ACTIVE COMPOSITE RIGHT/LEFT-HANDED LEAKY-WAVE ANTENNAS

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INTRODUCTION

Composite right/left-handed (CRLH) leaky-wave antennas (LWAs) have been shown as one of the applications of the CRLH transmission line (TL) metamaterials [1]. The first backfire-to-endfire CRLH LWA was demonstrated in 2002 [2], after left-handed backward-wave radiation was reported in [3]. An active CRLH LWA beam forming technique with an application to maximum directivity design was presented in [4]. In the present paper, two different active CRLH LWA configurations are proposed in order to improve the cross-polar discrimination (XPD) and to achieve 2D beam forming. An example of pencil-beam radiation pattern with maximum directivity is demonstrated. The proposed 2D design can also be extended to different current distributions and may therefore be used for static or dynamic beam forming.

HIGH-GAIN ACTIVE CRLH LWA

A novel active CRLH LWA for broadside radiation was recently presented in [4]. In contrast to its passive counterpart, this active antenna can provide arbitrarily high gain. This performance is achieved by power regeneration along the antenna structure, which compensates for the radiation loss and thereby enhances the effective aperture and gain. In the purely passive CRLH LWA, the effective aperture is limited by the length of the antenna beyond which all of the power has been radiated, i.e. by the leakage factor of the LWA. The active CRLH LWA includes several amplifiers interconnecting CRLH TL sections which support the leaky-wave (LW) radiation. The leaky wave propagating along the structure is regenerated by these amplifiers so as to generate quasi-uniform field profile along the radiating structure with an arbitrary effective aperture. In addition, a matching regeneration mechanism, related to the quasi-unilaterality of the amplifiers, contributes to increase the efficiency and hence the gain of the active CRLH LWA.

Since the far-field radiation pattern depends on the current distribution along the antenna, the integration of the amplifiers allows static or dynamic beam forming. The maximum directivity design was shown experimentally in [4], where an active CRLH LWA of 48 cells was presented. The active LWA prototype, built in a multilayer technology, is composed of several LW CRLH TL sections [see Fig. 1(a)] linked by the amplifiers placed in a different layer [see Fig. 1(b)], which represent the passive radiating and active amplifying elements of the LWA, respectively. In order to isolate the radiating layer from the active layer and to reduce the footprint, a microstrip-to-microstrip vertical double transition (from layer 1 to layer 2 and back to layer 1) was used [4]. This double transition, which stems from the one proposed in [5], consists of a double array of via holes interconnecting microstrip lines in different substrates through a slot etched in the common grounds of these two substrates. Fig. 1(c) shows the normalized E-plane (perpendicular to the plane which contains the antenna and in the direction of the antenna) field radiation pattern of the active CRLH LWA prototype of Figs. 1(a)-(b) compared with its purely passive counterpart (48-cell passive CRLH LWA). A remarkable enhancement of gain may be observed in the active CRLH LWA compared to that of the purely passive one.
NEW ACTIVE CRLH LWA CONFIGURATIONS

The active CRLH LWA shown in Figs. 1(a)-(b) has a fan-beam radiation pattern, narrower in the E-plane (along the axis of the antenna) and broader in the H-plane (perpendicular to the axis of the antenna). Another feature intrinsic to the CRLH TL configuration used in Fig. 1(a) is a relatively high cross-polar component. This low XPD is due to the in-phase currents existing in the short-circuited stubs. Two layout variants of the original active LWA of [4] are proposed here in order to increase the XPD and to achieve a high-gain pencil-beam radiation pattern instead of the fan-beam pattern previously described.

Fig. 2(a) shows a 1D 54-cell active CRLH LWA and Fig. 3(a) shows its co-polar and cross-polar components. A fan-beam radiation pattern with a XPD = 8.2 dB, due to the in-phase currents of the stubs, can be observed. A novel configuration of the CRLH TL is proposed in Fig. 2(b) in order to increase the XPD. Alternating the location of the stubs along the axis of the structure, the currents, which are prone to generate high cross-polar components, are out of phase and therefore cancelled out. As a result, cross-polar component is significantly reduced; this is shown in Fig. 3(b), where an XPD enhancement of 28.2 dB is observed.
Fig. 2. Different configurations of a 54-cell active CRLH LWA constituted by $9 \times 6$-cell LW CRLH TL sections linked by amplifiers. (a) 1D configuration with fan-beam radiation pattern. (b) 1D configuration with improved cross-polar discrimination (XPD). (c) 2D configuration with pencil-beam radiation pattern. (d) 2D configuration with improved XPD.

Fig. 3. Full-wave simulated (MoM) radiation patterns for the different 54-cell active LWA configurations shown in Fig. 2. (a) 1D configuration (fan-beam radiation pattern). (b) 1D configuration with improved XPD. (c) 2D configuration (pencil-beam radiation pattern). (d) 2D configuration with improved XPD.
As previously mentioned, the fan-beam radiation pattern of the active CRLH LWA can be transformed into a pencil-beam pattern. This is achieved by arraying the LWA, which results in a reduction of the half-power beamwidth (HPBW) of the H-plane. The corresponding 2D layouts representing the pencil-beam counterparts of the 1D configurations of Figs. 2(a)-(b), respectively, are shown in Figs. 2(c)-(d), and their radiation patterns are shown in Figs. 3(c)-(d). In the 2D configurations, 3 active CRLH LWAs of 18 cells are fed by a single source through a 3-way power divider (PD). As expected from the arraying mechanism, the H-plane radiation pattern has become much narrower (a reduction of 69.5º in the HPBW_{H-PLANE}) in the 2D configurations compared to their 1D counterparts. The fatter beams in the E-plane are due to the shorter lengths of the antennas (the total number of radiating sections is kept identical, 9, in all of the configurations).

CONCLUSION

A high-gain active CRLH LWA has been presented. Different modifications in the layout of the microstrip CRLH LW structure most commonly used up to now have been proposed. A remarkable reduction in the cross-polar component, increasing the XPD in more than 28 dB, and a beam forming from fan-beam to pencil-beam radiation pattern have been demonstrated. By means of the proper amplifier choice, the proposed maximum directivity design of the 2D active CRLH LWA can also be extended to different current distributions and may therefore be used for static or dynamic beam forming.

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REFERENCES


