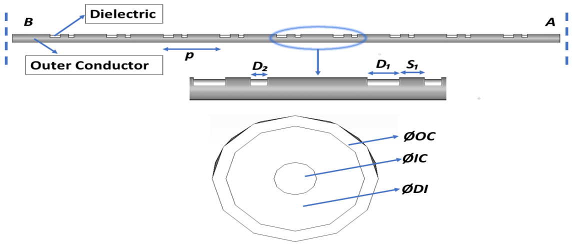

Fig. 1. Coaxial Periodic Leaky Wave antenna structural parameters

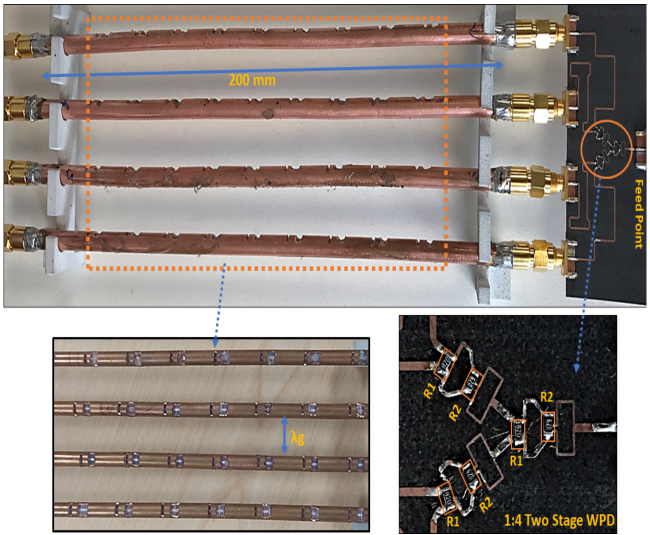

Fig. 2. Fabricated Design

Fig 1 shows a coaxial cable with the outer conductor diameter of $\phi_{oc} = 6.3$ mm and inner conductor diameter of $\phi_{ic} = 1.66$ mm and a PTFE dielectric with relative permittivity of 2.05 selected for the CPLW design.The guided wavelength λg is calculated as 20.7 mm at 10 GHz to calculate the slot period p. Since multiple cables are used, the length is selected as 200 mm with 9 unit slots on each cable. The slot dimensions [3] are chosen to be D_1 = 3 mm, D_2 = 1 mm, S_1 = 3 mm. The slot depth is 2.3 mm. The CPLW antennas are equally distanced at λg in the array design. To demonstrate the feasibility and performance of the design, a wideband 4-way two stages Wilkinson power divider was realised as shown in

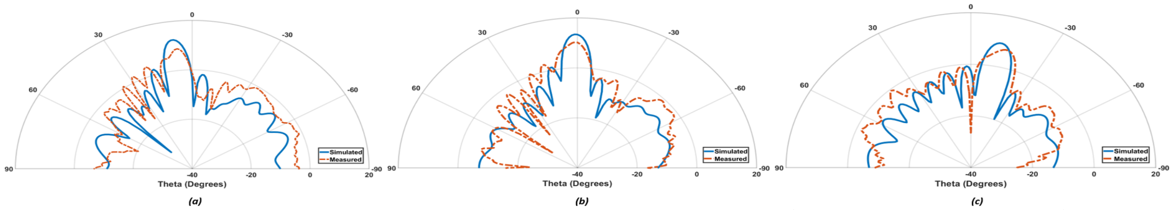

Fig. 3. Simulated (—) versus measured (· · ·) farfield radiation patterns at (a) 10.5 GHz, (b) 9.8 GHz and (c) 8.5 GHz

Fig. 2 to feed the CPLW antenna elements. Isolation resistors R1 and R2 are 62 Ω and 82 Ω, respectively. The Taconic TSM-DS3 substrate with ϵ_r of 3 and thickness of 0.254 mm was used. The Wilkinson power divider (WPD) splits the input power equally with <2.5 dB of amplitude imbalance, <10° of phase difference and insertion loss from 2 dB to 3 dB. The coaxial cables were manually etched using the Dremel tool and manual milling machine for the narrow and wide slots respectively. Therefore discrepancies between simulated and measured results can be expected. The size of the array design is 220x100mm.

III. RESULT AND DISCUSSION

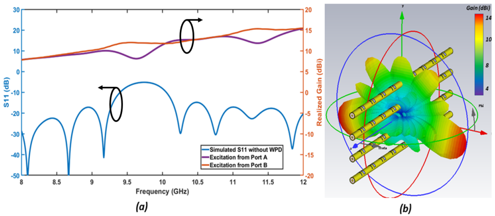

Fig. 4. (a) Simulated Realized Gain Without WPD (b) 3D Radiation Pattern

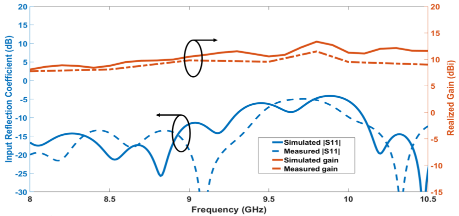

Fig. 5. Realized Gain and S11 of the Antenna Array

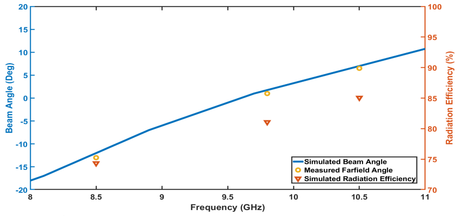

Fig. 6. Main beam angle variation with frequency

The CPLWA parrallel array is simulated without WPD and with WPD from port A and port B as shown in fig 1. For both cases, the other ports are considered to be 50 ohm terminated. It was found that excitation from port A of the structure gives a significant open stopband response whereas excitation from port B no stopband region appears in the realised gain as shown in fig 4(a). The realized gain improves from 8 dB to 12 dB at broadside frequency. Also the gain becomes linear with the frequency from 8.0 GHz to 12 GHz. The simulated and measured result of the CPLWA with WPD is shown in fig 5. The WPD has larger amplitude imbalance above 10.25 GHz leading to a gradual reduction in antenna gain and increased SLL as shown in fig 3. After fabrication, the slot dimensions are found to be within a tolerance of ±15 percent. The centre frequency lies on 9.8 GHz where the broadside beam is present. Measurements from 8.0 GHz to 10.5 GHz were made in an anechoic chamber to determine the farfield pattern and realized gain of the antenna. The parallel CPLWA array farfield patterns are measured at $\phi = 0°$ with θ scans from -90° to +90° in 1° steps due to symmetry beam at apposite side as shown in fig 4(b). The parallel CPLWA array shows a beam tilt toward negative Phi, therefore to measure the cut with the maximum gain, the array structure was elevated upwards by 10°. The farfield shows a good scanning range of 25° from 8.0 GHz to 10.5 GHz as shown in fig 6. The beam width is found to be 8.7° at 9.8 GHz. The antenna demonstrates an overall gain of greater than 10 dB over the frequency band of 8.0 to 10.25 GHz. The sidelobe levels (SLL) are less than -10dB over the frequency band of 8.0 to 10.25 GHz.

IV. CONCLUSION AND FUTURE WORK

The approach of combining multiple CPLW antennas in an array, which reduces the overall length of the antenna design, has been described. The simulated and measured results showed that the antenna performance at the broadside frequency (9.8 GHz) experiences no stopband gain reduction. The array of CPLWA shows a good linear gain of 10dB with frequency and reduced size. The beam width of the proposed array is around 9° with 25° beam scanning over the frequency band. The proposed CPLWA array is beneficial for applications such as cross-borehole radar, where the borehole diameter restricts the size of antenna deployable. The array produces two symmetry beams giving an advantage to cover the area around the borehole. Compact CPLWA arrays operating below X-band are even more challenging to design. However, our investigation has demonstrated that the size of CPLW antennas can be reduced significantly while maintaining good realized gain and achieving better stopband attenuation. Future work will investigate scaling of the new CPLWA array to the UHF bands for borehole applications.

REFERENCES

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