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# Antenna Design for Synthetic Aperture Radar Working on ISM Band

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**Abstract**

This paper describes some of the very fundamental characteristics and methods of antenna design for SAR systems operating in ISM band. The paper first explains the basic principles of antennas and their characteristics. Afterwards based on the required specifications, calculations have been done in order to determine the fabrication parameters.To amplify the radiation pattern of the antenna, a metal wall is placed at $\lambda/4$ distance behind the monopole wire. At ISM band this antenna has a gain of 10.01dB and has a circular waveguide with a length of 18.5cm and radius of 12.6cm. The parameters of the antenna thus obtained will later be used to fabricate two similar antennas for an SAR system working on ISM band.

**Keywords:** Gain, Radiation pattern, Power density, Antenna arrays, Waveguide, Microwave signal, SAR.

## 1. Introduction

Antenna is either a single or combination of multiple transducers which converts voltage signals to the electromagnetic waves and either transmits or receives it. A radar transmitter induces a time varying microwave signal that travels along a coaxial cable to the transmitting antenna. Time varying signal applied to the transmitting antenna induces an electric current on the antenna which produces electromagnetic radiation.

Electromagnetic waves travel at speed of light and they tend to reflect off an object. The reflected energy illuminates the receiving antenna and induces an electric current on antenna which induces a signal in the coaxial cable connected with the antenna. This cable guides the signal to the radar receiver and then this signal is post processed to obtain desired results. Following diagrams shows this phenomenon.

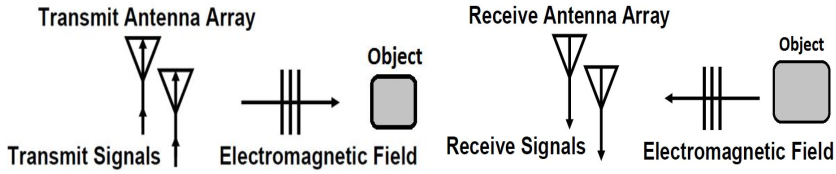


**Figure 1**: Transmission and Reception process.

Gain of a directional antenna is calculated or measured with respect to the isotropic antenna having same parameters. Power density decreases as range increases. Directional antenna produces a gain radiation pattern which depends on aspect angle. For a directional antenna peak gain and peak power density is higher when compared to an isotropic antenna. A directional antenna has main beam pointed in a particular direction and has side lobes away from the main beam. As the antenna diameter increases the main beam gain increases and beamwidth becomes narrower.

A phased array can also be used to form a directional radiation pattern.Isotropic array elements have an element radiation pattern that is independent of observation angles in spherical coordinates as $P_e(\theta, \varphi) = 1$

Radiation pattern for an 'n' element linear array of isotropic element is as follows;

$$\text{Array factor } AF(\theta, \emptyset) = \sum_{n=1}^{N} i_n \, e^{j\varphi n}$$

$$i_n = A_n e^{j\varphi n}$$

$$AF(\theta, \emptyset) = \sum_{n=1}^{N} A_n \, e^{j(\varphi_n + \varphi_{ns})}$$

$$\varphi_n = \beta \sin\theta \, (x_n \cos\emptyset + y_n \sin\emptyset)$$

$$\varphi_n = -\beta sin\ \theta_s (x_n \cos\emptyset_s + y_n \sin\emptyset_s)$$

$$\text{Where } \beta = \frac{2\pi}{\lambda}$$

$$AF(\theta, \emptyset) = \sum_{n=1}^{N} A_n \, e^{j\beta x_n(\sin\theta - \sin\theta_s)}$$

### 1.1 Antenna Array Elements

Most antenna array elements have an element radiation pattern that favors broadside scan and depends on observation angle that is $P_e(\theta, \varphi)$ has a peak at broadside and a taper over the scan sector.

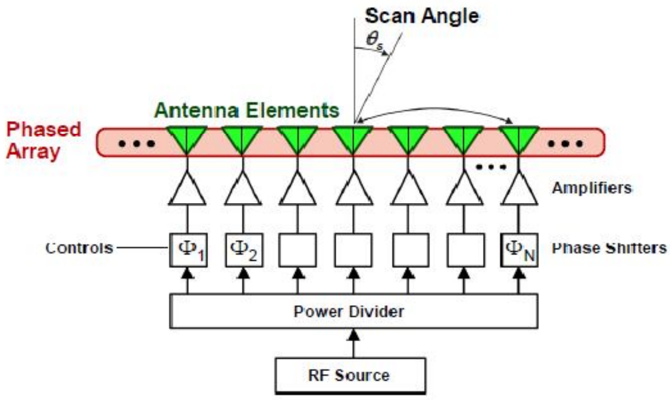


**Figure 2**: Phased array consisting N array elements.

$$AF(\theta,\emptyset) = \sum_{n=1}^{N} A_n\, e^{j(\varphi_n+\varphi_{ns})}$$

Array pattern $P(\theta,\varphi) = P_e(\theta,\varphi)$

Radiation Intensity $U(\theta,\varphi) = P(\theta,\varphi)^2$

Directivity $D(\theta,\varphi) = \frac{U(\theta,\varphi)}{U_{AVE}}$

### 1.2 Geometry for Plane Wave and Spherical Wave for a Linear Array

Linear array can be implemented by using a physical array aperture or a synthetic array aperture implies a single element moved over an aperture. Array can be focused either in the far field or near field region depending upon the application.

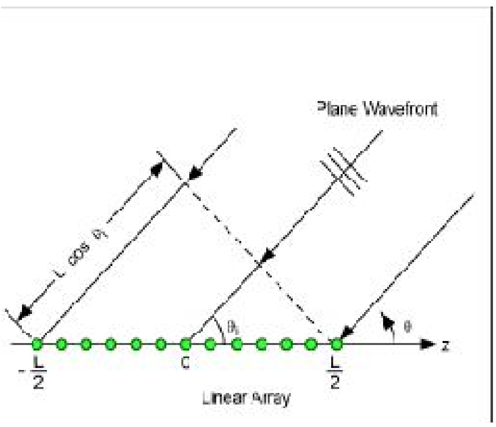


**Figure 3**: Near Field (Spherical Waves)

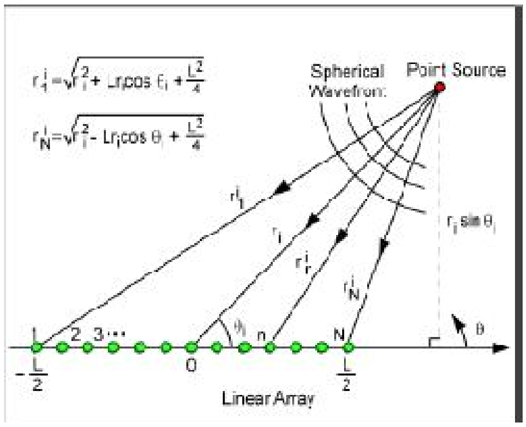


**Figure 4**: Far Field (Plane Wave)

## 2. Antenna Aperture Gain and Beamwidth

Gain of antenna aperture of any arbitrary shape

$$G = \frac{4\pi A_e}{\lambda^2}$$

Where $A_e$ is effective aperture area.

An antenna with circular aperture having diameter D has peak gain (in dB)

$$G_{m,dBi} = 10\ \log_{10}\left(\frac{\pi D}{\lambda^2}\right)$$

Antenna half power beamwidth $\mathrm{HPBW} = 58^0\frac{\lambda}{D}$

Effective isotropic radiated power of antenna$\mathrm{EIRP}(\theta,\varphi) = P_t G_t(\theta,\varphi)$

Radiated power density $P_d$ at 'r' distance from transmitter aperture is given by:

$$P_d(\theta,\varphi) = {}^{\mathrm{EIRP}}/_{4\pi r^2}$$

Power received $P_r = P_{di} A_e$

Where $P_{di}$ is incident power density.

Relative power coupled between two antennas can be expressed as$P_r(\theta,\varphi)/P_t = \frac{G_t(\theta,\varphi)G_r(\theta,\varphi)\lambda^2}{(4\pi r)^2}$

If relative power coupled between two identical antennas $(G_t = G_r = G)$ is measured then antenna gain can be easily calculated.

## 3. Calculation

Assuming operating frequency to be 2.4 GHz we get wavelength $\lambda = 0.125m$.

As received power $P_r(\theta,\varphi)/P_t = \frac{G_t(\theta,\varphi)G_r(\theta,\varphi)\lambda^2}{(4\pi r)^2}$ and both transmitting and receiving antennas are same hence

$$P_r(\theta,\varphi)/P_t = \frac{G^2\lambda^2}{(4\pi r)^2}$$

Or

$$G^2 = P_r(\theta,\varphi)/P_t \times ((4\pi r)^2/\lambda^2)$$

$$G_{dB} = \frac{1}{2}(10\log_{10}(P_r(\theta,\varphi)/P_t) + 20\log_{10}(4\pi r/\lambda))$$

Taking power coupling $P_r(\theta,\varphi)/P_t$ to be -12dB

$$G_{dB} = \frac{1}{2}(-12 + 22 + 18.1) = 14.05d$$

At$G_{dB} = 14.05dB$, and $\lambda = 0.125m$ the diameter of circular waveguide$D = 0.1263m = 12.6cm$.

Monopole wire length $L = \lambda/4$ where $\lambda = 0.125$ which gives $L = 0.03125\ m$ or 3.125cm.

$$G_{m,dBi} = 10\ \log_{10}\left(\frac{\pi D}{\lambda^2}\right)$$

Peak gain $G_{m,dBi} = 10.01dB$.

### 3.1 Guide Wavelength and cutoff Frequency

Cutoff frequency for TE11 mode waveguide can be calculated as following:

$\lambda_C = {}^{C}/_{f_C}$ And$\lambda_C = 1.705D$ Where 'D' is the diameter of waveguide =$12.6cm$.

Hence $\lambda_C = 1.705 \times 0.126 = 0.21483$.

Thus Cutoff Frequency of the waveguide $f_C = C/0.21483 = 13.396{\sim}1.4Ghz$.

Guide wavelength is calculated as $\lambda_g = \lambda / \sqrt[2]{1 - \lambda/(1.705D)^2}$

Substituting $\lambda = 0.125\, m$ we get $\lambda_g = 0.185\, m$.

From above result we can conclude that wavelength in the waveguide is actually greater than the wavelength in free space.

### 3.2 Microwave Phase Shift using a Metal Wall

Electromagnetic field has 1/r value field attenuation and a phase shift as it travels a distance r. As electric field $E = e^{-j\beta r}/r$ where $\beta = 2\pi/\lambda$ is phase constant, it can be said that if an electromagnetic wave travels one quarter of a wavelength the phase shifts by $^{\pi}/_{2}$ radians. To enhance the radiation of an antenna; a metal wall can be placed at a distance of $\lambda/4$. It will produce a total phase shift of $360^0$ (the reflected wave from metal wall adds up to the direct wave).

## 4. Results

From above calculations following conclusion can be derived:

1. The waveguide length of the antenna operating at ISM band is equal to or greater than 12.5cm preferably 18.5cm.
2. The length of the monopole wire is equal to 3.125cm to produce the ISM frequency electromagnetic waves.
3. To increase the radiation, the metal wall can be placed at $\lambda/4$ distance from the monopole wire.
4. The diameter of the waveguide is equal to 12.6 cm.
5. Antenna has a HPBW of $72.5^o$.
6. Peak gain of the antenna is 10.0dB.

Using these parameters a circular waveguide antenna can be fabricated suitable for a small SAR system.

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