Radar Systems - Delay Line Cancellers

In this chapter, we will learn about Delay Line Cancellers in Radar Systems. As the name suggests, delay line introduces a certain amount of delay. So, the delay line is mainly used in Delay line canceller in order to introduce a **delay** of pulse repetition time.

Delay line canceller is a filter, which eliminates the DC components of echo signals received from stationary targets. This means, it allows the AC components of echo signals received from non-stationary targets, i.e., moving targets.

Types of Delay Line Cancellers

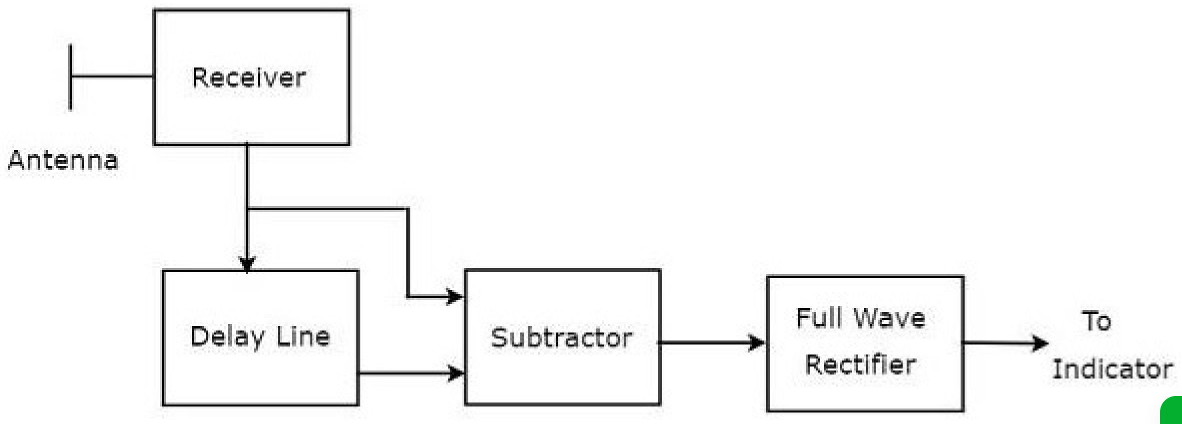
Delay line cancellers can be classified into the following **two types** based on the number of delay lines that are present in it.

- Single Delay Line Canceller
- Double Delay Line Canceller

In our subsequent sections, we will discuss more about these two Delay line cancellers.

Single Delay Line Canceller

The combination of a delay line and a subtractor is known as Delay line canceller. It is also called single Delay line canceller. The **block diagram** of MTI receiver with single Delay line canceller is shown in the figure below.



We can write the **mathematical equation** of the received echo signal after the Doppler effect as −

$$V_1 = A \sin[2\pi f_d t - \phi_0] \quad Equation\ 1$$

Where,

A is the amplitude of video signal

f_d is the Doppler frequency

ϕ_o is the phase shift and it is equal to $4\pi f_t R_o / C$

We will get the **output of Delay line canceller**, by replacing t by $t - T_P$ in Equation 1.

$$V_2 = A \sin[2\pi f_d (t - T_P) - \phi_0] \quad Equation\ 2$$

Where,

T_P is the pulse repetition time

We will get the **subtractor output** by subtracting Equation 2 from Equation 1.

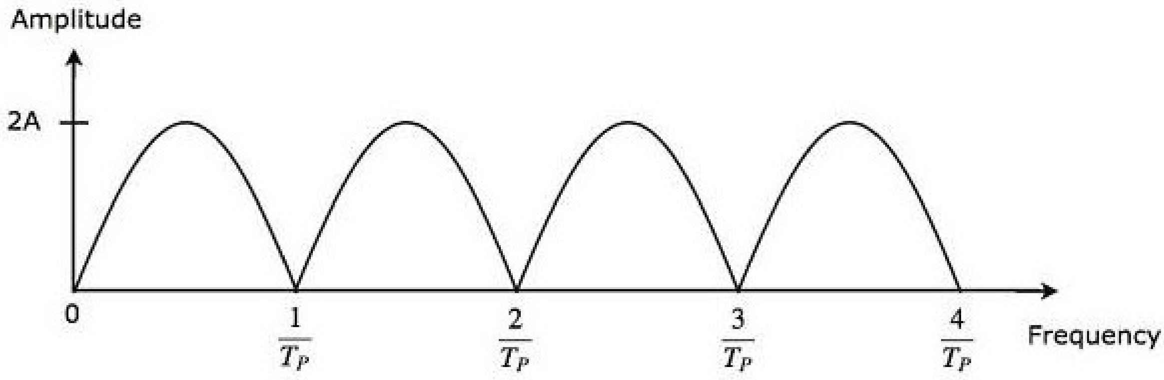
$$V_1 - V_2 = A \sin[2\pi f_d t - \phi_0] - A \sin[2\pi f_d (t - T_P) - \phi_0]$$

$$\Rightarrow V_1 - V_2 = 2A \sin\left[\frac{2\pi f_d t - \phi_0 - [2\pi f_d (t - T_P) - \phi_0]}{2}\right] \cos \left[\frac{2\pi f_d t - \phi_o + 2\pi f_d (t - T_P) - \phi_0}{2}\right]$$

$$V_1 - V_2 = 2A \sin\left[\frac{2\pi f_d T_P}{2}\right] \cos\left[\frac{2\pi f_d (2t - T_P) - 2\phi_0}{2}\right]$$

$$\Rightarrow V_1 - V_2 = 2A \sin\left[\pi f_d T_p\right] \cos\left[2\pi f_d \left(t - \frac{T_P}{2}\right) - \phi_0\right] \quad Equation\ 3$$

The output of subtractor is applied as input to Full Wave Rectifier. Therefore, the output of Full Wave Rectifier looks like as shown in the following figure. It is nothing but the **frequency response** of the single delay line canceller.



From Equation 3, we can observe that the frequency response of the single delay line canceller becomes zero, when $\pi f_d T_P$ is equal to **integer multiples of** π This means, $\pi f_d T_P$ is equal to $n\pi$ Mathematically, it can be written as

$$\pi f_d T_P = n\pi$$

$$\Rightarrow f_d T_P = n$$

$$\Rightarrow f_d = \frac{n}{T_P} \quad Equation\ 4$$

From Equation 4, we can conclude that the frequency response of the single delay line canceller becomes zero, when Doppler frequency f_d is equal to integer multiples of reciprocal of pulse repetition time T_P.

We know the following relation between the pulse repetition time and pulse repetition frequency.

$$f_d = \frac{1}{T_P}$$

$$\Rightarrow \frac{1}{T_P} = f_P \quad Equation\ 5$$

We will get the following equation, by substituting Equation 5 in Equation 4.

$$\Rightarrow f_d = nf_P \quad Equation\ 6$$

From Equation 6, we can conclude that the frequency response of the single delay line canceller becomes zero, when Doppler frequency, f_d is equal to integer multiples of pulse repetition frequency f_P.

Blind Speeds

From what we learnt so far, single Delay line canceller eliminates the DC components of echo signals received from stationary targets, when n is equal to zero. In addition to that, it also eliminates the AC components of echo signals received from non-stationary targets, when the Doppler frequency f_d is equal to integer **(other than zero)** multiples of pulse repetition frequency f_P.

So, the relative velocities for which the frequency response of the single delay line canceller becomes zero are called **blind speeds**. Mathematically, we can write the expression for blind speed v_n as −

$$v_n = \frac{n\lambda}{2T_P} \quad Equation\ 7$$

$$\Rightarrow v_n = \frac{n\lambda f_P}{2} \quad Equation\ 8$$

Where,

n is an integer and it is equal to 1, 2, 3 and so on

λ is the operating wavelength

Example Problem

An MTI Radar operates at a frequency of $6GHZ$ with a pulse repetition frequency of $1KHZ$. Find the first, second and third **blind speeds** of this Radar.

Solution

Given,

The operating frequency of MTI Radar, $f = 6GHZ$

Pulse repetition frequency, $f_P = 1KHZ$.

Following is the formula for **operating wavelength** λ in terms of operating frequency, f.

$$\lambda = \frac{C}{f}$$

Substitute, $C = 3 \times 10^8 m/sec$ and $f = 6GHZ$ in the above equation.

$$\lambda = \frac{3 \times 10^8}{6 \times 10^9}$$

$$\Rightarrow \lambda = 0.05m$$

So, the **operating wavelength** λ is equal to $0.05m$, when the operating frequency f is $6GHZ$.

We know the following **formula for blind speed**.

$$v_n = \frac{n\lambda f_p}{2}$$

By substituting, n=1,2 & 3 in the above equation, we will get the following equations for first, second & third blind speeds respectively.

$$v_1 = \frac{1 \times \lambda f_p}{2} = \frac{\lambda f_p}{2}$$

$$v_2 = \frac{2 \times \lambda f_p}{2} = 2\left(\frac{\lambda f_p}{2}\right) = 2v_1$$

$$v_3 = \frac{3 \times \lambda f_p}{2} = 3\left(\frac{\lambda f_p}{2}\right) = 3v_1$$

Substitute the values of λ and f_P in the equation of first blind speed.

$$v_1 = \frac{0.05 \times 10^3}{2}$$

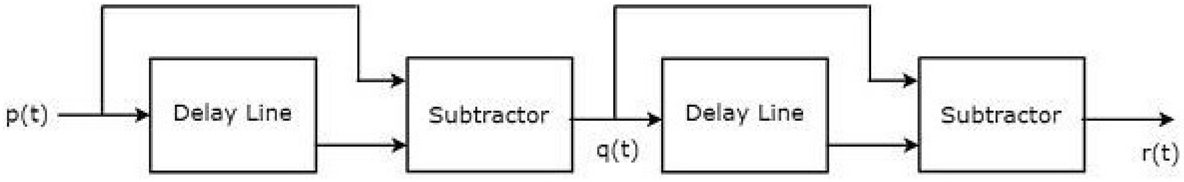
$$\Rightarrow v_1 = 25m/sec$$

Therefore, the **first blind speed** v_1 is equal to $25m/sec$ for the given specifications.

We will get the values of **second & third blind speeds** as $50m/sec$& $75m/sec$ respectively by substituting the value of $v1$ in the equations of second & third blind speeds.

Double Delay Line Canceller

We know that a single delay line canceller consists of a delay line and a subtractor. If two such delay line cancellers are cascaded together, then that combination is called Double delay line canceller. The **block diagram** of Double delay line canceller is shown in the following figure.



Let $p(t)$ and $q(t)$ be the input and output of the first delay line canceller. We will get the following mathematical relation from **first delay line canceller**.

$$q(t) = p(t) - p(t - T_P) \qquad Equation\ 9$$

The output of the first delay line canceller is applied as an input to the second delay line canceller. Hence, $q\,(t)$ will be the input of the second delay line canceller. Let $r\,(t)$ be the output of the second delay line canceller. We will get the following mathematical relation from the **second delay line canceller**.

$$r\,(t) = q\,(t) - q\,(t - T_P) \qquad Equation\ 10$$

Replace t by $t - T_P$ in Equation 9.

$$q\,(t - T_P) = p\,(t - T_P) - p\,(t - T_P - T_P)$$

$$q\,(t - T_P) = p\,(t - T_P) - p\,(t - 2T_P) \qquad Equation\ 11$$

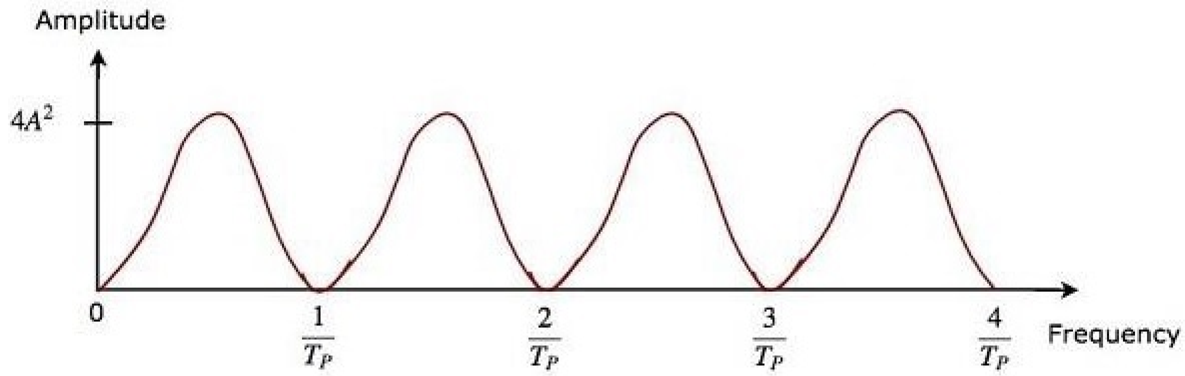
Substitute, Equation 9 and Equation 11 in Equation 10.

$$r\,(t) = p\,(t) - p\,(t - T_P) - [p\,(t - T_P) - p\,(t - 2T_P)]$$

$$\Rightarrow r\,(t) = p\,(t) - 2p\,(t - T_P) + p\,(t - 2T_P) \qquad Equation\ 12$$

The **advantage** of double delay line canceller is that it rejects the clutter broadly. The output of two delay line cancellers, which are cascaded, will be equal to the square of the output of single delay line canceller.

So, the magnitude of output of double delay line canceller, which is present at MTI Radar receiver will be equal to $4A^2(\sin[\pi f_d T_P])^2$.



The frequency response characteristics of both double delay line canceller and the cascaded combination of two delay line cancellers are the same. The **advantage** of time domain delay line canceller is that it can be operated for all frequency ranges.