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The LNM Institute of Information Technology

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Department: Electronics and Communication Engineering

Antenna Engineering (ECE3071)

Exam Type: End Term

Time:180 minutes **Date: April 30, 2019** **Max. Marks: 50**

Instructions: *1. All the questions are compulsory and are worth 5 marks each.*
2. You are allowed to bring an A4 size sheet with you, with information (written in your own handwriting) that you think can help you in performing better in this exam.

Q.1 The total radiated power of a center-fed half-wave dipole antenna radiating in air medium has been measured to be 106.8 Watts. (a). How much is the value of peak current in the antenna? (b). What would be the magnitudes of electric and magnetic field strengths at a distance of 3781 m from the antenna in a plane at 45-degree angle from the axis of the antenna? Assume far-field conditions.

Q.2 Calculate the effective area of an isotropic antenna at a) D.C., b) 1 MHz, and c) 100 MHz.

Q. 3 An antenna on an Indian Air Force (IAF) aircraft is being used to jam an enemy radar. The gain of the aircraft antenna is being adaptively maintained at 20 dB in the direction of interest whereas the gain of the antenna on the radar is unknown to IAF planners. The input power to the aircraft antenna is 10 KW and the aircraft is flying in a path so that it is maintaining an approximately-constant distance of 2 Km from the target radar. Assuming that the frequency of operation is 5 GHz, calculate how much EIRP would approximately be observed in the vicinity of the radar.

Q. 4 Rigorously derive the mathematical expression for the Array Factor of a uniform linear array of N isotropic antennas.

Q. 5 Design a 12-element uniform linear array at 900 MHz frequency so that the main beam lies at an angle of 45 degrees with respect to the line joining the elements. Assume isotropic elements and quarter-wave spacing between elements. Try to estimate the values of FNBW and HPBW.

Q. 6 Briefly discuss (in the context of propagation of EM waves) any five of the following: LOS, Ducting, Fading, Troposphere, Ionospheric Layers, Surface Wave, Space Wave, Ground Wave, Sky Wave, MUF, Skip Distance, Sunspot Activity, Solar Storms, Reflection, Refraction, Diffraction, Scattering, Doppler Shift, Multi-path propagation.

Q. 7 Design a pyramidal horn antenna to operate at 3 GHz center frequency with directivity of at least 20 dB. Use WR-284 waveguide (a = 72.136 mm, b = 34.036 mm) as the feed.

Q. 8 Design a rectangular patch antenna to operate at 4.2 GHz center frequency and estimate all its performance parameters. Use a 60-mil thick FR4 substrate (dielectric constant = 4.4). Also discuss how Babinet principle is used in analyzing/designing spiral antennas and slot antennas.

Q. 9 A loop antenna is to be designed so that it operates at 100 MHz frequency and its principle maximum is along the loop axis. What should be the perimeter of the loop? Also design an end-fire helix antenna with 12 dB directivity at 1200 MHz frequency and estimate the values of its various performance parameters.

Q. 10 Design a LPDA with 8 dB directivity, to operate over 470 MHz – 890 MHz frequency range and estimate the values of its various performance parameters. Also discuss in brief the roles played by Smart Antennas in today's world.

D = diameter of helix;
s = spacing between turns;
n = number of turns;
C = circumference of helix = πD;
L = length of one turn = $\sqrt{C^2 + s^2}$.

- Normalized circumference: $3/4 < C/\lambda < 4/3$;
- Spacing: $s \approx \lambda/4$;
- Pitch angle: $12° \leq \alpha = \tan^{-1}(s/C) \leq 15^0$;
- Number of turns: $n > 3$.

It has been found that the half-power beamwidth is roughly

$$HPBW \approx \frac{52°\lambda\sqrt{\lambda}}{C\sqrt{ns}} \tag{5.27}$$

It is inversely proportional to C and $\sqrt{ns}$. The beamwidth between first nulls is about

$$FNBW \approx \frac{115°\lambda\sqrt{\lambda}}{C\sqrt{ns}} \tag{5.28}$$

$D \approx 15C^2ns/\lambda^3$ $\qquad$ $D \approx 12C^2ns/\lambda^3$

$AR = (2n + 1)/(2n)$

L_n = the length of element n, and $n = 1, 2, \ldots, N$;
s_n = the spacing between elements n and $(n+1)$;
d_n = the diameter of element n;
g_n = the gap between the poles of element n.

They are related to the *scaling factor*:

$$\tau = \frac{L_2}{L_1} = \frac{L_{n+1}}{L_n} = \frac{s_{n+1}}{s_n} = \frac{d_{n+1}}{d_n} = \frac{g_{n+1}}{g_n} < 1 \tag{5.37}$$

and the *spacing factor*:

$$\sigma = \frac{s_1}{2L_1} = \frac{s_n}{2L_n} < 1 \tag{5.38}$$

As shown in Figure 5.20, two straight lines through the dipole ends form an angle 2α, which is a characteristic of the frequency-independent structure. The angle α is called the *apex angle* of the log-periodic antenna, which is a key design parameter and can be found as

$$\alpha = \tan^{-1}\left(\frac{(L_n - L_{n+1})}{2s_n}\right) = \tan^{-1}\left(\frac{L_n(1-\tau)}{2s_n}\right) = \tan^{-1}\left(\frac{(1-\tau)}{4\sigma}\right) \tag{5.39}$$

These relations hold true for any n. From the operational principle of the antenna and the frequency point of view, Equation (5.37) corresponds to:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{f_n}{f_{n+1}} \tag{5.40}$$

Taking the logarithm of both sides, we have

$$\log f_{n+1} = \log f_n - \log \tau \tag{5.41}$$

...y, the larger the scaling factor and spacing factor, but the smaller the apex angle.

Another important aspect of the design is the antenna input impedance, which can be tuned by changing the diameter d of the element and the feeding gap $g$between the two poles.

$$g = d\cosh(Z_0/120) \tag{5.42}$$

where Z_0 is the characteristic impedance of the feed line to be connected (the desired impedance). More details can be found in [2, 18].

In practice, the most likely scenario is that the frequency range is given from f_{min} to f_{max}; the following equations may be employed for design:

$$L_1 \geq \frac{\lambda_{max}}{2} = \frac{c}{f_{min}};\ L_N \leq \frac{\lambda_{min}}{2} = \frac{c}{f_{max}} \tag{5.43}$$

and

$$\frac{f_{min}}{f_{max}} = \frac{L_N}{L_1} = \tau\frac{L_{N-1}}{L_1} = \tau^{N-1} \tag{5.44}$$

Another parameter (such as the directivity or the length of the antenna) is required to produce an optimized design.

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

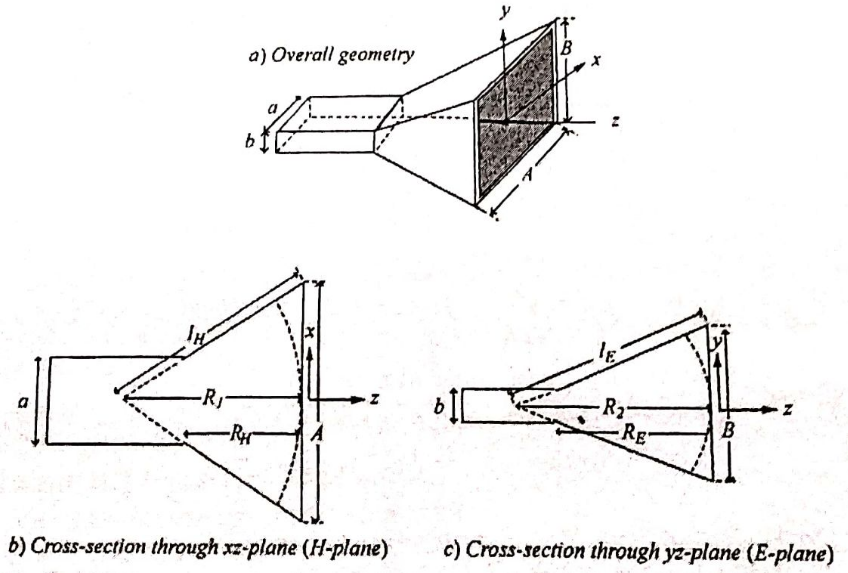

Figure 5.28 Pyramidal horn antennas with dimensional parameters: (a) Overall geometry (b) Cross-section through *xz*-plane (H-plane) (c) Cross-section through *yz*-plane (E-plane)

In the H-plane, the dimensions are linked by

$$l_H^2 = R_1^2 + (A/2)^2$$
$$R_H = (A - a)\sqrt{(l_H/A)^2 - 0.25} \tag{5.60}$$

and the maximum phase difference in the H-plane is

$$l_H - R_1 \approx \frac{1}{2R_1}\left(\frac{A}{2}\right)^2 = t\lambda \tag{5.61}$$

where t is the maximum phase deviation over the wavelength in the H-plane, i.e. $t = (l_H - R_1)/\lambda$. The larger the value of t, the broader the beamwidth. It has been found that $t = 3/8 = 0.375$ (but 0.25 for the E-plane) gives the optimum design [2, 3, 12, 20], which means

$$A = \sqrt{3\lambda R_1} \tag{5.62}$$

In the E-plane, the dimensions are linked by

$$l_E^2 = R_2^2 + (B/2)^2$$
$$R_E = (B - b)\sqrt{(l_E/B)^2 - 0.25} \tag{5.63}$$

and the maximum phase difference in the E-plane is

$$l_E - R_2 \approx \frac{1}{2R_2}\left(\frac{B}{2}\right)^2 = s\lambda \tag{5.64}$$

where s is the maximum phase deviation in the E-plane; the larger the value of s, the broader the beamwidth. It has been found that $s = 1/4 = 0.25$ gives the optimum design, which means

$$B = \sqrt{2\lambda R_2} \tag{5.65}$$

When both the E- and H-planes are put together to form the pyramidal horn, the following condition has to be satisfied in order to make it physically realizable and properly connected to the feed waveguide:

$$R_E = R_H \tag{5.66}$$

The directivity is related to the aperture efficiency factor η_{ap} and aperture size AB by Equation (4.22), that is

$$D = \frac{4\pi}{\lambda^2}(\eta_{ap} AB) \tag{5.67}$$

For the optimum gain horn, $\eta_{ap} \approx 0.51 = 51\%$.