Reflection and Transmission of Electromagnetic Waves in a Non-Stationary Medium

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Abstract

This paper surveys reflection and transmission of the electromagnetic waves in a non-stationary dielectric medium, moving with a uniform velocity '*v*' (i.e., independent of time and position). Initially, the problem was considered for both the cases when the medium was moving parallel and perpendicular to the interface, respectively. The focal point of the paper is to examine the behavior of electromagnetic wave propagation, which is normally incident to a dielectric interface that is moving with constant velocity *v* perpendicularly to the interface, and study the changes in various physical properties like the reflection and transmission coefficients, angles and frequencies compared to stationary medium. Moving Target Indicator (MTI) radars is one of the applications that will be discussed in order to relate the above.

Introduction

The reflection and transmission of electromagnetic waves from a non-stationary dielectric medium has been a fundamental problem of interest for several years. Numerous authors have investigated this problem as early as in 1958. Pauli and Sommerfeld discussed the frequency shift of the reflected wave by a moving mirror in detail [1], [2]. Later in 1965 the first solutions for the problem of reflection and transmission of plane waves by a dielectric half-space in vacuum moving parallel and perpendicular to the interface was solved [3], [4]. The work by Huang [5] discussed the problem of reflection and transmission of electromagnetic waves when the dielectric is moving in any arbitrary direction. The solution for this problem has applications in the fields of optics, radio sciences, and astrophysics. It is also of considerable practical interest in many monitoring and control applications, such as radio communication with moving spaceships; identifying echoes from moving targets from stationary targets; Moving Target Indicator radar system; plasma diagnostics; power amplification; and laser Doppler anemometry for fluid flow studies.

Theory

Plane waves can be defined as electromagnetic waves in free space which means that the electric and magnetic fields are confined to a plane and are uniform within the plane at all time. Electromagnetic waves travel at the speed of light $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3X10^8 m/s$. EM waves can be generated in different frequency bands like radio, microwave, infrared, visible, ultraviolet, x-rays, and gamma rays.

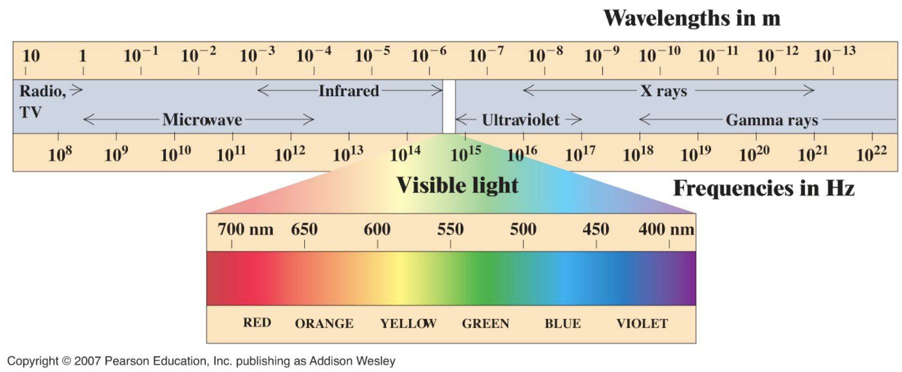

Figure 1: Electromagnetic Spectrum [6]

Figure1 shows the Electromagnetic spectrum where the visible portion of the spectrum is relatively narrow. The boundaries between various bands of the spectrum are not sharp, but instead are somewhat arbitrary. (1 nm = 10^{-9}m). When a light ray travels from one medium to another, part of the incident light is reflected and part of the light is transmitted at the boundary between the two media. The transmitted part is said to be refracted in the second medium. Polarization plays an import role in the wave propagation. The polarization of a uniform plane wave describes the shape and locus of the tip of the electric field vector *E* at a given point in space as a function of time. A wave is linearly polarized if Ex (z, t) and Ey (z, t) are in phase (d=0) or out of phase (d=p). For circular polarization, the magnitudes of the x- and y-components of E(z) are equal and the phase difference is d = ±p / 2 . From the point of view of the target looking at the transmitter, left-hand circular polarization has a phase difference of d=p/2 and right-hand circular polarization has a phase difference of d=-p/2.

Figure 2 shows the three wave polarizations Linear, Circular, Elliptical. If the vector that describes the electric field at a point in space as a function of time that is always directed along a line, which is normal for the direction of propagation, the field is said to be linearly polarized. In general, however, the figure that electrical field traces in an ellipse, and the field is said to be elliptically polarized. Linear and circular polarizations are special cases of elliptical, and they can be obtained when the ellipse becomes a straight line or a circle, respectively. The figure of the electric field is traced in a clockwise (CW) or counterclockwise (CCW) sense. Clockwise rotation of the electric field vector is also designated as right-hand polarization and counterclockwise as left-hand polarization.

In real world problems, the fields encounter boundaries, scatterers, and other objects. As a result, the fields must be found by taking into account these discontinuities. In general the reflection and transmission coefficients are complex quantities and their amplitudes and phases can be varied by controlling the direction of the wave travel (angle of incidence). In the face of one of the wave polarizations (parallel polarization), the reflection coefficient can be made equal to zero. The angle of incidence when this occurs is known as the *Brewster angle*. This principle is used in the design of many instruments (such as binoculars, etc).

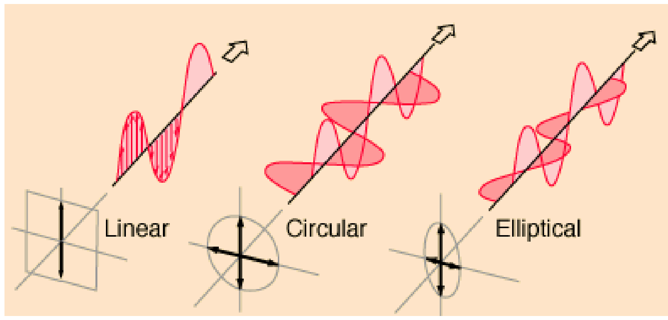

Figure 2: Variations of Electromagnetic Wave Polarizations [7]

The magnitude of the reflection coefficient can also be made to unity by selecting the wave incidence angle. This angle is known as the *critical angle*, and it is independent of wave polarization; however, in order for this angle to occur, the incident wave must exist in the denser medium. The critical angle concept plays an important role in the design of transmission lines (such as optical fiber, slab waveguides, and coated conductors; the micro strip is one example).

Reflection and Transmission Coeffecients for Stationery Medium Normal Incidence (*Lossless Medium*)

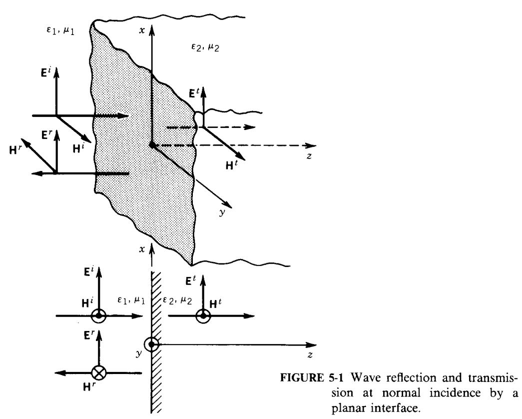

Figure 3: Wave Reflection and Transmission at Normal Incidence by a Planar Interface [8]

As shown in Figure 3 we assume the wave is travelling perpendicular (normal incidence) to the planar interface formed by the two semi-infinite lossless media as shown in the figure.

When the incident wave encounters the interface, a fraction of the wave intensity is reflected into medium 1 and part will be transmitted into medium 2.

Assuming the electric field is polarized in the x- direction, we can write expressions for its incident, reflected and transmitted electric field components, respectively as

$$E^i = \hat{a}_x E_0 e^{-j\beta_1 z} \quad \text{.... (1)}$$
$$E^r = \hat{a}_x \Gamma^b E_0 e^{+j\beta_1 z} \quad \text{.... (2)}$$
$$E^t = \hat{a}_x T^b E_0 e^{-j\beta_2 z} \quad \text{.... (3)}$$

where E^i is the incident electric field, E^r is the reflected electric field, E^t is the transmitted electric field and E_0 is the incident electric field amplitude.

The terms $\Gamma^b and\ T^b$ are used here to represent, respectively, the reflection and transmission coeffecients at the interface that are unknown and will be determined by applying the boundary conditions on the fields along the interface. Since the incident fields are linearly polarized and the reflecting surface is planar, the reflected and transmitted fields will also be linearly polarized. Using the right hand rule the magnetic field components can be written as

$$H^i = \hat{a}_y \frac{E_0}{\eta_1} e^{-j\beta_1 z} \quad \text{.... (4)}$$
$$H^r = -\hat{a}_y \frac{\Gamma^b E_0}{\eta_1} e^{+j\beta_1 z} \quad \text{.... (5)}$$
$$H^r = \hat{a}_y \frac{T^b E_0}{\eta_2} e^{-j\beta_2 z} \quad \text{.... (6)}$$

where H^i is the incident magnetic field, H^r is the reflected magnetic field, H^t is the transmitted magnetic field and η_1, η_2 are the wave impedances in medium 1 and medium 2 respectively.

The reflection and transmission coefficients will now be determined by enforcing continuity of the tangential components of the electric and magnetic fields across the interface. The plane wave reflection and transmission coefficients of a planar interface for normal incidence are given by

$$\Gamma^b = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} = \frac{E^t}{E^i} = -\frac{H^r}{H^t} \quad \text{... (7)}$$
$$\mathrm{T}^b = \frac{2\eta_2}{\eta_2 + \eta_1} = 1 + \Gamma^b = \frac{E^t}{E^i} = -\frac{\eta_2}{\eta_1}\frac{H^r}{H^t} \quad \text{... (8)}$$

The corresponding average power densities can be written as

$$S^i_{av} = \frac{1}{2} Re\left(E^i X H^{i^*}\right) = \hat{a}_z \frac{|E_0|^2}{2\eta_1} \quad \text{... (9)}$$

$$S_{av}^{r} = \frac{1}{2}Re\left(E^{r}XH^{r^{*}}\right) = -\hat{a}_{z}\left|\Gamma^{b}\right|^{2}\frac{|E_0|^2}{2\eta_1} == -\hat{a}_{z}\left|\Gamma^{b}\right|^{2}S_{av}^{i} \qquad \dots (10)$$

$$S_{av}^{t} = \frac{1}{2}Re\left(E^{t}XH^{t^{*}}\right) = -\hat{a}_{z}|T^{b}|^{2}\frac{|E_0|^2}{2\eta_2} = -\hat{a}_{z}|\mathrm{T}^{b}|^{2}\frac{\eta_2}{\eta_1}\frac{|E_0|^2}{2\eta_1} = -\hat{a}_{z}|\mathrm{T}^{b}|^{2}\frac{\eta_2}{\eta_1}S_{av}^{i}$$

$$= -\hat{a}_{z}\left(1 - \left|\Gamma^{b}\right|^{2}\right)S_{av}^{i} \qquad \dots.(11)$$

where $S_{av}^{i}$is the incident average power, $S_{av}^{r}$is the average reflected power and $S_{av}^{t}$is the average transmitted power densities. It is apparent that the ratio of reflected to the incident power densities is equal to the square of the magnitude of the reflection coefficient. The reflection and transmission coefficients from equations relate the reflected and transmitted field intensities to the incident field intensity. Since the total tangential components of these field intensities on either side must be continuous across the boundary, it is expected that the transmitted field can be greater than unity.

Normal Incidence (*Lossy Medium)*

When a uniform plane wave is normally incident upon a planar interface formed by two lossy media, the incident, reflected, and transmitted fields; reflection and transmission coeffecients, and average power densites are indentical to the normal incidence for a lossless media except that a) attentuation constant must be included in each field and b) the intrinsic impedences and attentutaion and phases constants must be modified to include the conductivites of the media.

$$E^{i} = \hat{a}_{x}E_{0}e^{-\alpha_1 z}e^{-j\beta_1 z} \qquad \dots (12)$$

$$E^{r} = \hat{a}_{x}\Gamma^{b}E_{0}e^{-\alpha_1 z}e^{+j\beta_1 z} \qquad \dots (13)$$

$$E^{t} = \hat{a}_{x}T^{b}E_{0}e^{-\alpha_2 z}e^{-j\beta_2 z} \qquad \dots (14)$$

$$H^{i} = \hat{a}_{y}\frac{E_0}{\eta_1}e^{-\alpha_1 z}e^{-j\beta_1 z} \qquad \dots (15)$$

$$H^{r} = -\hat{a}_{y}\frac{\Gamma^{b}E_0}{\eta_1}e^{+\alpha_1 z}e^{+j\beta_1 z} \qquad \dots (16)$$

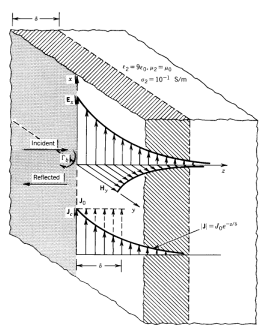

FIGURE 5-9 Electric and magnetic field intensities, and electric current density distributions in a lossy earth.

Figure 4: Electric and Magnetic Field Intensities and Electric Current Density Distribution in a Lossy Earth [8]

$$H^t = \hat{a}_y \frac{T^b E_0}{\eta_2} e^{-\alpha_2 z} e^{-j\beta_2 z} \quad \ldots (17)$$

$$\Gamma^b = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \; ; \; \mathrm{T}^b = \frac{2\eta_2}{\eta_2 + \eta_1} \quad \ldots (18)$$

$$S_{av}^i = \hat{a}_z \frac{|E_0|^2}{2\eta_1} e^{-2\alpha_1 z} Re\left(\frac{1}{\eta_1^*}\right) \quad \ldots (19)$$

$$S_{av}^r = -\hat{a}_z \left|\Gamma^b\right|^2 \frac{|E_0|^2}{2\eta_1} e^{+2\alpha_1 z} Re\left(\frac{1}{\eta_1^*}\right) \quad \ldots (20)$$

$$S_{av}^t = -\hat{a}_z |T^b|^2 \frac{|E_0|^2}{2\eta_2} e^{-2\alpha_1 z} Re\left(\frac{1}{\eta_1^*}\right) \quad \ldots (21)$$

The total electric and the magnetic fields in medium 1 can be written as

$$E^1 = E^i + E^r = \hat{a}_x E_0 e^{-\alpha_1 z} e^{-j\beta_1 z} \left(1 + \Gamma^b e^{+2\alpha_1 z} e^{+j2\beta_2 z}\right) \quad \ldots (22)$$

$$H^1 = H^i + H^r = \hat{a}_y \frac{E_0}{\eta_1} e^{-\alpha_1 z} e^{-j\beta_1 z} \left(1 - \Gamma^b e^{+2\alpha_1 z} e^{+j2\beta_2 z}\right) \quad \ldots (23)$$

Reflection and Transmission by a Medium Moving Perpendicular to the Interface (*Normal Incidence*)

Reflection and transmission by moving boundaries, such as reflection from a moving mirror, introduce Doppler shifts in the frequencies of the reflected and transmitted waves [7]. Here, we look at the problem of normal incidence on a dielectric interface that is moving with constant velocity *v* perpendicularly to the interface; that is, along the z-direction as shown in Figure 5 below.

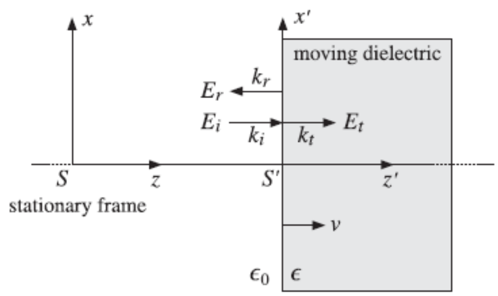

Figure 5: Reflection and Transmission at the Moving Boundary [9]

The dielectric is assumed to be non-magnetic and lossless with permittivity. The left medium is free space ϵ_0. The electric field is assumed to be in the x-direction and thus, the magnetic field will be in the y-direction. We consider two coordinate frames: the fixed frame S with coordinates {t, x, y, z}, and the moving frame S' with {t_, x_, y_, z_}. We are interested in determining the Doppler-shifted frequencies of the reflected and transmitted waves, as well as the reflection and transmission coefficients as measured in the fixed frame S.

The procedure for solving this type of problem—originally suggested by Einstein in his 1905 special relativity paper—is to solve the reflection and transmission problem in the moving frame $S^{'}$ with respect to which the boundary is at rest, and then transform the results back to the fixed frame S using the Lorentz transformation properties of the fields. In the fixed frame S, the fields to the left and right of the interface will have the forms:

Left side:

$$E_x = E_i e^{j(\omega t - k_r z)} + E_r e^{j(\omega_r t - k_r z)}$$
$$H_y = H_i e^{j(\omega t - k_r z)} - H_r e^{j(\omega_r t - k_r z)}$$

Right side:

$$E_x = E_i e^{j(\omega t - k_r z)}$$
$$H_y = H_i e^{j(\omega t - k_r z)}$$

where ω, ω_r, ω_t and $k_i k_r$, k_t are the frequencies and wave numbers of the incident, reflected, and transmitted waves measured in S. In the frame $S^{'}$ where the dielectric is at rest, all three frequencies are the same and set equal to $\omega^{'}$. This is a consequence of the usual tangential boundary conditions applied to the interface at rest. Note that ϕ_r can be written as $\phi_r = \omega_r$t – $(-k_r)$z implying that the reflected wave is propagating in the negative z-direction. In the rest-frame $S^{'}$ of the boundary, the wave numbers are

$$k_i^{'} = \frac{\omega^{'}}{c},\ k_r^{'} = \frac{\omega^{'}}{c}, k_t^{'} = \sqrt{\epsilon\mu_0} = n\frac{\omega^{'}}{c}.$$

where *c* is the speed of light in vacuum and $n = \sqrt{\epsilon/\epsilon_0}$ is the refractive index of the dielectric at rest. The phase velocities of the incident, reflected, and transmitted waves are

$$v_i = \frac{\omega}{k_i} = c, v_r = \frac{\omega_r}{k_r} = c, v_t = \frac{\omega_t}{k_t} = c\ \frac{1+\beta_n}{n+\beta}.$$

In the rest-frame $S^{'}$ of the dielectric, the fields have the forms

$$E_x^{'} = E_i^{'}\left(e^{j\phi_t^{'}} + \rho e^{j\phi_r^{'}}\right) \quad \dots (24)$$

$$H_y^{'} = \frac{1}{\eta_0}E_i^{'}\left(e^{j\phi_t^{'}} + \rho e^{j\phi_r^{'}}\right) \quad \dots (25)$$

$$E_x^{'} = \tau E_i^{'} e^{j\phi_r^{'}} \quad \dots (26)$$

$$H_y^{'} = \frac{1}{\rho}\tau E_i^{'} e^{j\phi_r^{'}} \quad \dots (27)$$

where $\eta = \frac{\eta_0}{n}, \rho = \frac{\eta - \eta_0}{\eta + \eta_0} = \frac{1-n}{1+n}, \tau = 1 + \rho = \frac{2}{1+n}.$

The corresponding reflection and transmission in the fixed frame *S* are

$$\frac{E_r}{E_i} = \rho\ \frac{1-\beta}{1+\beta}, \qquad \frac{E_t}{E_i} = \tau\ \frac{1+\beta_n}{1+\beta} \quad \dots (28)$$

Application

One of the major applications of EM waves in Radar systems is... The word radar is derived from an acronym for radio detection and ranging. Radar is an electronic and electromagnetic system that uses radio waves to detect and locate objects [10]. Radar operates by transmitting a particular kind of radio frequency waveform and detecting the nature of the reflected echo. When radio waves strike an object, some portion is reflected, and some of this reflected energy is returned to the radar set, where it is detected. The location and other information about these reflective objects, targets, can be determined by the reflected energy. Radio waves have many properties including speed, frequency, and power; they display many phenomena such as refraction, attenuation, and reflection. The known speed and reradiation properties of radio waves are fundamental to the theory of radar operation, since radar systems are, at their core, transmitters and receivers of radio waves.

Radio waves occupy a portion of the electromagnetic spectrum from frequencies of a few kilohertz to a few gigahertzes, less than one-billionth of the total electromagnetic spectrum.

In a vacuum, radio waves travel in straight lines. The speed of radio wave propagation in vacuum ($3\text{x}10^8$ m/s) is a universal constant, *c*. The speed of wave propagation differs from *c* if the medium of propagation is matter. When electromagnetic waves travel in non-conducting materials, such as air, the wave speed *v*, is slower than *c* and is given by

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \qquad \ldots (29)$$

where ε and μ are the permittivity and permeability of the material, respectively. A measure derived from this wave speed change is the index of refraction, *n*, given by

$$n = \frac{c}{v_{material}} \qquad \ldots (30)$$

A typical value of the index of refraction for air near the surface of the earth is 1.0003. A phenomenon called refraction occurs when radar waves pass through media with different indices of refraction. When a ray, the path of propagation of an electromagnetic wave, passes from a material having a smaller index of refraction to a material having a larger index of refraction, the ray is bent upwards. If the ray goes from a material having a larger index of refraction to a material with a smaller index of refraction, the ray is bent downwards. The index of refraction of the atmosphere is not constant and depends on temperature, air pressure, and humidity.

Since the velocity of propagation is inversely proportional to the index of refraction, radio waves move slightly more rapidly in the upper atmosphere than they do near the surface of the earth. From trigonometry, one can determine the radar horizon range, the maximum distance that radar can detect targets. The range is given by

$$r = \sqrt{2h_a k r_e} + \sqrt{2h_t k r_e} \qquad \ldots (31)$$

where kr_e is the effective radius and h_a and h_t are the heights of the transmitter and target respectively. Anomalous propagation, or ducting of electromagnetic waves occurs when the effective radius kr_e is greater than 2. This occurs when the gradient of the index of refraction of the atmosphere, *dn/dh*, is very large. Electromagnetic waves are traveling waves that transport energy from one region to another. The energy transfer can be described in terms of power transferred per unit area, for an area perpendicular to the direction of wave travel. In a vacuum, the energy flow per unit time per unit area, S, is given by

$$S = \frac{EB}{\mu_0} \qquad \ldots (32)$$

where E and B are the electric and magnetic field magnitudes respectively, and μo is the permeability of free space. This can also be defined as the Poynting vector,

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B} \qquad \ldots (33)$$

The total power out of any closed surface is then

$$P = \oint \vec{S} \, . \, d\vec{A} \qquad \ldots (34)$$

The atmosphere can cause power to attenuate, depending on range and frequency. Attenuation peaks at certain frequencies due to absorption by atmospheric gases, such as water vapor at 22.24 GHz and oxygen at 60 GHz. Heavy rainfall also attenuates radar waves increasingly at higher frequencies.

Doppler Effect and Moving Target Indication (MTI) Filtering

There are two types of basic radar: pulse transmission and continuous wave. The former transmits a series of pulses separated by non-transmission intervals, during which the radar “listens” for a return, and the latter is constantly emitting radar. Relative motion of either the radar or the target is required to indicate target position or frequency shift. The frequency and wavelength of electromagnetic waves are affected by relative motion. This is known as the Doppler effect. Only the radial (approaching or receding) component of motion produces this phenomenon. If the source of an electromagnetic wave is approaching an observer, the frequency increases and the wavelength decreases. If the source is receding, the frequency decreases and the wavelength increase. An object's motion causes a wavelength shift $\Delta\lambda$, that depends on the speed and direction the object is moving. The amount of the shift depends on the source's speed, and is given by

$$\Delta\lambda = \frac{\lambda_{rest} v_{radial}}{c} \qquad \ldots (35)$$

where c is the speed of light (or wave propagation speed if in material), λ_{rest} is the wavelength that would be measured if the source was at rest and v_{radial} is the speed of the source moving along the line of sight. The v_{radial} term only refers only to the component of velocity along the line of sight. If the target moves at an angle with respect to the line of sight, then the Doppler shift ($\Delta\lambda$) only informs about the part of motion along the line of sight.

Radars use the Doppler effect to determine a target's velocity. Many radars use Doppler information only for determining target motion direction, whereas others determine speed of motion more precisely. Radars transmit radio waves of a set wavelength (or frequency), which then reflect off the target. In this case, the target acts as a source, and its speed can be determined from the difference in the wavelength (or frequency) of the transmitted beam and reflected beam. Unwanted radio wave reflections in radar systems are called clutter. Since clutter is unwanted, radars try to eliminate it using signal and data processing techniques.

Using the Doppler effect's result that stationary objects will not have frequency shifts, the transmitted waveform frequency is filtered out of the received signal. As a result of this frequency domain filtering, only moving targets will remain. This process is called moving target indication filtering or MTI [11].

The purpose of MTI radar is to reject returns from fixed or slow-moving unwanted targets, such as buildings, hills, trees, sea, and rain, and retain for detection or display signals from moving targets such as aircraft. MTI radar utilizes the Doppler shift imparted on the reflected signal by a moving target to distinguish moving targets from fixed targets. A Doppler shift allows distinguishing between the target and the transmitter leakage. The amount of Doppler shift is determined by the radial velocity of the target since the radial velocity is the apparent speed that the target is closing on or going away from the radar. A target can move in any direction and in a wide range of speed; therefore, the radial velocity can change considerably.

Radar Range Equation

The radar range equation relates the range of a radar system to the characteristics of its transmitter, receiver, antenna, target, and environment. In the simple form of the equation, propagation effects discussed earlier are ignored. If the power of the radar transmitter, Pt, is transmitted through an isotropic antenna, which radiates uniformly in all directions, the power density at a distance R from the radar will be

$$\text{power density} = \frac{P_t}{4\pi R^2} \quad \dots (36)$$

Radars generally use directional antennas, which channel the transmitter power in a particular direction. The gain, G, of an antenna is the increased power in the direction of the target as compared to an isotropic antenna. When a directional antenna is used, the power density at distance R from the radar becomes

$$\text{density power of signal transmitted at target} = \frac{P_t G}{4\pi R^2} \quad \dots (37)$$

Radar cross section (RCS), Ao, is a measure of the electromagnetic energy intercepted and reradiated at the same frequency by an object. To determine the RCS of an object, the reradiation properties are compared to an idealized object that is large, is perfectly conducting, and reradiates isotropically. An example of this is a large copper sphere, whose RCS is given by

$$\text{RCS of copper sphere} = \pi r^2 \quad \text{… (38)}$$

where r is the radius of the sphere. When the transmitted pulse reaches the target, it is reradiated in all directions, so the power density of the echo signal at the radar is to

$$power\ density\ of\ echo\ at\ radar = \frac{P_t G A_0}{4\pi R^2 4\pi R^2} \quad \text{… (39)}$$

The radar antenna only captures a portion of the echo power. If the effective area of the radar antenna is denoted A_e, the power received by the radar, Pr, is

$$P_r = \frac{P_t G A_0 A_e}{4\pi R^2 4\pi R^2} = \frac{P_t G A_0 A_e}{(4\pi)^2 R^4} \quad \text{… (40)}$$

The maximum radar range R_{max} beyond which the radar cannot detect targets occurs when the received echo signal is the minimum detectable signal, P_{min}. Hence,

$$R_{max} = \sqrt[4]{\frac{P_t G A_0 A_e}{(4\pi)^2 S_{min}}} \quad \text{… (41)}$$

Conclusion

In concluding this paper, we summarized the operation of radar systems and the how the electromagnetic waves are used to transmit and receive the desired information from various targets. We also observe how the Doppler effect plays a vital role in practical radar systems determining the target velocity in Moving Target Indicator (MTI) radar systems. It is also shown that the Earth's atmosphere also plays a central role in radar operation, as it is the medium of propagation for the radio waveforms. The only focus of this paper was understanding how the electromagnetic waves travel when the medium is moving with a velocity perpendicular to the interface and compare the physical properties like the reflection and transmission coefficients, angles, and frequencies of both the moving and the stationary mediums.

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