LECTURE # 07 - TOPIC 03 (Part - I)

MODULATION : AM, DSB/SC, VSB, Angle Modulation, NBFM, WBFM, Diode Detector, Frequency Discriminator, AM & FM Transmitter

3.1 Introduction.

This topic is aimed at Covering Analog Modulation techniques and their various Modulation Schemes. Following is the plan to cover this Topic.

Analog Modulation Techniques Types.

- 3.2 Amplitude Modulation Technique (AM)
- 3.3 Frequency Modulation (FM)
- 3.4 AM & FM Transmitter.

Reference books for this topic

BOOKS

(i) Principles of Communication System by Taub & Schilling.
(ii) Electronic Communication Systems by George Kennedy
(iii) Electronic Communication System by Roddy Coolen.

This portion of Syllabus will be covered by taking up the Course Content in following Sequence

- 3.2 Amplitude Modulation Techniques.
- 3.3 Frequency Modulation Techniques.
- 3.4 AM & FM transmitter.

3.2 Amplitude Modulation Techniques/Schemes.

Before we take up various Amplitude Modulation Schemes and techniques it has to made clear the following question :- Q.) What is the need of Modulation? To get an answer to this question we shall first explain an important step to be taken when implementing various Schemes of Modulation. This is referred to as Frequency Translation. Here we thereby ask yet another question

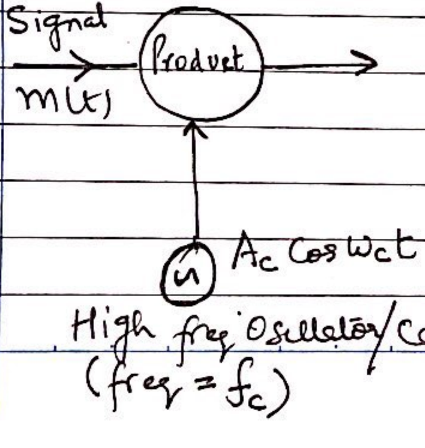
Q) What is Frequency Translation?

Q) What is the needs & benefits of Frequency Translation?

3.2.1 What is Frequency Translation?

Frequency Translation is the procedure undertaken both at the Transmitter of a Communication system and also at the Receiver of the Communication System. At the Trasmitter it is also referred to as Forward Frequency Translation. At the Receiver it also referred to as Reverse Frequency Translation.

Where implementation is concerned both Forward Frequency Trastation at Transmitter (Tx) and Reverse Frequency Traslation at Receiver (Rx) is same. In both cases the implementation involves multiplying a signal with a high frequency carrier. See Fig 3.1



$$(\text{Signal})(A_c \cos w_c t) = m(t) A_c \cos w_c t$$

Frequency Translated Signal

Fig 3.1 : Frequency translation of incoming Signal by a high frequency Carrier.

On double sided Spectrum (21)

3.2.2 Method of Frequency Translation

By multiply an incoming signal with a high frequency carrier generated by a high frequency oscillator (f_c) the signal is trasleted (shifted) from its orignal position in the spectrum to a new spectral range.

- This method shall be explained by considering three types of signal ($m(t)$)
  - (i) Single-tone signal
  - (ii) Multitone signal
  - (iii) Nonperiodic signal.

(i) Single-tone Signal

Let the input signal be $m(t) = A_m \cos \omega_m t$.

or $$\boxed{m(t) = A_m \cos (2\pi f_m) t} \quad \text{--- (3.1.a)}$$

The signal is called single-tone because it has only one frequency component.

Applying Euler's formula (Refer pg. 32 & 33 of Lecture #04) Equation (3.1.a) can be re-written as

$$\boxed{m(t) = \frac{A_m}{2}\left[\exp(j2\pi f_m t) + \exp(-j2\pi f_m t)\right]} \quad (3.1.b)$$

Equation (3.1.b) can be used to plot the corresponding double sided spectrum which will be discrete.

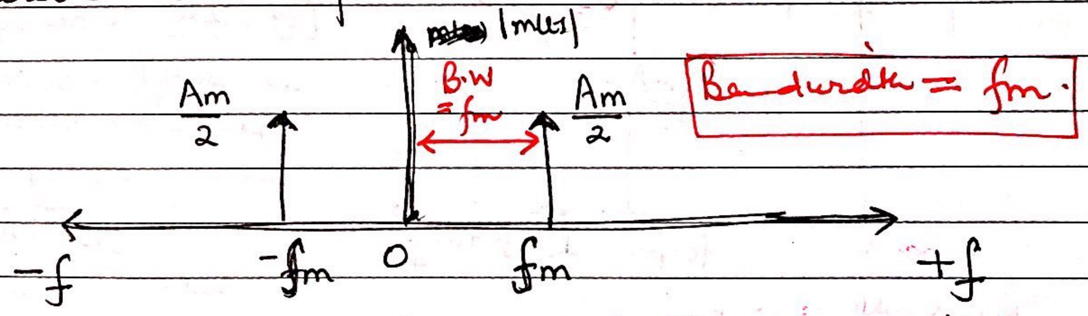


Fig 3.2: The double sided discrete spectrum of single-tone signal.

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The single-tone signal of frequency f_m is to be multiplied as shown in Fig 3.1 using a high frequency Local Oscillator producing the carrier $A_c \cos(2\pi f_c)t$ - where f_c is greater than f_m.

Therefore High frequency carrier is written as

$$\boxed{V_c(t) = A_c \cos(2\pi f_c)t} \quad \text{---- } (3.2.a)$$

Output of Multiplier = (Signal) $[A_c \cos(2\pi f_c)t]$.

Multiplier o/p $= m(t) A_c \cos(2\pi f_c)t$

Using (3.1.a) & (3.1.b) for m(t).

$$\therefore \text{Multiplier o/p} = [A_m \cos(2\pi f_m)t]\,[A_c \cos(2\pi f_c)t].$$

$$\therefore \boxed{m(t)\,V_c(t) = \frac{A_m A_c}{2}\left[\cos 2\pi(f_c+f_m)t + \cos 2\pi(f_c-f_m)t\right]}$$

This gives single sided spectrum discrete --- (3.3.a)

We can write above Equation (3.3.a) using Euler's formula to plot a double sided Spectrum.

$$\therefore \boxed{\begin{aligned} m(t)V_c(t) = \frac{A_m A_c}{4}\Big[&\exp j(\omega_c+\omega_m)t + \cancel{\exp j(\omega_c+\omega_m)t} \\ &+ \exp(-j)(\omega_c+\omega_m)t + \exp j(\omega_c-\omega_m)t \\ &+ \exp(-j)(\omega_c-\omega_m)t\Big] \end{aligned}}$$

This gives double sided spectrum discrete --- (3.3.b)

These are plotted below in Fig (3.2.a) & Fig (3.2.b)

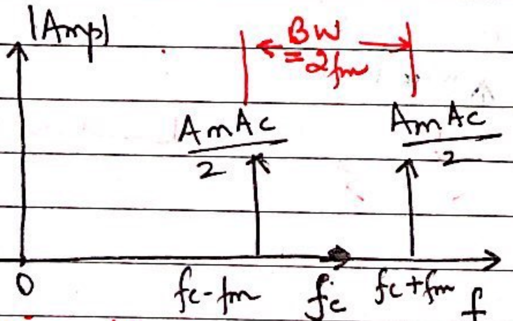


Fig (3.2.a) The figure shows a single-sided discrete spectrum where m(t) has been frequency translated around f_c. Now it is represented by two components $f_c + f_m$ & $f_c - f_m$.

Bandwidth $= (f_c+f_m) - (f_c-f_m)$
$= \cancel{f_c} + f_m - \cancel{f_c} + f_m = 2f_m$

On double sided Spectrum

$2 \, B.W = 2f_m + 2f_m = 4f_m$

or $\boxed{B.W = 2f_m}$

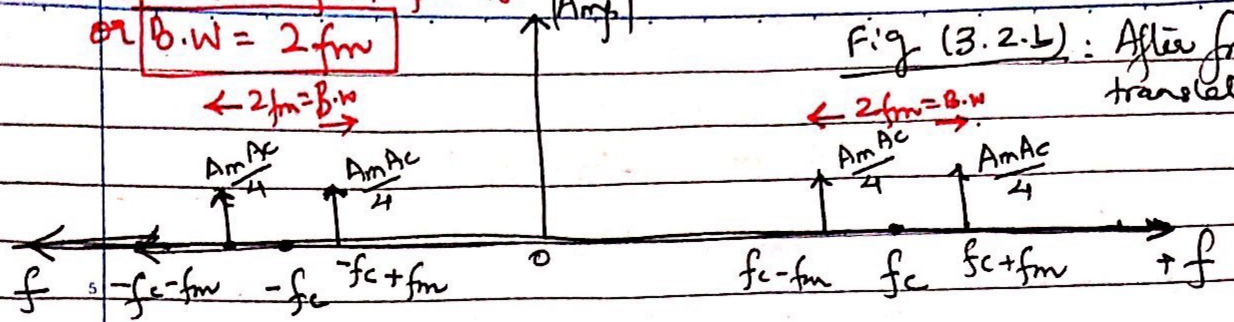


Fig (3.2.b): After frequency translation

Fig(3.2.b) The above figure is the Double sided Discrete Spectrum after Frequency Translation implementation. All components are of equal amplitude $\frac{A_m A_c}{4}$ as per Eqn (3.3.b). Each Component is spaced at f_m away from f_c & $-f_c$ respectively.

To sum it all up as is clear from either Single sided spectrum or equivalently from double side spectrum of Fig (3.2.a) & Fig (3.2.b) Respectively:

→ After frequency translation the original signal at f_m is shifted in frequency domain to a higher position around f_c. It is now represented by two components each of Amplitude $\frac{A_m A_c}{2}$ and frequency translated around f_c equally by f_m to positions $f_c + f_m$ & $f_c - f_m$. (See Fig 3.2.a)

or

→ After frequency translation the original signal at f_m is shifted in frequency domain to higher positions $+f_c$ & $-f_c$. It is represented after frequency translation by four components. On positive side the two components are at $f_c + f_m$ and $f_c - f_m$. On negative side two components are at $-f_c + f_m$ and $-f_c - f_m$. All are of equal amplitude $\frac{A_m A_c}{4}$. (See Fig 3.2.b).

In short we can say $m(t) A_c \cos \omega_c t = [A_m \cos(2\pi f_m) t] [A_m \cos(2\pi f_c t)]$. lead to frequency Translation around f_c leading to two components at $f_c + f_m$ & $f_c - f_m$ in single spectrum

(ii) Multi-tone Signal – Consider ~~only~~ four Components

Similar explanation applies to a multi-tone signal.

Let $m(t)$ = A multi-tone signal, i.e. more than one fm

$m(t) \equiv m_1(t);\ m_2(t);\ m_3(t);\ m_4(t)$

where

$$m_1(t) = Am_1 \cos(2\pi fm_1)t$$
$$m_2(t) = Am_2 \cos(2\pi fm_2)t$$
$$m_3(t) = Am_3 \cos(2\pi fm_3)t$$
$$m_4(t) = Am_4 \cos(2\pi fm_4)t$$

Here for simplicity assume $Am_1 = Am_2 = Am_3 = Am_4$

Output of Multiplier $= m(t)\, V_c(t)$ where $V_c(t) = A_c \cos(2\pi f_c t)$

& $f_c > fm_4 > fm_3 > fm_2 > fm_1$

We can directly show the Frequency translation in case of multitone – (4 component) signal.

bandwidth
$BW = (fm_4 - 0)$
i.e. Max. Frequency Component – Min Frequency Component
$\therefore BW = fm_4$

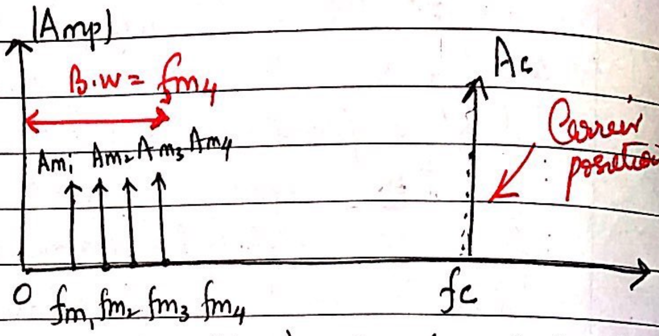


Fig (3.3.a): Spectral position in single sided spectrum before Frequency Translation.

B.W = (Max freq Component) – (Min freq Component)
$= (f_c + fm_4) - (f_c - fm_4)$
$\boxed{B.W = 2fm_4}$

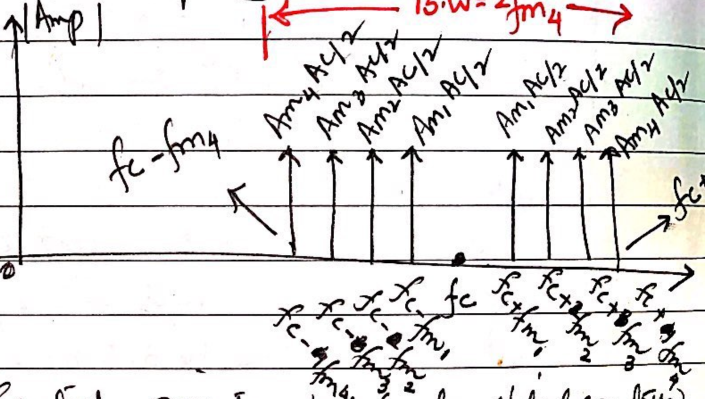
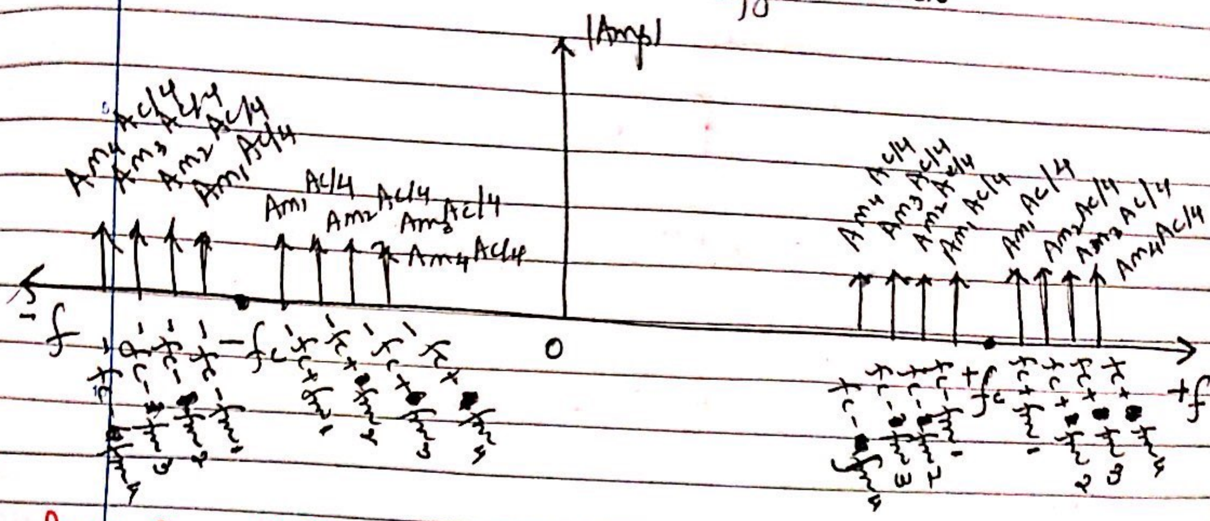


Fig (3.3.b): Spectral position in single sided spectrum after Frequency Translation. The components now have been Frequency translated around fc by

~~(fm1; fm1), (fm2, fm2), (fm3, 3fm), & (4fm, 4fm) respectively~~

$(f_c \pm f_{m_1})$; $(f_c \pm f_{m_2})$; $(f_c \pm f_{m_3})$; $(f_c \pm f_{m_4})$.

Fig(3.3.c) Here also we can repeat the illustration for a double sided spectrum as shown in figure below



B.W Consideration :- In above two cases we calculate BW (Bandwidth) of Signal as (Max frequency Component) – (Lowest Component) on Spectrum.

Thumbs rule 3.1

$$\boxed{B.W = \text{Max. Frequency Component} - \text{Min Frequency Component}}$$

So For Fig 3.2 $\quad B.W = (f_m) - 0 = f_m$. before Frequency Translation

For Fig 3.2.a $\quad B.W = (f_c + f_m) - (f_c - f_m) = 2f_m$ after Freq. Translation

For Fig 3.2.b (Double Spectrum) $\quad 2(B.W) = \left[(f_c+f_m) - (f_c - f_m)\right] + (-f_c + f_m) - (-f_c - f_m)$

$$\therefore 2\,B.W = (2f_m) + (2f_m) = 4f_m$$

$$\therefore B.W = 2f_m.$$

For Fig 3.3.b $\quad B.W = (f_c + f_{m_4}) - (f_c - f_{m_4}) = 2f_{m_4}$

For Fig 3.3.a (double sided spectrum)

$$2BW = \left[(f_c + f_{m_4}) - (f_c - f_{m_4})\right] + \left[(-f_c + f_{m_4}) - (-f_c - f_{m_4})\right]$$

$$2BW = 2f_{m_4} + 2f_{m_4} = 4f_{m_4}$$

$$BW = 2f_{m_4}$$

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Thumbs rule 3.2 :- Before Frequency Translation Bandwidth is equal to max frequency Component of the original signal.

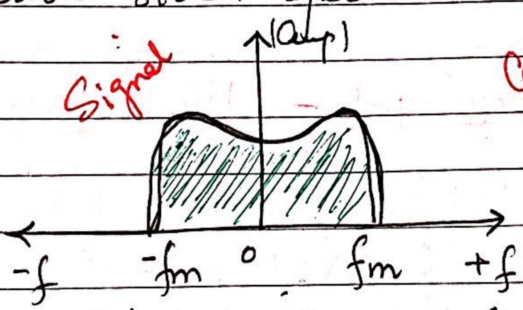
ie $B.W = f_{max}$

Thumbs rule 3.3: After Frequency Translation B·W is equal to twice the max frequency component.

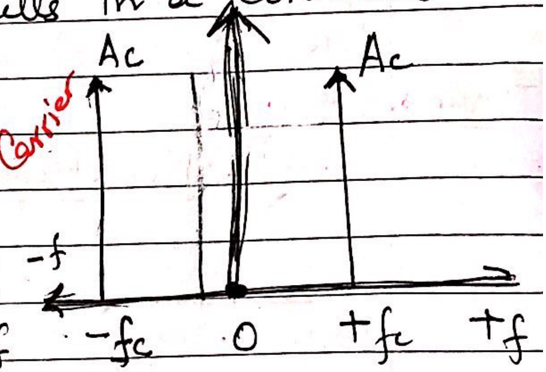
ie $B.W = 2f_{max}$.

(iii) Non-Periodic Signal

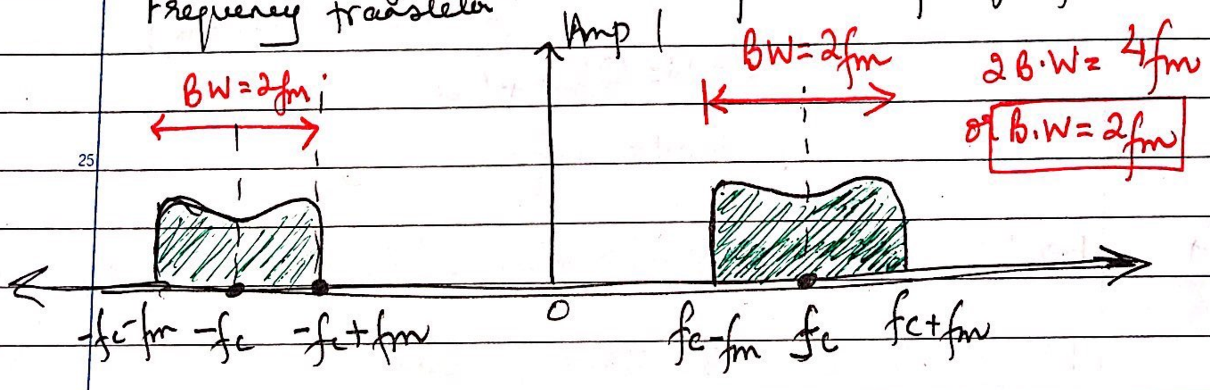
If $m(t)$ is a non-periodic signal then from discussion of Fourier Transform, it results in a Continuous double sided spectrum.



Fig(3.4.a) Double sided Continuous spectrum of signal before Frequency translation



Fig(3.4.b): Double sided Spectrum of High freq Carrier



Fig(3.4.c). After Frequency translation by multiplying a non periodic signal with a Single-tone Carrier at f_c then the signal is frequency translated both around $+f_c$ and around $-f_c$ in the double sided spectrum.

$\therefore 2B.W = [(f_c+f_m)-(f_c-f_m)] + [(-f_c+f_m)-(-f_c-f_m)] = 2f_m + 2f_m = 4f_m$

3.2.3 What is the need of Frequency Translation? What are its benefits

Various benefits of Frequency Translation are as follows:-

(i) Frequency Division Multiplexing (FDM)
(ii) Practicability of Antenna
(iii) Narrowbanding
(iv) Common Processing.

(i) Frequency Division Multiplexing (FDM):—
FDM is a technique that enables simultaneous transmission of several signals, staggered in frequency around carriers at different spectral position.
FDM allows the simultaneous transmission of each signal through a single communication channel. At the Rx the signals are seperately recoverable and distinguishable. Fig. (3.5) shows a FDM spectrum after four signals are frequency translated around 4 different ~~Carrier~~ Carriers.

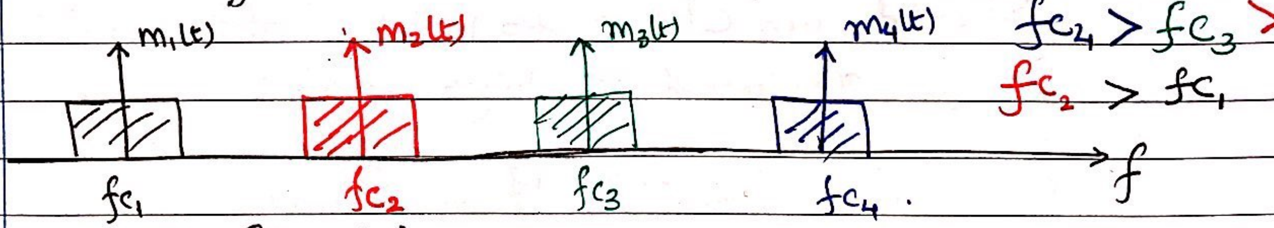


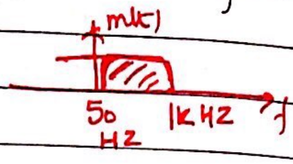
Fig 3.5.a: Four signals $m_1(t)$, $m_2(t)$, $m_3(t)$ & $m_4(t)$ in Frequency domain after $m_1(t)$ is frequency translated around f_{c_1}, $m_2(t)$ is frequency translated around f_{c_2}, $m_3(t)$ is frequency translated around f_{c_3} & $m_4(t)$ is frequency translated around f_{c_4} where $f_{c_4} > f_{c_3} > f_{c_2} > f_{c_1}$. Fig 3.5.a is an example of four signals in frequency domain after FDM.

(ii) Practicability of Antenna :- The method of Frequency translation allows practical Antenna ~~size~~ size to radiate and receive signal ~~when~~ ~~a signal is multi-tone~~!
Already explained on Pg 09 of lecture #02 ← Refer

(iii) Narrowbanding

Frequency translation allows an effective operation of an antenna for the multi tone signal.
Let the baseband signal be m(t) and let its range extend from $f_{min} = 50Hz$ to $f_{max} = 10^4 Hz$

$$\therefore \frac{f_{max}}{f_{min}} = \frac{10^4}{50} = 200$$



or Highest frequency = 200 (Lowest Frequency).

Now since from previous discussion for effective radiation antenna size $\simeq \lambda/10$

i.e. Antenna size $\simeq \frac{1}{10}[c/f]$ --- 2.c

Should we choose $f = 50Hz$ then antenna size required is very large.

Should we choose $f = 10^4 HZ$ then antenna size required is very small.

Fig

Since m(t) has both these frequency limits and m(t) is made up of range of components from $f_{min} = 50Hz$ to $f_{max} = 10^4 Hz$, thus effective radiation of all these component is not possible by a single antenna size.

Frequency Translation allows a single common size to allow f_{min} ~~as~~ to f_{max}, all frequencies to be radiated efficiently.

In the same example let carrier $f_c = 1MHZ$.
After frequency translation $m(t) \rightarrow$ (50HZ to 1KHZ) is frequency translated around $f_c = 1MHZ$.

50 Hz Frequency translated to higher position $(50\,Hz + 1\,MHz)$
10^4 Hz frequency translated to higher position $(10^4\,Hz + 1\,MHz)$

∴ After Frequency translation

$$\frac{f_{max}}{f_{min}} = \frac{(10^4\,Hz + 1\,MHz)}{(50\,Hz + 1\,MHz)} \simeq 1.01$$

Now $\boxed{f_{max} = 1.01\, f_{min}}$

Thus Antenna is suitable for use & effective radiation for both the lowest value of frequency in signal as well as for the highest frequency value in signal.

Frequency translation has ~~successfully~~ successfully changed wide band signal to Narrowband signal.

(iii) Common Processing

As we go from signal to signal the frequency range of processing unit has to be adjusted for the different ranges. Frequency translation allows the operation of the processing unit for a fixed frequency range. The different signals to be processed separately are frequency translated to the specific fixed frequency range and hence allowing common processing.