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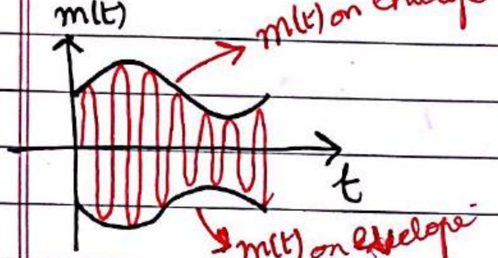
LECTURE #18 (PART III)

DSB-AM (Full Carrier) DETECTORS or DEMODULATORS

It has already been explained in Amplitude Modulation lectures that DSB-Full carrier signal is represented as

$$\boxed{V_{AM}(t) = A_c[1 + m(t)]\cos\omega_c t}$$

In time domain this signal has shape as follows.



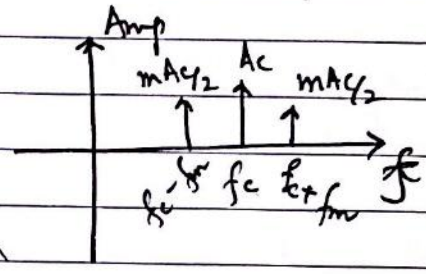


Figure:9 DSB-Full carrier in Time domain   DSB-Full carrier in Frequency domain

The time domain of DSB-Full carrier signal above in Figure:9 shows that envelope of the modulated signal has same variations as that of baseband signal m(t). Besides this even information content is present in the sidebands with amplitude $mA_c/2$ at $f_c \pm f_m$.

The same signal is transmitted over Communication channel ... to the Rx. We can use an envelope detector at the Receiver (Rx) to demodulate the DSB-Full carrier for recovering back m(t).

Q. What is an Envelope Detector? Explain its operation and Design Considerations.

Ans The Envelope Detector is housed at the Receiver (R_x) and it is used for demodulating the incomming standard AM signal ie a DSB-Full Carrier Signal.

The Demodulation process is also called Detection process. The most important condition for the successful detection of a DSB-Full carrier signal by an envelope detector is that modulation Index $m \leq 1$.

The Envelope Detector is also called a Diode Detector because a p-n jn diode is a very essential part of its circuitry.

The Diode Envelope Detector produces an output voltage proportional to the envelope of the input modulated DSB-Full carrier AM received signal at the receiver.

The circuit Realization of the Diode Envelope Detector is shown in figure 9 below:

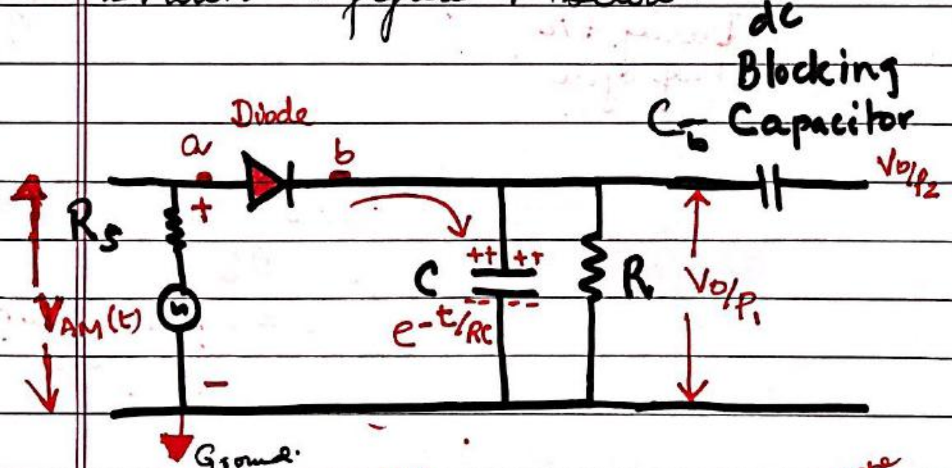
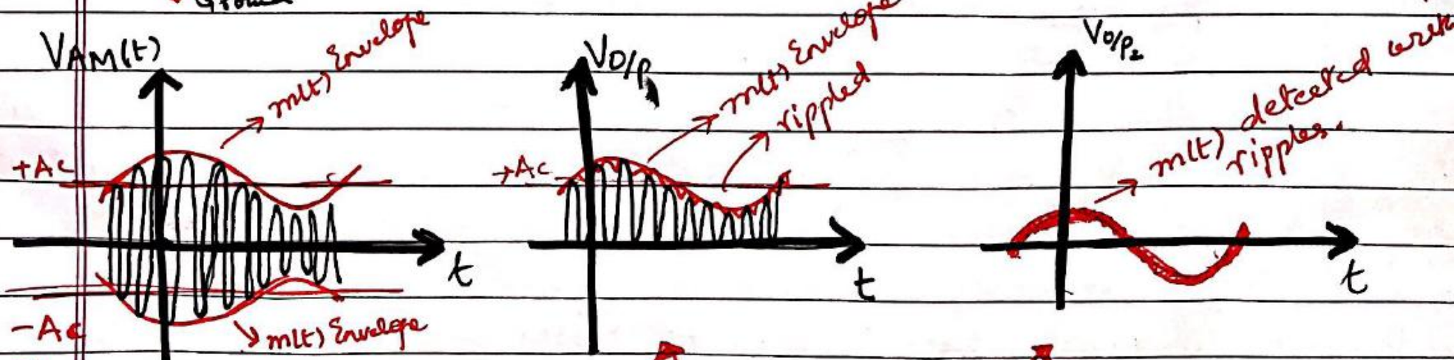


Figure 9: An Envelope diode detector and signal at positions for $V_{AM}(t)$ at input, V_{o/p_1} before C_b and V_{o/p_2} after C_b.



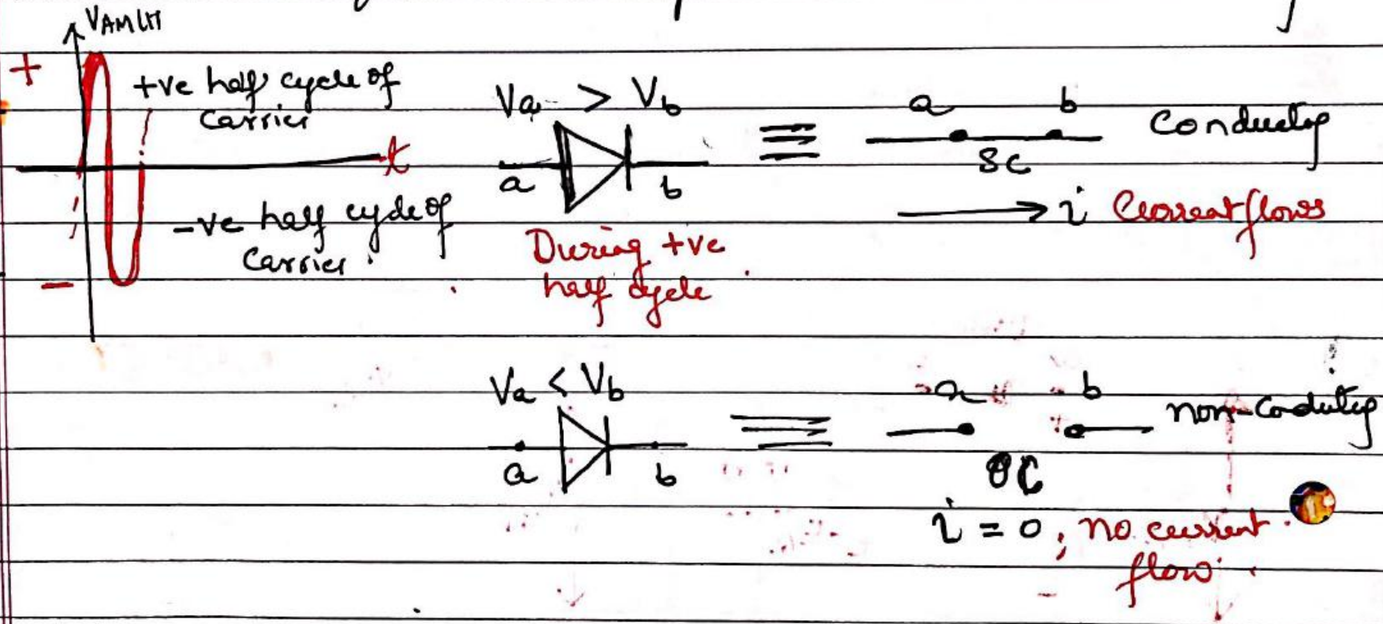
Received Input is DSB-Full carrier at Rx.

Rectified Signal at V_{o/p_1} before capacitor

dc offset Removed by capacitor & original baseband signal m(t) detected

R_S is the source resistance that is in series with the incomming DSB-Full carrier Signal represented as $V_{AM}(t)$. $V_{AM}(t)$ in time domain is also shown in Figure 9.
The rf carrier cycle swings from +ve to -ve values and then to +ve value through zero. When ever rf carrier cycle is +ve then a is +ve such that $V_a > V_b$ making diode forward biased and equivalent to a short circuit ie conducting. Whenever rf carrier cycle is -ve then a is -ve such that $V_a < V_b$ making diode reverse biased and equivalent to an open circuit ie non-conducting.

Figure: 10
$V_a > V_b$; $V_a < V_b$
Conditions of circuit



Hence the diode acts as a rectifier and can be considered as a switch.
During the +ve half cycle of the input DSB-full carrier cycle the diode is forward biased and is conducting. The current can flow now in a clockwise direction as shown in figure. The capacitor top plate becomes +ve induces -ve charge to lower plate. As such the capacitor charges to the peak value of input rf cycle.

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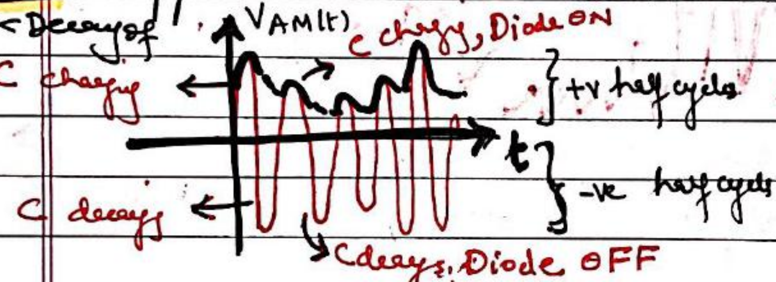
The resistor R is parallel to capacitor and V_{o/p_1} across R_L is equal to voltage across the capacitor.
During the negative half cycle of the rf modulated input $V_a < V_b$ so that diode is reverse biased and diode acts as an open circuit (OC). No current can flow in the circuit. The capacitor charge decays through external R_L till the next modulate rf positive cycle appears. So for all positive half of rf modulated input capacitor is charging and then decaying in negative half cycle. This process of charging and decays goes on. The decreased decayed voltage appears also across R_L.

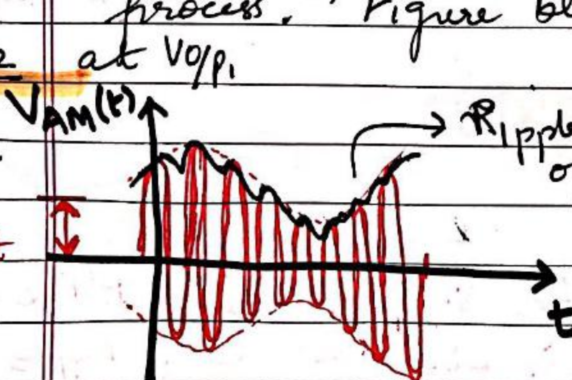
Figure: 11
Charging & Decay of C.



Time Constant $T = R_L C$
Decay rate is $\exp(-t/R_L C)$.

The capacitor during negative half cycle holds on to the positive charge previously received so that output voltage across R_L remains at the peak positive of cycle. In this process the negative half cycle of input is clipped off due to the half wave rectification process. Figure below shows the appearance of waveform at V_{o/p_1}

Figure: 12
Rippled output.



Rippled signal produced across R_L with a dc offset because of +AC volts. Lower half is completely rectified & clipped off. The rippled output will be in fact due to some loss of charge through the Resistor.

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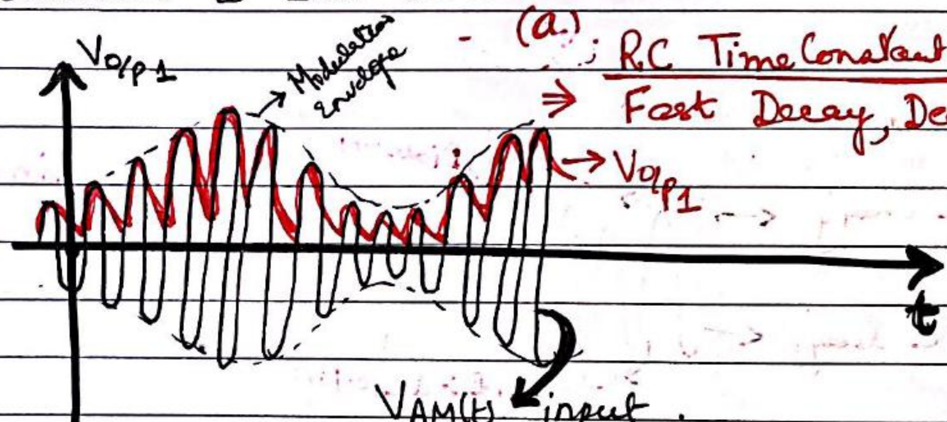
Design Considerations Regarding Decay time Constant RC

During negative downward swing of the input rf cycle the capacitor looses its charge through resistor R.
(a) The time constant RC of load has to be small enough to allow fast decay so that the output voltage is able to follow the modulating signal. (b) Otherwise in case RC time constant if large then decay is so slow that many input rf cycle peaks is missed and output is not able to follow the input envelope.
These two possibilities is show below

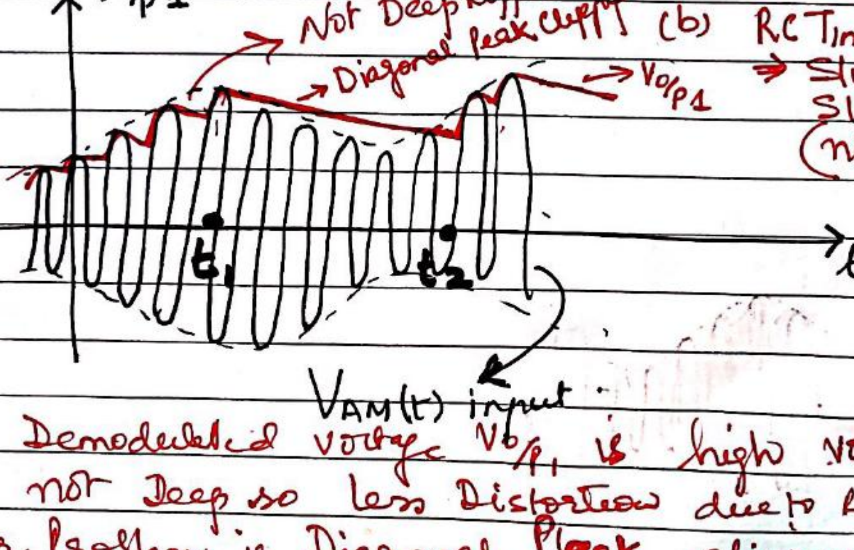
Figure 13
(a) RC time constant Small;
(b) RC time constant Large conditions.

Case (a) RC small



(i) Output Demodulated voltage $V_{o/p1}$ is relatively low.
(ii) Output Distortion due to deep Ripples.

Case (b) RC large.



(i) Output Demodulated voltage $V_{o/p1}$ is high voltage.
(ii) Ripples not Deep so less Distortion due to Ripples
(iii) Major Problem is Diagonal Peak clipping

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DIAGONAL PEAK CLIPPING

In Case (b) when RC time constant is large, the decay ripples are not deep and this help in maintaing a relatively high output voltage level of $V_{o/p}$. But a Serious problem that occurs is DIAGONAL PEAK CLIPPING. This is a form of distortion that occurs when time constant RC load is too long, thus preventing the output voltage from following the modulation i/p envelope ($V_{AM}(t)$). Over some portion of $V_{AM}(t)$ the decay is such that many cycles of rf input waveform is skipped till finally the decay curve (red line) finally catches up with $V_{AM}(t)$. In this way the o/p is not effectively following the envelope. In figure this type of distortion is shown to occur in rf cycles from time t_1 to t_2. Here from $t_1 - t_2$ output is distorted. At time t_1 the incoming modulation envelope starts to decrease more rapidly than the time taken by the capacitor to decay. The output again meets the modulation envelope at t_2.

Thus it can be concluded that the Decay Time Constant RC of load should not be too small and neither should it be too large. The circuit is designed in such a way to satisfy the condition.

$$\boxed{\text{Decay Time Constant } RC \geq T_p} \quad (1)$$

where $f_C = \frac{1}{T_p}$ is carrier frequency & T_p is the Time period of $V_{AM}(t)$.

Design Consideration Regarding Charging Time Constant $R_S C$

During positive half cycles of input $V_{AM}(t)$, $V_a > V_b$

and diode is forward biased and conducting. The current that flows through diode charges up the capacitor to the peak value of input rf cycle. Assuming that waveform $V_{AM}(t)$ is supplied by the source of internal resistance R_s then during positive modulation cycles R_s is involved.

Charging Time Constant $R_s C$ should be such that capacitor charges rapidly and does not miss any cycle of frequency f_c if it is high. To satisfy this constraint condition to be satisfied during charging of capacitor is

$$\boxed{\text{Charging Time Constant } R_s C \leq T_p} \quad -(2)$$

Combining condition (1) & (2) we have.

$$\boxed{R_s C \leq T_p \leq RC}$$

This means that to design the Envelope detector suitably the

Charging Time Constant ≤ Time Period ≤ Decay Time Con

Function of Blocking Capacitor – C_b

The dc level called the offset also is seen in $V_{o/p}$ demodulated signal. Also it is rippled envelope due to decay of capacitor through R in every negative rf cycles. We use a dc blocking ~~C~~ Capacitor (C_b) that blocks the offset bringing $V_{o/p}$ down to zero level. Further this signal is passed through a low pass filter (LPF) with cutoff of f_m so that ripples are smoothened out. The LPF blocks all high frequency components causing the ripples and passes on baseband components from 0 Hz to f_m Hz.

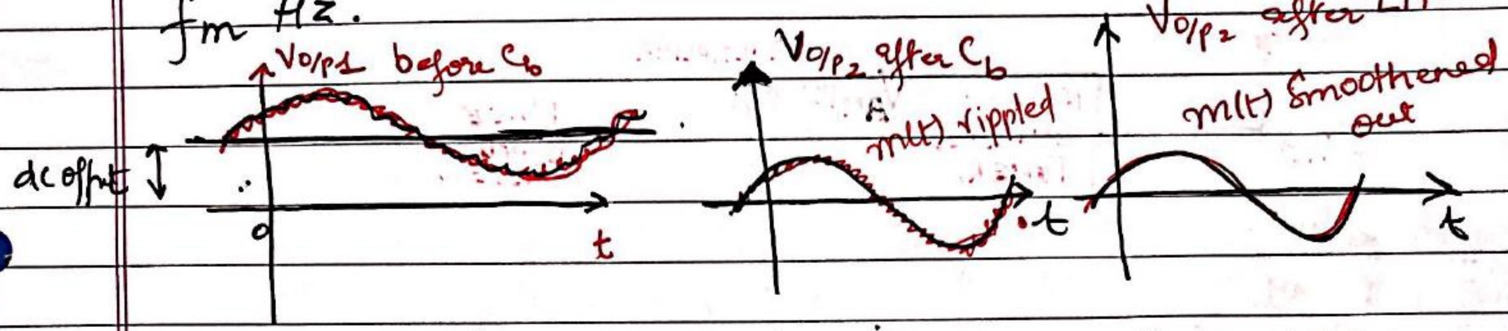

Figure 14:- Function of dc blocking Capacitor C_b and LPF.

C_b blocks the dc and only passes on the a.c component because $X_c = \frac{1}{j\omega C_b}$

Therefore for dc, $\omega = 0$ and $X_c \to \infty$

$\Rightarrow$ As $X_c \to \infty$; $C_b \equiv OC$ for dc level.

Q. Show that a DSB-Full Carrier Signal received at the Rx can also be demodulated by using
(a) A Coherent/Synchronous Product Detector
(b) A Square-law demodulator.

Solution:- (a) A Coherent/Synchronous Product Detector can also be used to demodulate the standard AM signal (DSB-full Carrier) represented as

$$V_{AM}(t) = A_c\left[1 + m(t)\right]\cos\omega_c t \quad (1)$$

Assume baseband signal $\boxed{m(t) = m \cos \omega_m t}$ where m is the modulation index and frequency f_m. Block diagram of this operation at Rx is shown in Figure 14 below. The functions of each block is explained.

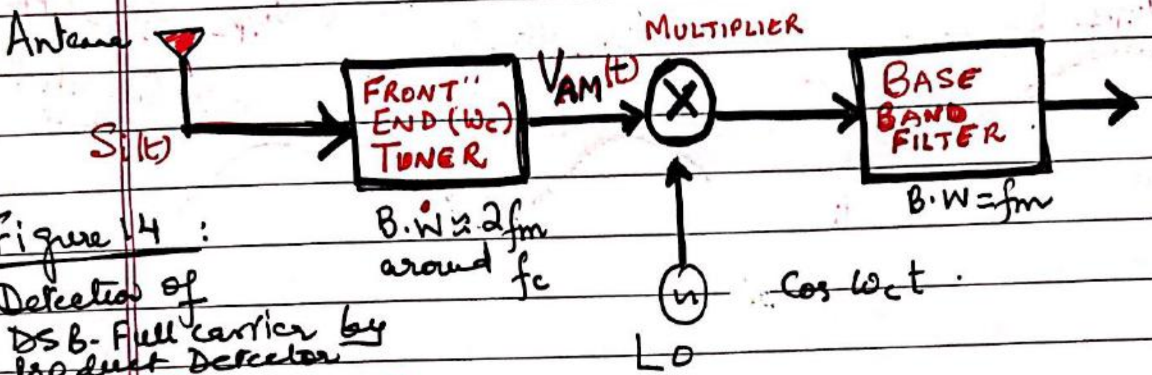

Figure 14 : Detection of DSB-Full carrier by Product Detector

FRONT END TUNER

At the Rx there is received signal comprising of many modulated channels. Out of these modulated channels we are interested in the detection of a particular channel $V_{AM}(t)$. The main function of the front End Tuner is to tune to the desired signal $V_{AM}(t)$ which is a DSB-Full carrier modulation around f_c and has $BW \simeq 2f_m$. All other channels are blocked.

MULTIPLIER

The multiplier input is $V_{AM}(t) = A_c[1 + m(t)] \cos \omega_c t$ (1) and LO generating a carrier $\cos \omega_c t$. Here we assume ideal conditions of carrier generated locally at Rx to be completely synchronized in phase & frequency with carrier that was used during modulation at Tx. Therefore output of multiplier is

$$\text{Multiplier O/p} = [V_{AM}(t)][\cos \omega_c t]$$

$$= \{A_c[1 + m(t)] \cos \omega_c t\} \cos \omega_c t \quad (2)$$

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Multipler output = $A_c[1+m(t)]\cos^2\omega_c t$.
Substitute $\cos^2\omega_c t = \frac{\cos(2\omega_c t)+1}{2}$.

$\therefore$ Multipler O/p $= A_c[1+m(t)]\left[\frac{\cos(2\omega_c t)+1}{2}\right]$ — (3)

$= \frac{A_c}{2}\left[\cos(2\omega_c t) + m(t)\cos(2\omega_c t) + 1 + m(t)\right]$.

Spectral Position of these Component :- At $2f_c$ At$(2f_c \pm f_m)$ At $f=0$ At f_m

$\cos(2\omega_c t)$ is at $2f_c$ → Not required
$m(t)\cos(2\omega_c t)$ is at $2f_c \pm f_m$ → Not required
$\frac{A_c}{2}(1)$ is at $f=0$ → Not required
$m(t)$ is at f_m. → The detected baseband signal

Base Band Filter:-
The multipler output has four components each of amplitude $\frac{A_c}{2}$. The baseband filter is used that passes on frequencies from min to max of f_m frequency of baseband signal which are part of $m(t)$. $\frac{A_c}{2}[1]$ is a dc component and can be blocked by a capacitor. All other frequency greater than f_m of $m(t)$ are attenuated & blocked by BaseBand Filter.
The O/p of Baseband filter $= \frac{A_c}{2}[m(t)]$.

$\boxed{\text{BaseBand Filter O/p} = \left[\frac{A_c}{2}(m)\right]\cos\omega_m t}$ represents — (4)
the detected & demodulated desired signal.

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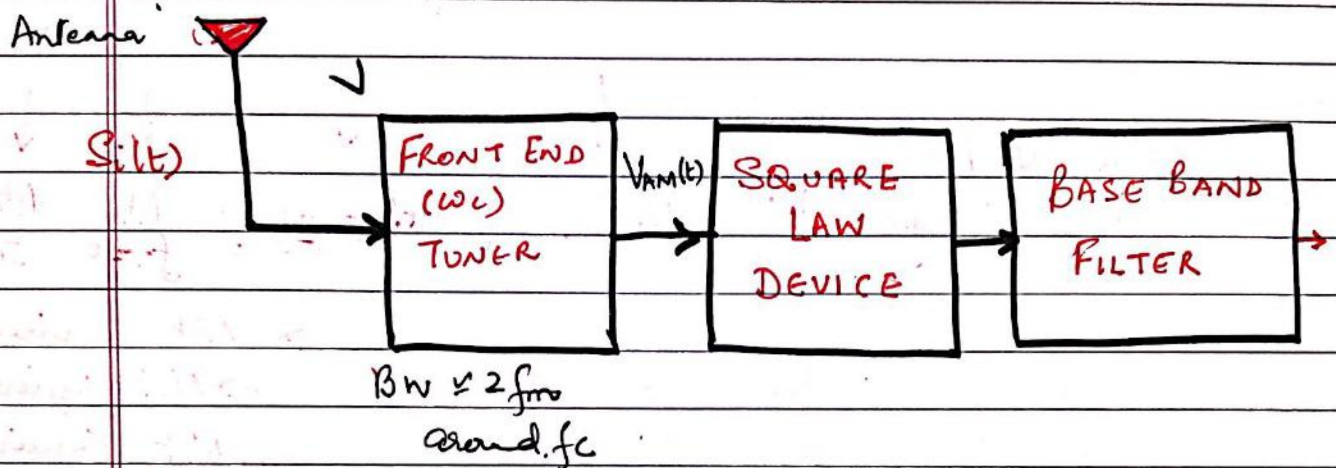
(b) A Square-law Demodulator can also be used for demodulation of a DSB-Full carrier signal of form

$$\boxed{V_{AM}(t) = A_c[1+m(t)]\cos\omega_c t} \quad \text{--- (1)}$$

The block diag employed is shown in Figure 15 below



Front End Tuner: The function of Front End Tuner is same as explained on page 203. The output is

$$V_{AM}(t) = A_c[1+m(t)]\cos\omega_c t.$$

Square Law Device: This block comprises of circuitry with an output that is proportional to square of input.

$$\underset{O/P}{\text{Square Law Device}} \propto \text{Input}.$$

$$\therefore \text{Square law Device } O/P = \lambda\,[V_{AM}(t)]^2 \quad \text{--- (5)}$$

Substitute $V_{AM}(t)$ from (1) in (5) above.

$$\therefore \text{Square Law Device} = \lambda\,\{A_c[1+m(t)]\cos\omega_c t\}^2$$
$$= \lambda\,[A_c^2\cos^2\omega_c t\,(1+m(t))^2]$$

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$$= \lambda A_c^2 \left[\frac{\cos(2\omega_c t) + 1}{2} \right] \left[1 + (m(t))^2 + 2m(t) \right].$$

$$= \frac{\lambda A_c^2}{2} \left[\cos(2\omega_c t) + 1 + m(t)^2 \cos(2\omega_c t) + m(t)^2 \right.$$
$$\left. + 2m(t)\cos(2\omega_c t) + 2m(t) \right].$$

Re arrang these ~~terms~~ 6 terms.

Square law Device o/p $= \frac{\lambda A_c^2}{2} \left[2m(t) \right] + \frac{\lambda A_c^2}{2} m(t)^2 + m(t)^2 \cos(2\omega_c t) \frac{\lambda A_c^2}{2}$
$$+ \frac{\lambda A_c^2}{2} \left[\cos(2\omega_c t) \right] + \frac{\lambda A_c^2}{2}$$
$$+ \frac{\lambda A_c^2}{2} \left[2m(t) \cos(2\omega_c t) \right] \Big].$$

Analyzing the frequency position of each of above components we observe.

(i) $\frac{\lambda A_c^2}{2}[2]\, m(t) \rightarrow$ is detected message signal at fm and amplitude λA_c^2. This is the desired component

(ii) $\frac{\lambda A_c^2}{2}\, m(t^2) \rightarrow$ This compont is at 2fm and has amplitude $\frac{\lambda A_c^2}{2}$. This is an unwanted component.

(iii) $\frac{\lambda A_c^2}{2}\, m(t)^2 \cos(2\omega_c t) \rightarrow$ These are two components each of amplitude $\frac{\lambda A_c^2}{2}$. These are at $2f_c \pm 2f_m$. Again these are unwanted components

(IV) $\frac{\lambda A_c^2}{2}\left[\cos(2\omega_c t)\right] \rightarrow$ This is at $2f_c$ and has amplitude $\frac{\lambda A_c^2}{2}$. It is also an unwanted component

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(V) $\frac{\lambda A_c^2}{2}$ → This is a dc component at $f = 0$ and has amplitude $\frac{\lambda A_c^2}{2}$.

(VI) $\frac{\lambda A_c^2}{2}[2m(t)][\cos(2\omega_c t)]$ → These are two components each of amplitude λA_c^2. These are unwanted component at $2f_c \pm f_m$.

Out of all above six components the only desired component is $\boxed{\lambda A_c^2 f_m}$.

Base Band Filter:- Finally this filter at the end of Rx has same function as that explained in case of Synchronous detector on page 204.
It attenuates all components and only passes $\lambda A_c^2 f_m$ which is the recovered & detected baseband signal.
The dc component $\frac{\lambda A_c^2}{2}$ can also be cancelled by using a blocking capacitor