3.4 MTI RADAR PARAMETERS, LIMITATIONS OF MTI PERFORMANCE

Q37. Explain the following limitations of MTI radar,

(a) Equipment instabilities

(b) Scanning modulation

(c) Internal fluctuation of clutter.

Nov.-11, Set-2, Q5

(or)

Explain the limitations of MTI performance.

Nov.-16, Set-1, Q4(a)

(or)

Discuss, what are the limits effects the MTI performance.

Ans: Oct./Nov.-18, Set-3, Q4(b)

(a) Equipment Instabilities

The improvement factor of an MTI radar may be degraded or reduced or lowered by pulse to pulse changes in the amplitude, frequency or phase of the transmitter signal. In designing, constructing and maintaining of MTI radar care must be taken. Otherwise performance of radar may be reduced, since, the equipment stability of MTI radar must be better than the ordinary radar.

If '$A \cos \omega t$' and $A \cos(\omega t + \Delta\phi)$ are the echos from stationary clutter on the first pulse and the second pulse.

Where, $\Delta\phi$ - Change in oscillator phase between two

Thus, the difference between the two echos are,

$$= A\cos\omega t - A\cos(\omega t + \Delta\phi)$$

$$= 2A\sin\left(\frac{\Delta\phi}{2}\right)\sin\left(\omega t + \frac{\Delta\phi}{2}\right)$$

For small phase errors i.e., for $\Delta\phi << 0$

$$2A\sin\left(\frac{\Delta\phi}{2}\right) \simeq 2A\,\frac{\Delta\phi}{2} \quad (\because \text{ for } \theta << 0 \ \sin\theta \simeq \theta)$$

$$\simeq A\Delta\phi$$

So, the limitation on the improvement due to oscillator instability is,

$$\boxed{I = \frac{1}{(\Delta\phi)^2}} \quad \ldots (1)$$

(b) Scanning Modulation

If a target is scanned by the antenna and observes the target for a finite time T_0 then,

$$T_0 = \frac{n_B}{f_P} = \frac{\theta_B}{\theta_S} \quad \ldots (2)$$

Where,

n_B – Number of bits required

θ_B – Antenna beam width

f_P – Pulse repetition frequency

θ_S – Antenna scanning rate.

The width of a frequency spectrum for the received pulse duration T_0 is proportional to $\frac{1}{T_0}$. There exists a finite width of the clutter spectrum corresponding to the finite time on the target, in the case of a perfectly stationary clutter. As the clutter spectrum is too wide, the observation time is too small and which affects the improvement factor. The above limitation is called scanning modulation or scanning fluctuations.

The limitation to the improvement factor caused by antenna scanning are,

For single canceller,

$$\boxed{I_{1S} = \frac{n_B^2}{1.388}} \quad \ldots (3)$$

For double canceller,

$$\boxed{I_{1S} = \frac{n_B^4}{3.852}} \quad \ldots (4)$$

(c) Internal Fluctuation of Clutter

Clutters like buildings, water towers, bare hills and mountains produce echo signals, that are constant in phase and amplitude or a function of time. As the echoes from trees, vegetation, sea, rain and chaff fluctuate with time, this limits the performance of MTI radar. It is very difficult to describe a clutter echo signal by its nature.

At the radar receiver, the echo is represented as a vector sum of echoes received from individual scatters.

The power spectrum of clutter signal by approximated experimental measurements is,

$$w(f) = |g(f)|^2 = |g|^2 \exp\left[-a\left(\frac{f}{f_0}\right)^2\right] \quad \ldots (5)$$

Where,

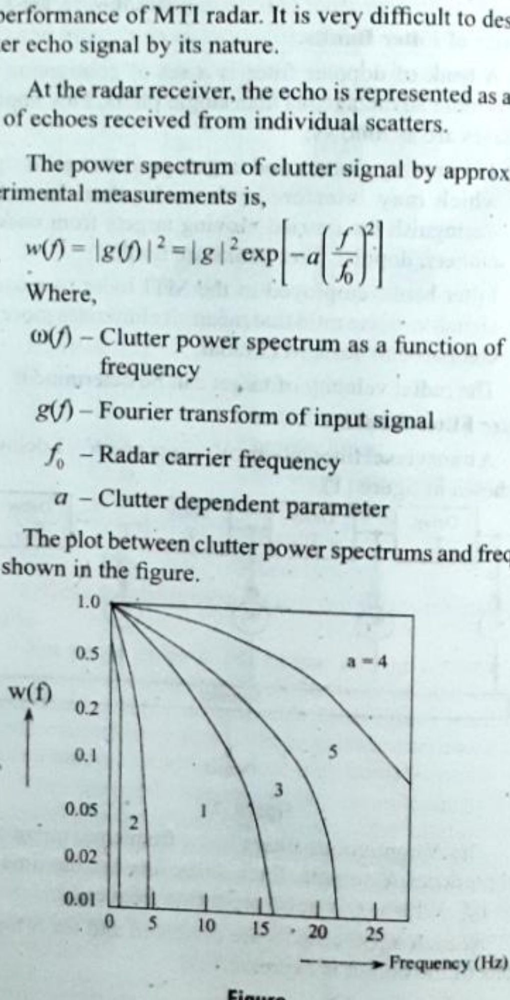
$\omega(f)$ – Clutter power spectrum as a function of frequency

$g(f)$ – Fourier transform of input signal

f_0 – Radar carrier frequency

a – Clutter dependent parameter

The plot between clutter power spectrums and frequency is as shown in the figure.



Figure

Mathematically the improvement factor can be written as,

$$I = \left(\frac{S_o/C_o}{S_i/C_i}\right)_{avg} = \left(\frac{S_o}{S_i}\right)_{avg} \times \frac{C_i}{C_o}$$

$$\Rightarrow \boxed{I = \left(\frac{S_o}{S_i}\right) \times CA} \quad \ldots (6)$$

Where,

$\left(\frac{S_o}{C_o}\right)$ – Output signal-to-clutter ratio

$\left(\frac{S_i}{C_i}\right)$ – Input signal-to-clutter ratio

CA – Clutter Attenuation.

$$CA = \frac{\int_0^\infty W(f)df}{\int_0^\infty W(f)|H(f)|^2 df}$$

The frequency response of canceler $H(f)$ is defined as,

$$H(f) = 1 - e^{-j2\pi fT}$$
$$= 2j\sin(\pi fT)\, e^{-j\pi fT}$$

On substituting $W(f)$ and $H(f)$ in CA, then

$$CA = \frac{f_p^2}{4\pi^2\sigma_c^2}$$

Where,

f_p – Pulse repetition frequency

Then, the improvement factor for single canceller is given by,

$$\boxed{I_{1C} = \frac{f_P^2}{2\pi^2\sigma_C^2}} \quad \ldots (7)$$

For double canceller,

$$\boxed{I_{2C} = \frac{f_P^2}{8\pi^4\sigma_C^4}} \quad \ldots (8)$$

Therefore, the generalized expression for improvement factor for N-pulse canceller with $N_l = N - 1$ delay lines is given by,

$$\boxed{I_{NC} = \frac{2^{N_l}}{N_l!}\left(\frac{f_p}{2\pi\sigma_C}\right)^{2N_l}}$$