ELEC1323 Communications

2 Analogue Carrier Modulation

Carrier vs baseband modulation schemes (CEP 1.5.3)

- We are typically interested in transmitting low frequency (baseband) signals such as audio (20 Hz – 20 kHz).

- In some channels such as a twisted pair of wires, baseband signals propagate fine and we don't need a carrier.

- However, in other channels such as radio or optical fibre, low frequencies don't propagate.

- In carrier modulation schemes, a baseband signal is relocated to a band of much higher frequencies by modulating it on to a sinusoidal carrier, having a high frequency f_c.

Advantages of carrier modulation schemes

- Frequency Division Multiplexing (FDM) allows different signals to be modulated into different bands of frequencies without interfering with each other.

- More channels can be accommodated at high frequencies because the bandwidth of each successive radio band (HF, VHF, UHF, etc) is ten times larger than the last.

- Radio frequencies (3 kHz to 300 GHz) are necessary for electromagnetic waves to propagate (different frequencies have different propagation characteristics). Higher frequencies allow smaller antennas to be used. Visible frequencies (e.g. 231 THz) are necessary for optical communications schemes.

Carrier wave parameters (CEP 2.3.2)

$$v_c(t) = A\cos(2\pi f_c t + \phi)$$

- Amplitude A

- Frequency f_c in cycles per second (Hz)
  - Angular frequency $\omega_c = 2\pi f_c$ in radians per second
  - Period $T = 1/f_c$ in seconds (s)
  - Wavelength $\lambda = c/f_c$ in metres (m), where the speed of light in a vacuum is $c = 3 \times 10^8 \text{ ms}^{-1}$

- Phase ϕ

Analogue and digital message signals can be used to vary (modulate) one or more of these parameters.

Analogue carrier modulation (CEP 4.3)

- Phase modulation

$$v_{pm}(t) = V_c \cos(2\pi f_c t + k_{pm} \cdot v_m(t))$$

- Frequency modulation

$$v_{fm}(t) = V_c \cos(2\pi [f_c + k_{fm} \cdot v_m(t)] t)$$

- These are parameterized by the modulation sensitivities k_{pm} and k_{fm}.

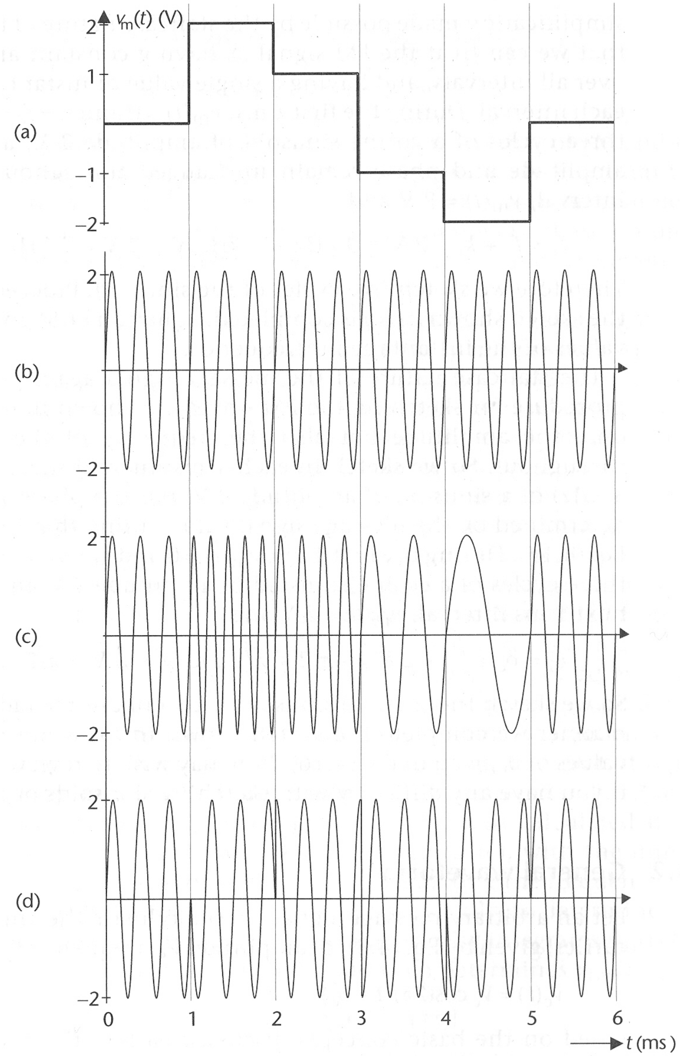
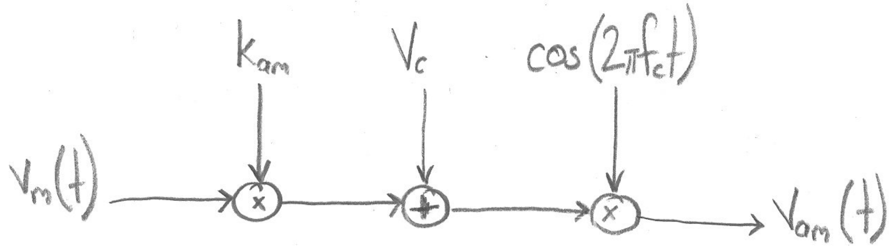


Figure 4.8 (a) Staircase-modulating signal; (b) carrier; (c) frequency modulated carrier; (d) phase-modulated carrier.

Analogue carrier modulation - amplitude modulation (CEP 3.2)

$$v_{am}(t) = (V_c + k_{am} \cdot v_m(t)) \cos(2\pi f_c t)$$



Parameterized by:

- DC offset V_c
- Modulation sensitivity k_{am}

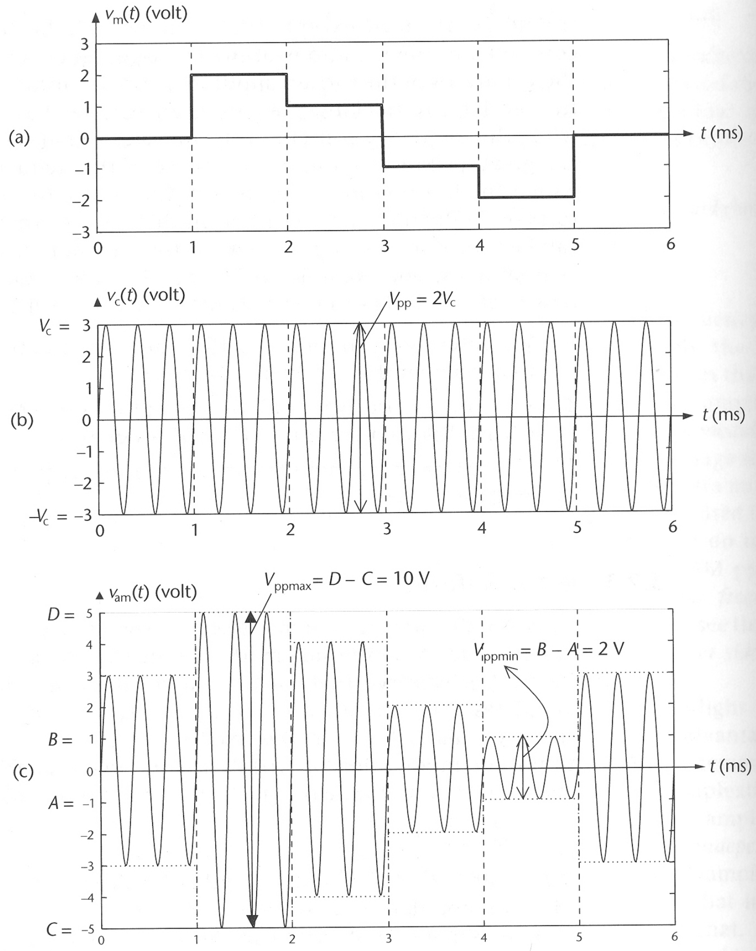


Figure 3.1 (a) Message signal; (b) carrier signal; (c) AM signal, with modulation sensitivity k = 1 volt/volt.

Amplitude modulation (CEP 3.2.1 and 3.2.3)

- Modulation factor $m = \frac{V_{ppmax} - V_{ppmin}}{V_{ppmax} + V_{ppmin}}$
- Modulation index is modulation factor expressed as a percentage.
- Undermodulation occurs when $m < 100\%$
- 100% modulation occurs when $m = 100\%$
- Overmodulation occurs when $V_c + k_{am} v_m(t) < 0$, preventing envelope detection.

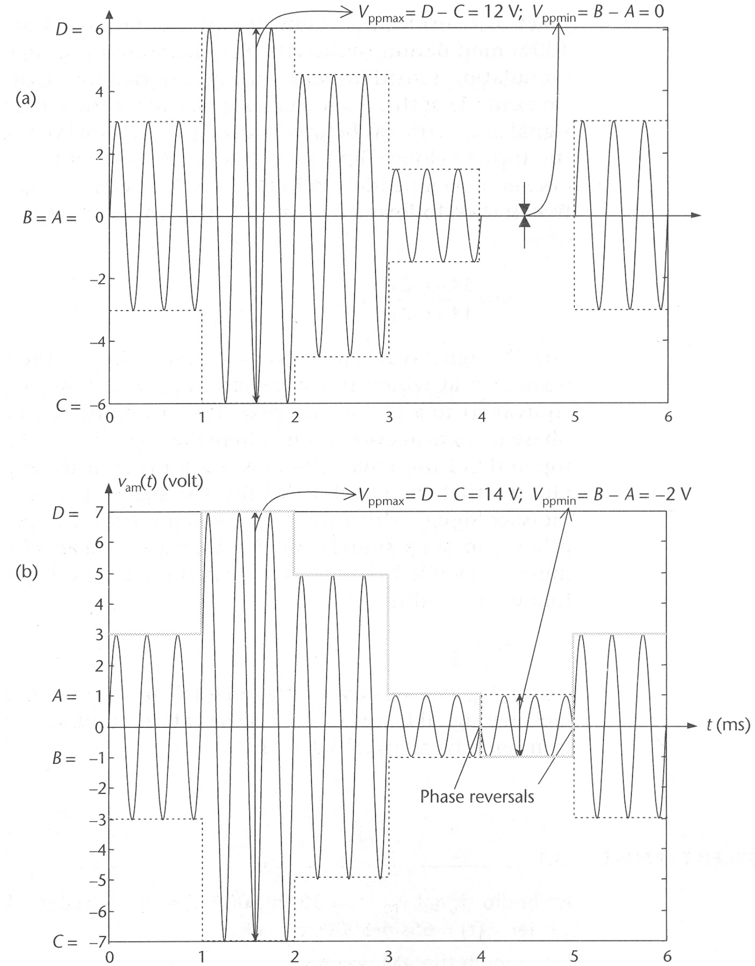


Figure 3.3 AM signal with (a) 100% modulation; (b) over-modulation.

Amplitude modulators (CEP 3.4)

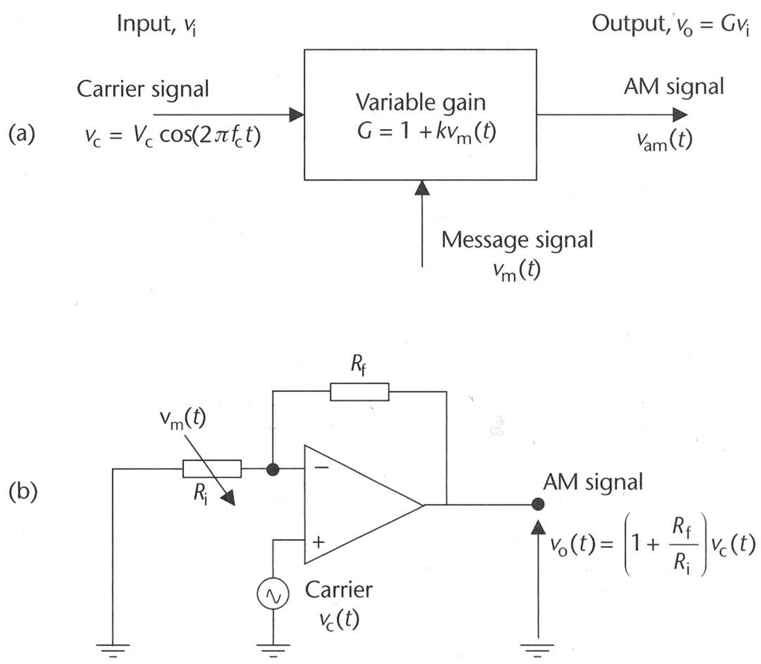


Figure 3.13 (a) AM generation using a variable gain device; (b) opamp implementation.

In a linearly varied gain modulator, R_i is provided by a Field Effect Transistor (FET), where $R_i = \frac{1}{av_m(t)}$.

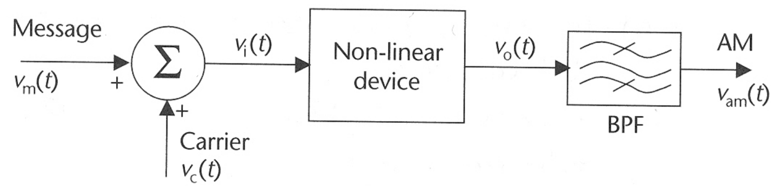
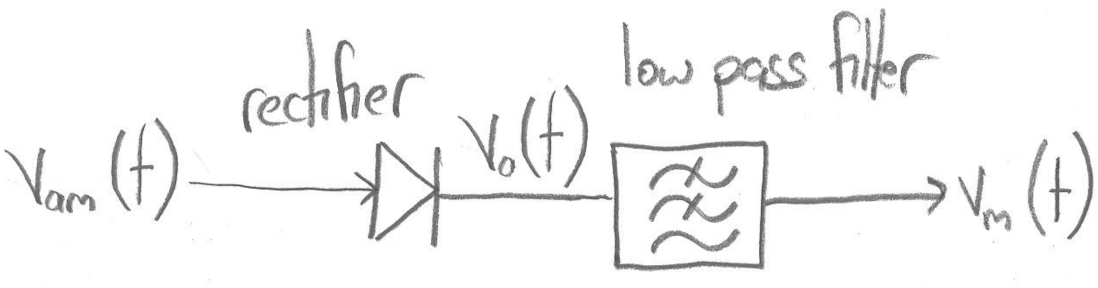
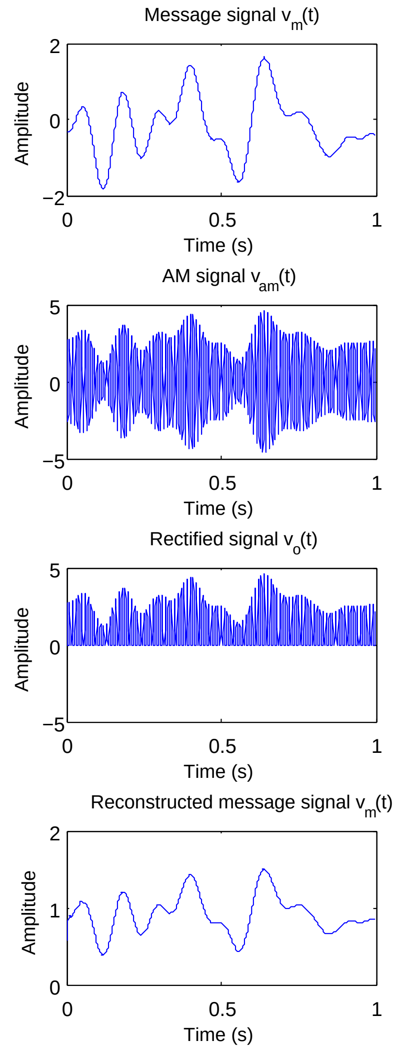


Figure 3.14 Square-law and switching (AM) modulator.

- Diodes or transistors are used for the Non-Linear Device (NLD).
- In a switching modulator, the NLD switches the signal on and off at the carrier frequency. Here, $v_o(t) = v_i(t)v_s(t)$, where $v_s(t)$ is a square wave.
- In a square law modulator, the resistance of the non-linear device depends on the input voltage. Here, $v_o(t) = av_i(t) + bv_i^2(t)$.
- In both cases, the band-pass filter is centred on the carrier frequency.

Amplitude demodulation (CEP 3.5.1)





- If the AM signal is not overmodulated, envelope detection can be used.
- This is non-coherent because it does not require exact knowledge of the carrier frequency or phase.
- The rectifier removes the negative-going part of the signal.
- The Low Pass Filter (LPF) smooths out the oscillations.
- The LPF cut-off frequency should be between the maximum frequency in the signal f_{max} and the carrier frequency f_c. The lower it is, the more channel-induced noise that can be removed.

Diode demodulator

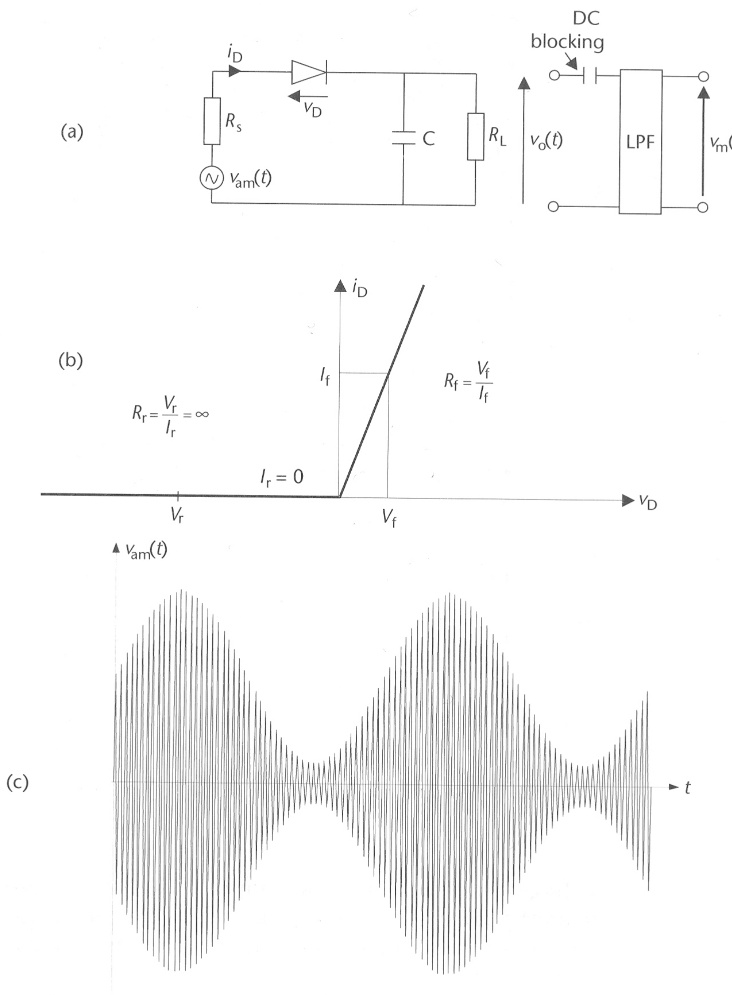


Figure 3.17 Diode demodulator: (a) circuit; (b) ideal diode characteristic; (c) input AM signal (*continues overleaf*).

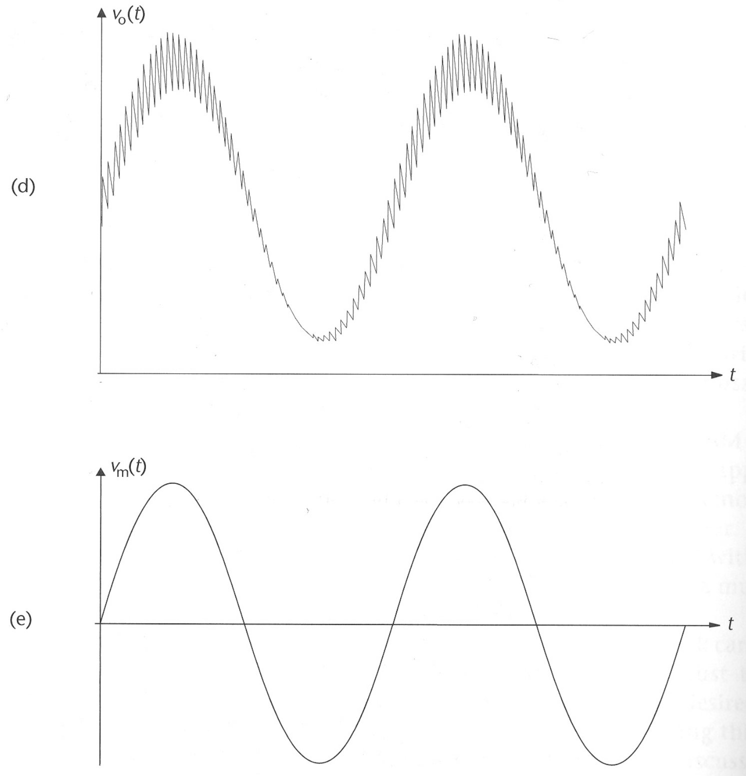


Figure 3.17 (*continued*) (d) Output signal; (e) message signal.

Diode demodulator

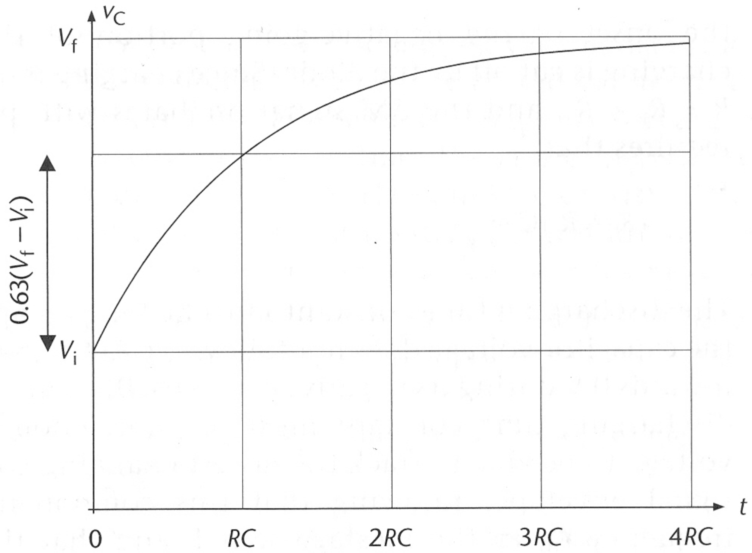


Figure 3.18 Exponential rise in voltage across a capacitor C that is charging through resistor R from an initial voltage V_i towards a final voltage V_f.

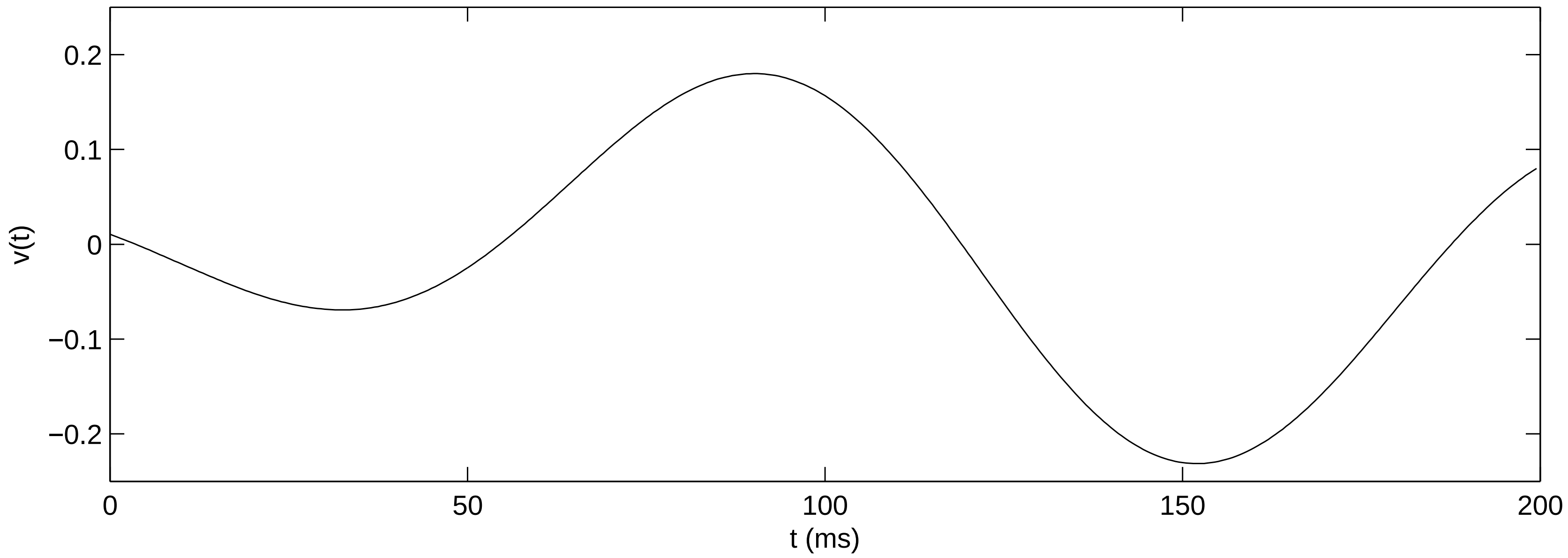
$$v_C(t) = V_f - (V_f - V_i)\exp\left(-\frac{t}{RC}\right)$$

- We need the capacitor to charge quickly through R_f and R_s, so that the voltage will follow the rising edges of the carrier wave.
$$(R_f + R_s)C \ll 1/f_c$$

- We need the capacitor to discharge quickly through R_L, so that the voltage will follow the falling part of the envelope
$$R_L C \ll 1/f_{max}$$

- ...but not quick enough for the voltage to follow the falling edges of the carrier wave
$$R_L C \gg 1/f_c$$

Exercise



1. Sketch the result of using an $f_c = 400$ Hz carrier and AM analogue carrier modulation to convey this signal, which contains a maximum frequency of $f_{max} = 10$ Hz. What is the DC offset, modulation sensitivity and modulation index in your sketch?

Exercise continued

2. For a linearly varied gain modulator using a FET for which $a = 2$, choose a value for the carrier amplitude V_c and the resistor value R_f that will AM modulate the signal with the same DC offset and modulation sensitivity that you used in your sketch.

3. For a diode demodulator in which $R_s = 50\ \Omega$ and $R_f = 20\ \Omega$, determine values for the capacitor C and load resistor R_L which will allow your AM signal to be demodulated.