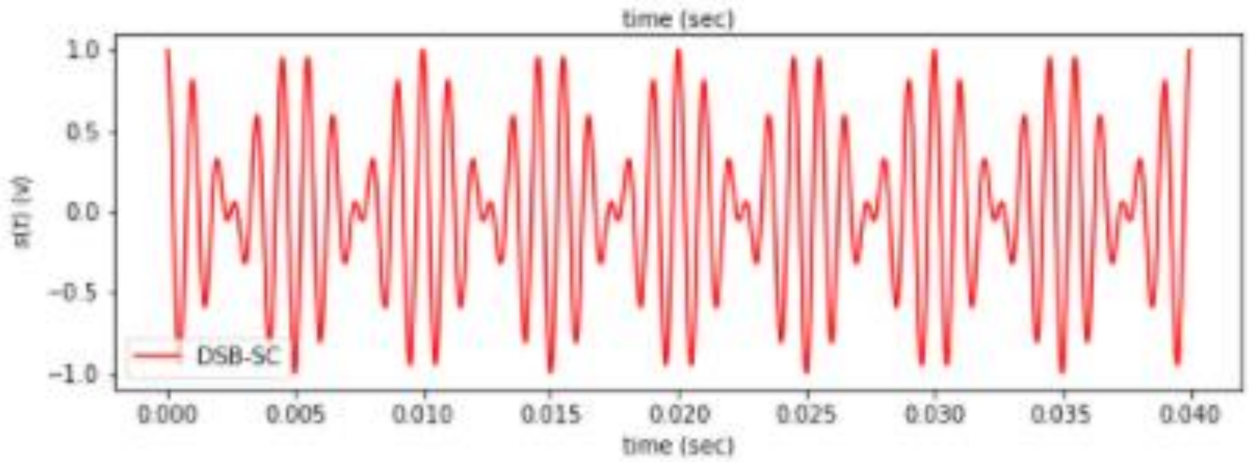
Double Sideband Suppressed Carrier (DSB-SC) Modulation: Lecture Outline

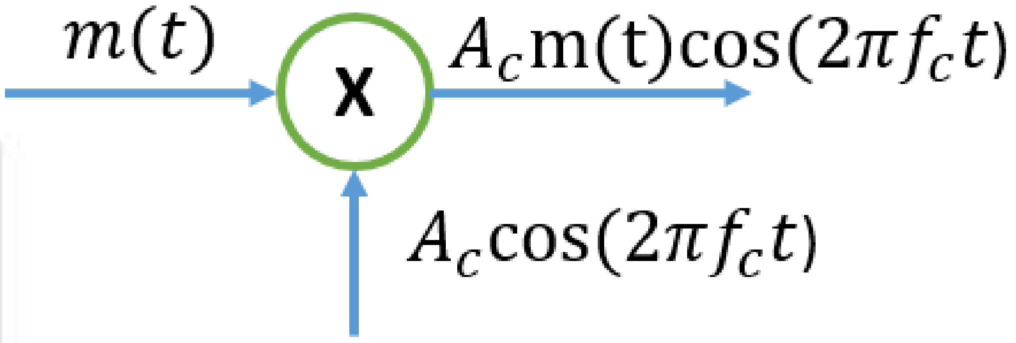
- In this lecture, we consider a second type of AM modulation called DSB-SC.
- We analyze this modulation technique in the time and frequency domains.
- Consider the generation and demodulation techniques.
- Study the effect of non-coherence in the phase and frequency of the locally generated carrier at the receiver on the demodulated signal.

Double Sideband Suppressed Carrier (DSB-SC) Modulation

- A DSB-SC signal is an amplitude-modulated signal that has the form
- $\boldsymbol{s(t) = A_c m(t)\cos(2\pi f_c t)}$, where
- $c(t) = A_c \cos(2\pi f_c t)$: is the carrier signal
- $m(t)$: is the baseband message signal
- $f_c >> W$, W is the bandwidth of the baseband message signal $m(t)$

FIGURE: $\boldsymbol{m(t)c(t)}$
$\boldsymbol{m(t) = cos(2\pi(100)t)}$
$\boldsymbol{c(t) = cos(2\pi(1000)t);}$





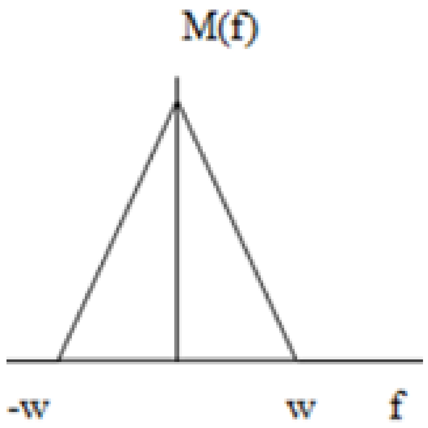
Generation of a DSB-SC Signal

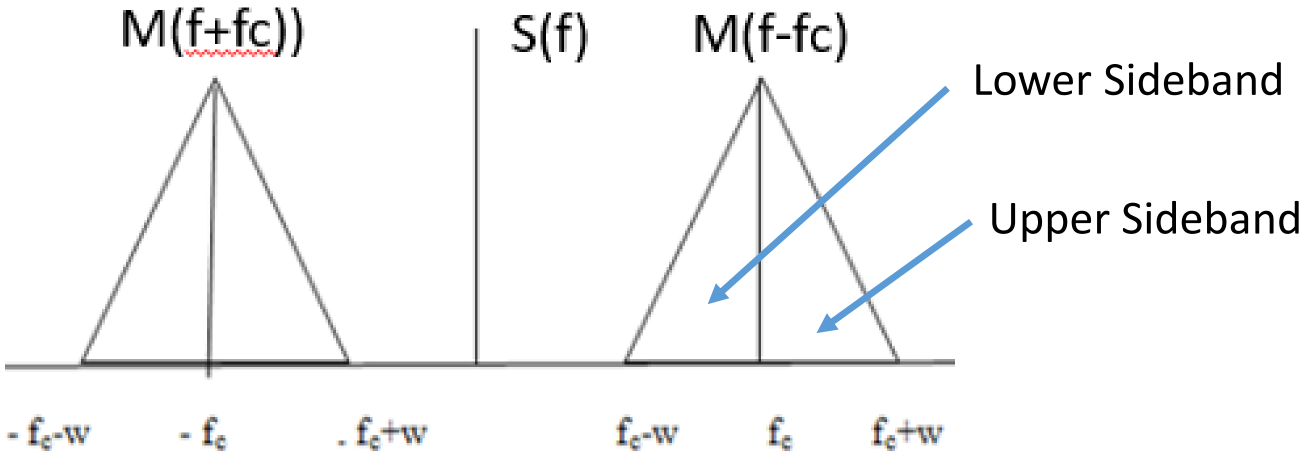
Spectrum of the Double Sideband Suppressed Carrier (DSB-SC)

- **DSB-SC:** $s(t) = A_c m(t)\cos(2\pi f_c t)$
- $S(f) = \Im\{A_c m(t)\cos(2\pi f_c t)\} = \frac{A_c}{2}[M(f - f_c) + M(f + f_c)]$

Remarks: *Similarities and Differences with Normal AM*

- 1. No impulses are present in the spectrum at $\pm f_c$, i.e., no carrier is transmitted as in the case of AM
- 2. The transmission B.W of s(t) = 2W; twice the message bandwidth (same as that of normal AM).
- 3. Power efficiency = $\frac{power\ in\ the\ side\ bands}{total\ transmitted\ power}$ = 100%. This is a power efficient modulation scheme.
- 4. Coherent detector is required to extract m(t) from s(t), as we shall demonstrate shortly.
- 5. Envelope detection cannot be used for this type of modulation.



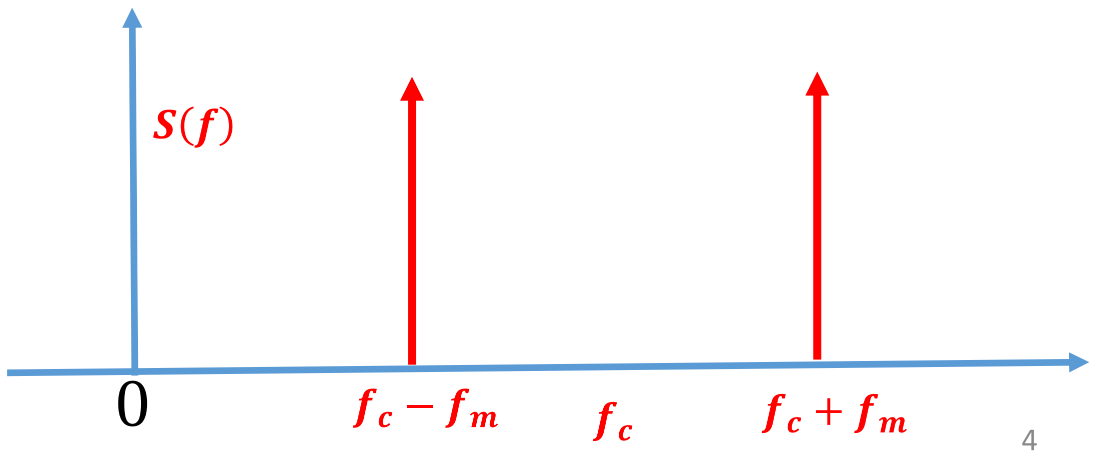


Spectrum of DSB-SC: Sinusoidal Modulation

- **Example**: Consider the sinusoidal modulation case where $c(t) = A_c \cos(2\pi f_c t)$; $m(t) = A_m \cos(2\pi f_m t)$; plot m(t), c(t), s(t) and find their spectrum.

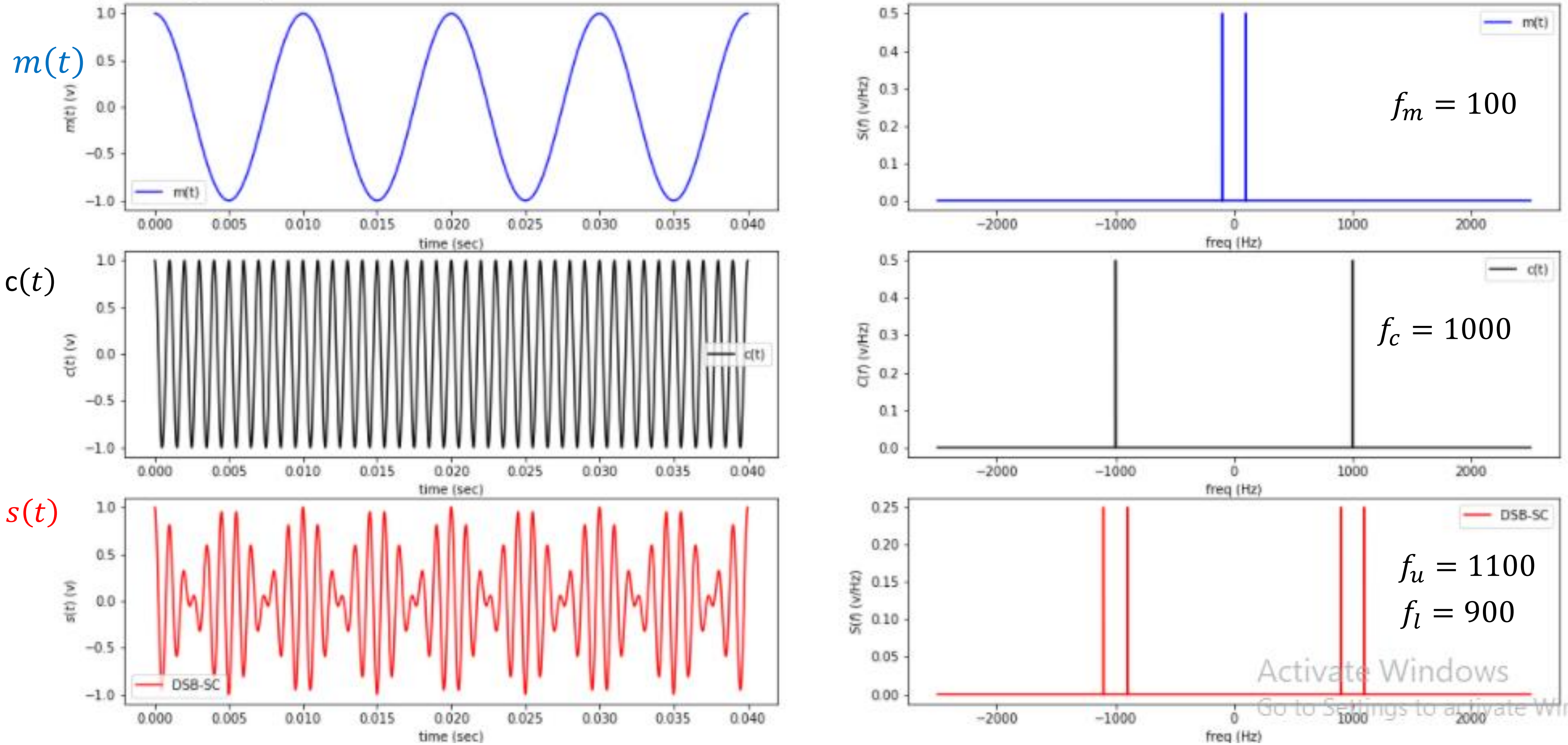
Solution:

- $s(t) = A_c m(t) cos(2\pi f_c t) \; = A_c cos(2\pi f_c t) \, A_m cos(2\pi f_m t)$;
- $\qquad = \frac{A_c A_m}{2} cos(2\pi(f_c + f_m)t) + \frac{A_c A_m}{2} cos(2\pi(f_c - f_m)t)$
- $S(f) = \Im\{A_c m(t) co\, s(2\pi f_c t)\} \; = \frac{A_c}{2}[M(f - f_c) + M(f + f_c)]$
- $\mathrm{M(f)} = \frac{A_m}{2}\delta(f - f_m) + \frac{A_m}{2}\delta(f + f_m)$
- The next figure shows all the plots when $f_m = 100$ Hz and $f_c = 1000$ Hz



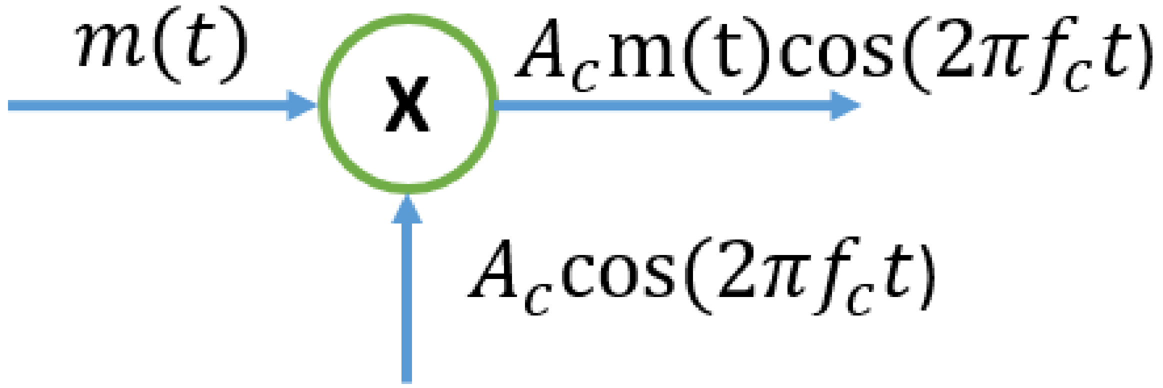
Spectrum of the DSB-SC Signal: Sinusoidal Modulation

$m(t) = A_m cos(2\pi(100)t)$; $c(t) = cos(2\pi(1000)t)$; $s(t) = A_c m(t) cos(2\pi f_c t)$;



Generation of DSB-SC: The Product Modulator

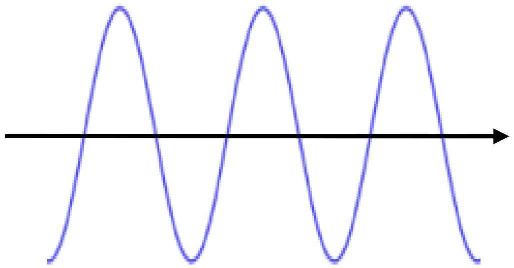
- **Product Modulator**: It multiplies the message signal m(t) with the carrier c(t). This technique is usually applicable when low power levels are possible and over a limited carrier frequency range.

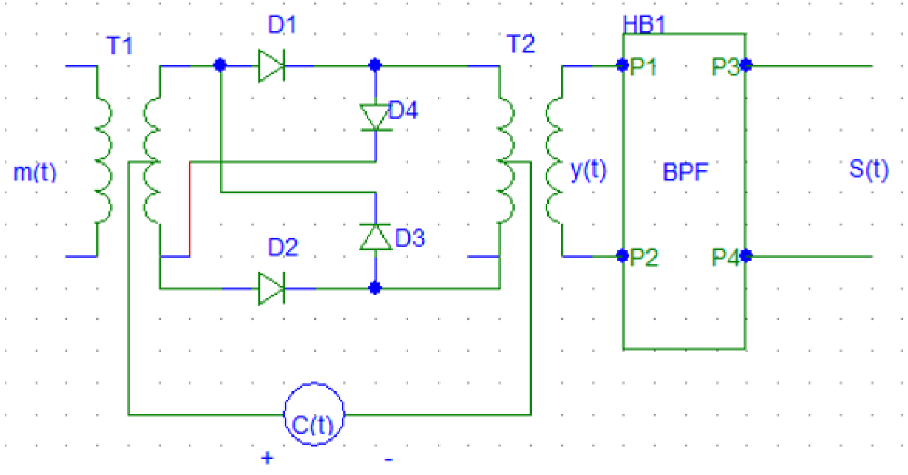


Generation of a DSB-SC Signal

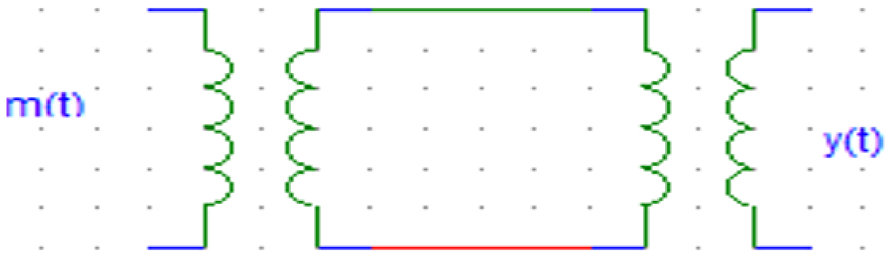
Generation of DSB-SC: The Ring Modulator

- Consider the scheme shown in the figure.
- Let c(t) >> m(t). Here the carrier c(t) controls the behavior of the diodes .
  - During the positive half cycle of c(t), c(t) > 0, and D1 and D2 are ON while D3 and D4 are OFF. Here, **y(t) = m(t).**
  - During the negative half cycle of c(t), c(t) < 0 and D3 and D4 are ON while and D1 and D2 are OFF. Here, **y(t) = - m(t).**
  - So m(t) is multiplied by +1 during the +ve half cycle of c(t) and m(t) is multiplied by -1 during the -ve half cycle of c(t)





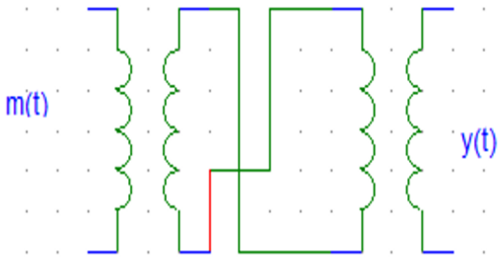
D1 and D2 ON



c(t) > 0

y(t) = m(t)

D3 and D4 ON



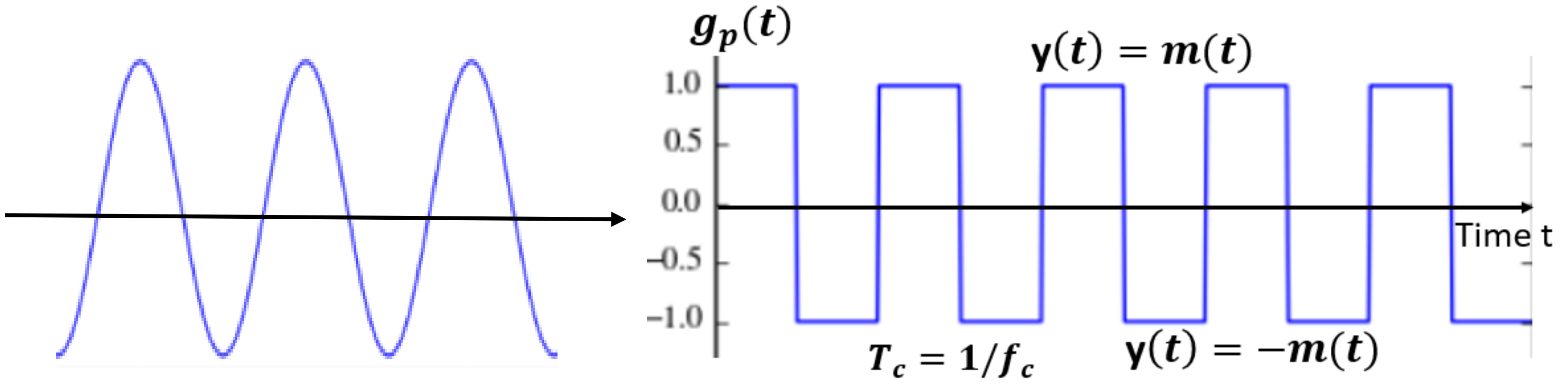
c(t) < 0

y(t) = - m(t)

Generation of DSB-SC: The Ring Modulator

- So m(t) is multiplied by +1 during the +ve half cycle of c(t) and m(t) is multiplied by -1 during the -ve half cycle.
- Mathematically, y(t) behaves as if m(t) is multiplied by the switching function $g_p(t)$ where $g_p(t)$ is the square periodic function with period $T_c = \frac{1}{fc}$; T_c the period of c(t). By expanding $g_p(t)$ in a Fourier series, we get
- **$y(t) = m(t)\, g_p(t)$** $= m(t)[\frac{4}{\pi}\cos 2\pi f_c t - \frac{4}{3\pi}\cos 3(2\pi f_c t) + \frac{4}{5\pi}\cos 5(2\pi f_c t)]$
- $= m(t)\frac{4}{\pi}\cos 2\pi f_c t - m(t)\frac{4}{3\pi}\cos 3(2\pi f_c t) + m(t)\frac{4}{5\pi}\cos 5(2\pi f_c t)$
- When y(t) passes through the BPF with center frequency f_c, and bandwidth = 2W, the only component that appears at the output is the desired DSB-SC signal, which is

$$\boldsymbol{s(t) = \frac{4}{\pi} m(t) cos 2\pi f_c t}$$

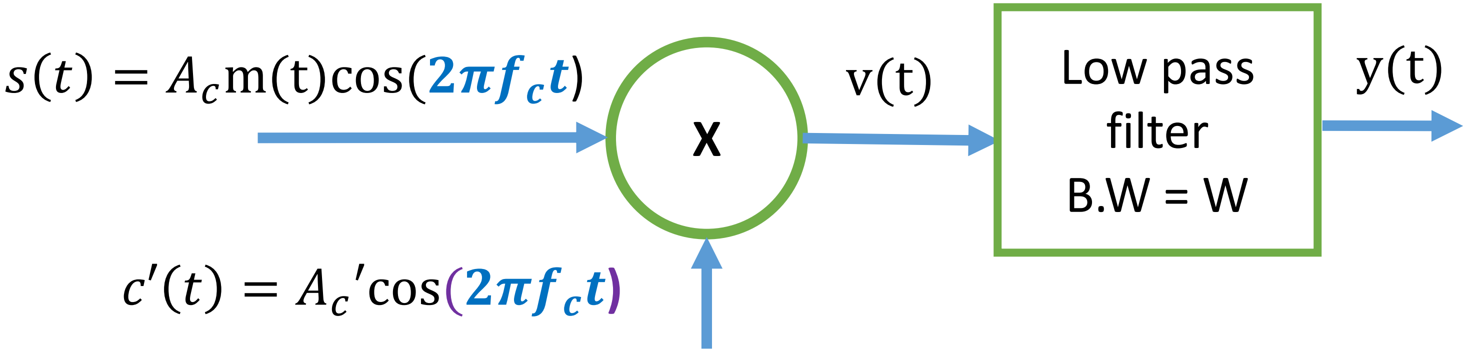


Demodulation of DSB-SC

- A DSB-SC signal is demodulated using what is known as ***coherent demodulation***. This means that the modulated signal s(t) is multiplied by a locally generated signal at the receiver which has the same frequency and phase as that of the carrier c(t) at the transmitting side

Perfect Coherent Demodulation

- Let $c(t) = A_c \cos(2\pi f_c t)$
- $c'(t) = A_c' \cos(2\pi f_c t)$

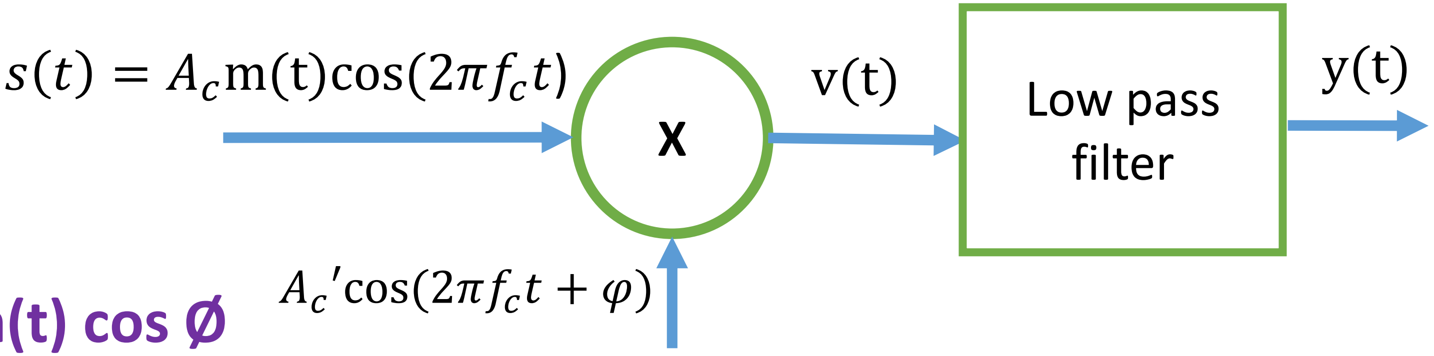


- Mixing the received signal with the version of the carrier at the receiving side, we get
- $\mathrm{v(t)} = s(t) A_c' \cos(2\pi f_c t) = A_c A_c' \, m(t) \cos^2 2\pi f_c t$
- $= \frac{A_c A_c'}{2} m(t) [1 + \cos 2 (2\pi f_c t)] = \frac{A_c A_c'}{2} \mathbf{m(t)} + \frac{A_c A_c'}{2} m(t) \cos 2(2\pi f_c t)$
- The first term on the RHS is proportional to $m(t)$, while the second term is a DSB signal modulated on a carrier with frequency $2 f_c$. The high frequency component can be eliminated using a LPF with B.W = W. The output is $\boldsymbol{y(t) = \frac{A_c A_c'}{2} m(t)}$
- Therefore, $m(t)$ has been recovered from $s(t)$ without distortion, i.e., the whole modulation-demodulation process is distortion-less.

Effect of Carrier Non-Coherence on Demodulated Signal: Constant Phase Shift

A constant phase difference between c(t) and $c'(t)$

- Let c(t) = $A_c\cos 2\pi f_c t$, $c'(t) = A_c'\cos(2\pi f_c t + \varphi)$
- We use the same demodulator
- v(t) = $A_c m(t)\cos 2\pi f_c t \cdot A_c' \cos(2\pi f_c t + \emptyset)$
- $= \frac{A_c A_c'}{2} m(t)[\cos(4\pi f_c t + \emptyset) + \cos\emptyset]$
- $= \frac{A_c A_c'}{2} m(t)\cos(4\pi f_c t + \emptyset) + \frac{A_c A_c'}{2} m(t)\cos\emptyset$



- The low pass filter suppresses the first high frequency term and admits only the second low frequency term. The output is $y(t) = \frac{A_c A_c'}{2} m(t)\cos\emptyset$
- For $0 < \emptyset < \frac{\pi}{2}$, $0 < \cos\emptyset < 1$, y(t) suffers from an attenuation due to Ø.
- However, **for $\emptyset = \frac{\pi}{2}$, cos Ø = 0 and y(t) = 0, i.e., receiver loses the signal.**
- The disappearance of a message component at the demodulator output is called ***quadrature null effect***. This highlights the importance of maintaining synchronism between the transmitting and receiving carrier signals $c'(t)$ and c(t).

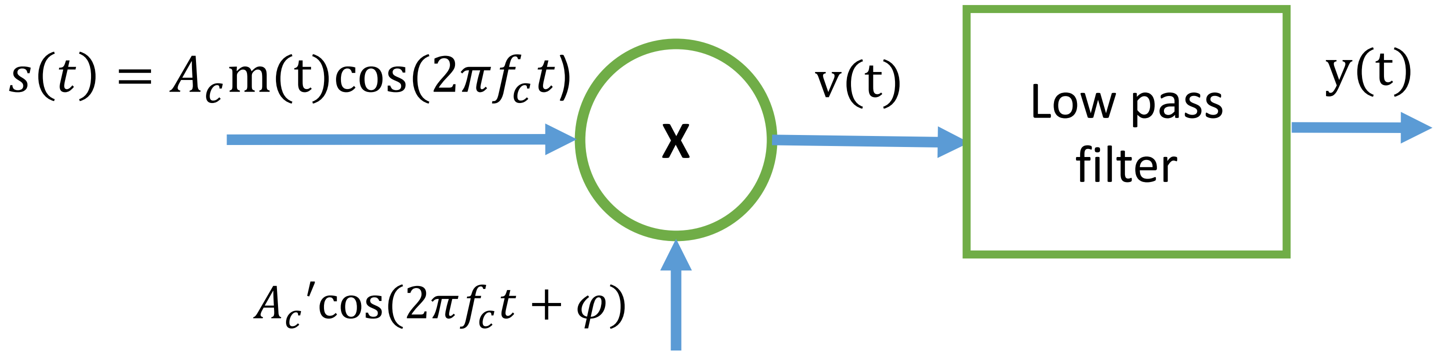
Effect of Carrier Non-Coherence on Demodulated Signal: Constant Phase Shift

Example: Let $m_1(t) = \cos 2\pi(1000)t$; $m_2(t) = \cos 2\pi(2000)t$; $m(t) = m_1(t) + m_2(t)$

$c(t) = \cos 2\pi(10000)t$ and let ϕ = 50 degrees.

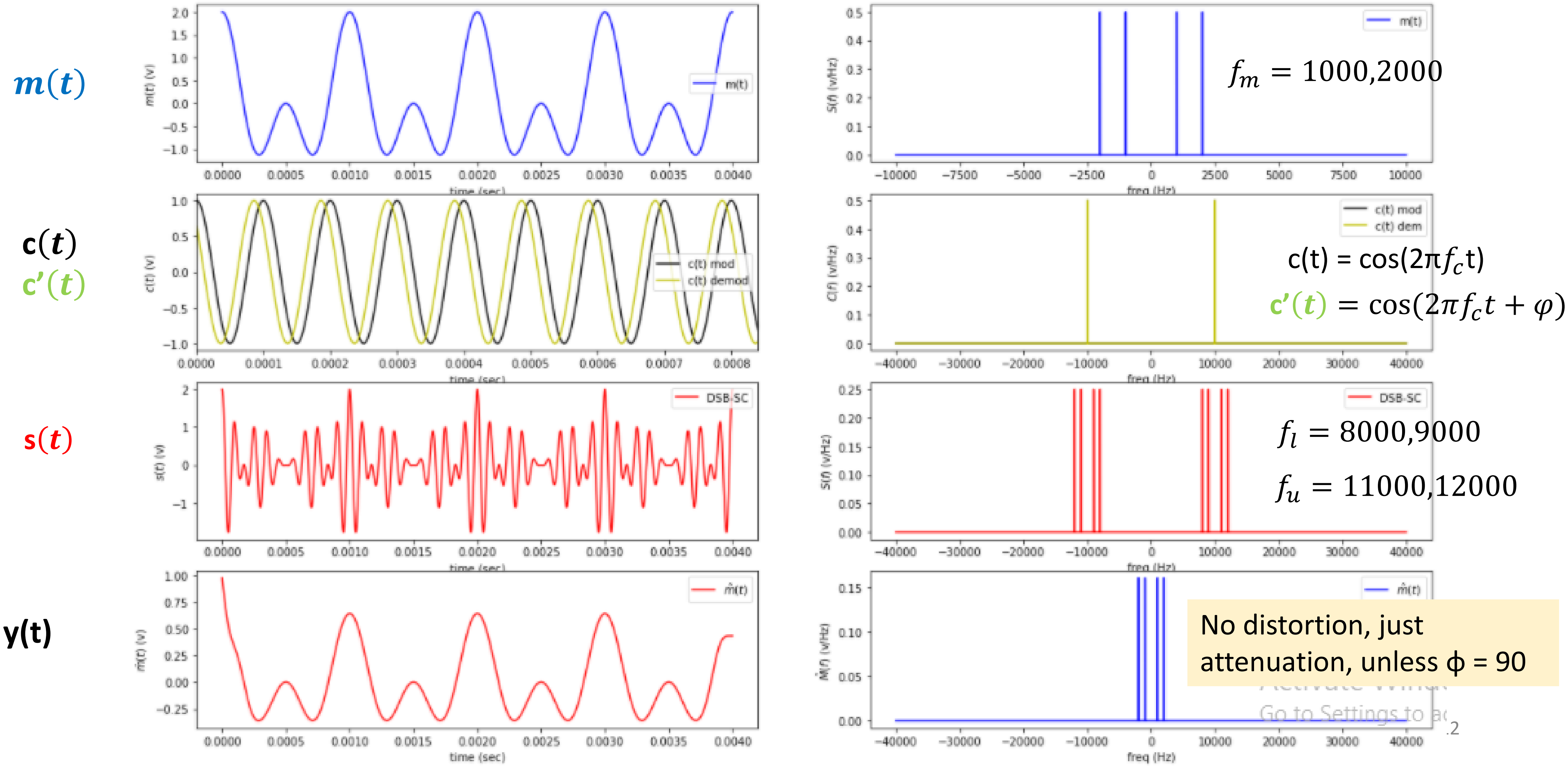
Solution: From the analysis above,

- $$\boldsymbol{y(t) = \frac{A_c A_c'}{2} m(t) \cos\emptyset}$$
- The next figure shows the input message, carrier, modulated, and demodulated signals in the time and frequency domains.



Effect of Carrier Non-Coherence on Demodulated Signal: Constant Phase Shift

$m_1(t) = \cos 2\pi(1000)t$; $m_2(t) = \cos 2\pi(2000)t$; **$m(t) = m_1(t) + m_2(t)$** $c(t) = \cos 2\pi(10000)t$ and let ϕ = 50 degrees.



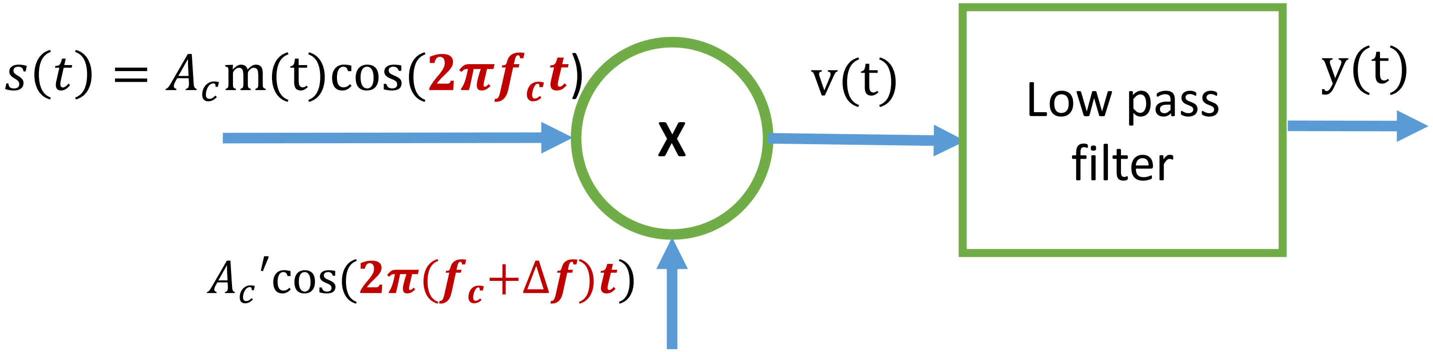
No distortion, just attenuation, unless ϕ = 90

Effect of Carrier Non-Coherence on Demodulated Signal: Constant Frequency Difference

Constant Frequency Difference between c(t) and $c'(t)$

- Let c(t) = $A_c\cos 2\pi f_c t$, $c'(t) = A_c{}' \cos(2\pi(f_c+\Delta f)t)$
- Again, we use the same receiver structure as before.
- $v(t) = A_c \mathrm{m(t)}\cos(2\pi f_c t).\, A_c{}' \cos(2\pi(f_c+\Delta f)t)$
- $= \frac{A_c A_c{}'}{2} m(t)[\cos(4\pi f_c t + 2\pi\Delta f t) + \cos 2\pi\Delta f t]$
- After low-pass filtering,

$$y(t) = \frac{A_c A_c'}{2} m(t)\cos(2\pi\Delta f t)$$



- As you can see, $y(t) \neq km(t)$, but rather $m(t)$ is multiplied by a time function. Hence, the system is not distortion-less.
- In addition, y(t) appears as a **double side band modulated signal with a carrier with magnitude Δf**. The next example illustrates this case more.

Effect of Carrier Non-Coherence on Demodulated Signal: Constant Frequency Difference

Example: Let m(t) = cos2π(1000)t; c(t) = cos2π(10000)t and let Δf =500 Hz

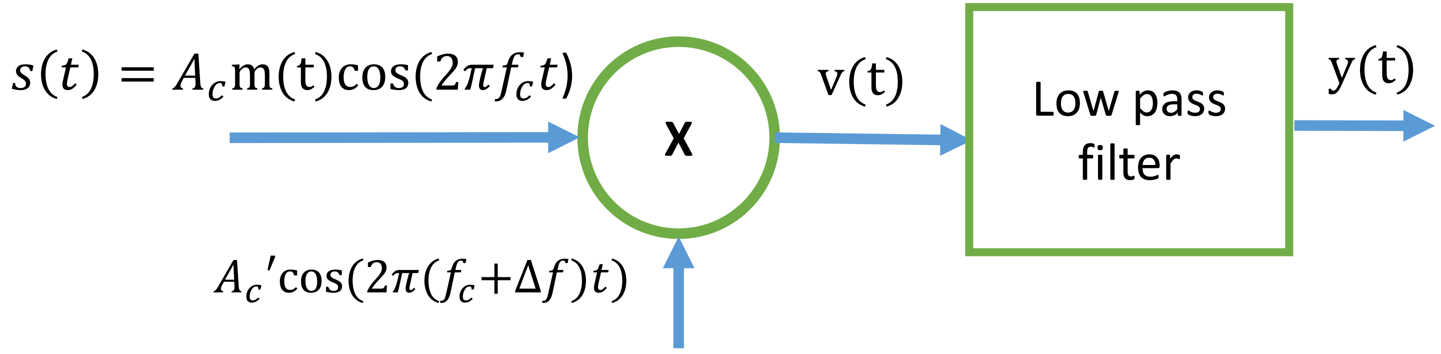
Solution: From the analysis in case 2 above,

$$y(t) = \frac{A_c A_c'}{2} m(t) cos(2\pi\Delta f t)$$

$$y(t) = \frac{A_c A_c'}{2} \cos 2\pi(1000)t \cos 2\pi(500)t$$

$$= \frac{A_c A_c'}{4}[\cos 2\pi(1500)t + \cos 2\pi(500)t]$$

- The original message is a signal with a single frequency of 1000 Hz, while the output consists of a signal with two frequencies at f_1 =1500 Hz and f_2 = 500 Hz
- ⇒ ***Distortion***)



Effect of Carrier Non-Coherence on Demodulated Signal: Constant Frequency Difference

$m(t) = A_c cos(2\pi(1000)t)$; $c(t) = cos(2\pi(10000)t)$; $c'(t) = cos(2\pi(10500)t)$; $\Delta f = 500$

$m(t)$

$c(t)$
$c'(t)$

$s(t)$

$y(t)$