EEEN 322
Communication Engineering

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Spring 2019

Week 6

Modulation - Demodulation Circuits for Amplitude Modulation (DSB+C)

- **Modulation:**
  - All the modulators that are used for DSB-SC can also be used here

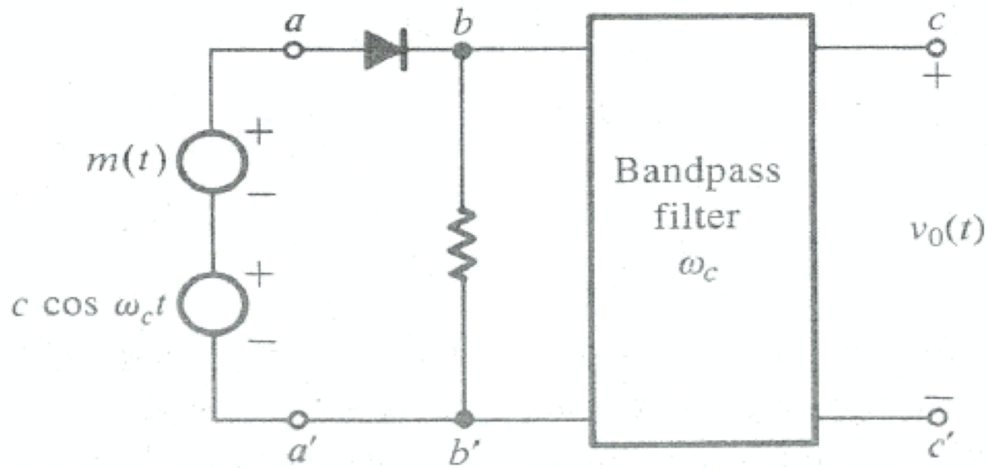
    However: Since the carrier is not suppressed, there is no need to use balanced modulators; we may use a simple switching modulator with a single diode
- **Demodulation**
  - If $\mu > 1$: Coherent demodulation is a must. Then, use a demodulator that you use for DSB-SC
  - If $\mu \leq 1$: Simpler demodulators are better, such as
    - Rectifier detector
    - Envelope detector

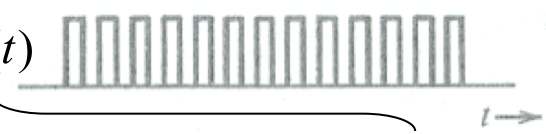
Switching Modulator for Amplitude Modulation (DSB+C)

→ Switching action of diode is controlled by

$c\cos\omega_c t$

$c >> m(t)$



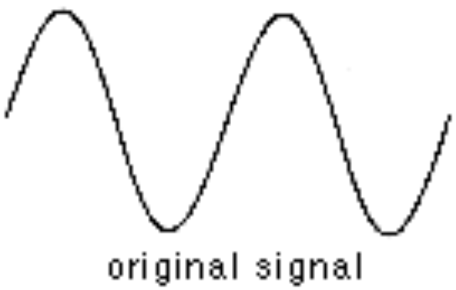


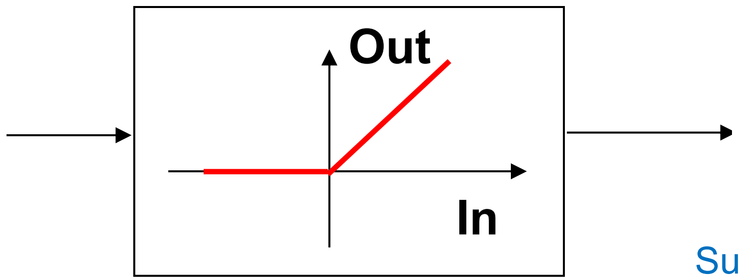
$$v_{bb'}(t) = \left[c\cos\omega_c t + m(t)\right] w(t)$$

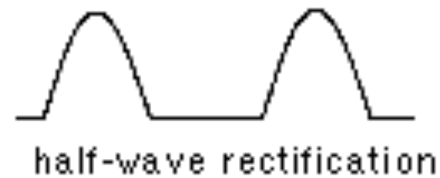
$$\Rightarrow v_{bb'}(t) = [c\cos\omega_c t + m(t)]\overbrace{\left[\frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 5\omega_c t - \ldots\right)\right]}^{w(t)}$$

$$\Rightarrow v_{bb'}(t) = \underbrace{\left[\frac{c}{2} + \frac{2}{\pi}m(t)\right]\cos\omega_c t}_{\text{AM signal}} + \underbrace{\text{other\_terms}}_{\text{Filtered out by BPF}}$$

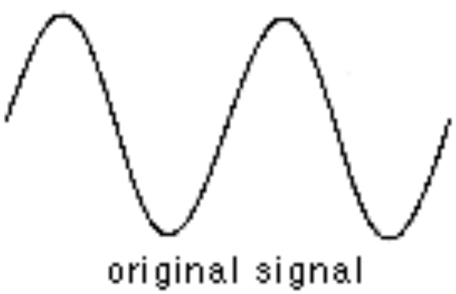
Signal Rectification

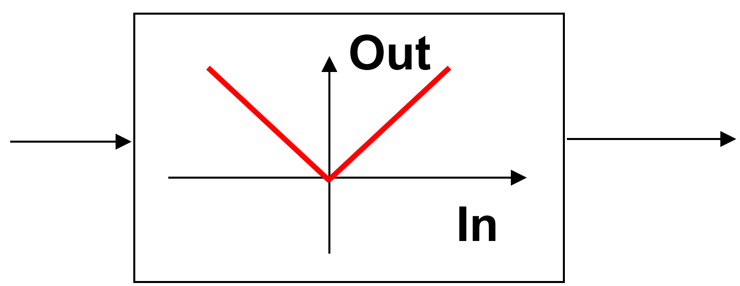






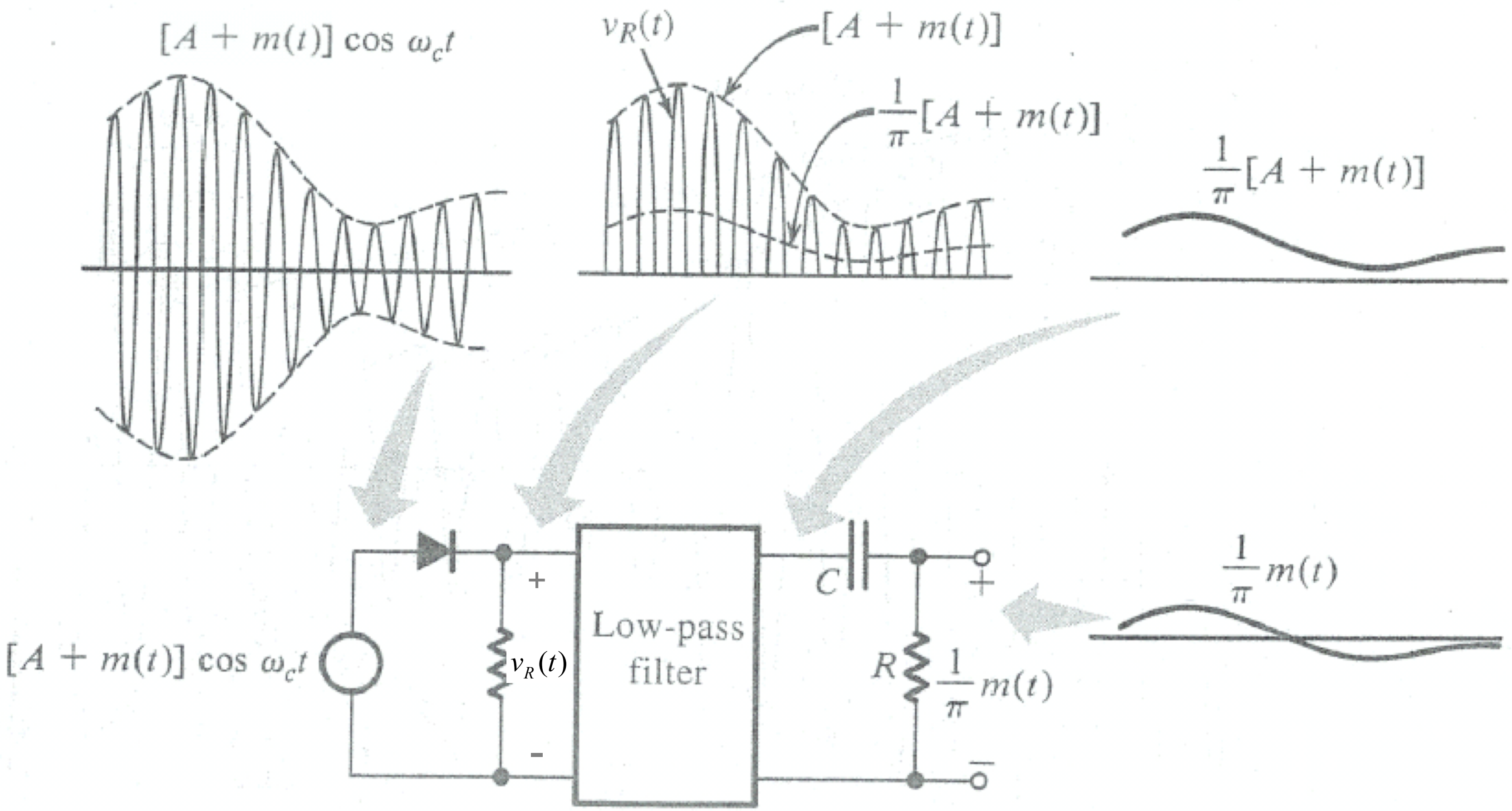
Suppresses negative part of the signal



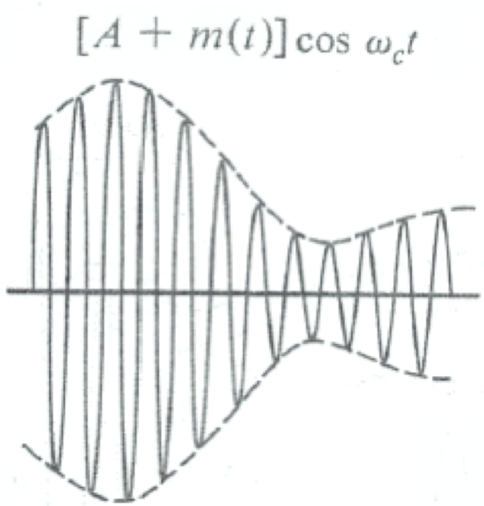


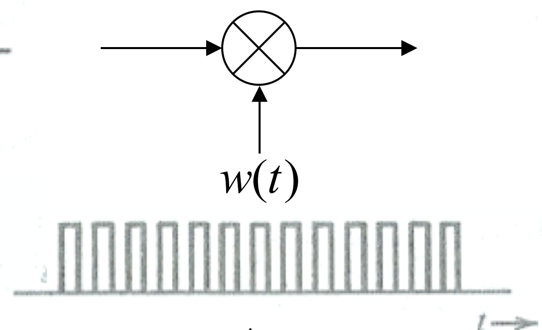
Absolute value of signal

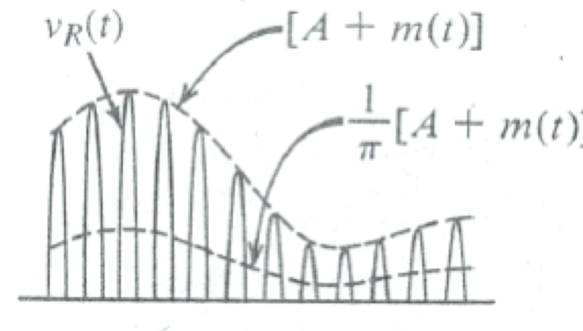
Demodulation of AM Signals: Rectifier Detector



Demodulation of AM Signals: Rectifier Detector (cont'd)







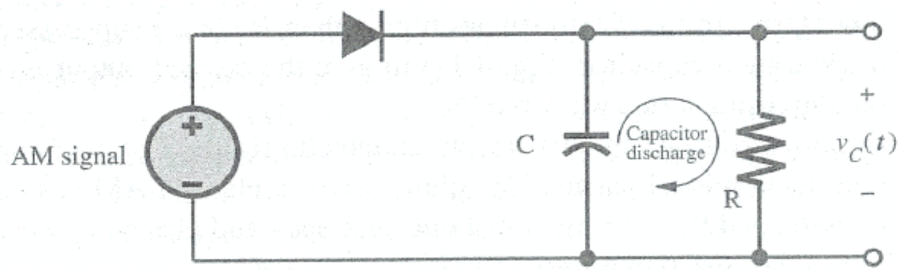
Like coherent demodulation performed without using a local carrier

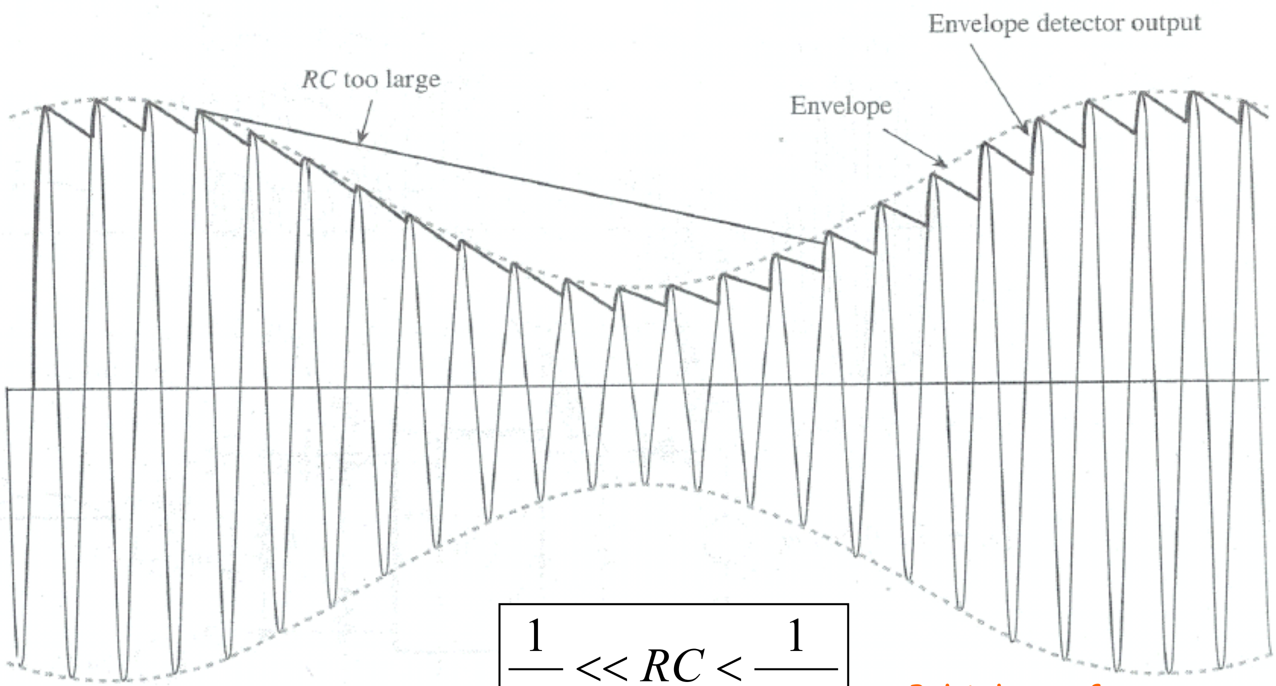
$$v_R(t) = [A + m(t)]\cos\omega_c t \overbrace{\left[\frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 5\omega_c t - \ldots\right)\right]}^{w(t)}$$

$$\Rightarrow v_R(t) = \frac{1}{2}[A + m(t)]\cos\omega_c t + \frac{2}{\pi}[A + m(t)]\underbrace{\cos^2\omega_c t}_{\frac{1}{2}[1 + \cos 2\omega_c t]} + \text{other\_terms}$$

$$\Rightarrow v_R(t) = \underbrace{\frac{1}{2}[A + m(t)]\cos\omega_c t}_{\text{Filtered out by LPF}} + \underbrace{\frac{1}{\pi}[A + m(t)]}_{\text{Desired part}} + \underbrace{\frac{1}{\pi}[A + m(t)]\cos 2\omega_c t + \text{other\_terms}}_{\text{Filtered out by LPF}}$$

Demodulation of AM Signals: Envelope Detector





$$\boxed{\frac{1}{\omega_c} << RC < \frac{1}{2\pi B}}$$

B: highest frequency (Hz) in *m(t)*

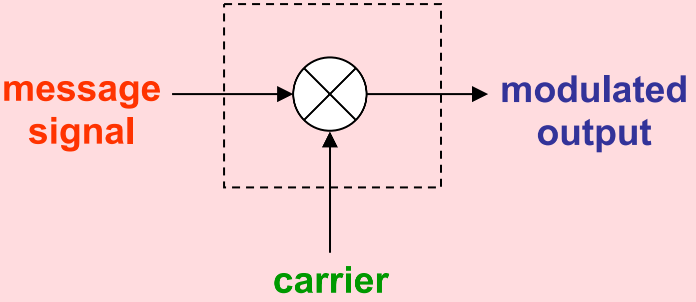
don't discharge the capacitor too fast w.r.t. carrier

be fast enough to track the envelope

Up to now…

	Suppressed Carrier	With Carrier
Double Sideband (DSB)	**DSB-SC**	**DSB+C (a.k.a. AM)**
Single Sideband (SSB)	**SSB-SC**	**SSB+C**
Vestigial Sideband (VSB)	**VSB-SC**	**VSB+C**

In general: The **amplitude** of the **carrier** is changed by the **message signal**



$\varphi_{DSB-SC}(t) = m(t)\cos\omega_c t$

Multiplier, nonlinear, switching modulator; coherent demodulator

$\varphi_{AM}(t) = [A + m(t)]\cos\omega_c t$

Same modulators and demodulator as in DSB-SC work here also
BUT: Simpler modulator (single-diode switching) and simpler demodulator (envelope detector, rectifier detector) also work

$\mu = \dfrac{m_p}{A}$

Condition for envelope detection:
$A \geq m_p$ **or** $0 \leq \mu \leq 1$

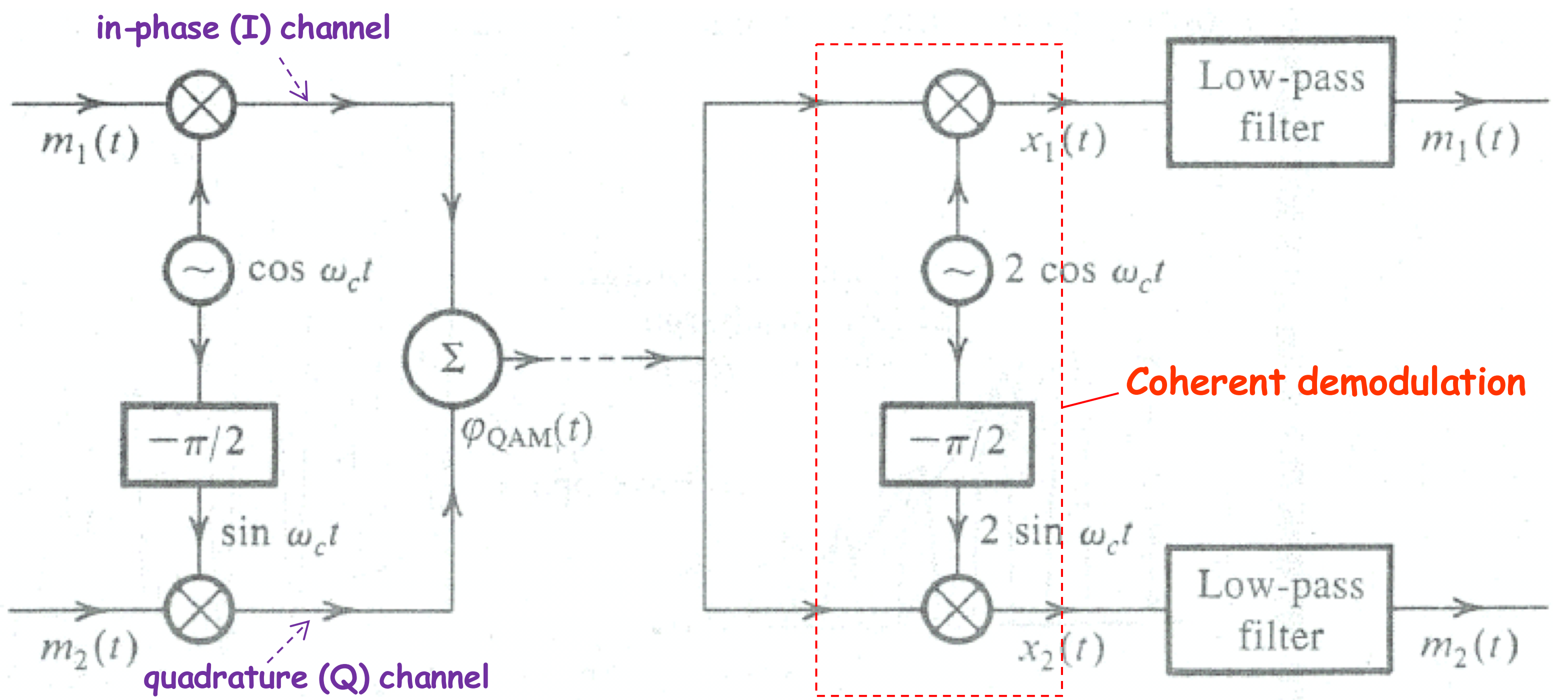
Sending Two Signals at the Same Time by Using the Same Carrier Frequency: Quadrature Amplitude Modulation (QAM)

$$\boxed{\varphi_{QAM}(t) = m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t}$$

- **Modulation:**
  - Any modulator you use for DSB-SC
  - Multiply $\boldsymbol{m_1(t)}$ by $\mathbf{cos}\boldsymbol{\omega_c t}$ and $\boldsymbol{m_2(t)}$ by $\mathbf{sin}\boldsymbol{\omega_c t}$
- **Demodulation:**
  - Coherent demodulation (the method you use for DSB-SC)
  - Multiply the modulated signal by $\boldsymbol{\cos\omega_c t}$ to obtain $\boldsymbol{m_1(t)}$ and by $\mathbf{sin}\boldsymbol{\omega_c t}$ *to obtain* $\boldsymbol{m_2(t)}$

- Used in color TV to multiplex the chrominance signals
- A slight error in the frequency or phase of the carrier at the demodulator results in
  - Loss and distortion of signals
  - Interference between the two channels (co-channel interference)

Modulation and Demodulation for QAM



$$\varphi_{QAM}(t) = m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t$$

$$\begin{aligned} x_1(t) = 2\varphi_{QAM}(t)\cos\omega_c t &= 2\left[m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t\right]\cos\omega_c t = 2\left[m_1(t)\cos^2\omega_c t + m_2(t)\cos\omega_c t\sin\omega_c t\right] \\ &= m_1(t)(1+\cos 2\omega_c t) + m_2(t)\sin 2\omega_c t \\ &= m_1(t) + m_1(t)\cos 2\omega_c t + m_2(t)\sin 2\omega_c t \end{aligned}$$

$$\begin{aligned} x_2(t) = 2\varphi_{QAM}(t)\sin\omega_c t &= 2\left[m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t\right]\sin\omega_c t = 2\left[m_1(t)\cos\omega_c t\sin\omega_c t + m_2(t)\sin^2\omega_c t\right] \\ &= m_1(t)\sin 2\omega_c t + m_2(t)(1-\cos 2\omega_c t) \\ &= m_2(t) + m_1(t)\sin 2\omega_c t - m_2(t)\cos 2\omega_c t \end{aligned}$$

Will be filtered out by the LPF