Millimeter Wave Radiator: Actively and Passively Excited Sinusoidal PCB Strip and Microstrip Antennas

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***Abstract*—In this paper, the millimeter-wave radiation properties of actively and passively excited sinusoidal PCB strip and microstrip antennas are investigated. The main advantage of constructing PCB antennas is the reduction of antenna size comparing with the wire structures. The constructed antennas can be used as small-sized and frequency-sacnning antennas in millimeter wave radars.**

I. Introduction And Background

THE millimeter-wave radiation properties of an active [1] and passive [2] sinusoidal wire structures were investigated before. This structure is a traveling wave antenna which can be analyzed by introducing an electric current. A sinusoidal strip or a microstrip line can also be considered as the similar kind of traveling wave structures [3]. In the literature, the first examples of the traveling wave sinusoidal strip and microstrip antennas were investigated in microwave frequencies [4, 5]. In our study, the operation frequency is increased to the millimeter-wave region. Additionally, the measured patterns of the antennas are compared with calculated and simulated patterns both. The calculated patterns are obtained using a written code based on the mathematical model below. The simulated patterns are obtained using HFSS software. The passively-excited sinusoidal antenna is applied to PCB strip and microstrip structures for the first time.

The sinusoidal thin strip line can be analyzed by defining an electric current (Fig.1). For a sinusoidal thin strip lying down in x-z plane, the electric current at an arbitrary point r' on the sinusoidal structure can be given as, $\vec{I}_e(\vec{r}') = \hat{a}_\ell I_e(\vec{r}') = \hat{a}_\ell I_{e0} \exp\left[-\gamma_\ell z'\right]$, where, I_{e0} is the amplitude of the electric current and γ_ℓ is the propagation constant defined by $\gamma_\ell = \alpha_\ell + j\beta_\ell$ [1]. For a nonmagnetic medium, the magnetic vector potential at an arbitrary point $P(r,\theta,\phi)$ in space can be written as

$$\vec{A}(\vec{r}) = (\mu_0 / 4\pi)\int_L d\vec{A}(\vec{r}') = (\mu_0 / 4\pi)\int_{-z_0}^{z_0} \vec{I}(\vec{r}')(\mathrm{e}^{-jkR} / R) d\ell' ,$$

where k is the phase constant of the wave propagates in free space and $\vec{r}$ is the position vector of the point where the magnetic vector potential is calculated. The infinitesimal length element can be written in the Cartesian coordinates as $\overrightarrow{d\ell'} = dx'\hat{a}_x + dz'\hat{a}_z$. Using the mathematical definition of sine function $x' = -L_0 \sin(2\pi / \Lambda)z'$ and rewriting magnetic vector potential in the spherical coordinates, the radiated far zone electric fields $\vec{E} = -j\omega\vec{A}$ can be obtained.

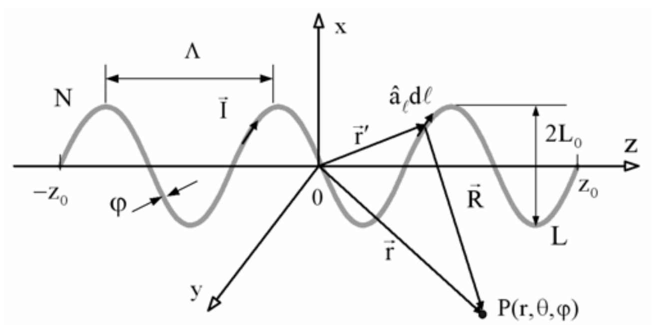

Fig.1. The sinusoidal thin strip traveling wave antenna that has an amplitude L_0, a period Λ, and number of periods N, after [1] and [3].

This antenna can be considered as actively excited antenna because the electric current flows directly along structure. Another kind of excitation type is the passive excitation. A sinusoidal strip is located near a Goubau line strip and induced electric current flows along sinusoidal strip. In this case, structure can be considered as a standing wave structure and the current is defined as the combination of forward and reflected backward currents, $\vec{I}_t(\vec{r}') = \vec{I}_f + \vec{I}_b = \hat{a}_\ell[s_f \exp(-\gamma_\ell z') + s_b \exp(\gamma_\ell z')]$, where s_f and s_b are current coefficients, which are complex in general, of forward and backward currents respectively. These coefficients are chosen as complex variables to take into account all contributions of coupled current by Goubau line and the boundary conditions and obeying the rule $\left|s_f\right| \geq \left|s_b\right|$. The forward current in magnetic vector potential in the far zone electric field is replaced with this total current for standing wave case.

II. Experiment and Results

Actively and passively excited sinusoidal strip and microstrip antennas are designed (Fig.2). R-Duroid 5880 ($\varepsilon_r = 2.2$) and FR-4 are used as dielectric substrates of antennas. 3-D HFSS models of actively-excited sinusoidal PCB strip and microstrip (ground metal-backed) antennas are shown in Fig.3.

[1] α_ℓ is the attenuation constant (in Np/m) and β_ℓ is the phase constant (in rad/m) of wave.

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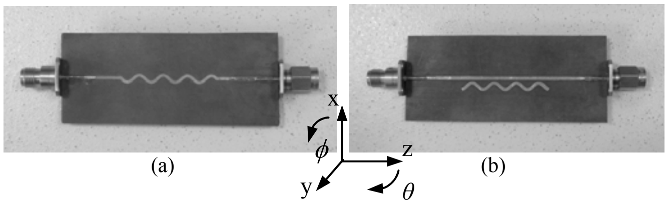

Fig.2. Designed antenna structures made from R-Duroid 5880: (a) actively-excited and, (b) passively-excited, after [3]. 50 Ω resistive load connected to the end of the antennas are not shown in the figure.

Measured SWR graphs of actively and passively-excited microstrip and strip antennas in wide frequency range are given in Fig.4. One can see that the antenna has a good match with the standard coaxial line in a very wide frequency range.

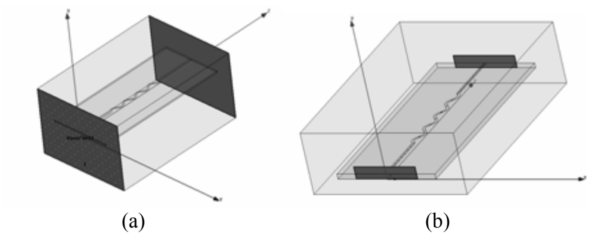

Fig.3. 3-D HFSS models of actively-excited sinusoidal a) PCB strip and b) microstrip (ground metal-backed) antennas. Dark colored faces are excitation and termination faces, after [3].

Measured, calculated and simulated normalized field patterns of actively excited microstrip (Fig.5), strip (Fig.6) and passively excited strip (Fig. 7) antennas made from R-Duroid 5880 and FR4, respectively, are given below.

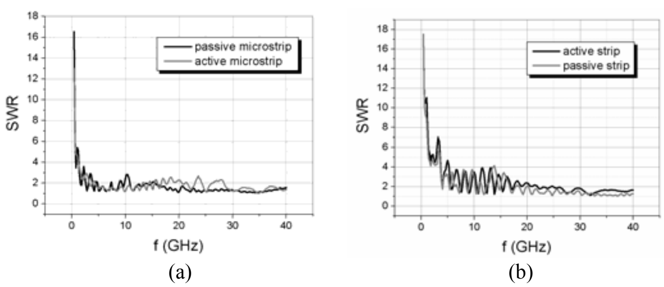

Fig. 4. Measured SWR graphs of actively and passively-excited (a) microstrip and (b) strip antennas in wide frequency range, after [3].

The E_x patterns are measured in the y-z plane (θ varies, $\phi = \pi / 2$). The calculated velocity ratio and the attenuation constant are also given in the figure. A good match can be observed between the measured, calculated and the simulated patterns. Both antenna types are frequency-scanning antennas.

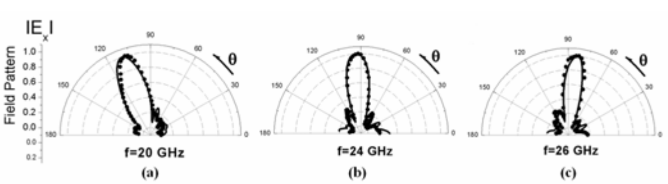

Fig. 5. • measured and — simulated (by HFSS) normalized patterns of actively-excited microstrip (R-Duroid 5880) antenna at (a) 20 GHz, (b) 24 GHz and (c) 26 GHz , after [3].

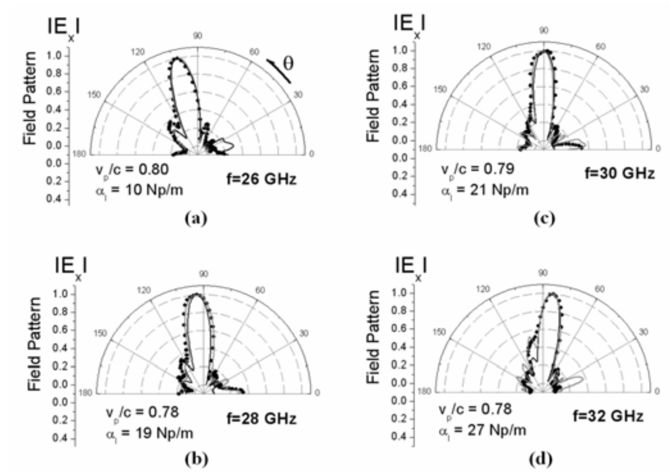

Fig. 6. • measured, — calculated and — simulated (by HFSS) normalized patterns of actively-excited PCB strip (R-Duroid 5880) antenna at (a) 26 GHz, (b) 28 GHz, (c) 30 GHz and (d) 32 GHz , after [3].

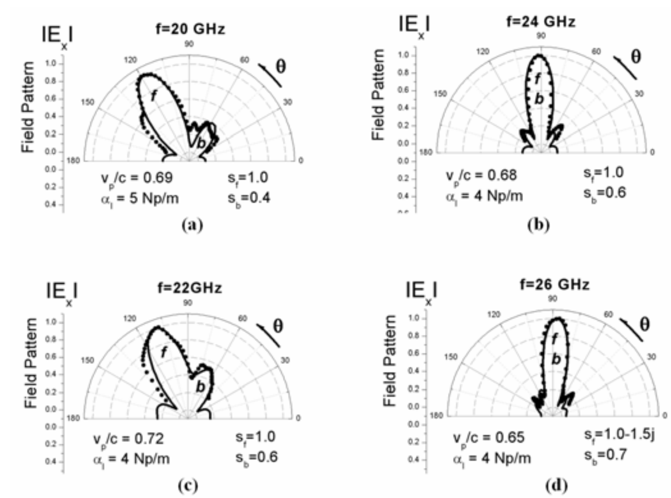

Fig. 7. • measured and — calculated normalized patterns of passively-excited PCB strip (FR-4) antenna at a) 20 GHz, b) 22 GHz, b) 24 GHz and c) 26 GHz. f and b letters label the lobes of forward and backward currents, respectively, after [3].

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