Short-Pulse Radiation With Low Cross-Polarization and a Related New Pulse Ringing Phenomenon in a Printed Antenna Element Covered by a Polarization Strip Grating

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Abstract—**Suppression of unwanted cross-polar radiation from a printed antenna element by placing a printed strip-grating on top is demonstrated for short-pulse radiation. It is discovered that an interesting pulse ringing can occur due to a new "grating resonance." A full-wave analysis is outlined that models the effect of the strip grating placed on top of a microstrip antenna element and predicts the new pulse-ringing effect.**

I. Introduction

PRINTED ANTENNAS are attractive elements for broad-band/short-pulse radiation [1], [2] and are particularly suited for integration with microwave and optoelectronic circuits. However, it is usually difficult to obtain low cross-polar radiation from such printed antennas over an ultra-broad bandwidth and/or a wide beam angle. Significant levels of cross-polarized radiation can be introduced in nonprincipal planes due to presence of the dielectric substrate of the antenna. Also, radiation from the feed circuitry and other integrated components of the substrate is often an unavoidable source of cross-polar radiation. It is necessary to avoid or sigificantly suppress such unwanted cross-polar radiation for applications in radar and communication.

Strip-gratings printed on a thin substrate have been used for the suppression of cross-polarization. Although in the past the use of gratings has been limited to narrow-band operations, with proper design they can be equally effective under ultra-wideband or short-pulse applications [3]. In this paper we outline a full-wave analysis of short-pulse radiation from a printed antenna element loaded on top by a strip-grating. Demonstrative results of suppression of the cross-polar radiation are presented. However, it is discovered that a new resonance of the cross-polar field can occur between the grating and the groundplane of the printed antenna. This can result in unwanted ringing of the co-polar component of the radiation field.

II. Time-Harmonic Analysis

Fig. 1 shows the geometry of a printed antenna element covered by a periodic strip-grating. The grating can be placed immediately on top of, or properly spaced above, the antenna element. Standard geometries of printed antennas on single or multiple dielectric substrates can be analyzed for time-harmonic excitation using a spectral-domain moment method approach [4], [5]. However, when an additional grating layer is included, the antenna can not be directly analyzed using the spectral-domain Green's functions. This is because, unlike a dielectric layer, the grating introduces a nonuniformity in the transverse plane.

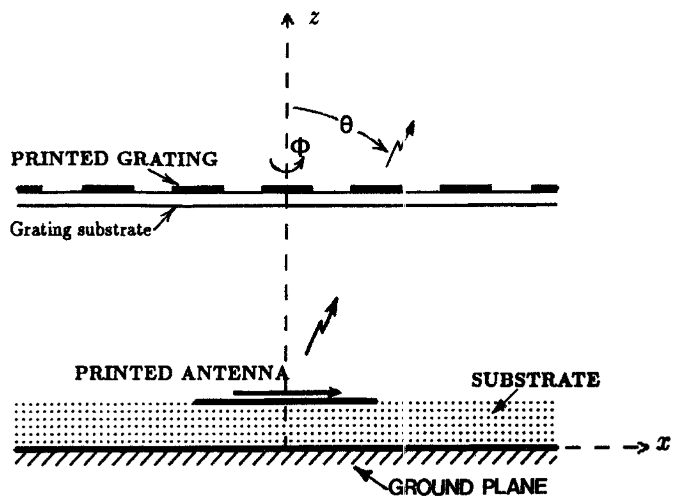

Fig. 1. Periodic strip-grating to suppress the cross-polarized radiation from a printed antenna for broadband/short-pulse applications. The printed grating may be placed directly on top, or properly spaced above, the antenna surface.

We account for the grating effects in the spectral domain using a new "hybrid" approach. First, we separately analyze the strip grating in the presence of all dielectric substrates, excited by a "spectral current sheet" placed on the plane of the antenna. Under this current-sheet excitation, an infinite number of plane wave modes (the Floquet modes) produced due to the periodic strip grating are included to describe the resulting field. Then, we assume an elemental spatial impulse current on the antenna and express it as a spectral decomposition of phased current sheets. The field contribution due to each of these decomposed current sheets in the presence of the grating are now individually obtained using the Floquet-mode analysis discussed above, and the total field is then computed via a

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spectral inverse integration. Any arbitrary current distribution on the antenna can be solved via basis expansion and a moment method. Finally, the far field radiation is deduced from the known antenna currents using a stationary phase evaluation method. It should be noted that without the strip grating, only a part of the spatial-spectral components of the antenna current, with $k_x = k_0 \sin\theta \cos\phi$ and $k_y = k_0 \sin\theta \sin\phi$ (see Fig. 1), contribute to the far field. But when the grating is introduced, it also diffracts some of the evanescent fields of the antenna into the far-field radiation. In a specific case when the separation between the antenna and the grating is sufficiently large, the evanescent coupling from the antenna to the grating is small and may be neglected for far-field computation. This may significantly reduce the computation time.

III. Results of Pulse Radiation

The above analysis assumes a harmonic time-dependence, with which a pulsed radiation is simulated via a spectral-synthesis. The short dipole antenna is excited by a current pulse with a specrtum:

$$F(\omega) = \frac{(\omega t_\iota)^4}{12} e^{-|\omega| t_\iota}, \quad (1)$$

with $1/t_\iota = 30$ GHz. The radiation characteristics in the direction $\theta = 45°$, $\phi = 45°$ are presented in Figs. 2–4.

Referring to Fig. 1, if there was no dielectric substrate (the dielectric substrates are replaced by air), the radiation from the dipole without the grating on top is purely TM_x. When one or more dielectric substrates are introduced, the radiation is still TM_x along the principal planes, but some TE_x radiation will be present in off-broadside directions along nonprincipal planes. Therefore, in the absence of the grating, the TM_x and TE_x components are considered the co-polarization and cross-polarization components, respectively. To achieve an effective suppression of the cross-polarized radiation, the grating strips must be placed perpendicular (y) to the dipole. Now, the TE_y field components of the antenna will almost pass through, whereas the TM_y fields will be strongly reflected by the grating. Therefore, when the grating is introduced, the far-field radiation is predominantly TE_y and, hence, the TE_y radiation is justifiably considered the co-polarized component.

Fig. 2 shows the radiation from a dipole printed on a dielectric substrate, without a grating layer, at an off-broadside direction along the diagonal plane. It can be seen that there is a significant level of cross-polarized radiation from the antenna due to the effect of the dielectric substrate. As mentioned, much higher levels of cross-polar radiation should be expected due to spurious radiation from the feeding circuits and active components. Fig. 3 shows the new results including a grating layer on top. It can be seen that the level of cross-polarization has been significantly reduced. A lower level of the cross-polar radiation is achieved using a grating with narrower strip-widths and/or smaller strip-spacings.

As discussed, the TM_y (see Fig. 1) component radiated from the antenna is strongly reflected from the grating layer. The reflected TM_y (cross-polar) fields again get reflected back by the groundplane below the antenna. As expected, it establishes an oscillation between the groundplane and the

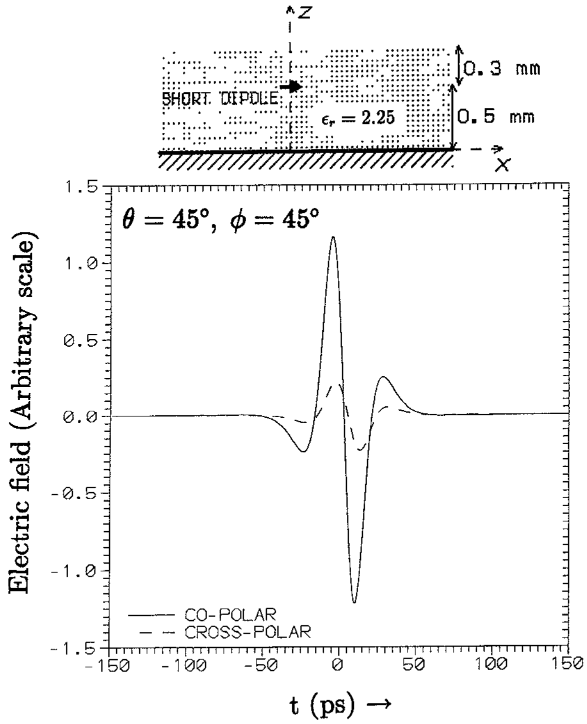

Fig. 2. Dielectric layers introduce cross-polarization in directions away from the principal planes.

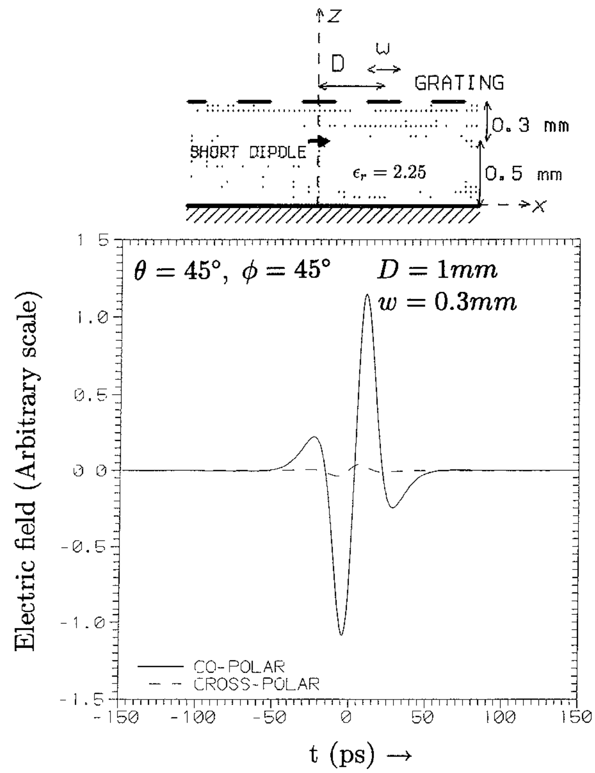

Fig. 3. Suppression of a cross-polar radiation using a strip-grating on top of the antenna element over a broad pulse bandwidth of about 60 GHz.

strip-grating layer due to multiple reflections. Ideally, when all the dielectric substrates are removed (replaced by air), this oscillation of the TM_y fields will be confined only between the

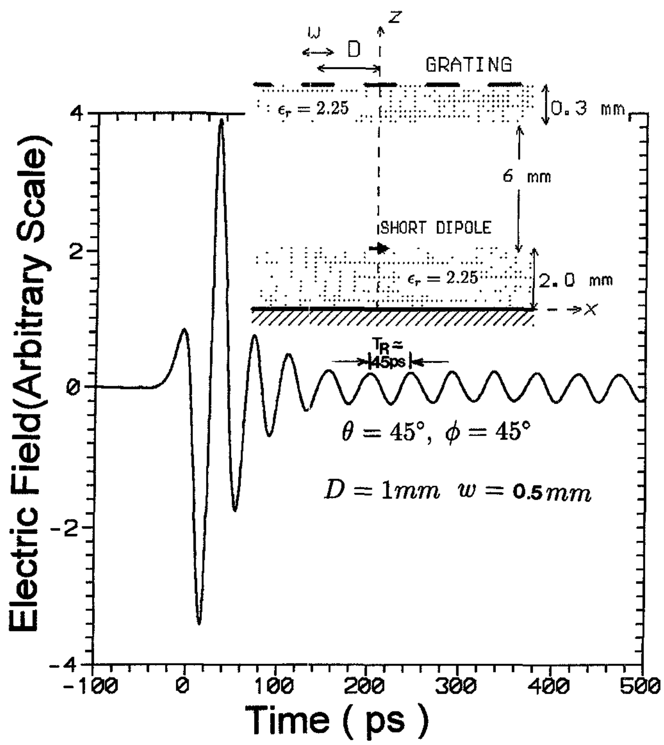

Fig. 4. Pulse-ringing of the co-polar component caused by the grating resonance. Here, the ringing period $T_R \simeq 45$ ps, which compares well with the approximately calculated value of $T_R = 44.55$ ps.

groundplane and the grating layer and will not escape through the y-directed strips of the grating into free-space radiation. However, when the antenna and/or the grating substrate is introduced (see Fig. 1), through every reflection the dielectric substrate(s) will convert a part of the TM_y fields to TE_y (co-polar) fields, which will now escape through the grating to far-field radiation. The external radiation, therefore, will exhibit a strong oscillation of the co-polar field in the time domain. More interestingly, the frequency of this oscillation, f_R, will be a function of the angle of observation, θ. The relationship between f_R and θ can be shown to be approximately expressed as: $H \cos\theta = c/(2f_R)$ where H is the electrical distance between the grating and the groundplane, and $c =$ the velocity of light in free space. As has been computationally verified, the amplitude of this oscillation increases for thicker substrates due to increased cross-coupling between the TM_y and TE_y fields. Fig. 4 clearly shows this interesting resonance effect. The time period of ringing of the radiated pulse agrees with the above approximate calculations.

IV. Conclusion

Analysis of a printed antenna element covered with an additional layer of a metal strip-grating is presented. Through the results of analysis, it is demonstrated that significant suppression of the cross-polarized radiation can be achieved for short-pulse/ultra-wideband applications. As a result, however, a strong pulse-ringing of the co-polar radiation can occur due to an interesting "grating resonance" effect, with the ringing frequency dependent on the angle of observation. This unwanted ringing should have to be suppressed by careful design. As a reciprocal receiving antenna, such a strong, angle-dependent ringing in the late-time of the received signal may find useful in radar applications.

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