# Electronics for Amplitude Modulation and Demodulation

EE 340: Prelab Reading Material for Experiment 3

August 4, 2016

As discussed in the reading material for Experiment 2, in amplitude modulation (AM), the amplitude of the carrier wave, $c(t) = A_c \cos(2\pi f_c t)$, is varied with the message signal $x(t)$ to obtain the desired modulated signal $s(t)$. In case of DSB-FC (double-sideband with full carrier) modulation, the modulated signal spectrum contains the carrier wave as well. If the message signal is $x(t) = A_m \cos(2\pi f_m t)$, the amplitude modulated DSB-FC can be expressed as

$$\begin{aligned} s_{DSB-FC}(t) &= A_c \cos(2\pi f_c t) \times \Big(1 + mA_m \cos(2\pi f_m t)\Big) \\ &= A_c \cos(2\pi f_c t) + \frac{mA_cA_m}{2}\Big(\cos(2\pi(f_c - f_m)t) + \cos(2\pi(f_c + f_m)t)\Big), \end{aligned} \tag{1}$$

for which $mA_m$ is the modulation index. For DSB-SC signal, the carrier can be suppressed by subtracting it from the DSB-FC signal, to get

$$\begin{aligned} s_{DSB-SC}(t) &= A_c \cos(2\pi f_c t) \times \Big(1 + mA_m \cos(2\pi f_m t)\Big) - A_c \cos(2\pi f_c t) \\ &= \frac{mA_cA_m}{2}\Big(\cos(2\pi(f_c - f_m)t) + \cos(2\pi(f_c + f_m)t)\Big). \end{aligned} \tag{2}$$

## 1 Mixers for Amplitude Modulation

In this experiment, you will be designing DSB-FC and DSB-SC amplitude modulators in hardware, in which, implementation of a *good* multiplier is one of the main challenges. The multiplier, also know as the "mixer" in the hardware terminology, can be implemented using switches, as shown in Fig. 1. In the figure, when $\cos(2\pi f_c t) > 0$, S1 is ON and S2 is OFF, and when $\cos(2\pi f_c t) < 0$, S1 is OFF and S2 is ON. Therefore, due to the switching action, the signal gets multiplied by effectively a square-wave (instead of a sine-wave) of frequency $f_c$.

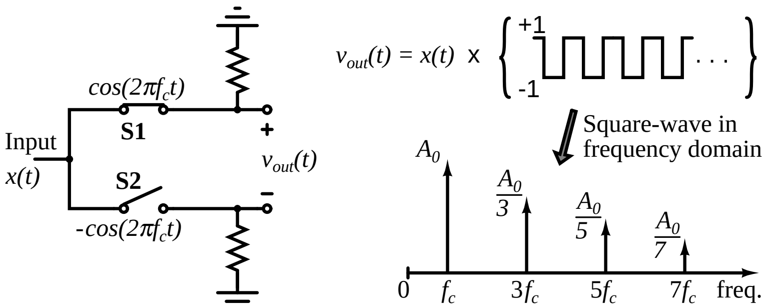


Figure 1: A pair of switches being used for mixing. Spectrum of the square wave is shown with amplitudes of the harmonics relative to the amplitude of the fundamental.

Unfortunately, the square wave also contains odd harmonic components of $f_c$, i.e., $3f_c, 5f_c, 7f_c$, and so on, with significant amplitudes (verify the relative amplitudes yourself). As a result, the input signal $x(t)$ gets multiplied not just by a sinusoid of frequency $f_c$, but also by its harmonics, which generate undesired frequency components at the output and result in inefficient utilization of the spectrum. In order to avoid the harmonics of $f_c$, various hardware techniques are used (including

of course filtering), but the discussion of these techniques is beyond the scope of material. Filtering alone may not be sufficient because the harmonic components are very strong.
The implementation of DSC-FC modulator (with the mixer) is shown in Fig. 2a. The transistor Q3 converts the input message signal $x(t)$ to the time varying current signal $i_{x(t)}$ that rides over a non-zero DC current $I_{DC}$ ($I_{DC} > i_{x(t)}$ is required to ensure that the transistor is biased properly and is always operating in the forward active region). The switching pair Q1-Q2 multiplies this current with the square wave of frequency $f_c$, as discussed previously. Load resistors $R_C$ convert the output currents again to a (differential) voltage signal, i.e. $v_{out}(t)$, which is the desired output.

The multiplication of the square-wave with the DC current $I_{DC}$ and the signal current $i_{x(t)}$ results the carrier and the signal sidebands at the output, respectively. However, due to harmonics of $f_c$ introduced at the switching-pair, the output contains undesired frequency components as well. *Predict the output waveforms and spectrum qualitatively if the message signal is* $x(t) = A_m \cos(2\pi f_m t)$*!*

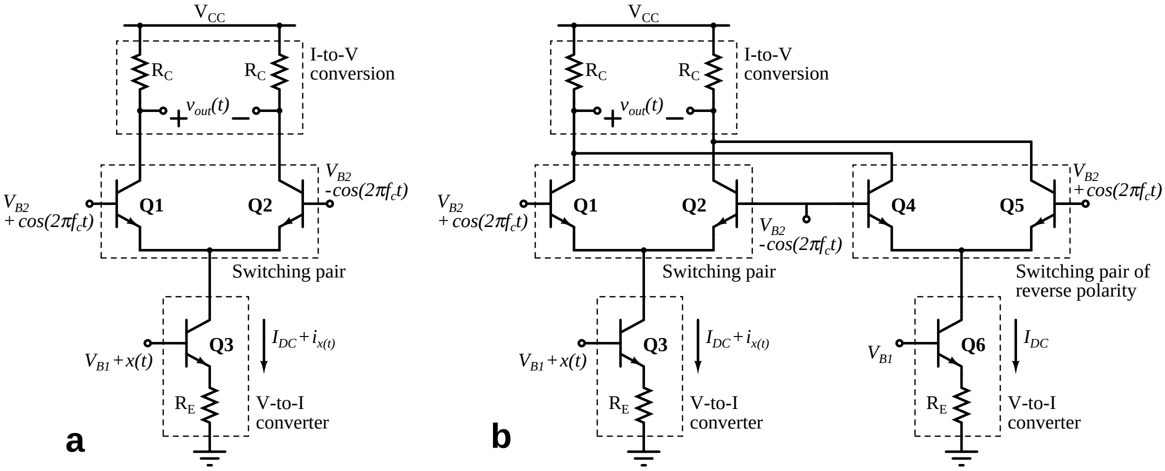


Figure 2: Simplified mixer circuits for amplitude modulation are shown ($V_{B1}$ and $V_{B1}$ are DC bias voltages). In actual implementation, the amplitude of the carrier-wave should be less than 1 V. a) A single-balanced mixer for DSB-FC modulation. b) A double-balanced mixer for DSB-SC modulation.

To achieve DSB-SC amplitude modulation, another switching pair can be added to suppress the carrier at the output, as shown in Fig. 2b. In this case, the transistor Q6 carries only the bias current $I_{DC}$ (without any time-varying current). The polarity of the carrier $\cos(2\pi f_c t)$ input to the switching-pair Q4-Q5 is reversed. As a result, the currents due to $I_{DC}$ at the carrier frequency (and its harmonics) going to the output from the two switching pairs get canceled mutually, and only the component corresponding to $i_{x(t)}$ multiplied by the square-wave remains.

## 2 Envelope Detector for DSB-FC Demodulation

A simple envelope detector can be used for demodulating DSB-FC amplitude modulated signals. As shown in Fig. 3, the envelope detector can be implemented as a rectifier that is followed by an RC low pass filter to filter out the carrier frequency ripples. To ensure a decent rejection of ripples of the carrier frequency $f_c$ in the circuit of Fig. 3, the low pass filter pole frequency $1/(2\pi R_L C_L) \ll f_c$. At the same time, the low pass filter should not significantly affect the message signal, which demands that its cut-off frequency $1/(2\pi R_L C_L) \gg f_m$, where $f_m$ is the highest frequency component contained in the message signal. Also to ensure that envelope detector circuitry does not load the signal source (having source resistance $R_S$), $R_L$ should be chosen such that $R_L \gg R_S$.

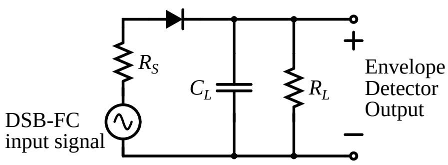


Figure 3: The schematic of an envelope detector for demodulating DSB-FC signals.