Electronics for Amplitude Modulation and Demodulation

EE 340: Prelab Reading Material for Experiment 3

August 26, 2019

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 obtained 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 $x(t) = A_m \cos(2\pi f_m t)$, 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 known 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.

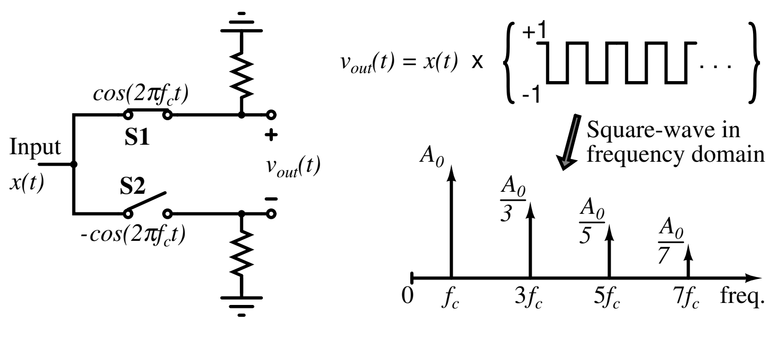

Figure 1: A pair of switches being used for mixing. Spectrum of the square wave is shown with amplitudes of the harmonics relative to the amplitude of the fundamental.

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 generates undesired frequency components at the output and results 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.

The implementation of DSB-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). The switching pair Q1-Q2 multiplies this current with the square wave of frequency f_c, as discussed previously. Using the load resistors R_C, the output currents are again converted to the differential voltage signal $v_{out}(t)$, 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* $x(t) = A_m \cos(2\pi f_m t)$*!*

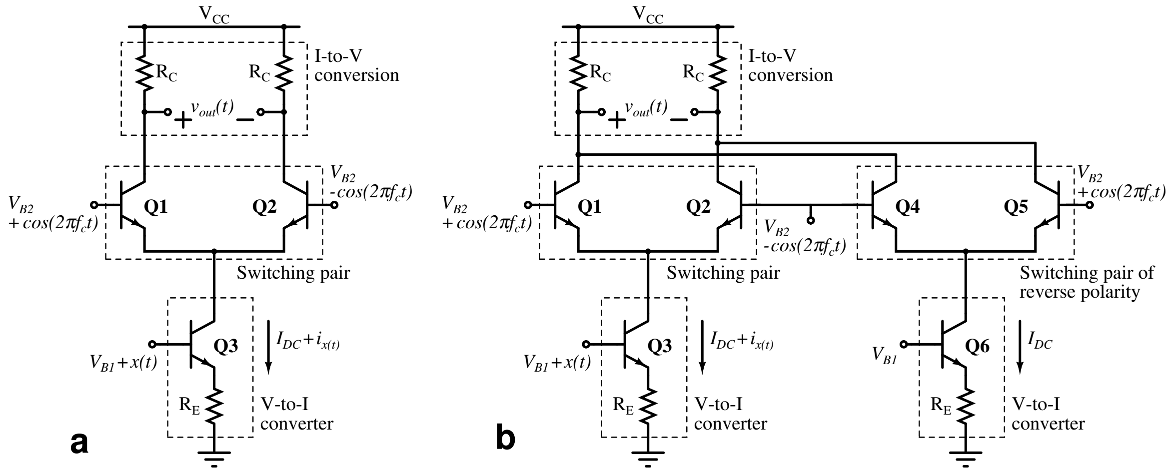

Figure 2: Simplified mixer circuits for amplitude modulation are shown (V_{B1} and V_{B2} are DC bias voltages). In actual implementation, the amplitude of the carrier-wave should be less than 1 V. a) A single-balanced mixer for DSB-FC modulation. b) A double-balanced mixer for DSB-SC modulation.

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 cancelled 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 $R_L \gg R_S$.

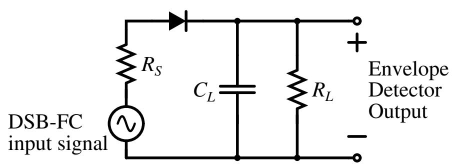

Figure 3: The schematic of an envelope detector for demodulating DSB-FC signals.