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CHARACTERISTICS OF LEAKY WAVE ANTENNAS - A REVIEW

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Leaky wave antennas [1-4] constitute a class of travelling wave antennas and are characterised by propagation of a leaky wave along an interface. These antennas are capable of providing very narrow beams, can be flush mounted (for example, with aircraft body) and possess frequency scanning characteristics. The present review of leaky wave antenna characteristics includes discussion on leaky waves, on various types of leaky wave structures, radiation characteristics and design equations.

1. LEAKY WAVES

A leaky wave is a wave which can be supported by an interface, is described by a complex propagation constant and leaks energy into space away from the interface. A convenient way to characterize leaky waves is in terms of the wave number in a direction transverse to the interface. The field variation for a leaky wave can be represented by $\exp[-j\omega t + jk_0(hx + \gamma z)]$ where $h(= h_r + jh_i)$ and $\gamma(= \beta + j\alpha)$ represent normalized wave numbers in transverse and longitudinal directions respectively. The necessary condition for a leaky wave may be expressed as $h_r > 0$ which implies wave propagation in transverse direction also. Imaginary part h_i can be positive (indicating decay of field in transverse direction) or negative (indicating growth in transverse direction). These correspond to spectral and non-spectral (or non-modal) leaky waves respectively. The latter type is encountered in most of the leaky wave antennas. The non-modal character of this type of leaky waves is illustrated in Fig. 1 where the rays represent radiation from a leaky interface. The leaky wave field exists only in the wedge shaped region as shown. If the field were modal it would be valid everywhere and would consequently diverge at infinity.

The guiding structures for leaky waves can be divided into two types : perturbed waveguide type (Fig. 2a) and open guiding type (Fig. 2b). The radiation characteristics of these leaky wave structures are determined by the propagation constant γ which can be obtained by solving Maxwell's equations with the associated boundary conditions, or by using transverse resonance technique, or variational formulation. For some structures, usually open types, it is possible to formulate the boundary value problem, obtain the dispersion relation and solve for γ. This has been reported for plasma slabs [1], dielectric slabs [1,3], thin wall leaky wave structure [5], artificial dielectric structure [6-8], etc. For many other structures, approximate methods are needed.

2. ANTENNA CHARACTERISTICS

Radiation pattern : The far field radiation of leaky wave antennas has been evaluated by two different methods : steepest descent method (SDM) [1,4,9] and Kirchhoff-Huygens method (KHM) [1,4]. KHM is applicable to both infinite as well as finite length structures. For infinite length the radiation patterns $R(\theta)$ are given by [1,4]

$$R_b(\theta) = |\gamma \cos\theta/(\sin^2\theta - \gamma^2)|^2 \quad \text{(for bidirectional excitation)} \tag{1}$$

$$R_u(\theta) = |\cos\theta/(\sin\theta - \gamma)|^2 \quad \text{(for unidirectional excitation)} \tag{2}$$

For finite lengths (2L for bidirectional and L for unidirectional excitations) the corresponding relations are [1,4,6], using $k_0L/2 = d$:

$$R_{bf}(\theta) = \left| \frac{\cos\theta}{\sin^2\theta - \gamma^2} \left\{ e^{j\gamma d} (\sin\theta - \gamma)\sin[d(\sin\theta + \gamma)] + e^{-j\gamma d} (\sin\theta + \gamma)\sin[d(\sin\theta - \gamma)] \right\} \right|^2 \tag{3}$$

$$R_{uf}(\theta) = |\cos\theta \sin[d(\sin\theta - \gamma)]/[d(\sin\theta - \gamma)]|^2 \tag{4}$$

For narrow beam antennas the radiation characteristics, viz., beam position, beamwidth, gain, sidelobe level and efficiency are nearly same for the two excitations.

Design equations : The expressions given below are for uniform antennas (the propagation constant does not vary along the length) with unidirectional excitation. It is assumed that either because of radiation, the power left at the far end is negligible, or the antenna is terminated in a matched load.

Beam direction [2], θ_m

$$\theta_m = \sin^{-1}\left[\frac{(1 + \beta^2 + \alpha^2) - [(1 + \beta^2 + \alpha^2)^2 - 4\beta^2]^{\frac{1}{2}}}{2\beta}\right] \simeq \sin^{-1}(\beta) \quad (\text{for } \alpha^2 \ll \beta^2) \tag{5}$$

For perturbed waveguide (broad dimension 'a') we have,

$$\theta_m \simeq \sin^{-1}[(1 - \lambda^2/4a^2)^{\frac{1}{2}}] \tag{6}$$

Beamwidth, BW(radians)

$$BW = 2\alpha/(1 - \beta^2)^{\frac{1}{2}} \quad \text{(for infinite antennas [2])} \tag{7a}$$

$$BW = \sin^{-1}[\beta + (|A| + 0.165)/d] - \sin^{-1}[\beta - (|A| + 0.165)/d] \quad \text{(for finite antennas [6])} \tag{7b}$$

where
$$|A| = 0.866\left\{-\left[\frac{\sinh^2(\alpha d)}{(\alpha d)^2} - 2\right] + \left[\left\{\frac{\sinh^2(\alpha d)}{(\alpha d)^2} - 2\right\}^2 + 2.667\sinh^2(\alpha d)\right]^{\frac{1}{2}}\right\}^{\frac{1}{2}}$$

Gain, G

$$G = (1 - \beta^2)/[\alpha(1 - \beta^2)^{\frac{1}{2}} - \alpha^2] \quad \text{(for infinite cylindrical antenna)} \qquad (8a)$$

$$G = \cos\theta_m[4\pi WL/\lambda^2][\tanh(\alpha d)/(\alpha d)] \quad \text{(for finite planar antenna of width } W\text{, [2])} \qquad (8b)$$

Sidelobe level [2], SL(-dB)

$$SL = 10 \log[\{(3\pi/2)^2 + (\alpha d)^2\}\{(1 - \beta^2)/[1 - (\beta - 6\pi/d)^2]\}\{\tanh^2(\alpha d)/(\alpha d)^2\}] \qquad (9)$$

Efficiency [2], η

$$\eta = 100(1 - \alpha_c/\alpha)[1-e^{-4\alpha d}] \qquad (10)$$

where α_c is the normalized attenuation constant due to ohmic losses.

Typical performance : Experimental results for various leaky wave antennas have been reported in literature. Three of these antennas operating at 10 GHz are compared in Table 1. Inductive grid antenna [10] has been designed for low sidelobe characteristics using tapered amplitude distribution, artificial dielectric (AD) slab antenna was designed for narrow beam [8] (also for fast frequency scanning [7]) using uniform amplitude distribution. All of these antennas have demonstrated predictable radiation characteristics.

References

1. R.E. Collin and F.J. Zucker (Eds.), Antenna Theory, Part II, McGraw-Hill, New York, 1969.
2. I.J. Bahl and K.C. Gupta, Proc. IEE, Vol.123, p.1302, 1976.
3. C.H. Walter, Travelling Wave Antennas, McGraw-Hill, 1965.
4. T. Tamir and A.A. Oliner, Proc.IEE, Vol.110, p.310, 1963.
5. R. Garg et al., IEEE Trans. AP-23, pp 107-112, 1975.
6. I.J. Bahl and K.C. Gupta, IEEE Trans. AP-22, p.119, 1974.
7. I.J. Bahl and K.C. Gupta, IEEE Trans. AP-23, p.584, 1975.
8. I.J. Bahl and K.C. Gupta, J. Instn. Electronics Telecom. Engrs.(India), Vol.22, pp.778-780, 1976.
9. K.C. Gupta, Electron. Lett., Vol. 7, pp. 16-17, 1971.
10. R.C. Honey, IRE, Trans. AP-7, pp.320-329, 1959.

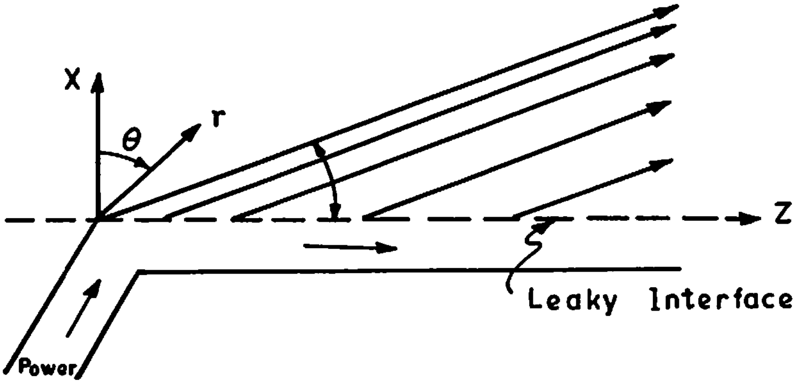
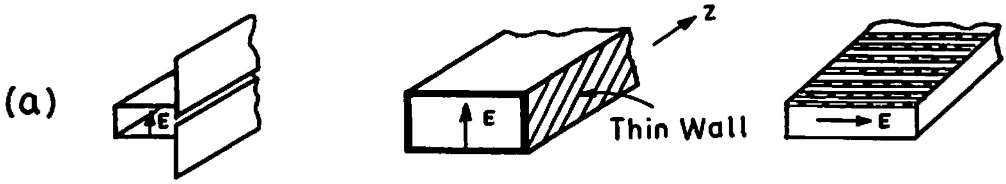
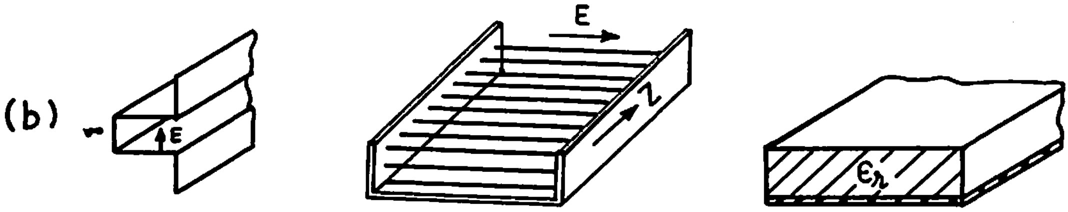


Fig. 1 Radiation from a leaky interface



Slotted waveguide Thin wall waveguide Inductive grid waveguide



Channel waveguide Artificial dielectric Grounded dielectric slab

Fig.2(a) Perturbed waveguide structures;
(b) Open guiding structures

Table 1

Relative performance of three leaky wave antennas

Antenna structure	Beam position (degree)	Beamwidth (degree) H-plane	Beamwidth (degree) E-plane	First side lobe level (-dB)	Physical dimensions L/λ	Physical dimensions W/λ
Inductive grid[10]	50	5.4	3.5	28	20.3	15.2
AD [8]	36	2.8	10	11.5	26.7	6.67
TLA [5]	50	11	-	9	6.67	0.76