An Improved Compact CPLWA Array in Adjacent Structure for Confined Space Applications

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***Abstract*—The paper presents an improved array configuration called a coaxial periodic leaky wave antenna (CPLWA) array in the adjacent structure. The design is compact in size, exhibits a gain of more than 11 dB at a broadside frequency of 9.8 GHz, and yields a sidelobe level of at least -10 dB from 8 to 12 GHz bandwidth with no open stop band attenuation(OSBA) gain reduction at the broadside frequency. The beam scanning of atleast 35° is observed from 8 to 12 GHz. Because of the portable design, the antenna is highly suitable for confined space applications such as ground-penetrating borehole radar. Compared to the other fabricated structure called CPLWA in the parallel array, the simulated results are discussed with significantly reduced size and backlobe/sidelobe levels.**

***Index Terms*—periodic leaky-wave antennas, compact array antennas, borehole deployable radar antennas.**

I. Introduction

Ground penetrating radar (GPR) has been widely utilized to provide subsurface tomographic images, playing a crucial role in various applications including cross-borehole GPR systems where the intended use of a CPLWA array has been illustrated, as shown in Fig 1(a). Traditional cross-borehole radar requires manually positioning the transmitting and receiving antennas at discrete positions below the ground surface. The diameter of the borehole is typically less than 15 cm and is dictated by the drilling process. A CPLWA with its frequency-dependent beam scanning feature can be an excellent choice to reduce the steps taken manually to position the radar antennas. The antenna used in a borehole radar is directive, compact in size and rigid to ensure a smooth and hazard-free operation due to the air pressure inside a borehole.

In [2], we proposed a parallel configured array structure shown in Fig 1(b), in which CPLW antennas were placed at a distance of g=λ_g guided wavelength which is calculated as 20.7mm at 10 GHz broadside frequency ($\lambda_g = c/f\sqrt{\epsilon_r}$). However, for a restraint size of less than 15cm of a borehole with antenna protection cover required, the size needed to be reduced further for more space required for the embedded electronics. The structure was fed by a 1 to 4 way split Wilkinson power divider, which equally split the power with an amplitude imbalance of less than 1 dB and insertion loss of 2-4 dB over the frequency band of 8 to 12 GHz.

This paper discusses another array structure called CPLWA in an adjacent array with the same slot dimensions and periodicity as the parallel array. The adjacent CPLWA array achieves a different radiation pattern that produces a more directive and narrow beam than the parallel configuration. Additionally, it achieves a low backlobe level without an external reflector, making it suitable for deployment into a borehole.

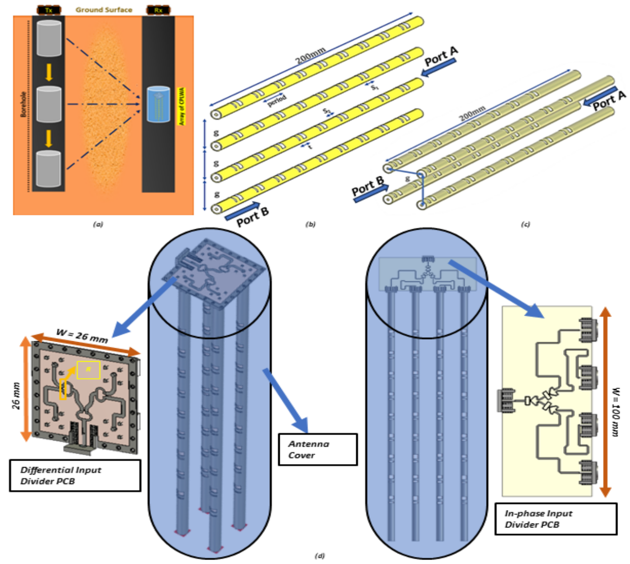

Fig. 1: (a) Antenna deployment for cross-borehole GPR (b) CPLWA in parallel array (c) in adjacent array (d) 3D Models of Both Structures

II. Antenna Design

Four coax cables of 0.63cm, 0.166cm and 2.04 for outer copper conducting material, inner copper conducting material and ε_r were chosen to design the array structures respectively. The slots dimensions [3] are S_1 = 3mm for thick slot, S_2 = 1mm for thin slot and the distance between slots S_1 and S_2 t=3mm is used to match the Bloch impedance of the coaxial leaky wave structure. The length of the coax cables is 20cm long, with the spacing g between unit cells chosen to be λ_g to form a narrow beam array for both structures. For each cable, 9 matching unit slots are designed with a slot depth of 2.35mm.

Two ports named Port A and Port B, as shown in Fig 1(b) and (c) are used to feed the arrays. In [2], we concluded that no OSBA is observed when we excite the structure from Port A. For the adjacent array, we follow the same port excitation. While exciting the structure from Port A, we assume that all the ports in Port B are considered to be terminated with 50-ohm-matched loads. All the ports are fed with the in-phase split signal for the parallel structure to excite the antenna array. For the adjacent configured CPLWA array, the top two CPLWAs are fed with the in-phase signal, while the bottom two CPLWAs are fed with the differential signals simultaneously. Three isolation resistors for the adjacent configured array PCB are 82 ohm(s), and the differential difference between the ports is realised by lengthening the output port's electrical length with respect to the other ports.

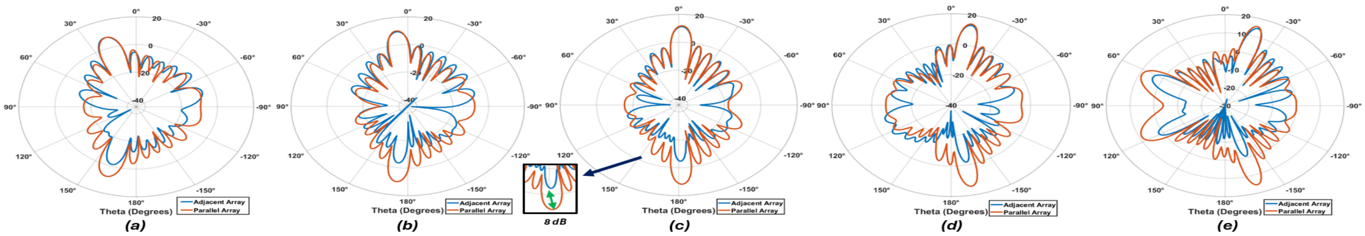

Fig. 2: Simulated adjacent (—) and parallel (—) arrays far-field radiation patterns at (a) 8 GHz, (b) 9 GHz (c) 10 GHz, (d) 11 GHz and (e) 12 GHz

III. Results and Discussion

The simulated results of both the parallel and adjacent configured CPLWA array are presented in Fig(s) 2, 3 and 4. The simulated results show that the input return loss $|S_{11}|$ for both the array structures experiences an open stop attenuation at 9.8 GHz broadside frequency with return loss less than -4.5 dB; however, for the adjacent array that improved to -6dB. The $|S_{11}|$ other than the broadside frequency remained <-10dB over the frequency band. The realised gain of the parallel structure and adjacent array remained greater than 10 dB and gradually increased over the frequency band. The realised gain is greater than 8dB from 8-9 GHz and ranges from 10 to 15 dB from 9-12 GHz. The gain was linear with the frequency at broadside frequency, and no open stop band gain reduction was observed.

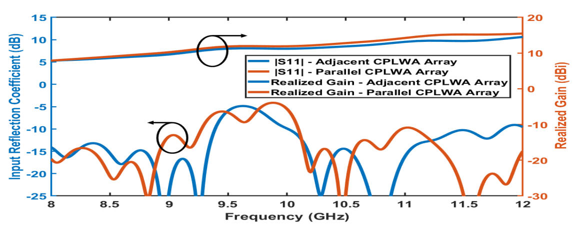

Fig. 3: Simulated S_{11} & Realized Gain of Adjacent & Parallel array

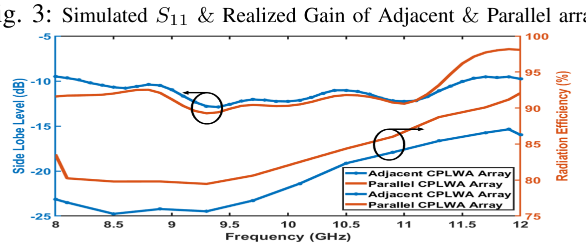

Fig. 4: Simulated SLL and Radiation efficiency

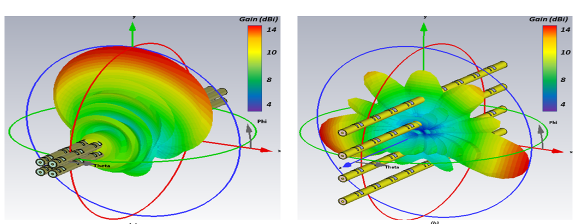

Fig. 5: 3D radiation pattern (a) adjacent parallel (b) parallel CPLWA array

The radiation efficiency for both the structures remained above 75% and 80% at broadside frequency 9.8 GHz. The adjacent CPLWA array design performed well by reducing the sidelobe and backlobe levels, which remained <-10dB over the frequency band of 8-12 GHz compared to the parallel array. The backlobe was also improved by 8dB at the broadside frequency. The size of the parallel structure is supposed to be 3.269λ x 2.236λ x 6.538λ while the adjacent configured structure is found to be 0.849λ x 0.849λ x 6.538λ with the PCB sizes included considering λ as free space wavelength at 9.8 GHz. As shown in Fig 5, the parallel structure array exhibits a two-beam at both sides of the antenna design, i.e. at $theta$ +90° and $theta$ -90° whereas the adjacent configured CPLWA exhibits a directive beam at phi +90°. The radiated beam scans from 8 to 12 GHz with 35° scanning range. Table I highlights the improvement made by adjacent CPLWA over the parallel CPLWA array.

TABLE I: Comparison of Adjacent and Parallel CPLWA Array

Figure of Merit	Remarks
$\|S_{11}\|$ (other than broadside frequency)	Remained below -10 dB from 8 to 12 GHz.
$\|S_{11}\|$ (at broadside frequency)	**Improved** from -4.5 dB to -6 dB.
Sidelobe level (SLL) (8 to 10 GHz)	**Improved** and remained less than -10 dB over the frequency band.
Backlobe level (at broadside frequency)	**Improved** by 8 dB.
Width Size in mm	**Improved** and reduced from 3.269λ(100 mm) to 0.849λ(26 mm).
Realized Gain	Remained the same from 8 to 12 GHz.

IV. Conclusion

The paper proposes a new CPLWA array design with improved sidelobe/back lobe levels and significantly reduced size while maintaining a good realized gain. The adjacent CPLWA array maintains the simulated gain of more than 10 dB over the frequency band of 8 to 12 GHz while reducing the back lobe by at least 8 dB without the need for any external reflector structure and a SLL of less than -10 dB is achieved from 8 to 12 GHz. Future work is investigating a scaled-down version of both array structures to the L-band frequencies.

References

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