Radar Systems - Doppler Effect

In this chapter, we will learn about the Doppler Effect in Radar Systems.

If the target is not stationary, then there will be a change in the frequency of the signal that is transmitted from the Radar and that is received by the Radar. This effect is known as the **Doppler effect**.

According to the Doppler effect, we will get the following two possible cases −

- The **frequency** of the received signal will **increase**, when the target moves towards the direction of the Radar.
- The **frequency** of the received signal will **decrease**, when the target moves away from the Radar.

Now, let us derive the formula for Doppler frequency.

Derivation of Doppler Frequency

The distance between Radar and target is nothing but the **Range** of the target or simply range, R. Therefore, the total distance between the Radar and target in a two-way communication path will be 2R, since Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar.

If λ is one wave length, then the number of wave lengths N that are present in a two-way communication path between the Radar and target will be equal to $2R/\lambda$.

We know that one wave length λ corresponds to an angular excursion of 2π radians. So, the **total angle of excursion** made by the electromagnetic wave during the two-way communication path between the Radar and target will be equal to $4\pi R/\lambda$ radians.

Following is the mathematical formula for **angular frequency**, ω −

$$\omega = 2\pi f \qquad Equation\ 1$$

Following equation shows the mathematical relationship between the angular frequency ω and phase angle ϕ −

$$\omega = \frac{d\phi}{dt} \qquad Equation\ 2$$

Equate the right hand side terms of Equation 1 and Equation 2 since the left hand side terms of those two equations are same.

$$2\pi f = \frac{d\phi}{dt}$$

$$\Rightarrow f = \frac{1}{2\pi}\frac{d\phi}{dt} \qquad Equation\ 3$$

Substitute, $f = f_d$ and $\phi = 4\pi R/\lambda$ in Equation 3.

$$f_d = \frac{1}{2\pi}\frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right)$$

$$\Rightarrow f_d = \frac{1}{2\pi}\frac{4\pi}{\lambda}\frac{dR}{dt}$$

$$\Rightarrow f_d = \frac{2V_r}{\lambda} \qquad Equation\ 4$$

Where,

f_d is the Doppler frequency

V_r is the relative velocity

We can find the value of Doppler frequency f_d by substituting the values of V_r and λ in Equation 4.

Substitute, $\lambda = C/f$ in Equation 4.

$$f_d = \frac{2V_r}{C/f}$$

$$\Rightarrow f_d = \frac{2V_r f}{C} \qquad Equation\ 5$$

Where,

f is the frequency of transmitted signal

C is the speed of light and it is equal to $3 \times 10^8 m/sec$

We can find the value of Doppler frequency, f_d by substituting the values of V_r, f and C in Equation 5.

Note − Both Equation 4 and Equation 5 show the formulae of Doppler frequency, f_d. We can use either Equation 4 or Equation 5 for finding **Doppler frequency**, f_d based on the given data.

Example Problem

If the Radar operates at a frequency of $5GHZ$, then find the **Doppler frequency** of an aircraft moving with a speed of 100KMph.

Solution

Given,

The frequency of transmitted signal, $f = 5GHZ$

Speed of aircraft (target), $V_r = 100KMph$

$$\Rightarrow V_r = \frac{100 \times 10^3}{3600} m/sec$$

$$\Rightarrow V_r = 27.78 m/sec$$

We have converted the given speed of aircraft (target), which is present in KMph into its equivalent m/sec.

We know that, the speed of the light, $C = 3 \times 10^8 m/sec$

Now, following is the **formula for Doppler frequency** −

$$f_d = \frac{2Vrf}{C}$$

Substitute the values of Vr, V_r, f and C in the above equation.

$$\Rightarrow f_d = \frac{2\,(27.78)\left(5 \times 10^9\right)}{3 \times 10^8}$$

$$\Rightarrow f_d = 926HZ$$

Therefore, the value of **Doppler frequency**, f_d is $926HZ$ for the given specifications.