Study of Metal Strip Grating Antenna and its Radiation characteristics

Dr. Reena Kumari[1] & Dr. Ashok Kumar[2]

[1]*Department of Physics, L. N. Mithila University, Darbhanga, Bihar, India.*
[2]*Professor of Physics, M.L.S.M. College, Darbhanga, L.N. Mithila University, Darbhanga, Bihar, India.*

Abstract: *In this present paper we studied about metal strip grating antenna using Fabry-Perot Cavity design and its radiation characteristics.*

Keywords: **Antenna, Metal Strip Grating, Fabry-Perot Cavity, Microstripline.**

I. Introduction

The possibility of achieving highly directive radiation from simple sources embedded in planar, partially openstructures has been explored by many authors, starting from the seminal work of von Trentini in 1956 [1]. Different types of partially-reflecting surfaces have been exploited to form Fabry-Perot cavities including, more recently, photonic-band gap or metamaterial media [2, 3].Highly directive radiations might have been achieved by using Fabry-Perot cavities made by a wire medium, i.e., a collection of parallel metal wires [4].A simple example of such an FPC antenna constitutes a metal strip grating (MSG) above a perfectly conducting ground plane.

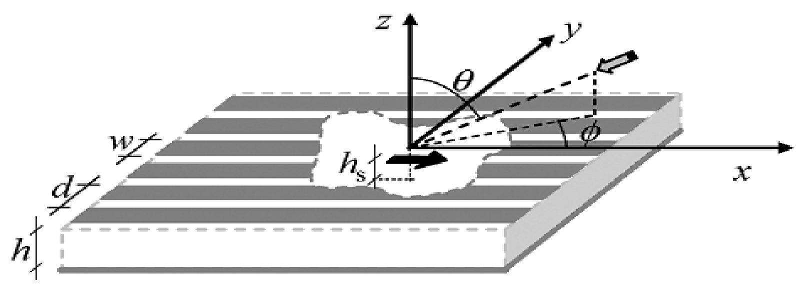


Fig. 1. Metal strip grating above a ground plane

Metal strip grating above the ground plane is excited by a horizontal electric dipole, with the relevant physical and geometric parameters; also shown is a uniform plane wave incident from the direction, used in the calculation of the far field radiated by the dipole based on reciprocity. This was among the first leaky-wave antennas, proposed by Honey in the 1950s [5]. It is similar in geometry, but very different in operating principle, from periodic leaky wave antennas that also use MSGs but radiate from thespace harmonic [6, 7]. The radiation properties of this structure have recently been studied in [8] via the array-scanning method and periodic method of moments (MOM) when excited by an electric or a magnetic line source. In this work we aim at showing that, when an electric dipole parallel to the strips is used as an excitation, azimuthally omnidirectional pencil beams pointing at broadside or nearly omnidirectional conical beams scanned off broadside can be produced with excellent polarization properties. For the usual FPC structures nearly omnidirectional pencil beams at broadside can be produced, but the degree of Omni directionality degrades rapidly as the beam is scanned away from broadside to become a conical beam. Similar results have recently been reported for a groundedwire-medium slab excited by an electric dipole and have been shown to be related to the excitation of a cylindrical leaky wave having isotropic propagation features that can be explained by resorting to an equivalent homogenized representation of the wire medium and by noticing that it possesses spatial dispersion [9]. For the antenna considered here, an approximate homogenized network representation of the MSG, which takes into account its spatially dispersive nature, allows us to analytically prove that, also in this case, the wavenumber of the dominant leaky wave is independent of the azimuthal propagation angle. The radiated beam is almost azimuthally omnidirectional, asconfirmed by rigorous simulations of the actual periodic structure performed with the MOM.

Furthermore, in this work we also show the interesting polarization properties of this FPC antenna; the homogenized representation of the MSG is then used to provide an analytical proof that the polarization of the FPC antenna is essentially the same as that of a dipole in free space. It will be shown that the radiation mechanism of the considered antenna is different from that of other FPC antennas, since it is based on the excitation of a single leaky mode rather than a pair of leaky modes. This leads to the interesting properties of this antenna in terms of polarization purity and beam symmetry. We would like to stress that the leaky wave excited in thisstructure radiates through the fundamental spatial harmonic of the periodic structure.the structure is thus in the category of a quasi-uniform leaky-wave antenna, which is physically periodic but acts as a uniform structure .We recall that there is another class of leaky-wave antennas based on using a guiding structure with periodic perturbations spaced on the order of a wavelength apart, radiating from the space harmonic. These are referred to as periodic leaky-wave antennas.

2.Analysis via Homogenization

The FPC antenna, consisting of an MSG placed in air above a perfectly conducting ground plane and a horizontal electric dipole parallel to the strip axis at a height above the ground plane, is shown in Fig. 1 together with the relevant geometric and physical parameters. Although an infinitesimal-directed electric dipole is used as the source (feed), the radiation patterns would not be significantly different when using a practical feed such as a slot or a patch antenna inside the cavity, since the pattern is mainly determined by the leaky wave. Input impedance could only be studied when using a practical feed. Since the dipole direction is parallel to the axis and the strips are embedded in a homogeneous medium,a purelytransverse magnetic field is excited; hence, the transverse electric polarization will be of no concern in the analysis.In this section an approximate model for determining the radiation properties of the considered FPC antenna is presented, based on a homogenization of the MSG valid in the limit of large wavelengths. The model is based on the use of a transverse equivalent network (TEN) to represent the fields in the FPC structure. This is useful to derive and explain the peculiar features of the analyzed structure. it constitutes a simple design tool when aiming for certain antenna specifications. Homogenization of the MSG is possible because this type of leaky-wave antenna radiates from the fundamental space harmonic and the period of the strip grating is kept small relative to a wavelength. For periodic leaky-wave antennas that radiate from a higher-order space harmonic [10] the period is not small relative to a wavelength and such a homogenization is not possible. A. Transverse Network Representation of the Grating As is well known, a TEN can be used to model planarly layered structures, assuming that fields have an exponential dependence on the coordinates. The presence of a metal screen periodic along one or two directions can be taken into account through a suitable multiport network coupling. The propagation modes supported by the structure can be naturally classified.Assuming that the period of the MSG is much smaller than the free-space wavelength; the effect of the MSG can be accounted for through a single shunt equivalent susceptance.

$$k_{z0} = \sqrt{k_0^2 - k_x^2 - k_y^2} \quad (1)$$

$$Y_{c0}^{\mathrm{TM}_x} = \frac{k_0 k_{z0}}{\eta_0 (k_0^2 - k_x^2)}. \quad (2)$$

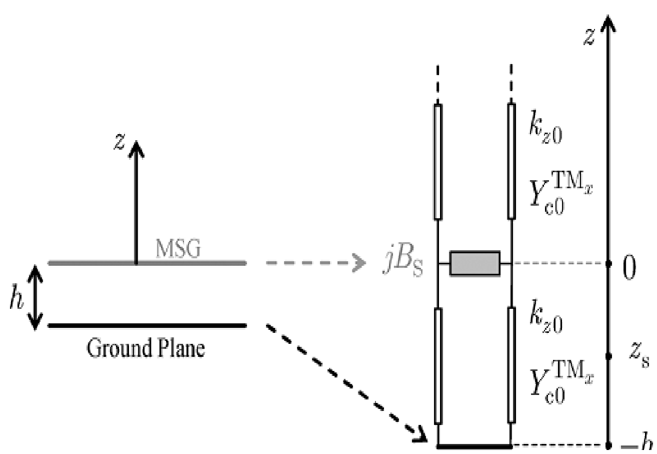


Fig. 2.Transverse-equivalent-network representation of the MSG in air above a ground plane polarization.

The vertical location of the source can be derived from the generalized Sakurai-Vainshtein-Sivov boundary condition for the averaged fields of the zeroth order space harmonic [11].

$$B_{\mathrm{S}}(k_x, k_0) = -\frac{2\pi}{\eta_0} \frac{k_0}{d(k_0^2 - k_x^2) \ln\left[\csc\left(\frac{\pi w}{2d}\right)\right]} \quad 3$$

This equation is valid under the assumption that the period is small compared to wavelength and the strip width is small compared to the period. It should be pointed out that the susceptance in (2) depends on both the frequency and the spatial wavenumber, i.e., it is both temporally and spatially dispersive. This fact has crucial consequences in establishing the radiative and modal properties of the considered structure. It should be noted that this particular symmetry, exhibited here for inductive strips in air canbe easily shown to hold also for capacitive strips in air (polarization); however, it would not hold, instead, for MSGs placed above a dielectric slab, or for more general 2-D grids such as patch, fishnet, orslab. If the strip-grating structure consists of narrow strips that are continuous in the direction and closely spaced in the direction, the current flow on the grating due to a planewave excitation having wavenumbers will physically resemble that of an infinite linearly-polarized phased current sheet.This matching condition ensures that the wave reflection does not depend on the incident angle, allowing for the wave reflection of plane waves impinging on the grating to remain unchanged as the angle of propagation changes. Othertypes of screens, in contrast, are not directly equivalent to a linearly polarized phased current sheet and hence do not exhibit this property.

3. Fabry-Perot Cavity Design

An FPC antenna can generally be regarded as a leaky parallel-plate waveguide excited by a finite source. The upper plate, either in the form of a dielectric screen or of a patch or slot array, allows radiation to leak out of the region between the parallel plates. To achieve a wide effective antenna aperture, and hence a directive radiation pattern, the leakage rate should be small; this is the case if, the upper plate has a low transmission coefficient. This happens when the equivalent susceptance of the upper FPC screen is much larger than the characteristic admittance. Assuming that the susceptance tends to infinity, an approximate design equation for the antenna thickness can be derived in order to achieve directive radiation at a given angle [12]

$$\frac{h}{\lambda_0} = \frac{0.5}{\sqrt{\varepsilon_{\mathrm{r}} - \sin^2\theta_p}} = \frac{0.5}{\cos\theta_p} \quad 4$$

Here the last expression holds for the case considered here in which, the relative dielectric constant of the medium filling the parallel-plate region, is equal to one. A more refined analysis, which takes into account the finite value shows that in the planes the following relation holds:

$$\cot(k_{z0}h) \simeq \frac{B_{\mathrm{S}}}{Y_{\mathrm{c}0}} \quad 5$$

Wherethe characteristic admittance refers to the equivalent transmission lines associated to thepolarizations [13; in theplane. The particular spatial dispersion of the MSG is such that the dependence of and on the wavenumber is the same; hence, the right-hand side in equation (4) has the same value in the principal planes. This crucial factimplies that a unique antenna thickness can be found that produces a scanned beam at the same angle in the principal planes. A high degree of azimuthal omni directionality of the resulting radiation pattern can then be expected. Interesting correlations exist between the problem of radiation from the considered MSG FPC antenna and the behavior of the same structure under plane-wave incidence.It can be verified that the condition of zero phase for the plane-wave reflection coefficient at the MSG plane is exactly given by (4); therefore, by the above-mentioned symmetry, the MSG above a ground plane behaves as a high-impedance surface at the same frequency in both principal planes, for both inductive and capacitive Far-Field Pattern. The component of the electric far field iswritten as:

$$E_p^{\mathrm{ff}}(\theta, \phi) = E_x^{\mathrm{pw}}(0, 0, z_{\mathrm{s}}) \quad 6$$

$$E_{\mathrm{co}}^{\mathrm{ff}} = f(\theta)\left(\cos\theta\cos^2\phi + \sin^2\phi\right) \quad 7$$

$$E_{\mathrm{cross}}^{\mathrm{ff}} = f(\theta)\left(\cos\theta - 1\right)\sin\phi\cos\phi. \quad 8$$

At any elevation angle, the cross-polarized component is identically zero in the principal plane.Since these are symmetry planes. At any aspect ratio, the co-to-cross polarization ratio, defined as:

$$R = \left|\frac{E_{\mathrm{co}}^{\mathrm{ff}}}{E_{\mathrm{cross}}^{\mathrm{ff}}}\right| \quad 9$$

can be calculated from (5.10) in closed form as a function of the spherical angles

$$R = \left| \frac{\cos\theta\cos^2\phi + \sin^2\phi}{(\cos\theta - 1)\sin\phi\cos\phi} \right| .$$ 10

The factor in (8) cancels out in (12), hence we get the remarkable result that the co-to-cross polarization ratio of the considered antenna does not depend on frequency nor on any of the physical parameters of the structure and it coincides with that of an elemental dipole in free space. The fact that there is cross polarization for an elemental dipole in free space is a consequence of the definition employed. If we had used Ludwigs second definition instead [13], the cross polarization would be zero. The third definition corresponds to that which is more commonly measured in practice .The angular range for where is larger than a prescribed value can then be determined in each elevation plane.

$$\cos\theta > \frac{R_{\min}\sin\phi\cos\phi - \sin^2\phi}{\cos^2\phi + R_{\min}\sin\phi\cos\phi} .$$ 11

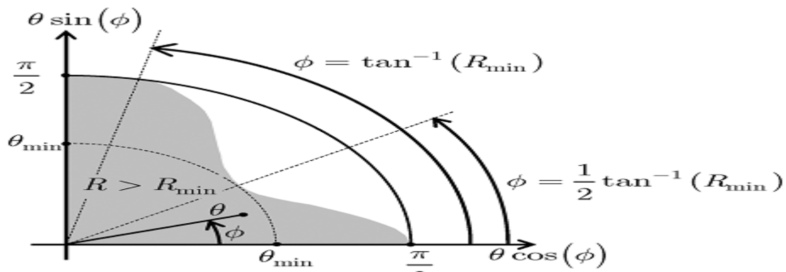


Fig. 3. Illustration of the angular region in the quadrant where the co-to-cross polarization ratio is larger than (shaded area).

A straightforward analysis of (13) shows that is larger than for all angles in the angular region, whereas for it gives.

$$\theta < \cos^{-1}\left(\frac{R_{\min}\sin\phi\cos\phi - \sin^2\phi}{\cos^2\phi + R_{\min}\sin\phi\cos\phi}\right) .$$ 12

From (14) it is found that the minimum value for is achieved in the elevation plane .

$$\theta_{\min} = \cos^{-1}\left(\frac{\sqrt{R_{\min}^2+1}-1}{\sqrt{R_{\min}^2+1}+1}\right) .$$ 13

4. Radiation from a Horizontal Electric Dipole

The radiation features of the antenna shown in Fig1 are illustrated by providing numerical results for a specific structure with parameters. The value of the thickness has been determined by maximizing at this frequency the power density radiated at broadside.

To assess quantitatively the accuracy of the approximate homogenized model of the antenna, a comparison is presented between results obtained with the TEN representation based on the temporally and spatially dispersive susceptance and full-wave results obtained with the MOM in the spatial domain. Here wehave assumed an infinitesimal horizontal electric dipole source in the middle of the cavity.

The far field is calculated again via reciprocity by letting a plane wave impinge on the structure. The Floquet-periodicity of the field allows for a restriction of the analysis domain to a single spatial period (unit cell of the structure); the MOM

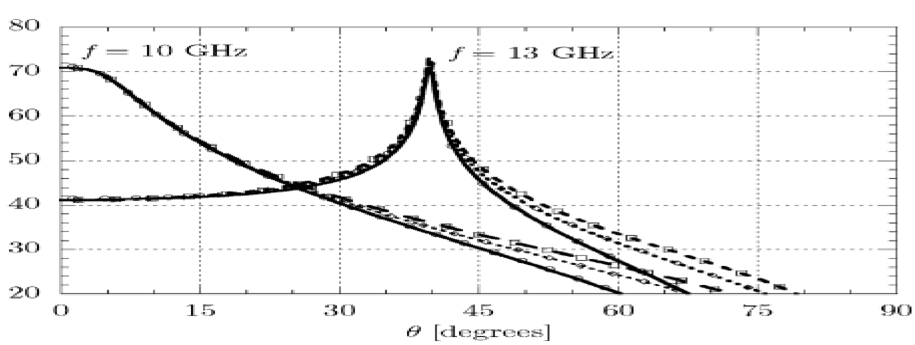


Fig. 4: Radiation patterns of the antenna in Fig. 1 .

Comparison at two different frequencies between the homogenized model (TEN) and the method of moments (MOM). Parameters: Legend: plane: solid lines (MOM), circles (TEN); plane: dashed lines (MoM), squares (TEN); plane: dotted lines (MoM), diamonds (TEN).then uses a periodic Greens function to enforce the electric field integral equation on the strip conductor inside the unit cell. Entire-domain basis functions of Chebyshev type with the proper edge-singularity factor have been employed and the periodic Greens function has been accelerated by using the Ewald method.Moreover, in the MOM code the cylindrical symmetry of the structure along the strip axis is exploited to reduce the problem of plane-wave incidence from an arbitrary direction to a problem of incidence in the plane.Azimuthally Omnidirectional Radiation and Frequency Scanning Properties. In Fig.5, far-field radiation patterns in the planes are shown for a structure asin Fig. 4. The radiated beam is seen to be scanned in elevation by varying frequency; in fact, starting from and increasing frequency, the beam opens up becoming conical in shape, with an angle of maximum radiation that covers the range from 0 to 75 in the frequency band from 10 to 35 GHz. At 30 GHz. The maximum directivity of the beams radiated at the considered frequencies are: 24.3 dBi at 10 GHz, 20.9 dBi at 11 GHz, 20.7 dBi at 13 GHz, 19.8 dBi at 20 GHz, 16.8 dBi at 30 GHz, and 14.1 dBi at 35 GHz.As it is shown in figure 5.

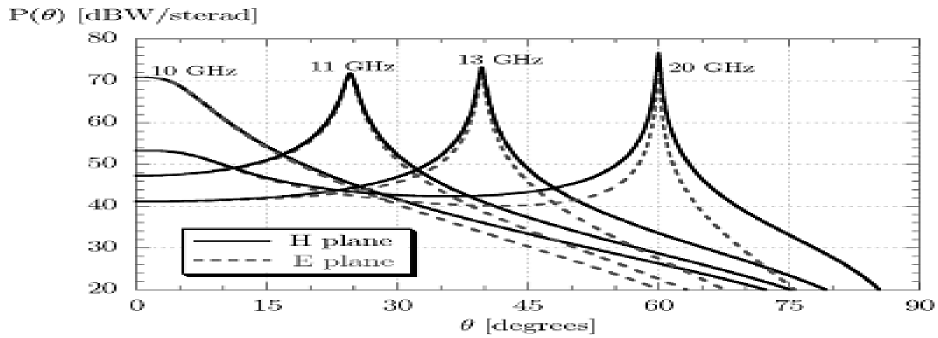


Figure 5: The directivity of the beam at different frequency

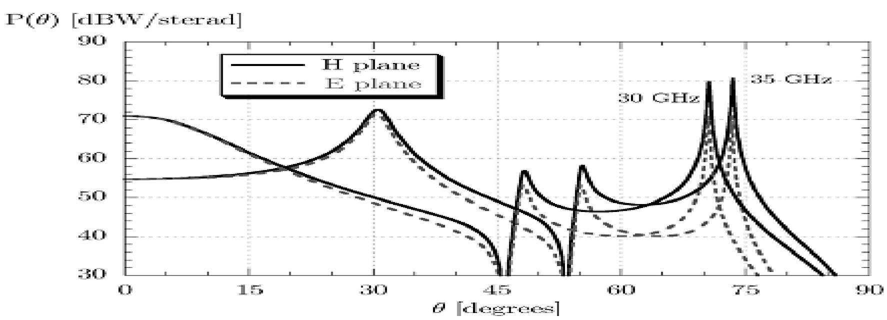


Fig. 6: Frequency scanning of the beam radiated in the planes for an MSG FPC antenna

It can be observed that, at each of the considered frequencies, the direction of maximum radiation is the same in theplanes. The degree of azimuthal omnidirectionality of the radiation pattern can be appreciated from the exact values over the entire radiation sphere.

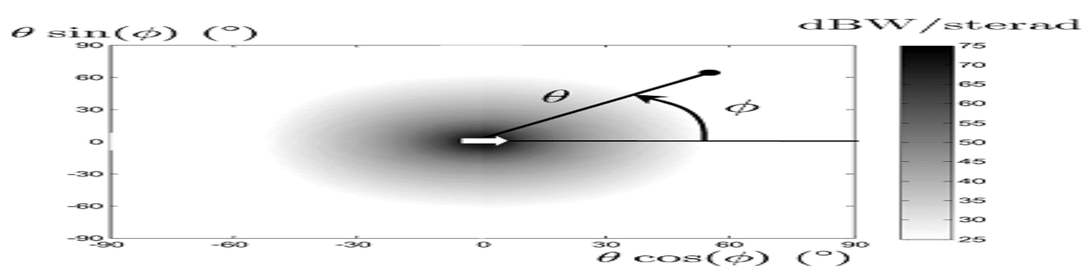


FIgure7: Gray scale representation of the radiation pattern of an MSG –FPC Antenna
F= 10 GHZ Broad side beamθp=0

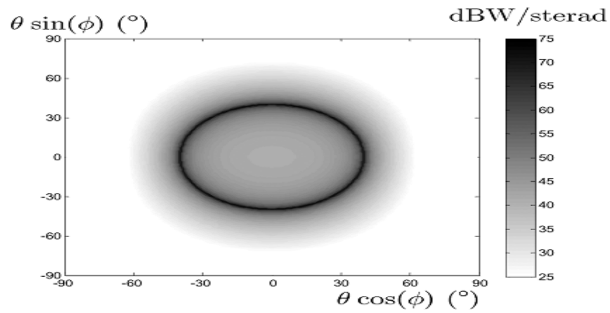
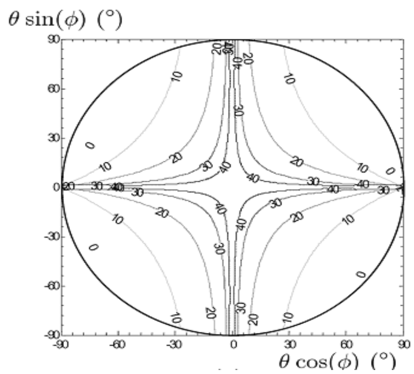


FIgure8: Gray scale representation of the radiation pattern of an MSG –FPC Antenna F= 13 GHZ Broad side beam ,$\theta p = 39.7$

The two properties (circular conical beam shape and constant beamwidth) are peculiar features of the MSG geometry, and it is not possessed by other designs of FPCs based on FSS-like PRSs.As concerns the peak intensity, in the plane it remains con-As concerns the peak intensity, in the plane it remains constant as the frequency is increased.



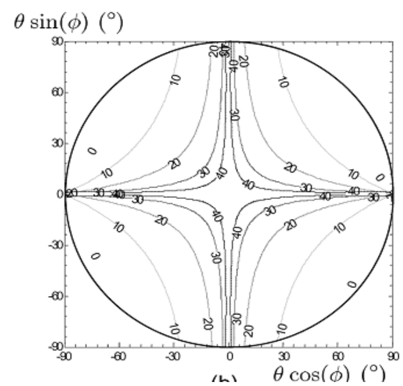


Figure9Figure10

4.1.*Polarization Properties*

The polarization features of the considered FPC antenna are illustrated by adopting the same polar scale as in Fig. 6 and displaying contour plots of the co-to-cross polarization ratio (in dB), defined in (12), calculated with the MoM approach.In Fig. 7 , the case of a broadside beam is considered, at ; in Fig. 8, the case of a scanned beam isconsidered, at (corresponding to a scan angle). A very good polarization purity of the far field canbe observed. Remarkably, Fig. 7 and 8 are indistinguishable: in fact, as expected from the analysis. the cross-polarization performance of the considered antenna is independent of frequency, and hence is the same for broadside and scanned beams, and is the same as that exhibited by a horizontal elemental dipole radiating either in free space or above a ground plane.

5. Conclusion

A Fabry-Perot cavity antenna comprised of a MSG above a ground plane excited by a horizontal electric dipole has been studied by means of rigorous full-wave simulations. Remarkable omnidirectionality and polarization purity of the directive radiation patterns have been studied.due to the excitation of a single leaky mode along the antennaaperture that propagates omnidirectionally and has current flow only in the direction. This makes the considered MSG unique among the class of partially-reflecting surfaces employed in this type of antenna. An accurate equivalent network has also been adopted to model the antenna, based on the representation of the grating through an equivalent homogenized admittance that is both temporally and spatially dispersive. The particular dependence of such admittance on the spatial wavenumbers is shown to be the key element in establishing the peculiar observed radiation properties.From a mathematical point of view, such a dependence isrelated to the underlying geometric properties of the grating, which is uniformalong the -direction, whereas it is periodic along the orthogonal -direction. These symmetries are shared with the wire-medium slab considered which shows similar radiation properties. The continuous translational symmetry of the structure is responsible for the occurrence of spatial dispersion, which manifests itself in a special dependence of the relevant homogenized parameters on the wavenumber .From a physical point of view, the continuous translational symmetry of the MSG, together with the gaps between the strips, allows the MSG to act as a linearly-polarized phased current sheet. It was shown here that any grating that behaves as a linearly-polarized phased current sheet will have the remarkable property of allowing for omnidirectional leaky-wave propagation.The particular dependence of the grating admittance on the spatial wavenumbers accounts for i) the azimuthal omnidirectionality of the patterns, either in the form of pencil beams pointing at broadside or of conical scanned beams; ii) the excellent polarization purity of the far field, expressed in terms of co-to-cross polarization ratio, that turns out to be independent of frequency and equal to that of a dipole in free space; and iii) the propagation of cylindrical leaky waves, with respect to the strip direction, whose excitation determines the shape of the radiation patterns and whose wavenumber is independent of the azimuthal propagation angle.

References

[1] *G. von Trentini, Partially reflecting sheet arrays, IRE Trans. Antennas Propag., vol. AP-4, pp. 666671, Oct. 1956.*

[2] *D. R. Jackson and N. G. Alexpoulos, Gain enhancement methods for printed circuit antennas, IEEE Trans. Propag., vol. AP-33, no. 9, pp. 976987, Sep. 1985.*

[3] *A. P. Feresidis, G. Goussetis, S. Wang, and J. C. Vardaxoglou, Artificial magnetic conductor surfaces and their application to low profile high-gain planar antennas, IEEE Trans. Antennas Propag., vol. 53, no. 1, pp. 209215, Jan. 2005.*

[4] *G. Lovat, P. Burghignoli, F. Capolino, and D. R. Jackson, High directivity in low-permittivity metamaterial slabs: Ray-optic vs. leaky wave models, Microwave Opt. Techn. Lett., vol. 48, no. 12, pp. 25422548, Dec. 2006.*

[5] *R. Honey, A flush-mounted leaky-wave antenna with predictable patterns, IEEE Trans. Antennas Propag., vol. AP-7, no. 4, pp. 32029, Oct. 1959.*

[6] *K. L. Klohn, R. E. Horn, H. Jacobs, and E. Freibergs, Silicon waveguide frequency scanning linear array antenna, IEEE Trans. Microw. Theory Tech., vol. MTT-26, no. 10, pp. 764773, Oct. 1978.*

[7] *M. Guglielmi and G. Boccalone, A novel theory for dielectric-inset waveguide leaky-wave antennas, IEEE Trans. Antennas Propag., vol. 39, no. 4, pp. 497504, Apr. 1991.*

[8] *Y. Kaganovsky and R. Shavit, Analysis of radiation from a line source in a grounded dielectric slab covered by a metal strip grating, IEEE Trans. Antennas Propag., vol. 57, no. 1, pp. 135143, Jan. 2009.*

[9] *G. Lovat, P. Burghignoli, F. Capolino, D. R. Jackson, and D. R. Wilton, High-gain omnidirectional radiation patterns from a metal strip grating leaky-wave antenna, in IEEE AP-S Int. Symp. Antennas Propag. Digest, Honolulu, HI, Jun. 1015, 2007, pp. 57975800.*

[10] *P. Burghignoli, G. Lovat, F. Capolino, D. R. Jackson, and D. R. Wilton, Modal propagation and excitation on a wire-medium slab, IEEE Trans. Microw. Theory Tech., vol. 56, no. 5, pp. 11121124, May 2008.*

[11] *M. Guglielmi and D. R. Jackson, Broadside radiation from periodic leaky-wave antennas, IEEE Trans. Antennas Propag., vol. 41, no. 1, pp. 3137, Jan. 1993.*

[12] *R. R. deLyser and E. F. Kuester, Homogenization analysis of electromagnetic strip gratings, J. Electromagn. Waves Applicat., vol. 5, no. 11, pp. 12171236, Nov. 1991.*

[13] *T. Zhao, D. R. Jackson, J. T. Williams, and A. A. Oliner, General formulas for 2-D leaky-wave antennas, IEEE Trans. Antennas Propag., vol. 53, no. 11, pp. 35253533, Nov. 2005.*