A Printed ‘Bull-Eye’ Leaky-Wave Antenna Fed by a Non-Directive Surface-Wave Launcher

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***Abstract*— A planar ‘bull-eye’ antenna design that utilizes surface-waves (SWs) for leaky-wave (LW) excitation is investigated for millimeter-wave frequencies of operation. Specifically, a planar non-directive surface-wave launcher (SWL) is employed as the antenna feed, generating bidirectional SW field distributions on a grounded dielectric slab (GDS). By the addition of annular metallic strip gratings, LWs can be excited on the planar guiding surface, defining the practical 2-D leaky-wave antenna (LWA).**

I. Introduction

Recently, novel ‘bull-eye’ and circular leaky-wave antenna (LWA) configurations have seen much interest within the electromagnetics community [1]-[4]. These printed high-gain LWAs are attractive for their compatibility with other planar technologies, low cost and ease of fabrication. In addition, such 2-D planar LWAs can be designed for broadside radiation and beam scanning as a function of frequency.

In [1] the first ‘bull-eye’ LWA structure was introduced. It was defined by an annular geometry of periodic metallic strip gratings on a grounded dielectric slab (GDS). Theoretical leaky-wave (LW) modes were numerically investigated and beam patterns were provided by the assistance of a commercial solver. Proposed antenna feeding topologies for this design included a center fed coaxial transmission line (TL) or a two-layered guiding structure (defined by a microstrip TL where energy can be coupled into a rectangular slot in the antenna ground plane). Practically, such feeding topologies can be problematic at millimeter-wave frequencies, and in some situations, these coaxially-feed and multi-layered coupling configurations can increase complexity in the design as well as cost. Thus single layer feeding topologies may be optimal when low-cost uniplanar designs are required. A ‘bull-eye’ LWA design (as illustrated in Figs. 1 and 2) is considered in this work using a surface-wave launcher (SWL) as the planar antenna feed. The effectiveness of this design is verified both with dispersion analysis, as in [1], and with numerical simulations using Ansoft HFSS.

II. The Surface-Wave Launcher Antenna Source

The proposed structure is shown in Fig. 1. A set of annular rings are printed on a GDS and the antenna is fed by a planar SWL source. Essentially, the slotted configurations act as magnetic dipole sources for the planar LWA structure. Specifically, a non-directional SWL (as shown in the inset of Fig. 1) generates bidirectional SW field distributions on the guiding surface [5], [6]. The completely planar SWL is fed by a coplanar-waveguide (CPW) TL allowing for simple integration with other planar designs and circuit topologies. Essentially, the input signal is inductively coupled into the dominant TM_0 SW mode of the slab and the half wavelength slot in the ground plane defines the main SW radiating element of the non-directive SWL [5], [6]. Substrate properties and frequency of operation were properly chosen such that the input power is efficiently coupled into the dominant TM_0 SW mode of the GDS. In fact, increased SW coupling efficiencies can be observed after the TE_1 SW mode cutoff frequency of the slab [5].

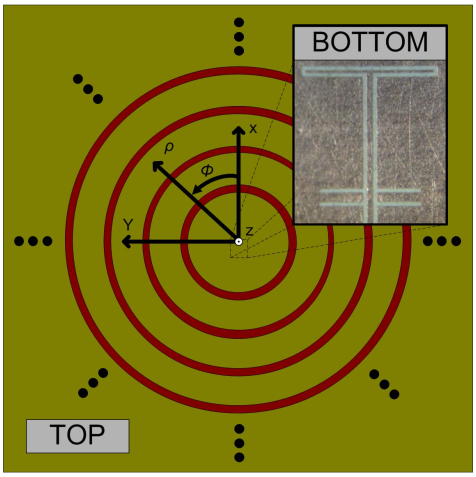

Fig. 1. The planar ‘bull-eye’ LWA considered in this work defined by annular periodic metallic strip gratings on a GDS. A slotted magnetic dipole source, realized by a non-directive SWL [6], acts as the practical antenna feed.

It should be noted that the CPW feeding TL may perturb the SW modes excited on the GDS, causing unwanted and spurious radiation, effecting the quality of the main beam pattern. But there is a cutoff frequency (f_c) that identifies this unwanted frequency region; the intersection of the dispersive phase propagation constants of the dominant mode of the CPW

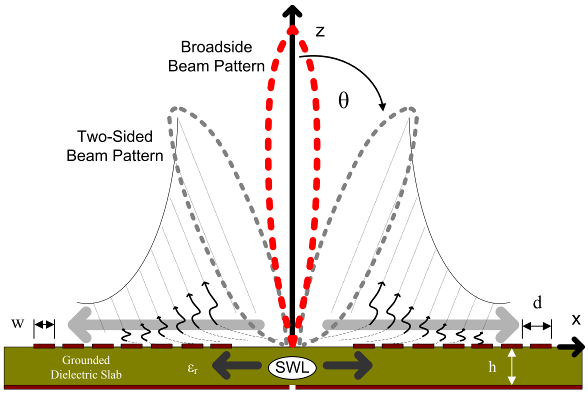

Fig. 2. By the addition of concentric metallic strips grating (width, w and pitch, d) LWs can be excited on the planar guiding surface generating broadside ($f = f_b$) or two-sided beam patterns ($f >> f_b$) in the far field.

TL and the supporting SW modes of the slab [7], [8]. Thus, to minimize spurious leakage from the CPW TL feed, operation for the proposed 'bull-eye' LWA should be below this cutoff frequency.

III. Theoretical Considerations and Results for the Practical 'Bull-Eye' Leaky-Wave Antenna

By the use of annular metallic strip rings the perturbed TM_0 SW mode (generated by the SWL) can excite cylindrical LW field distributions on the planar 'bull-eye' antenna structure [1]. Beyond the near-field region, each mode has a similar radial propagation constant, k_ρ, to that of a corresponding infinite linear array of metallic strips (i.e., a MSG-GDS) with the same physical and geometrical parameters equal to that of the circular gratings [2]. Thus, the design of such a 'bull-eye' configuration can be based on the modal analysis of an infinite 2-D structure with propagation normal to the strip gratings. Knowledge of the phase constant of the radiating spatial harmonic, β_{-1}, and the modal attenuation constant, α, is essential to a systematic design procedure. Once β_{-1} and α are known as a function of frequency and cross-sectional geometry, the beam direction, the beamwidth, the radiation efficiency, and the variation of the scan angle with frequency can be determined. In particular, the phase constant is fundamental when predicting the pointing angle, whereas the attenuation constant is a measure of power leaked per unit length and defines the effective aperture of the antenna [9].

The grating periodicity, d, and strip width, w, for the investigated design are 7 and 1.25 mm, respectively. The metallic strips were offset from the center of the antenna structure (by 9.3 mm) to ensure unwanted coupling between the slotted SWL source configuration and the gratings. In Fig. 3(a) the Brillouin diagram for the corresponding MSG-GDS is reported. The structure radiates by excitation of the $n = -1$ spatial harmonic (which is the perturbation of the TM_0 SW mode of the GDS) approximately between 16.5 and 21.4 GHz. The perturbed TE_1 mode has a cutoff frequency at 20.81 GHz and is in a narrow passband regime between 20.81 and 21.45 GHz. In this region the antenna radiates a broadside beam as illustrated in the far field patterns of Fig. 4.

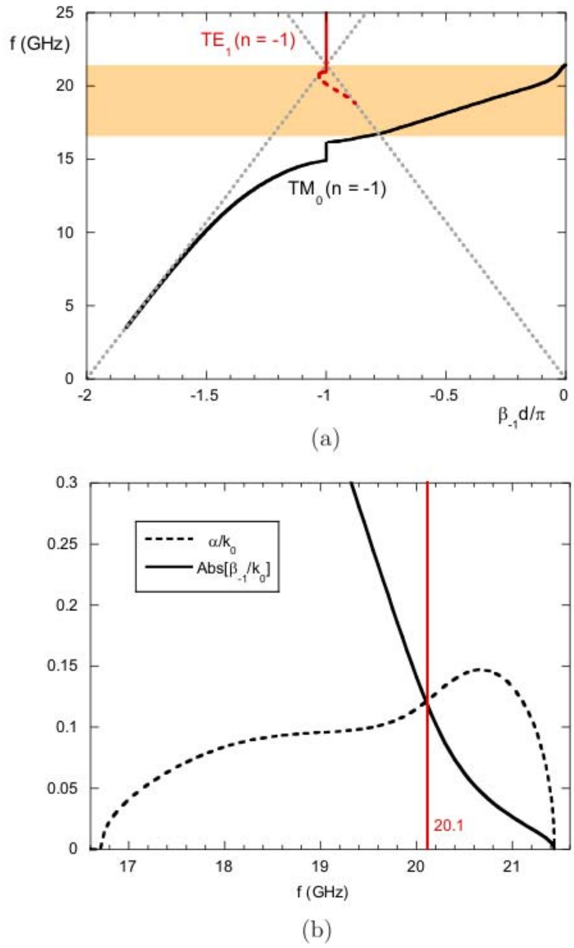

Fig. 3. (a) Brillouin diagram for the MSG printed on a GDS ($\varepsilon_r = 10.2$) with thickness $h = 1.27$ mm, and period $d = 7$ mm. The strip width is $w = 1.25$ mm. (b) Phase (*solid line*) and attenuation (*dashed line*) constants normalized to the free-space wavenumber as a function of frequency for the same structure as in (a).

A detailed description of the dispersion behavior is also reported in Fig. 3(b), where the phase and attenuation constants for the radiating harmonic are shown as a function of frequency and normalized with respect to the free-space wavenumber, k_0. The antenna is designed in order to satisfy the condition $\beta_{-1} = \alpha$ at $f_0 = 20.1$ GHz. At this frequency a high gain should be observed, with a beam pointing at broadside. For frequencies above f_0 and below 21.4 GHz, $\beta_{-1} < \alpha$, a beam at broadside can also expected but with significantly lower gain values [10].

In order to verify the 'bull-eye' LWA structure, comprising the SWL source, the rings and the CPW feeding TL, simulations were completed using Ansoft HFSS. The relevant reflection loss values (see Fig. 5) show a good matching within a wide frequency range. However, the radiation properties do not show a complete agreement with the dispersion diagrams (Fig. 3), deduced by observation of the far field beam patterns in the $x - z$ plane (Fig. 4), for different frequencies near

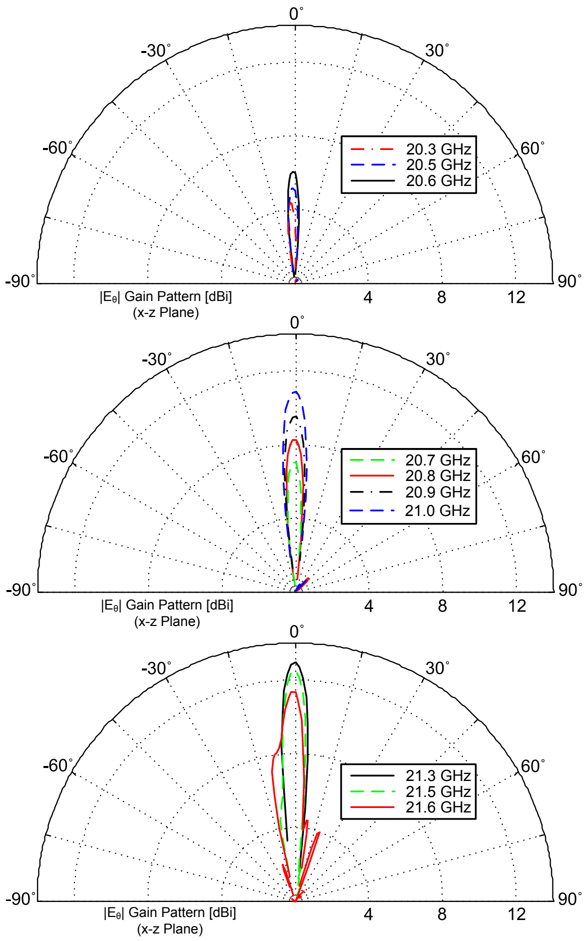

Fig. 4. $E_\theta(\phi = 0°)$ gain patterns (in the $x-z$ plane) for the LWA structure. A broadside beam is first observed at 20.5 GHz and a maximum is achieved at $f_{b,max}$ = 21.3 GHz. Gain reduces with an increase in frequency.

f_0 = 20.1 GHz. For instance, a frequency range exists for which the antenna radiates a beam pointing at broadside, but these frequencies have a lower limit of 20.5 GHz which is close to f_0. Furthermore, this frequency does not correspond to a gain maximum. In fact, the maximum gain is observed at 21.3 GHz.

This discrepancy could be related to the presence of the CPW feeding line, which can couple with the circular gratings on top of the slab, forming a structure that is slightly different from the numerically analyzed MSG-GDS configuration (linear array of printed metallic strips on top of a slab). Physically, the phase velocity of the guided-waves may be slightly altered by the CPW feeding TL. In addition, peaks in the broadside beam patterns appear to be related to particular resonances on the bull-eye structure, more specifically, the azimuthally directed current distribution on various annular rings.

The physical interaction between the rings, CPW feeding line and the SWL source still requires further investigation, along with the scanning properties away from broadside. Improvements may be possible by shortening the length of the CPW TL. Moreover, the 'bull-eye' ring structure may also

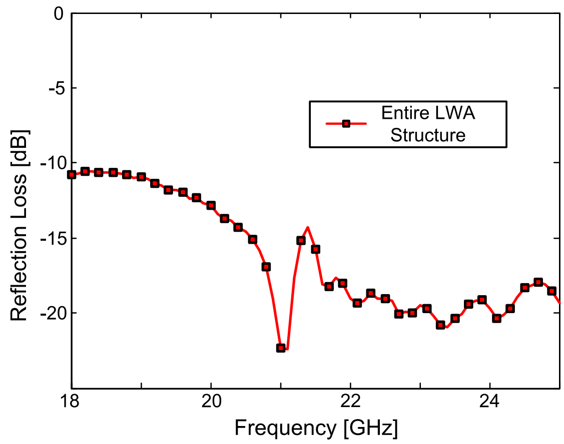

Fig. 5. Simulated reflection loss values for the investigated LWA design.

be optimized in order to have the TM_0 harmonic exist in the radiation regime, and the TE_1 mode below cutoff in the same frequency range. This can be accomplished by choosing the appropriate grating width and periodicity, and thus perhaps, realizing a more efficient design.

IV. Conclusions

A printed 'bull-eye' LWA structure is presented for broadside beam patterns in the far field. By a planar non-directive SWL feed on a GDS, a practical LWA can be realized for high gain and low cost radar or satellite applications.

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