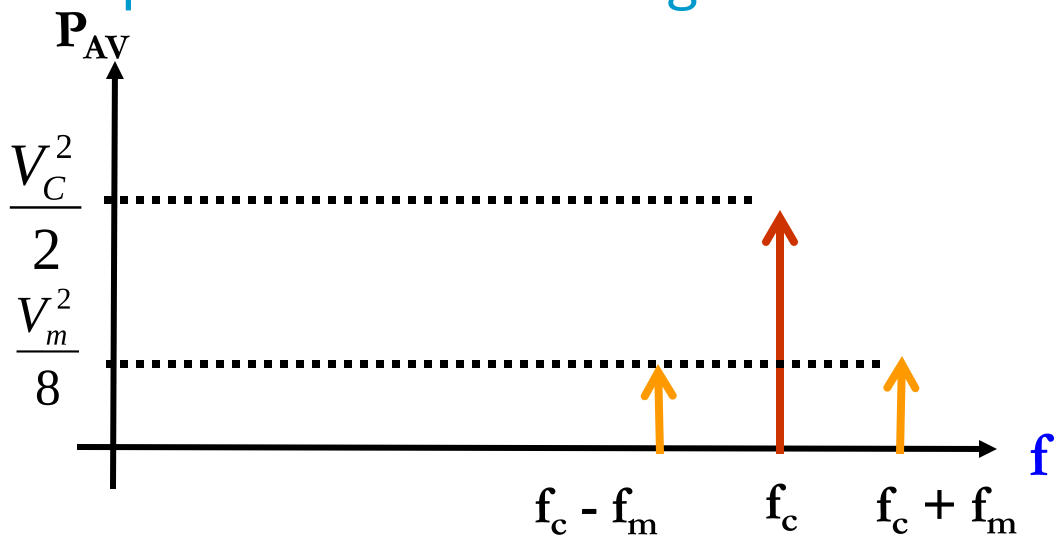
Amplitude Modulation:

Double Sideband Suppressed carrier

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier (SC)?

This is the power spectrum of an AM signal:



Power Spectrum

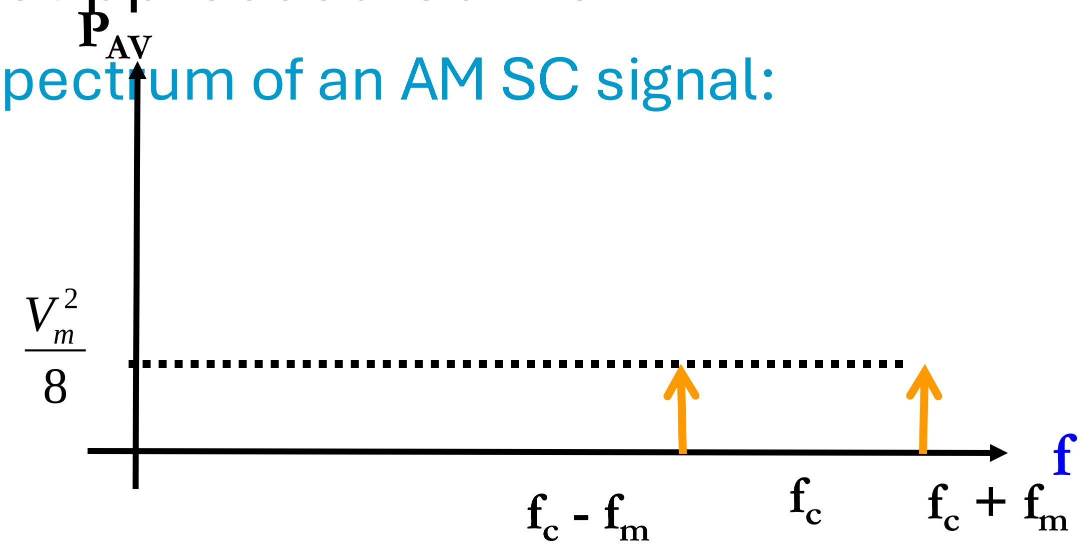
For m=1:

$$\mu = \frac{P_{SB}}{P_T} = \ldots\ldots\ldots\ldots$$

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier?

This is the power spectrum of an AM SC signal:



Power Spectrum

$$\mu = \frac{P_{SB}}{P_T} = 1$$

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier in the Time Domain?

In the Frequency Domain:

$$V_{AM}(f) = \frac{V_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right]$$

$$+\frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right] + \frac{V_m}{4}\left[\delta(f - f_{LSB}) + \delta(f + f_{LSB})\right]$$

$$V_{DSB-SC}(f) = \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right] + \frac{V_m}{4}\left[\delta(f - f_{LSB}) + \delta(f + f_{LSB})\right]$$

In the time domain:

$$v_{DSB-SC}(t) = \frac{V_m}{2}\cos(2\pi\ f_{USB}\ t) + \frac{V_m}{2}\cos(2\pi\ f_{LSB}\ t)$$

DSB - Suppressed carrier

Q: What is AM Suppressed Carrier in the Time Domain?

In the time domain:

$$v_{DSB-SC}(t) = \frac{V_m}{2}\cos(2\pi\ f_{USB}\ t) + \frac{V_m}{2}\cos(2\pi\ f_{LSB}\ t)$$

$$v_{DSB-SC}(t) = \frac{V_m}{2}\cos(2\pi\,(f_c + f_m)\,t) + \frac{V_m}{2}\cos(2\pi\,(f_c - f_m)\,t)$$

$$v_{DSB-SC}(t) = V_m\cos(2\pi\ f_m t) \bullet \cos(2\pi\ f_c\ t)$$

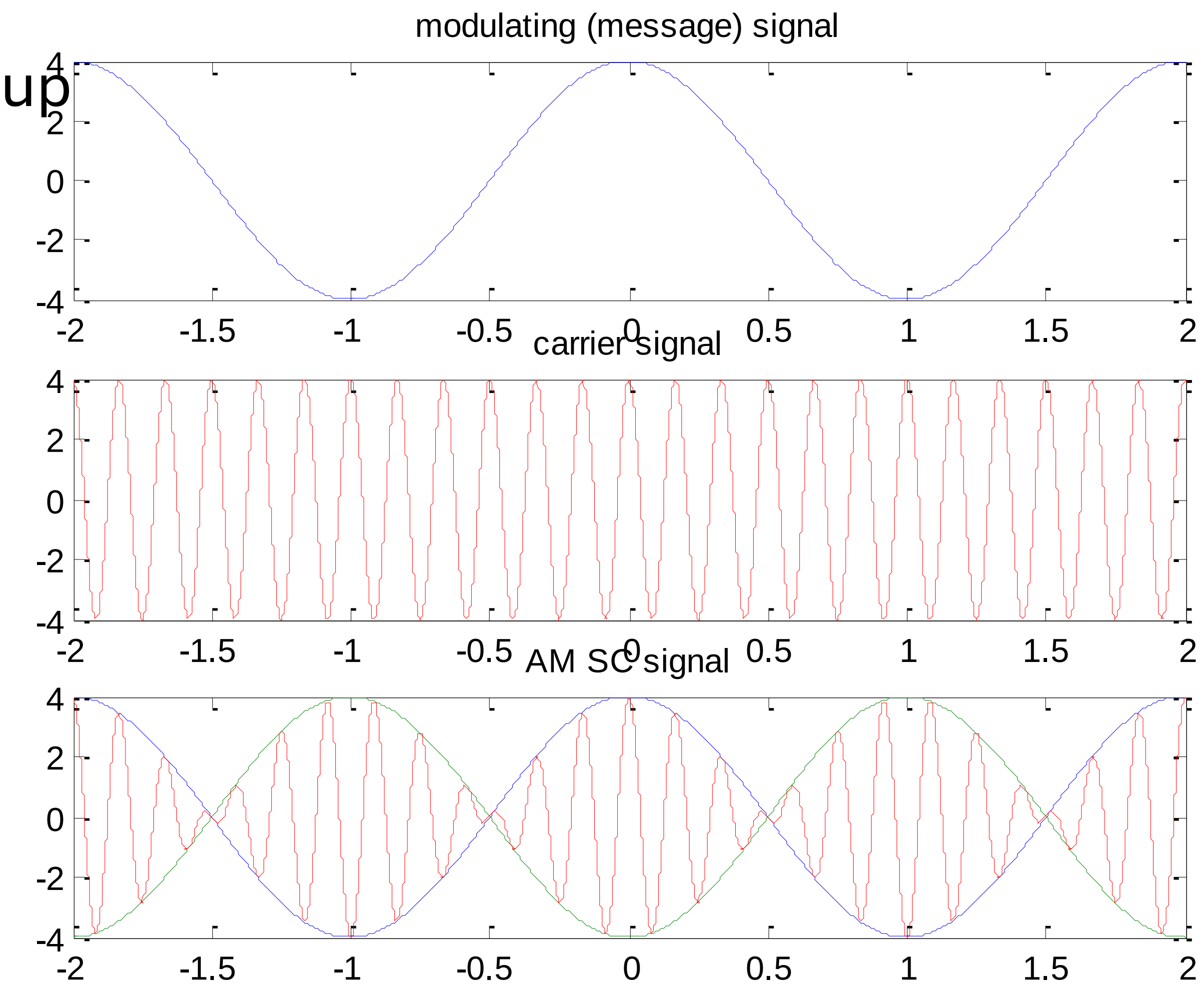
Compare to:

$$v_{DSB-TC}(t) = \left(V_c + V_m\cos(2\pi\ f_m\ t)\right)\ \cos(2\pi\ f_c\ t)$$

$$v_{DSB-TC}(t) = V_c\cos(2\pi\ f_c\ t) + V_m\cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$

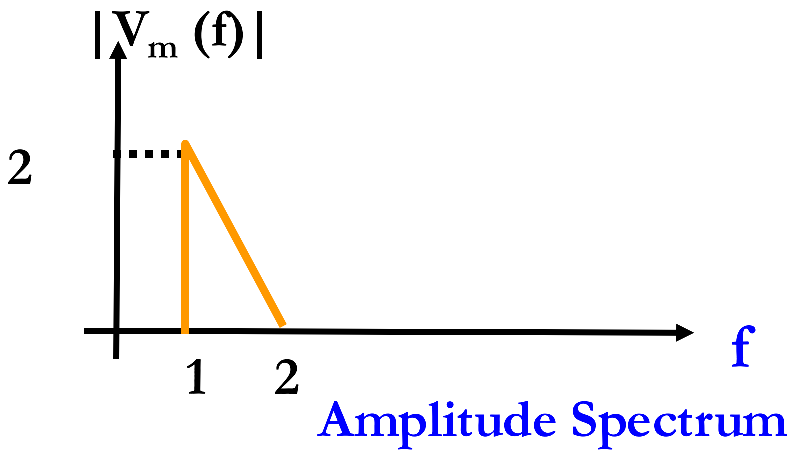
DSB Suppressed carrier

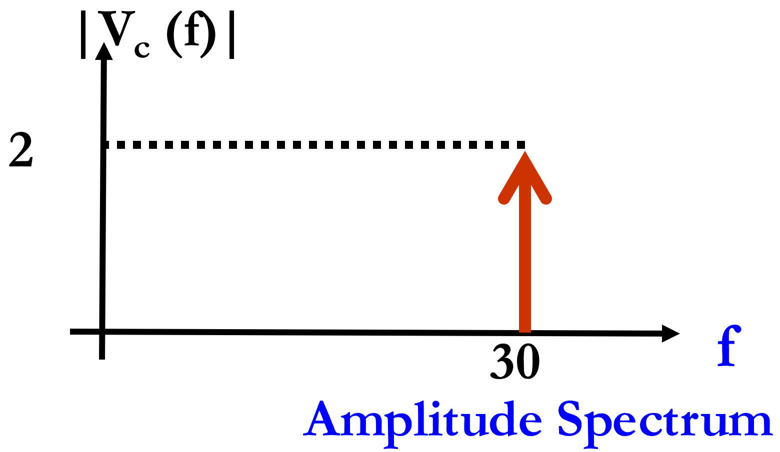
Q: What is AM Sup

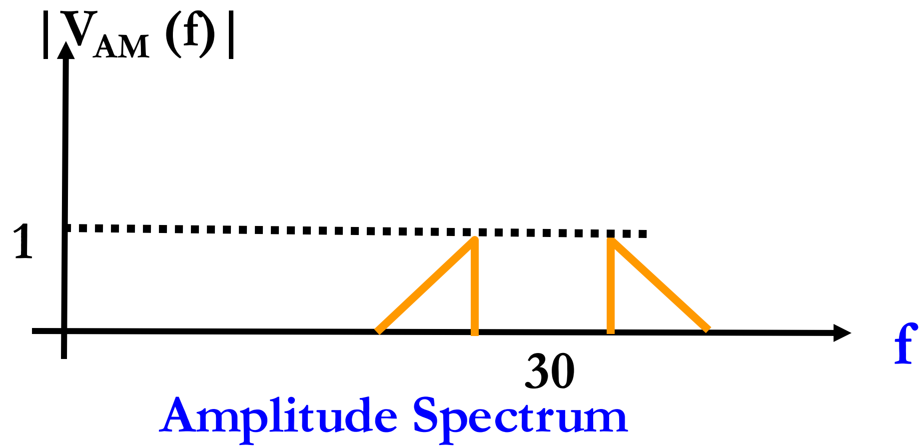


DSB-SC spectrum

Example: Find the spectrum of the following DSB-SC signal.







$$BW = f_{USB} - f_{LSB} = 2\,f_{\max}$$

DSB still requires twice the information BW

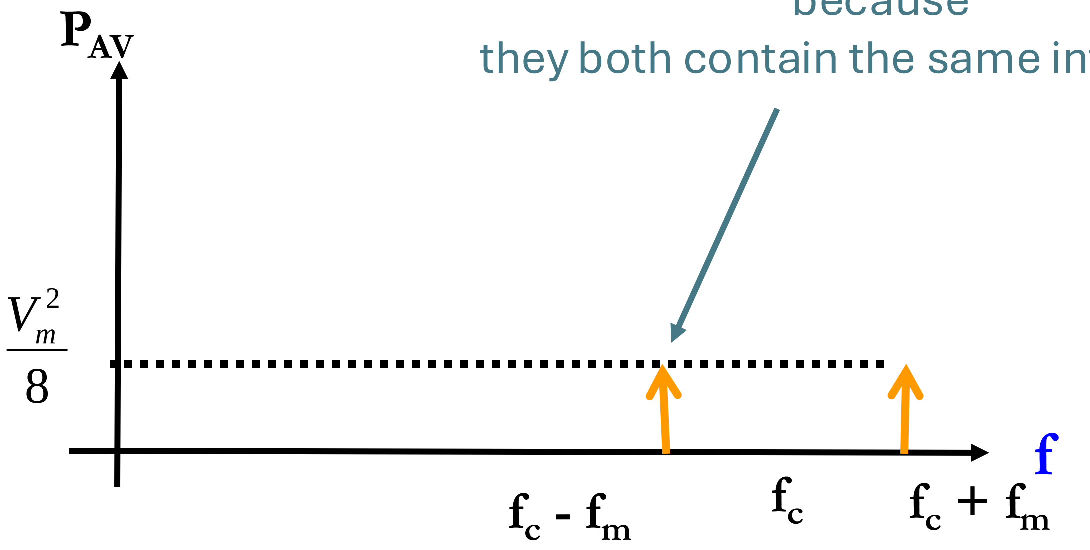
Amplitude Modulation:
Single Sideband (SSB)

Single Side Band AM

Q: What is Single Side Band AM?

Looking at the power spectrum of an DSB we notice that:

One side band may be removed because they both contain the same information



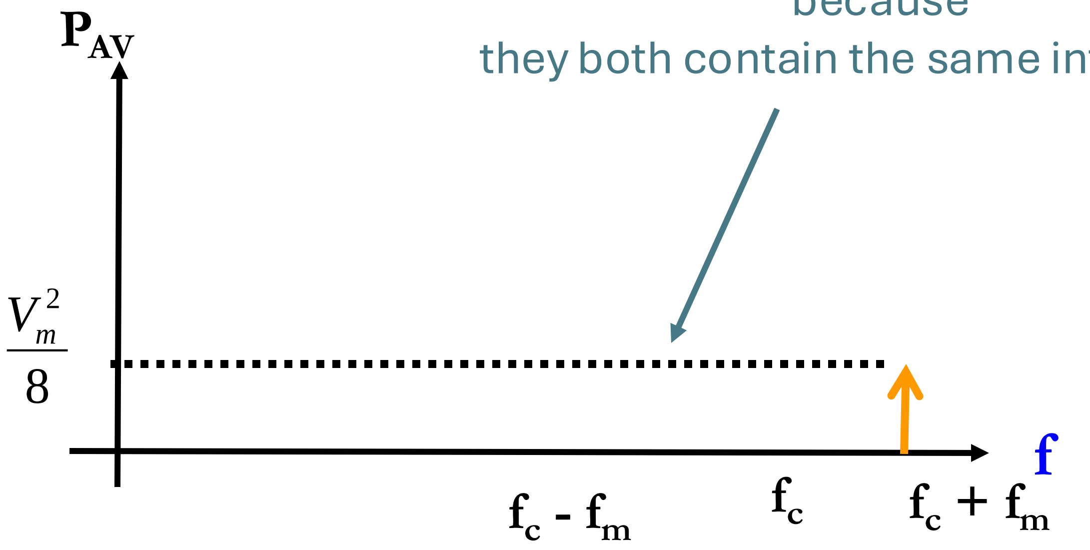
Power Spectrum

Single Side Band AM

Q: What is Single Side Band AM?

This is the power spectrum of an AM SSB signal:

One side band is removed
because
they both contain the same information



Power Spectrum

Single Side Band AM

Q: What is SSB in the Time Domain?

In the Frequency Domain:

$$V_{DSB-SC}(f) = \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right] + \frac{V_m}{4}\left[\delta(f - f_{LSB}) + \delta(f + f_{LSB})\right]$$

$$V_{SSB}(f) = \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right]$$

In the time domain:

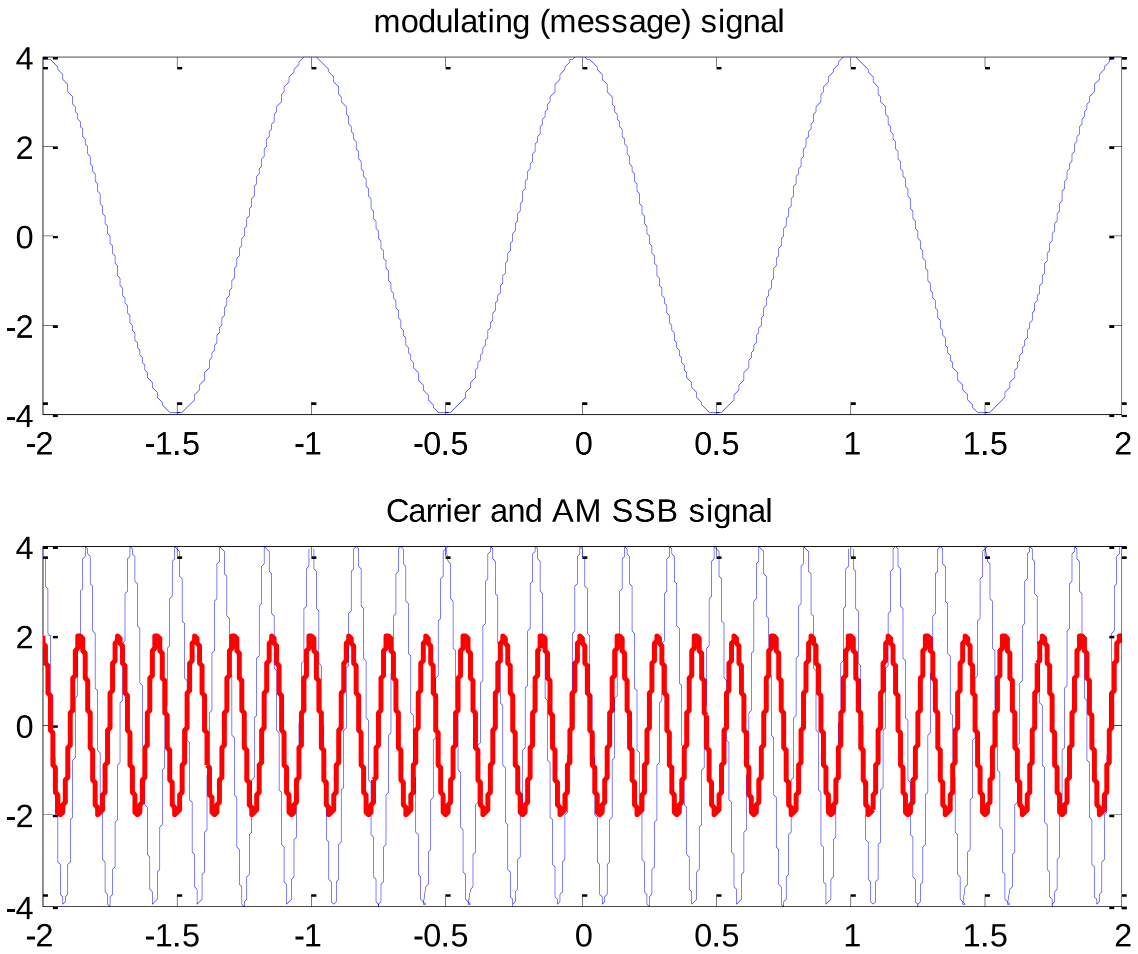
$$v_{SSB}(t) = \frac{V_m}{2}\cos(2\pi\ f_{USB}\ t)$$

$$v_{SSB}(t) = \frac{V_m}{2}\cos(2\pi\,(f_c + f_m)\,t)$$

Single Side Band AM

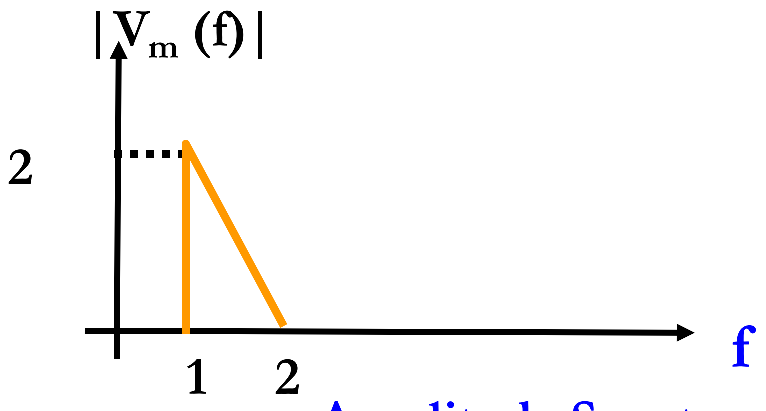
Q: What is Single Side Band AM in the Time Domain?

For tone modulation:

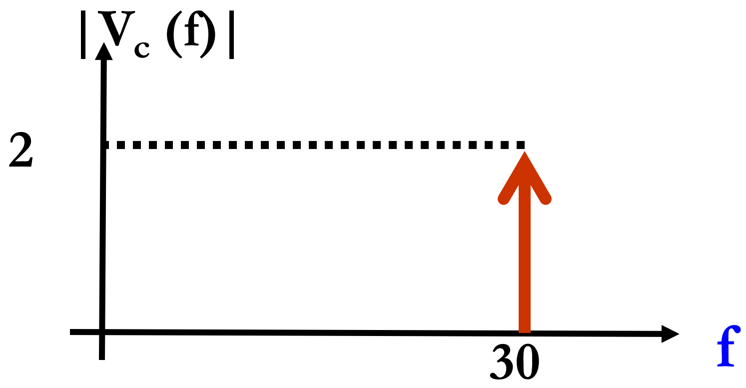


SSB spectrum

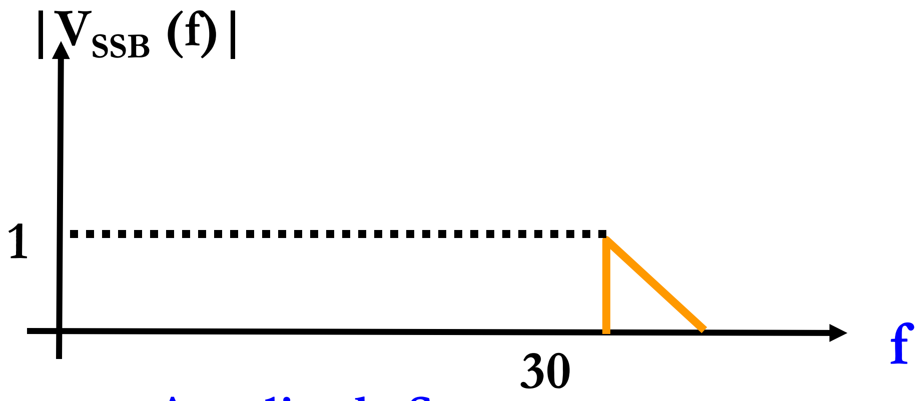
Exercise: Find the spectrum of the following DSB-SC signal.



Amplitude Spectrum



Amplitude Spectrum



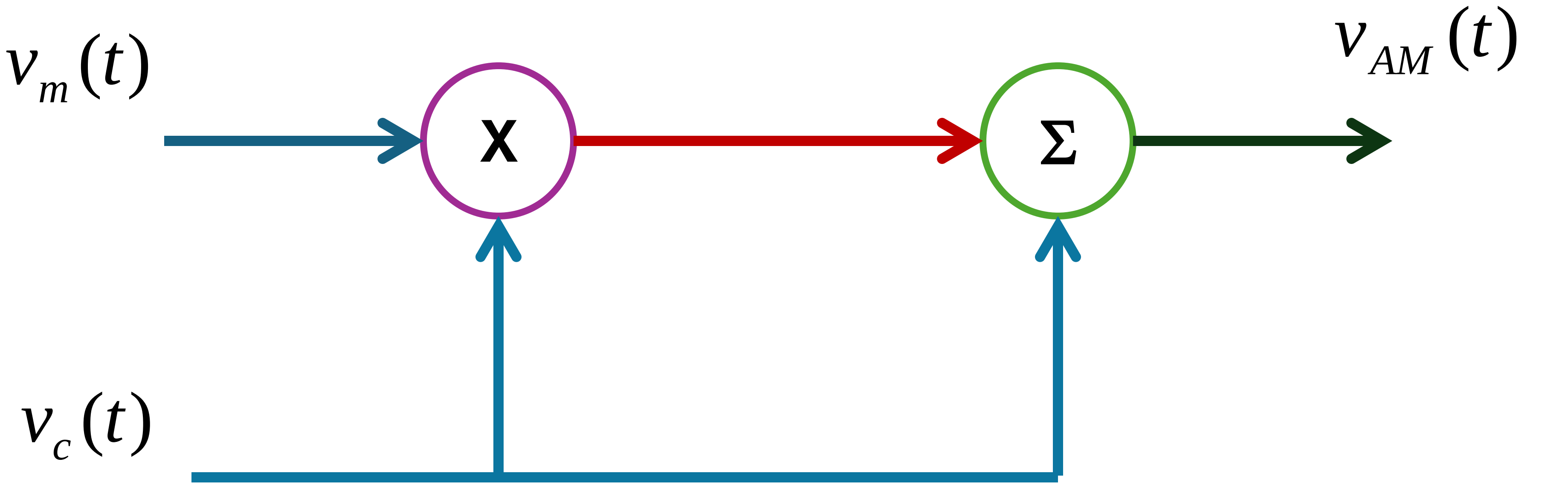
Amplitude Spectrum

$BW = \ldots\ldots\ldots\ldots$

Amplitude Modulation: Generation DSB-TC

Generation DSB-TC

$$v_{AM}(t) = V_c \cos(2\pi\ f_c\ t) + V_m \cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$



Generation DSB-TC

Q: How is a DSB-TC signal generated?

Using a modulator system.

In general to modulate mean mixing frequencies to get a different frequency.

A linear system will not do that for us:

We need nonlinear systems to modulate

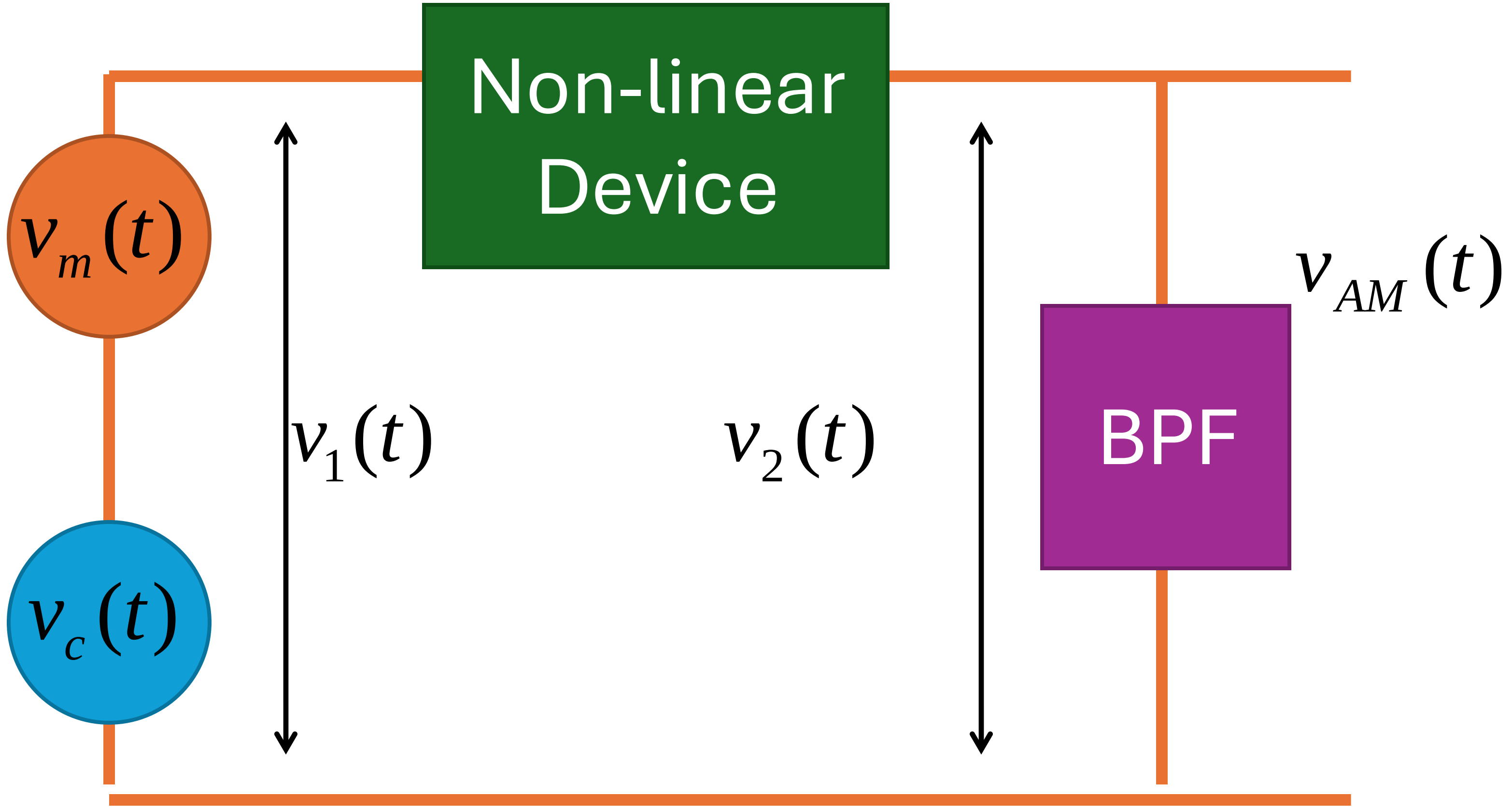
Generation DSB-LC

Q: What is an AM modulator?

We will study Square Law Modulator with non-linear device

Square Law Modulator

Q: What is a square law modulator?



Square Law Modulator

Q: What is a square law modulator?

The input to the Nonlinear Devices (NLD) is equal to:

$$v_1(t) = v_m(t) + v_c(t)$$

$$v_1(t) = v_m(t) + V_c \cos(2\pi\ f_c t)$$

The output of the NLD is:

$$v_2(t) = a_0 + a_1 v_1(t) + a_2 v_1^{\ 2}(t) + a_3 v_1^{\ 3}(t) + ...$$

We consider only second order terms:

$$v_2(t) \approx a_0 + a_1 v_1(t) + a_2 v_1^{\ 2}(t)$$

Square Law Modulator

Q: What is output of the nonlinear device?

Substituting:

$$v_2(t) \approx a_0 + a_1\left[v_m(t) + V_c \cos(2\pi\ f_c t)\right] + a_2\left[v_m(t) + V_c \cos(2\pi\ f_c t)\right]^2$$

$$v_2(t) \approx a_0 + a_1 v_m(t) + a_1 V_c \cos(2\pi\ f_c t)$$
$$+ 2a_2 v_m(t) V_c \cos(2\pi\ f_c t) + a_2\left[v_m(t)\right]^2 + a_2 V_c^2 \cos^2(2\pi\ f_c t)$$

$$v_2(t) \approx a_0 + a_1 v_m(t) + a_1 V_c \cos(2\pi\ f_c t)$$
$$+ 2a_2 v_m(t) V_c \cos(2\pi\ f_c t) + a_2\left[v_m(t)\right]^2 + \frac{a_2 V_c^2}{2}\left[1 + \cos(4\pi\ f_c t)\right]$$

Square Law Modulator

Q: What is output of the nonlinear device in the frequency domain?

Taking the Fourier Transform:

$$V_2(f) = \left[a_0 + \frac{a_2 V_c^2}{2}\right]\delta(f) + a_1 V_m(f) + \frac{a_1 V_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right]$$

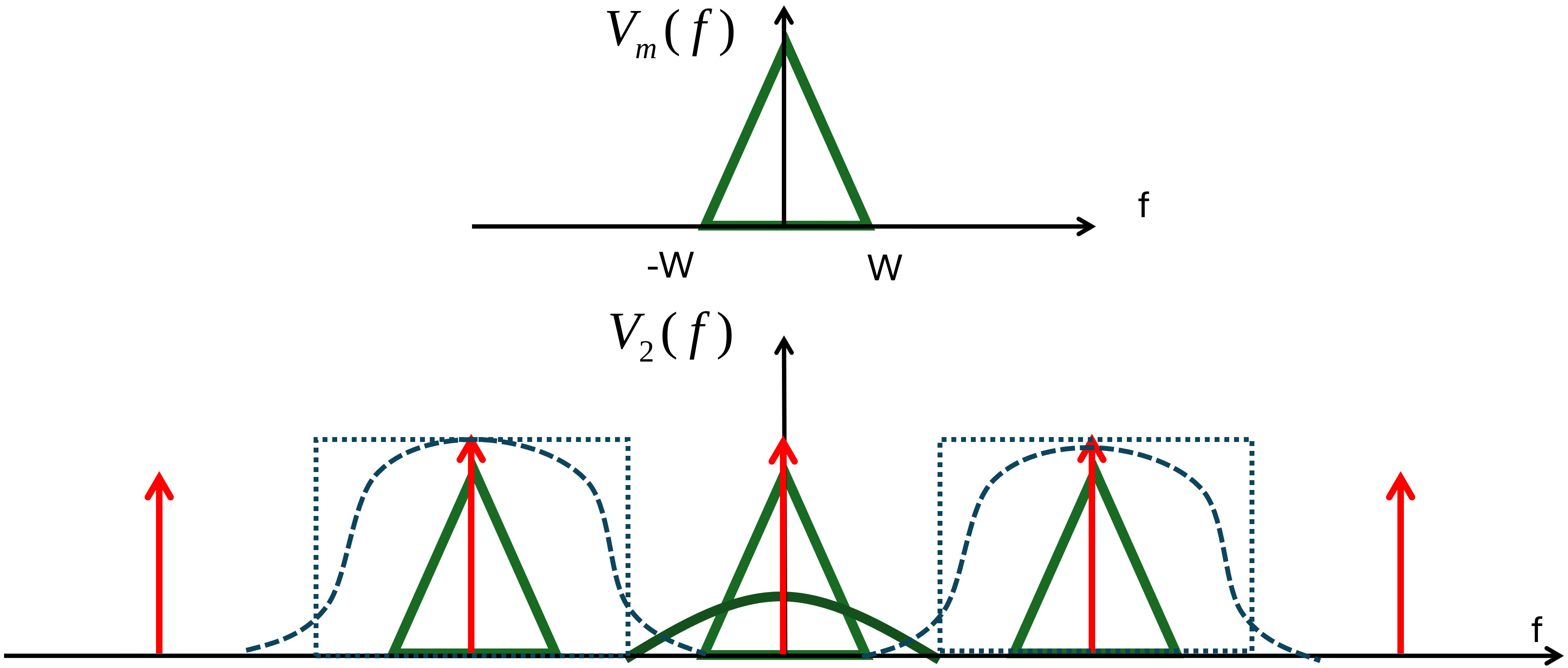
$$+ 2a_2 V_m(f) * \frac{V_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + a_2\left(V_m(f) * V_m(f)\right) + \frac{a_2 V_c^2}{4}\left[\delta(f - 2f_c) + \delta(f + 2f_c)\right]$$

$$V_2(f) = \left[a_0 + \frac{a_2 V_c^2}{2}\right]\delta(f) + a_1 V_m(f) + \frac{a_1 V_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right]$$

$$+ a_2 V_c\left[V_m(f - f_c) + V_m(f + f_c)\right] + a_2\left(V_m(f) * V_m(f)\right) + \frac{a_2 V_c^2}{4}\left[\delta(f - 2f_c) + \delta(f + 2f_c)\right]$$

Square Law Modulator

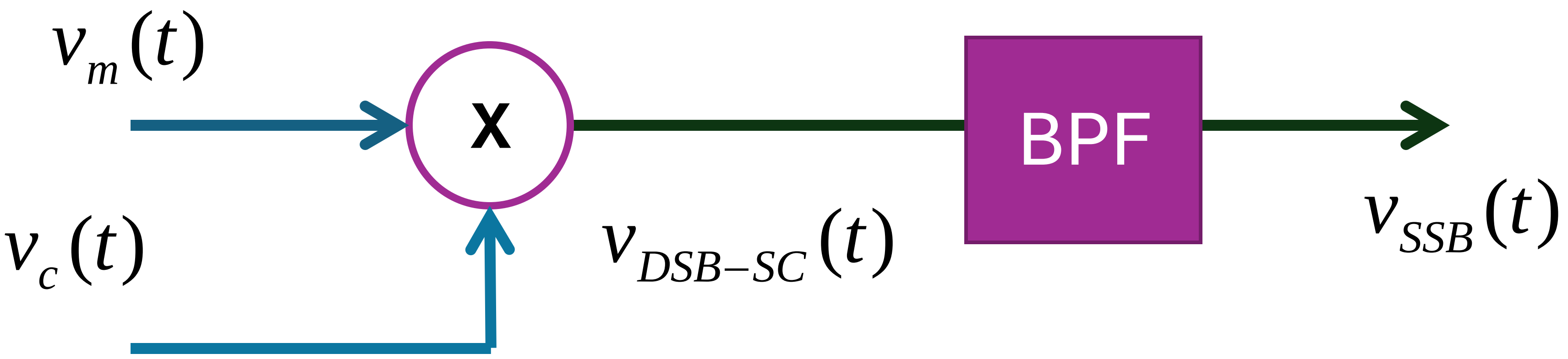
Q: Assuming the spectrum of the information signal, draw the $V_2(f)$.

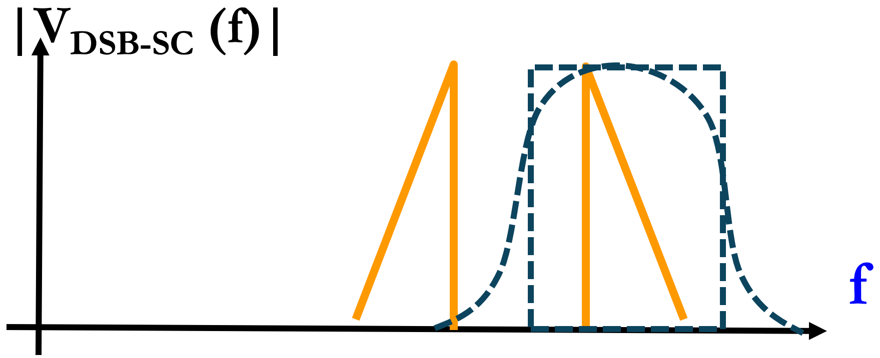


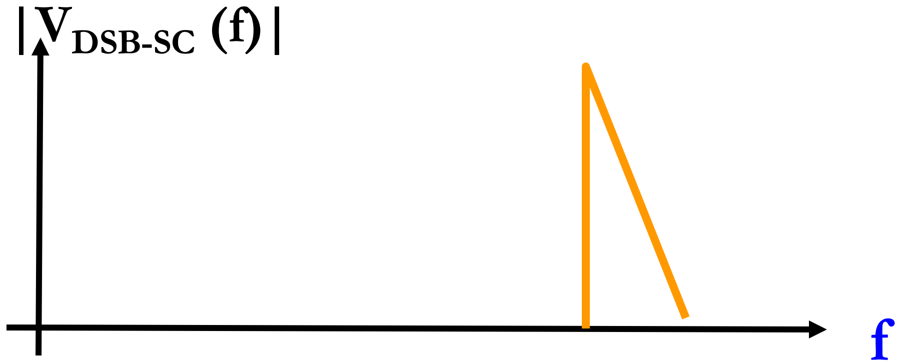
Amplitude Modulation: Generation SSB

Filtering Method

$$v_{SSB}(t) = \cos(2\pi\left(f_c + f_m\right)\ t) = \cos(\left(\omega_c + \omega_m\right)\ t)$$

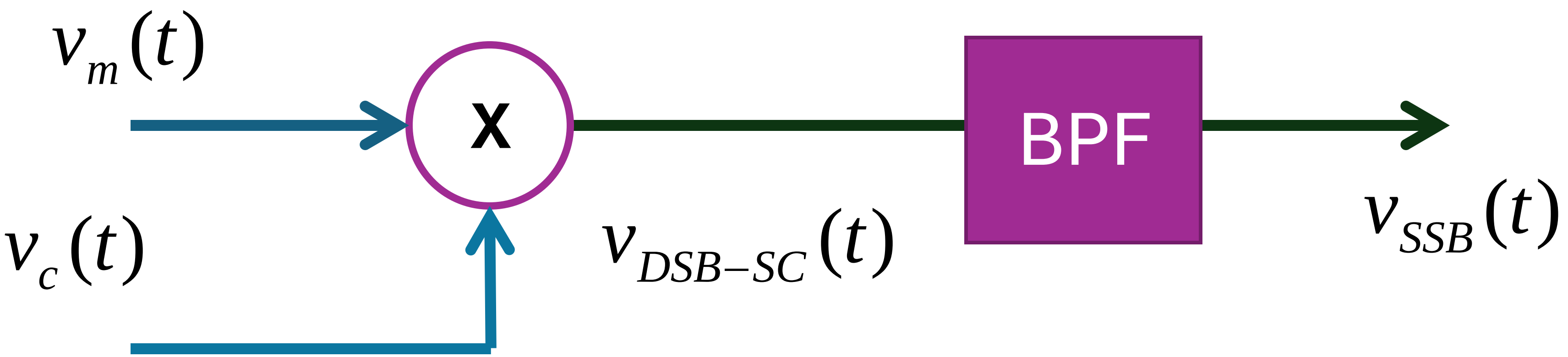


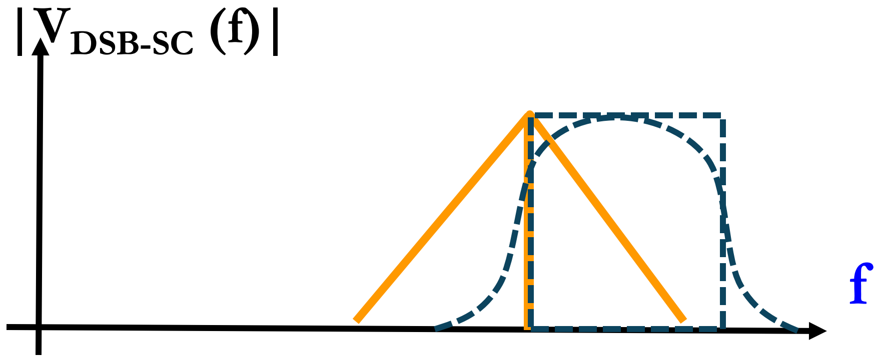


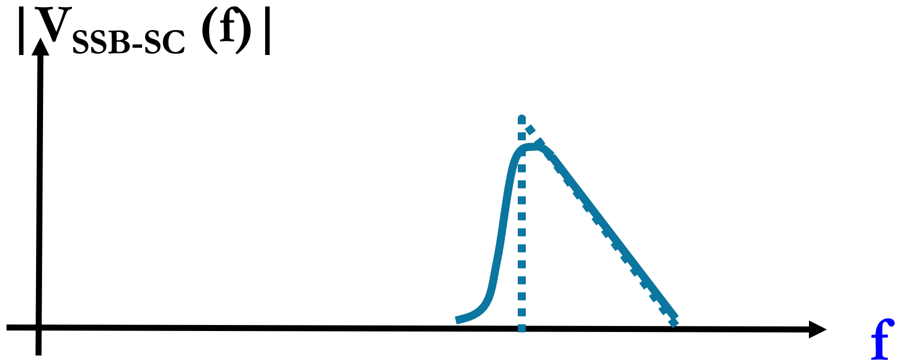


Limitations of Filtering Method

$$v_{SSB}(t) = \cos(2\pi\left(f_c + f_m\right)\ t) = \cos(\left(\omega_c + \omega_m\right)\ t)$$







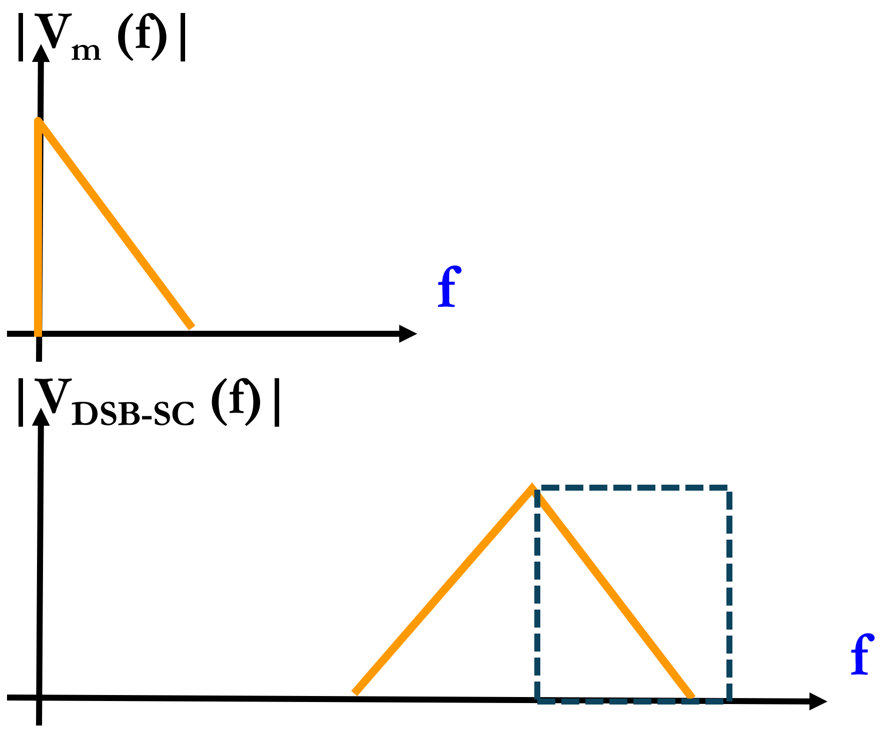
Amplitude Modulation: VSB

Vestigial Side Band (VSB

Q: What is Vestigial Side Band Modulation?

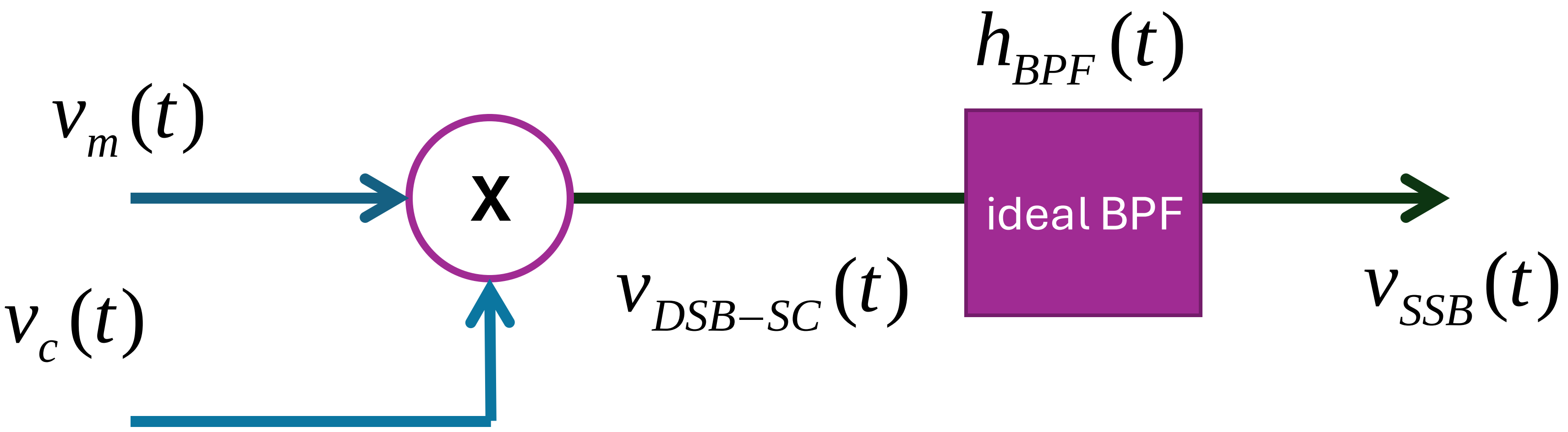
It is between DSB and SSB

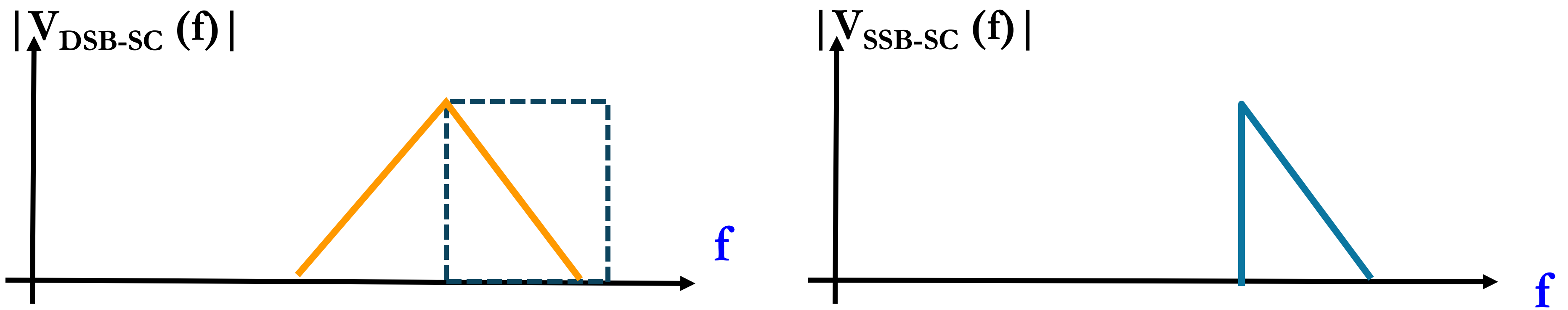
It is used for examples where it is difficult to filter out the LSB because the message signal contains frequencies down to DC



Vestigial Side Band (VSB)

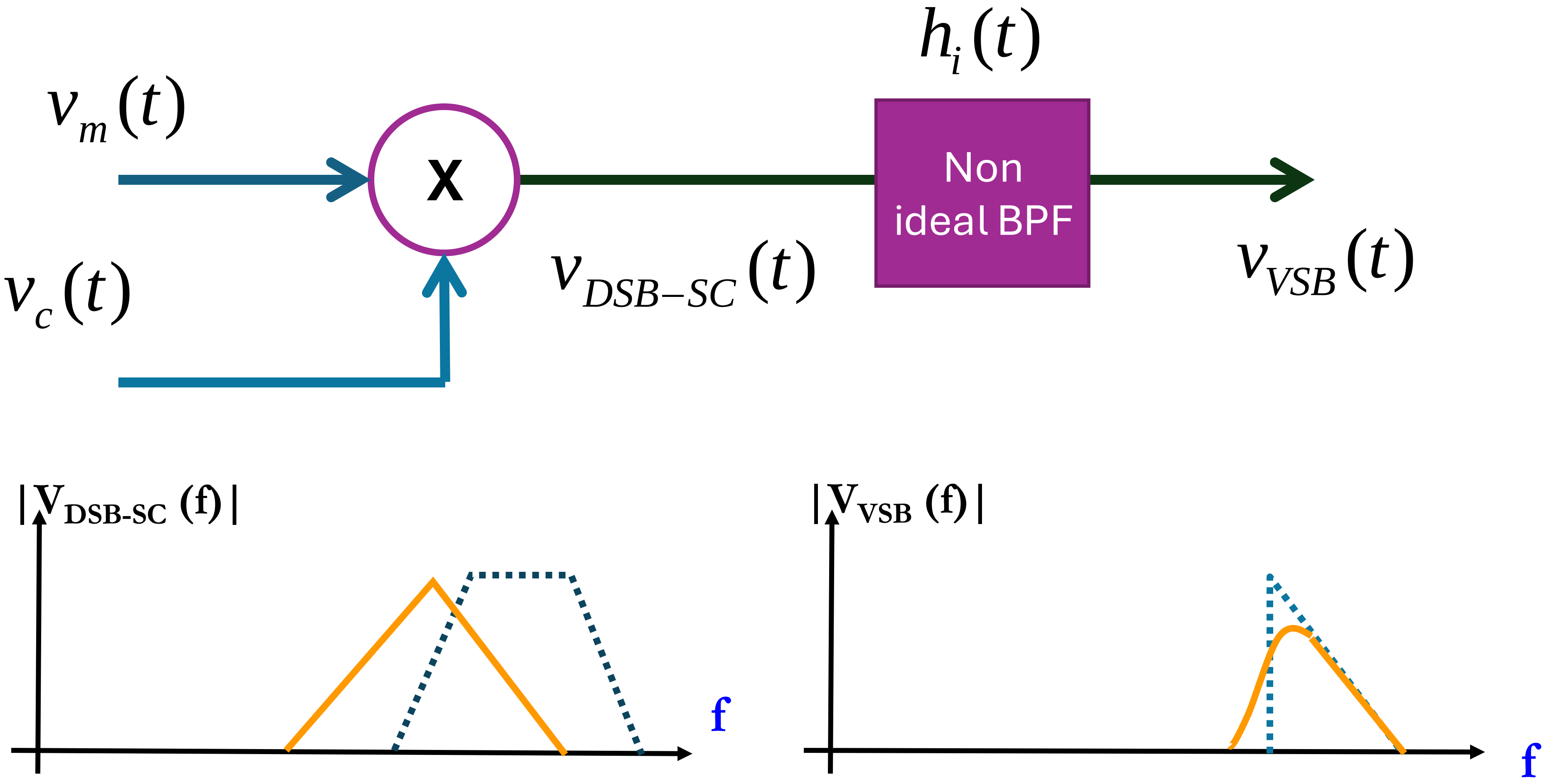
$$v_{DSB-SC}(t) = V_m \cos(2\pi\, f_m\, t)\cos(2\pi\, f_c\, t)$$





Vestigial Side Band (VSB)

$$v_{DSB-SC}(t) = V_m \cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$



Vestigial Side Band (VSB)

$$v_{SSB}(t) = v_{DSB-SC}(t) * h_{BPF}(t)$$

For SSB: $$V_{SSB}(f) = V_{DSB-SC}(f) \bullet H_{BPF}(f)$$

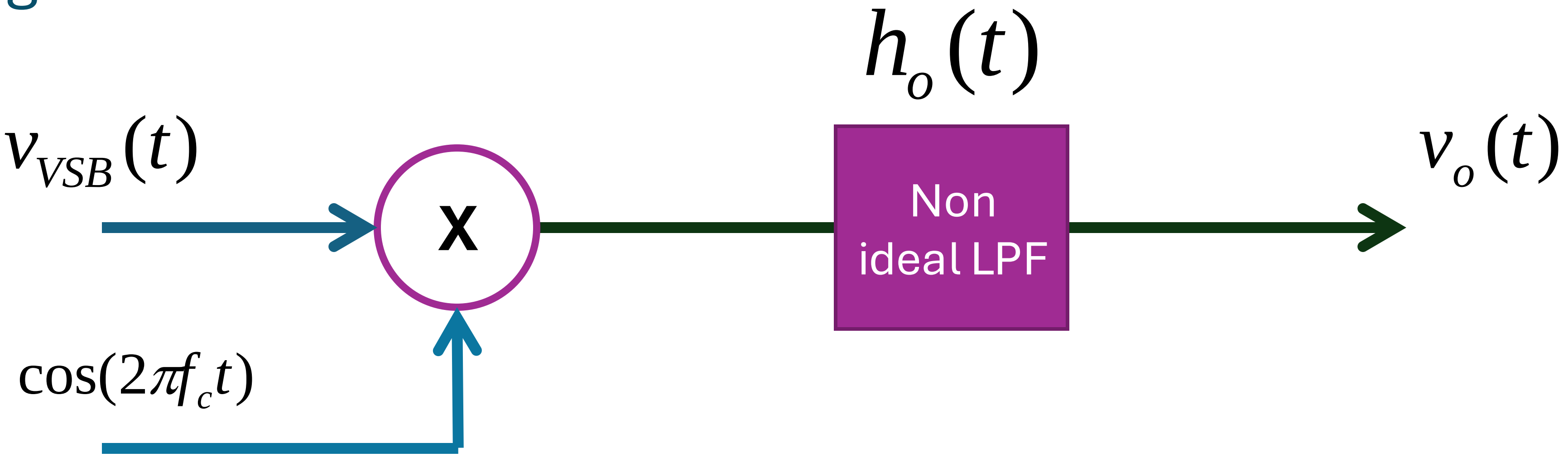
$$H_{BPF}(f) = \begin{cases} 1 & f_c \le f \le f_c + f_m \\ 0 & otherwise \end{cases}$$

For VSB: $$v_{VSB}(t) = v_{DSB-SC}(t) * h_i(t)$$

$$V_{VSB}(f) = V_{DSB-SC}(f) \bullet H_i(f) = \frac{1}{2}\left[V_m(f + f_c) + V_m(f - f_c)\right] \bullet H_i(f)$$

Vestigial Side Band (VSB)

We need to know the value of the filter such that we can recover the message when we demodulate.



$$v_o(t) = v_{VSB}(t)\cos(2\pi f_c t) * h_o(t)$$

$$V_o(f) = \frac{1}{2}\left[V_{VSB}(f - f_c) + V_{VSB}(f + f_c)\right] \bullet H_o(f)$$

Amplitude Modulation: Demodulation

Demodulation

Q: What is demodulation?

Demodulation is recovering the original message signal. Also known as detection.

Q: What is a demodulator?

It is a circuit that accepts a modulated signal and recovers the original message signal.

AM Demodulator

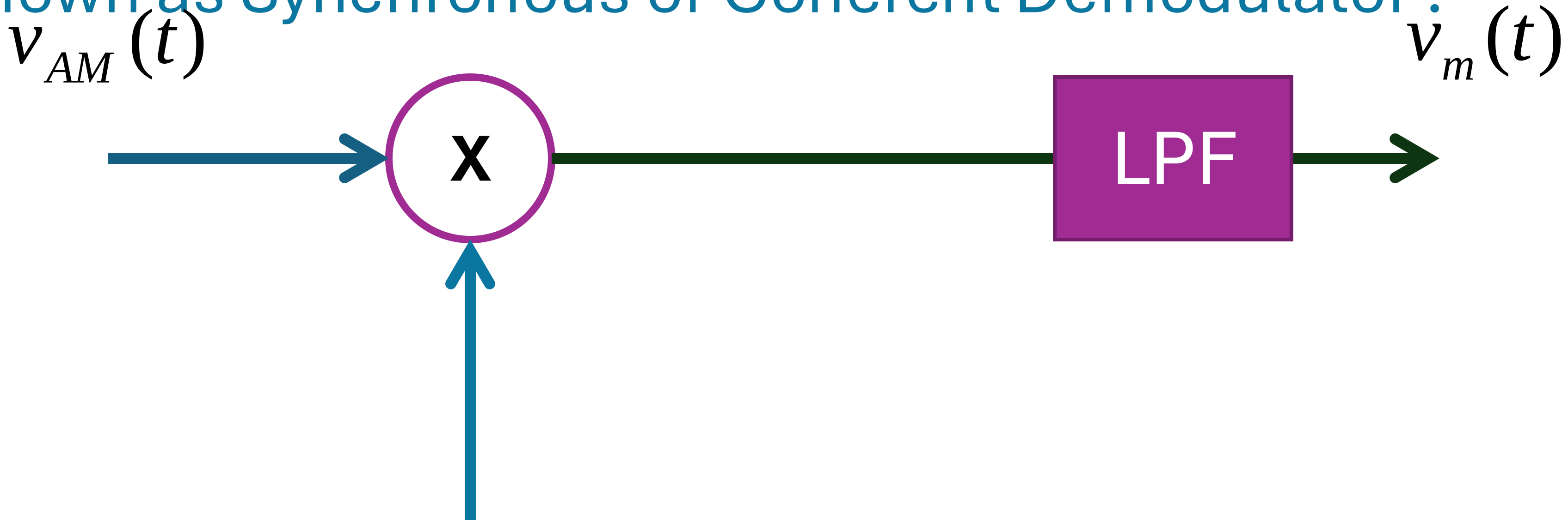
Q: What is an AM Demodulator?

A simple AM demodulator is an Envelope detector. It is circuit that detects the envelope of an AM signal, which is the information signal.

Homodyne Demodulator

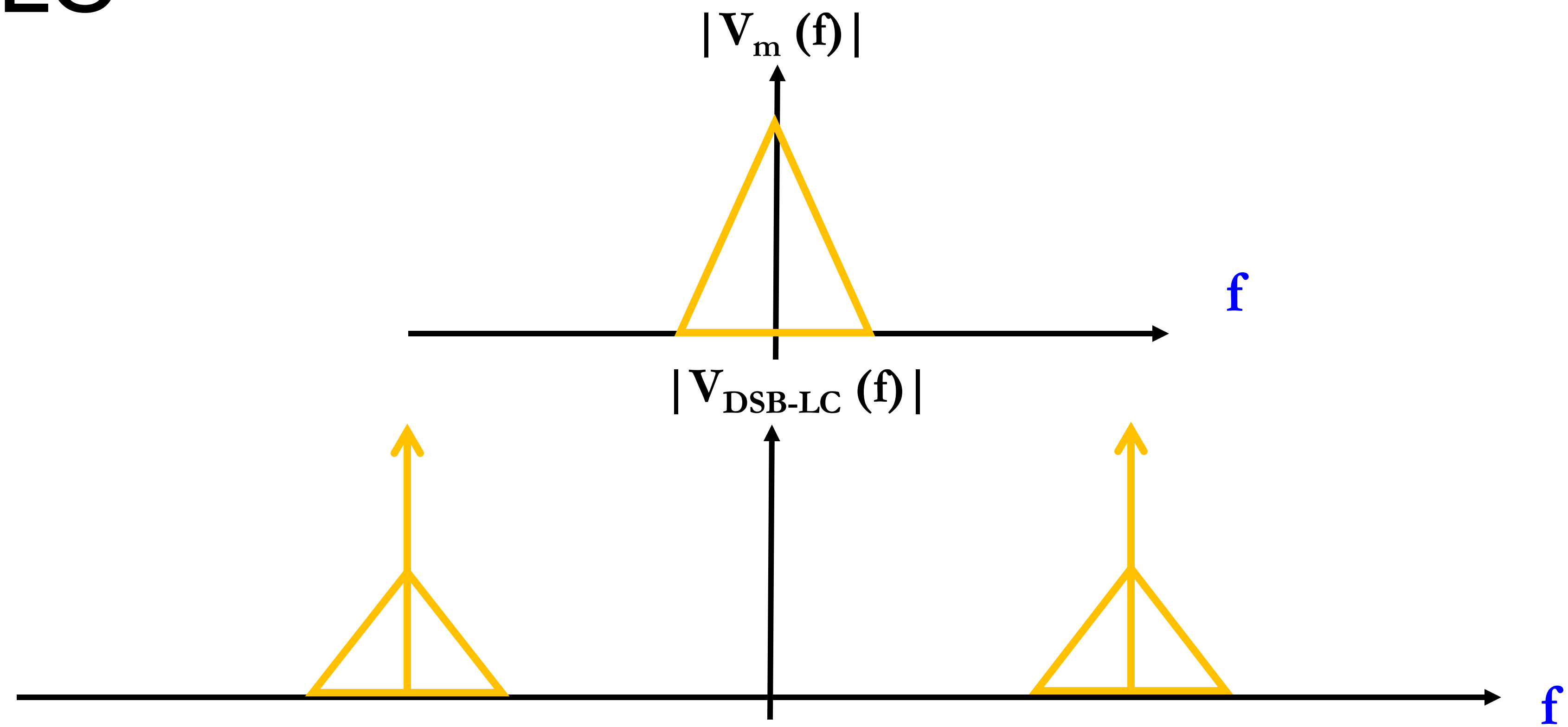
Q: What is a Homodyne Demodulator?

Also known as Synchronous or Coherent Demodulator :



$$v_c(t) = \cos(2\pi f_c t)$$

DSB-LC



Homodyne Demodulator

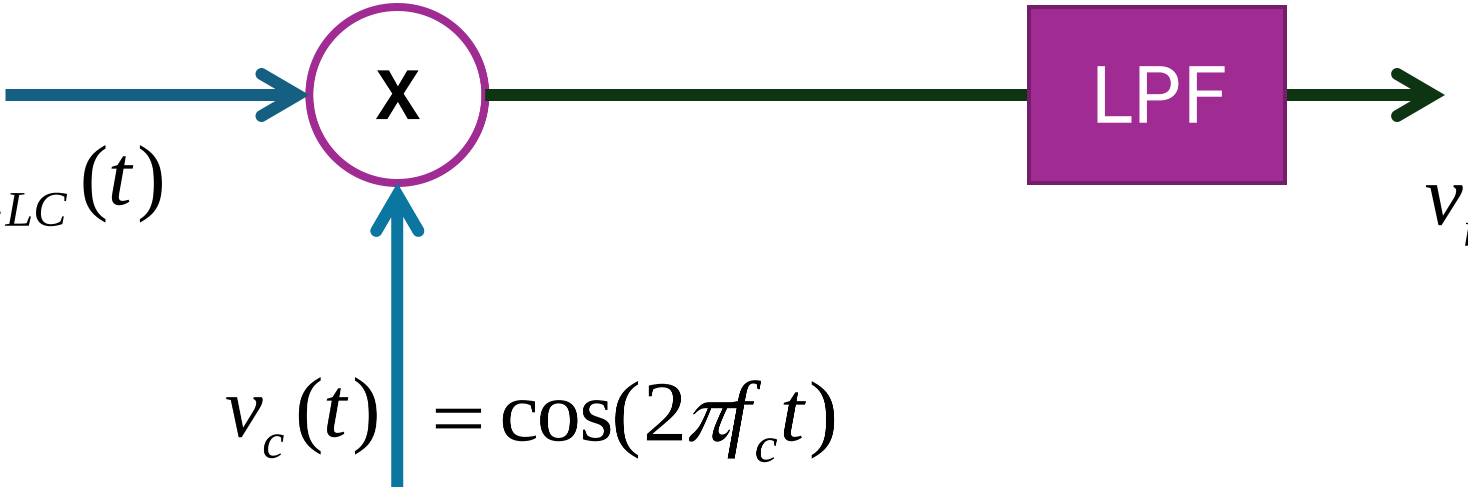
Q: What if the input is DSC-LC?

Also known as Synchronous or Coherent Demodulator :

$$v_{DSB-TC}(t) = V_c \cos(2\pi\ f_c\ t) + V_m \cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$

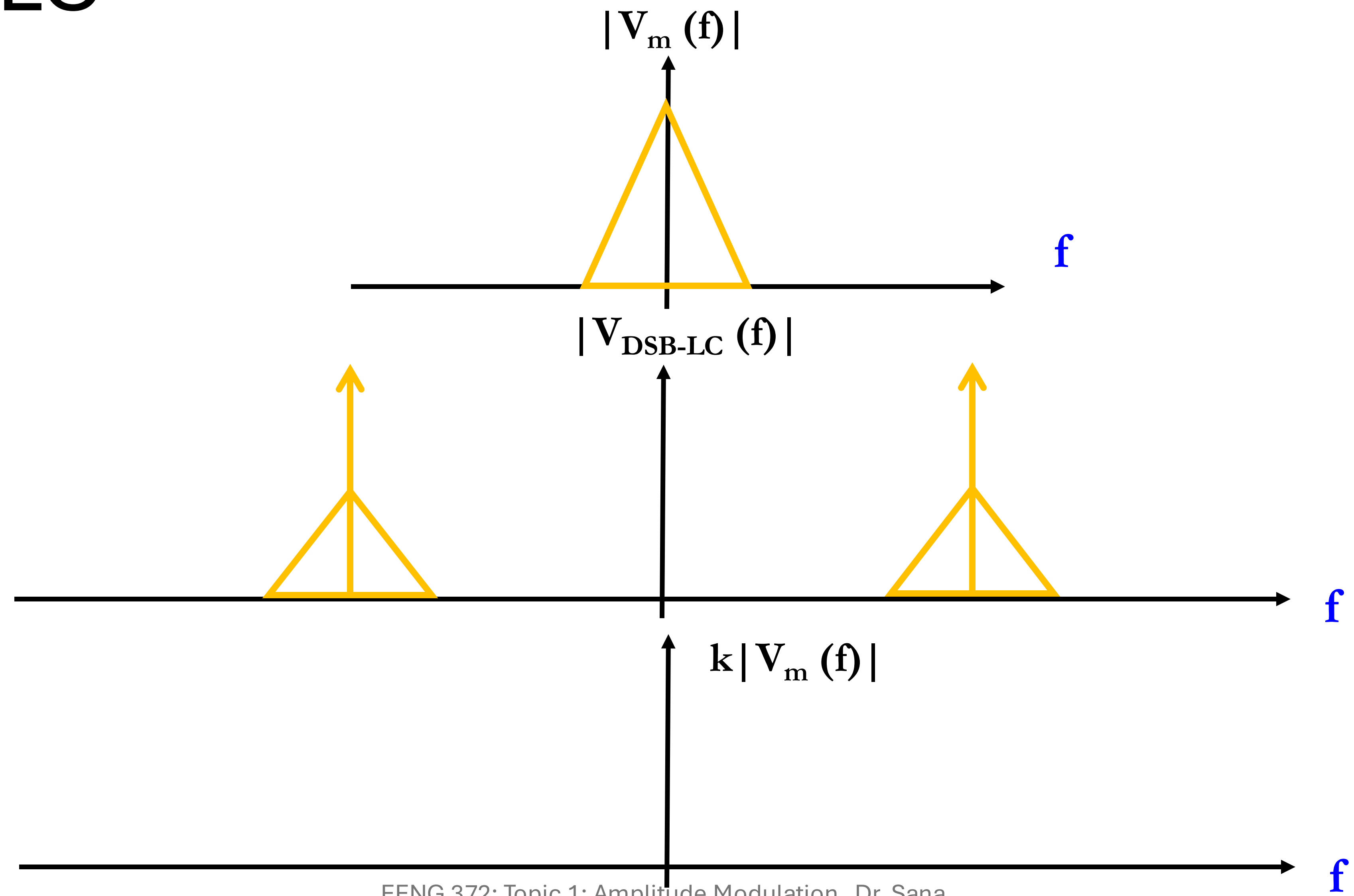
$$V_{DSB-LC}(f) = \frac{V_c}{2}[\delta(f - f_c) + \delta(f + f_c)]$$

$$+\frac{1}{4}[V_m(f - f_{USB}) + V_m(f + f_{USB})] + \frac{1}{4}[V_m(f - f_{LSB}) + V_m(f + f_{LSB})]$$

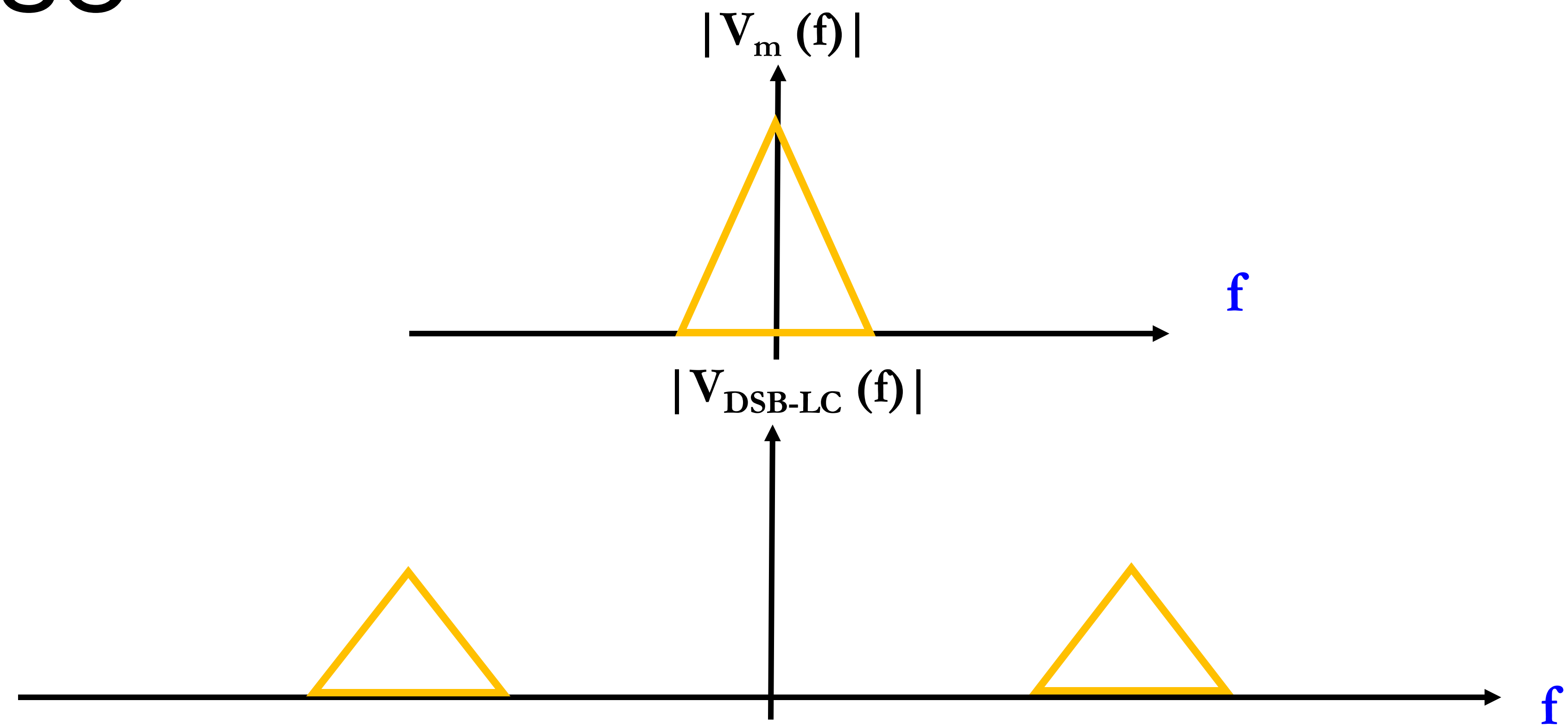


$v_{DSB-LC}(t)$ $v_m(t)$ $v_c(t) = \cos(2\pi f_c t)$

DSB-LC



DSB-SC



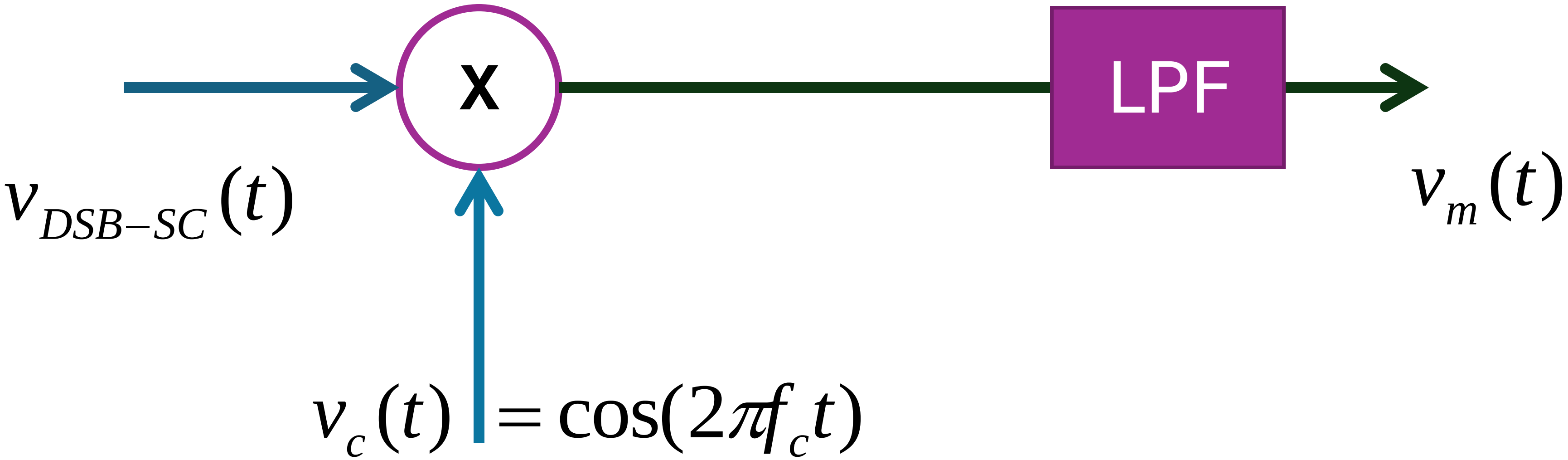
Homodyne Demodulator

Q: What if the input is DSC-SC?

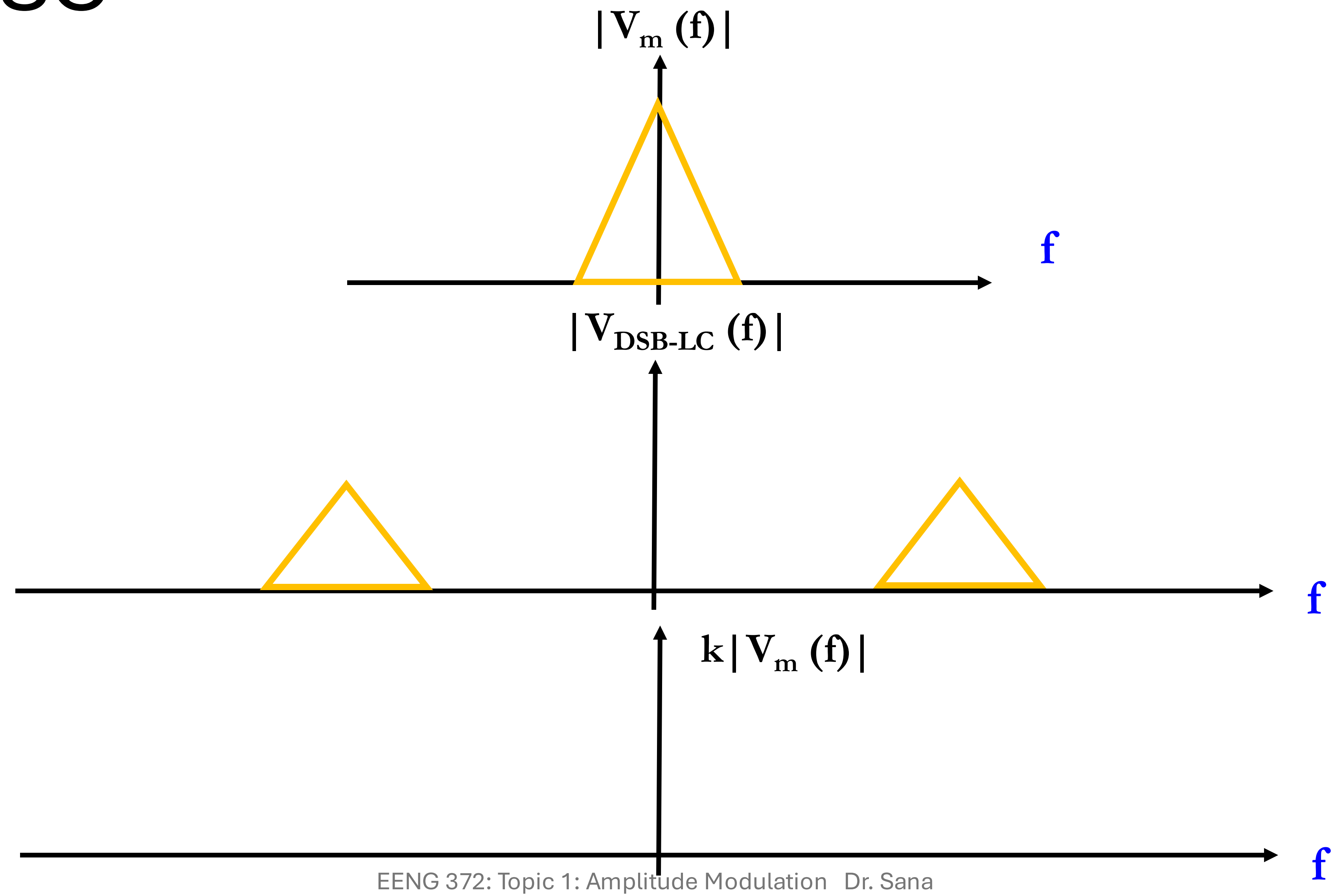
Also known as Synchronous or Coherent Demodulator :

$$v_{DSB-SC}(t) = v_m(t)\cos(2\pi f_c t)$$

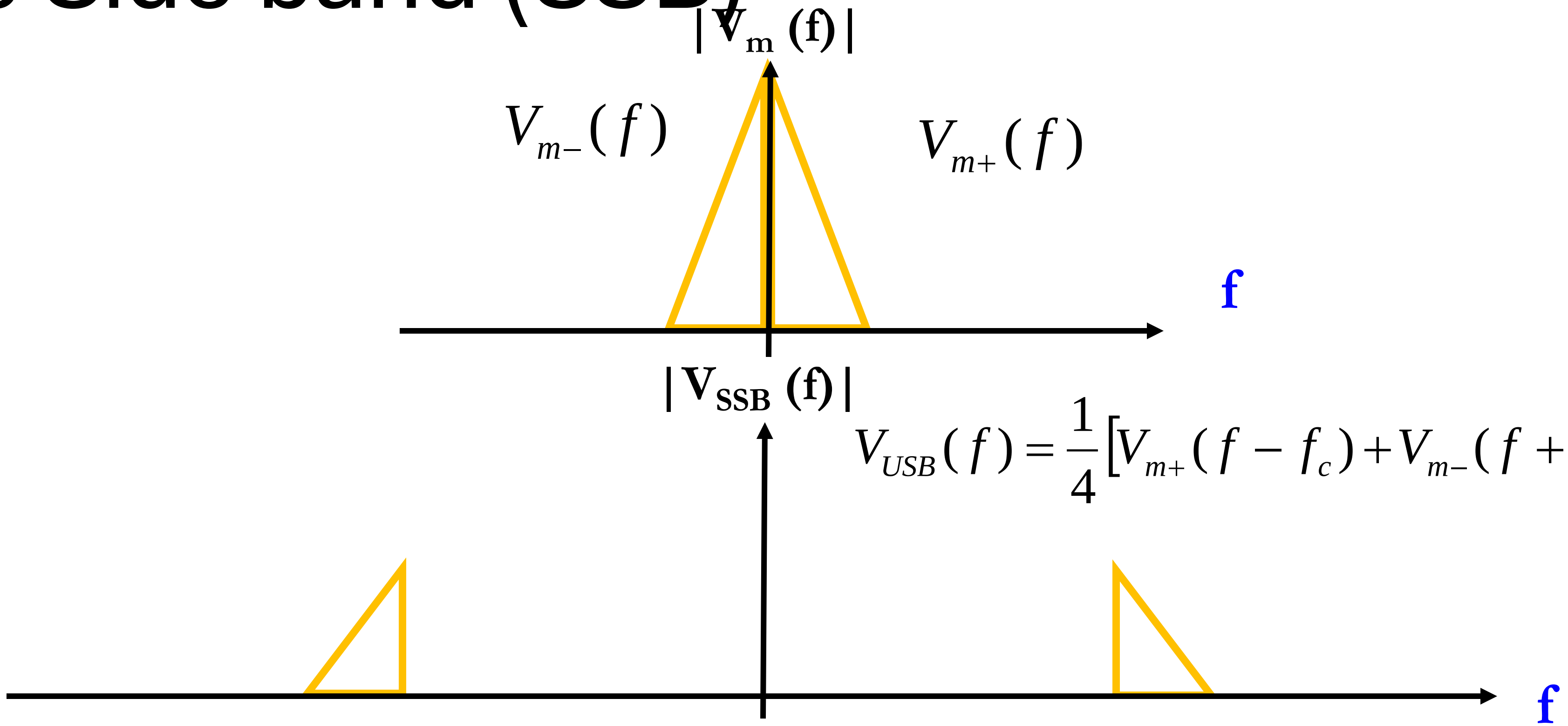
$$V_{DSB-SC}(f) = \frac{1}{2}\left[V_m(f - f_c) + V_m(f - f_c)\right]$$



DSB-SC



Single Side band (SSB)



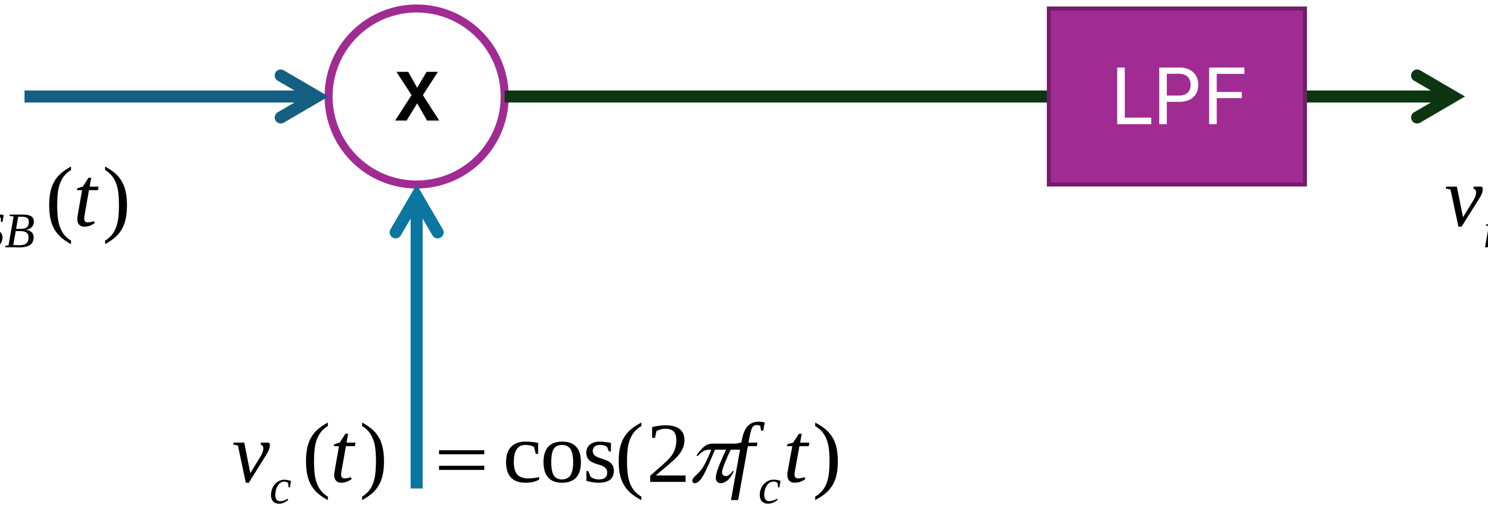
$$V_{USB}(f) = \frac{1}{4}\left[V_{m+}(f - f_c) + V_{m-}(f + f_c)\right]$$

Homodyne Demodulator

Q: What if the input is SSB?

Also known as Synchronous or Coherent Demodulator :

$$V_{USB}(f) = \frac{1}{4}\left[V_{m+}(f - f_c) + V_{m-}(f + f_c)\right]$$

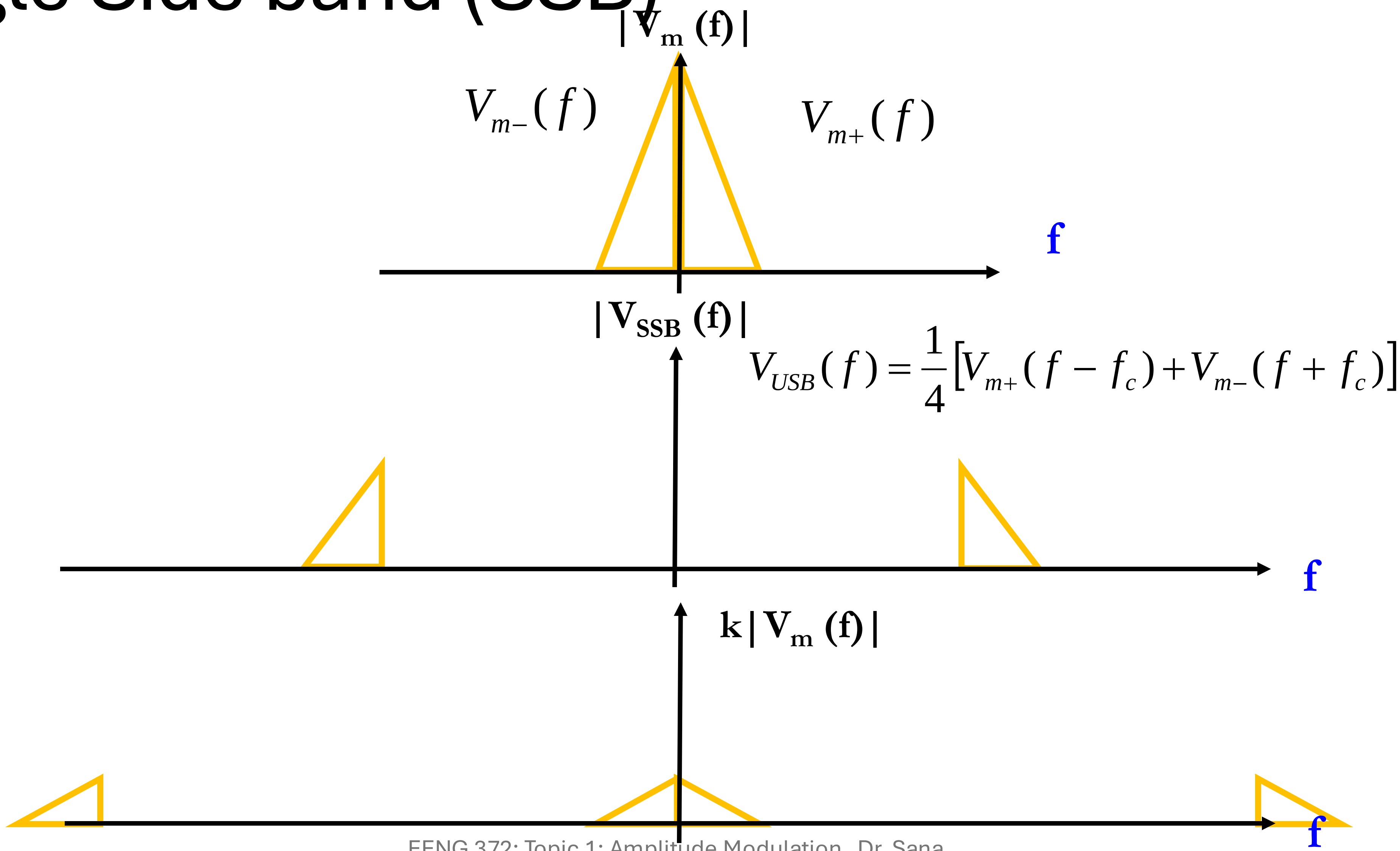


$v_{SSB}(t)$

$v_m(t)$

$v_c(t) = \cos(2\pi f_c t)$

Single Side band (SSB)



Frequency Division Multiplexing (FDM)