WS 1.2 Analogue and Digital Modulation

This Mathcad 14 worksheet is designed to accompany the author's book "Microwave and RF Vacuum Electronic Power Sources", Cambridge University Press (2018). The section, equation, and figure numbers refer to the corresponding sections, equations, and figures in the book. Data input fields are highlighted in yellow and output fields are highlighted in green.

Sections 1.6.2: Analogue Modulation

See for example: J. Dunlop and D. G. Smith, *Telecommunications Engineering*. Wokingham, UK: Van Nostrand Reinhold (UK) Co. Ltd, (1984).

The signals are defined in the time domain, sampled, and converted to the frequency domain using the Mathcad fast Fourier transform (fft). The amplitudes of the spectral lines are displayed normalised to the maximum amplitude of the spectrum.

Carrier frequency $f_c := 16$

Modulation frequency $f_m := 2$

Sampling frequency $f_s := 32 \cdot f_m$

$n1 := 12$ $nn := 2^{n1}$ $nn = 4096$

Sampling points in the time domain $j := 0 .. nn - 1$

Sampling points in the frequency domain $ii := 0 .. \frac{nn}{2}$

Note: $f_s = 32*f_m$ gives cleanest spectra but $f_s = 64*f_m$ or greater is necessary to reproduce the original waveform using the inverse Fourier transform (ifft).

Double sideband amplitude modulation

Modulation amplitude $modA := 0.5$

Signal $S_{AM}(t) := \cos\left(2\cdot\pi\, f_m\cdot t\right)$

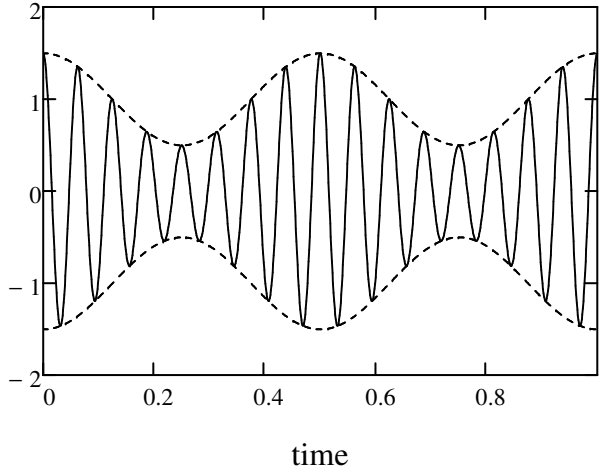
Modulated carrier $f_{dsb}(t) := \left(1 + modA\cdot S_{AM}(t)\right)\cdot\cos\left(2\cdot\pi\, f_c\cdot t\right)$ Equation 1.44

Sampled carrier $fdsb_j := f_{dsb}\left(\frac{j}{f_s}\right)$

Fast Fourier transform $gdsb := fft(fdsb)$

Amplitude of the spectrum $v1_{ii} := \left|gdsb_{ii}\right|$

Normalised amplitude in dB $S1_{ii} := 20\cdot\log\left(\frac{v1_{ii}}{\max(v1)}\right)$



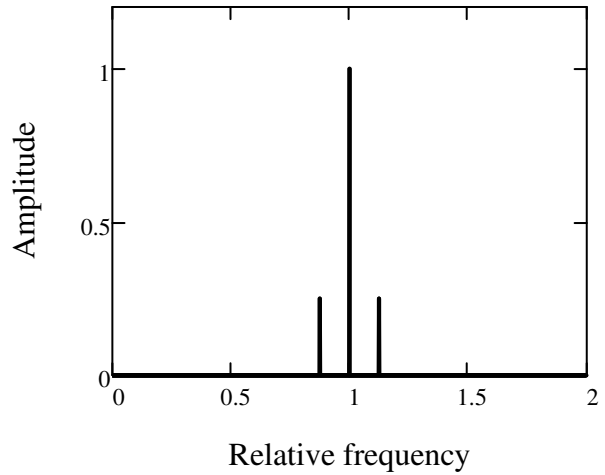


Figure 1.12 (a) and (b)

Double sideband suppressed carrier amplitude modulation

Modulation amplitude $modB := 1$

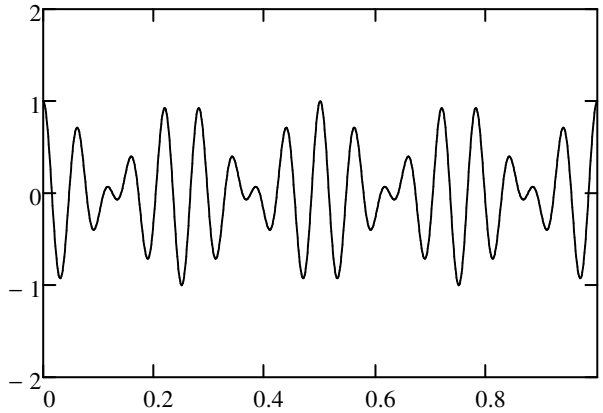
Modulated carrier $f_{sc}(t) := modB \cdot S_{AM}(t) \cdot \cos(2 \cdot \pi \cdot f_c \cdot t)$ Equation 1.45

Sampled carrier $fsc_j := f_{sc}\left(\frac{j}{f_s}\right)$

Fast Fourier transform $gsc := fft(fsc)$

Amplitude of the spectrum $v2_{ii} := |gsc_{ii}|$

Normalised amplitude in dB $S2_{ii} := 20 \cdot \log\left(\frac{v2_{ii}}{max(v2)}\right)$



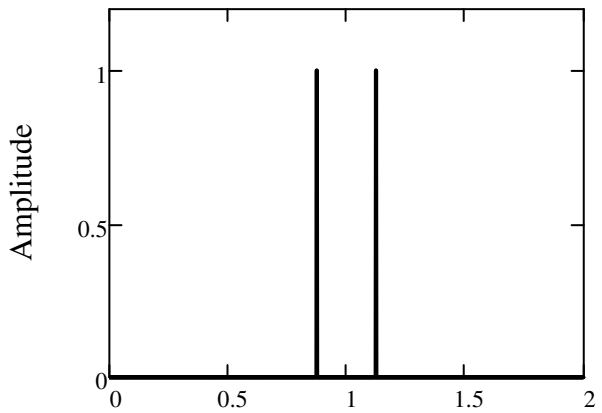


Figure 1.12 (c) and (d)

Phase modulation

Amplitude of phase modulation $\Delta\theta := 60\cdot deg$

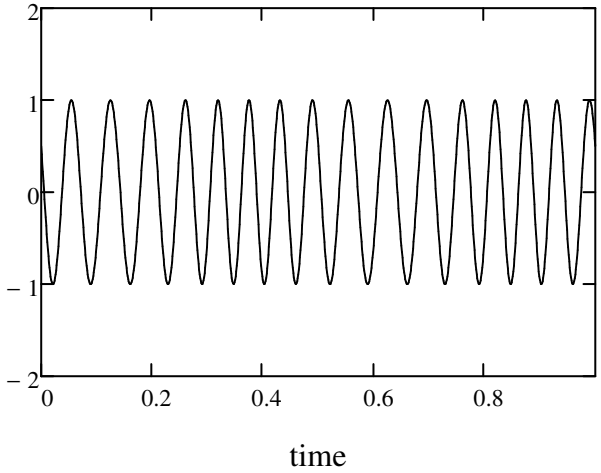
Modulated carrier $f_{pm}(t) := \cos\left(2\cdot\pi\, f_c\cdot t + \Delta\theta\cdot S_{AM}(t)\right)$ Equation 1.46

Sampled carrier $fpm_j := f_{pm}\left(\frac{j}{f_s}\right)$

Fast Fourier transform $gpm := fft(fpm)$

Amplitude of the spectrum $v4_{ii} := \left|gpm_{ii}\right|$

Normalised amplitude in dB $S4_{ii} := 20\cdot\log\left(\frac{v4_{ii}}{\max(v4)}\right)$



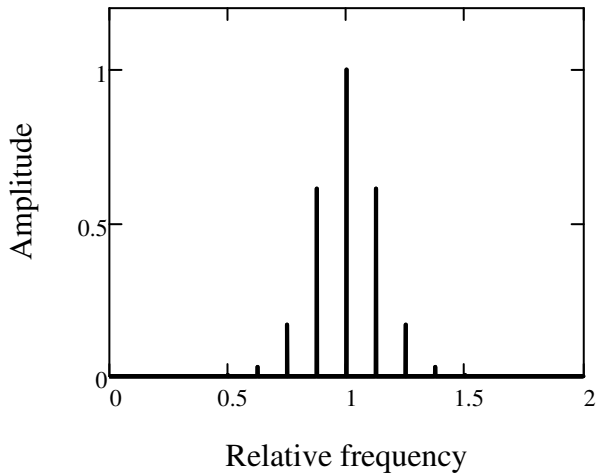


Figure 1.12 (e) and (f)

Section 1.6.3: Digital modulation

The modulating signal is binary defined by $S_m(t) := \begin{cases} m \leftarrow 1 & \text{if } \sin(2\cdot\pi\cdot f_m\cdot t) \geq 0 \\ m \leftarrow 0 & \text{otherwise} \end{cases}$

Amplitude shift keyed modulation

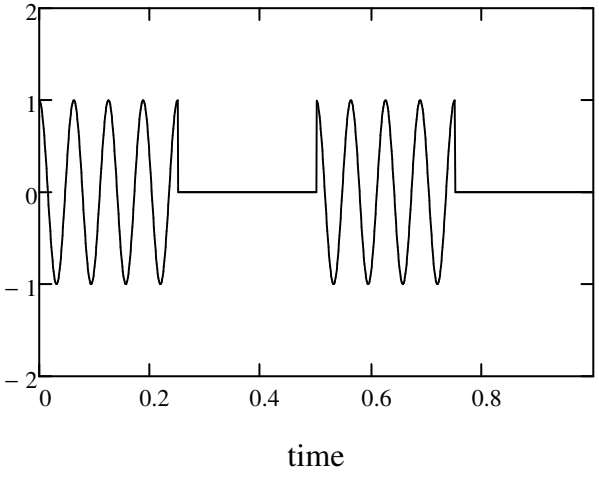
Modulated carrier $f_{ask}(t) := S_m(t)\cdot\cos(2\cdot\pi f_c\cdot t)$

Fast Fourier transform $gask := fft(fask)$

Sampled carrier $fask_j := f_{ask}\left(\frac{j}{f_s}\right)$

Amplitude of the spectrum $v6_{ii} := |gask_{ii}|$

Normalised amplitude in dB $S6_{ii} := 20\cdot\log\left(\frac{v6_{ii}}{max(v6)}\right)$



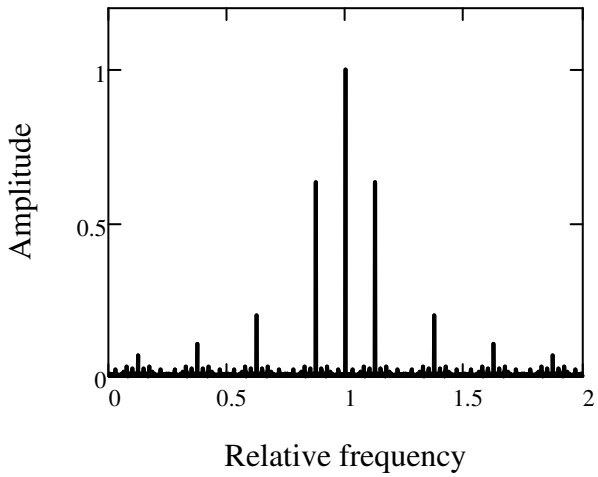


Figure 1.13 (a) and (b)

Binary phase shift keyed modulation

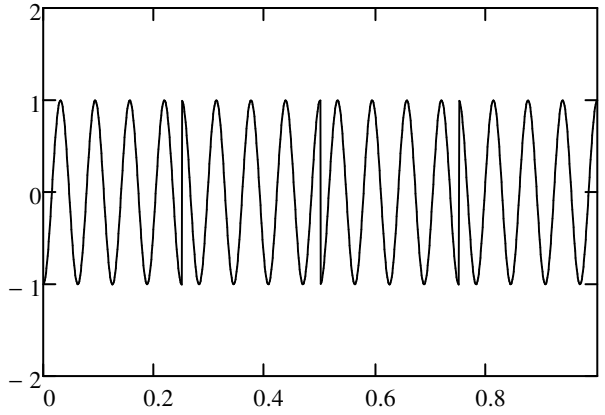
Modulated carrier $f_{psk}(t) := \cos\left(2\cdot\pi\, f_c\cdot t + \pi\cdot S_m(t)\right)$

Fast Fourier transform $gpsk := fft(fpsk)$

Sampled carrier $fpsk_j := f_{psk}\left(\frac{j}{f_s}\right)$

Amplitude of the spectrum $v7_{ii} := \left|gpsk_{ii}\right|$

Normalised amplitude in dB $S7_{ii} := 20\cdot\log\left(\frac{v7_{ii}}{\max(v7)}\right)$



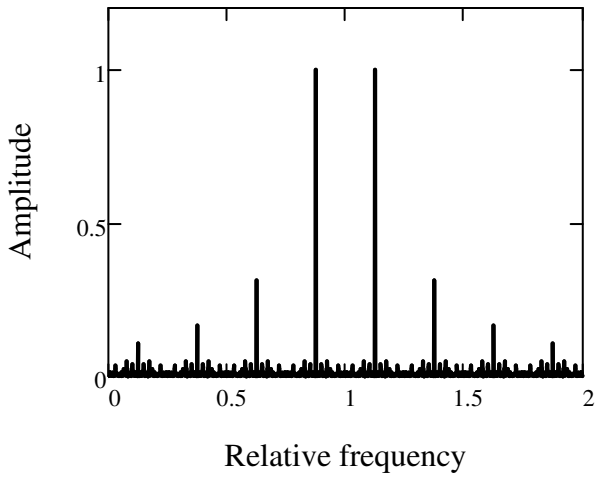


Figure 1.13 (c) and (d)

Binary frequency shift keyed modulation

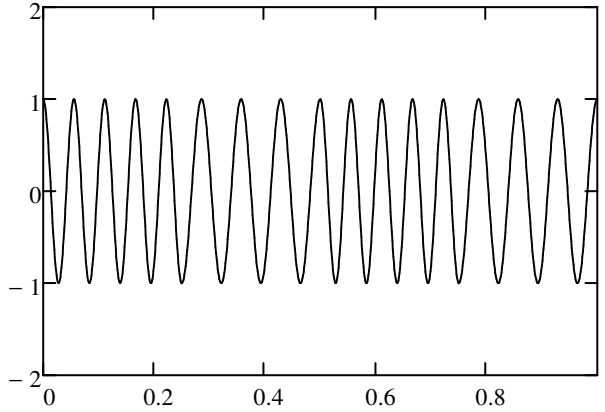
Modulated carrier $f_{fsk}(t) := \cos\left[2\cdot\pi\left[\left[f_c + 2\cdot f_m\cdot\left(S_m(t) - 0.5\right)\right]\cdot t\right]\right]$

Fast Fourier transform $gfsk := \mathrm{fft}(ffsk)$

Sampled carrier $ffsk_j := f_{fsk}\left(\frac{j}{f_s}\right)$

Amplitude of the spectrum $v8_{ii} := \left|gfsk_{ii}\right|$

Normalised amplitude in dB $S8_{ii} := 20\cdot\log\left(\frac{v8_{ii}}{\max(v8)}\right)$



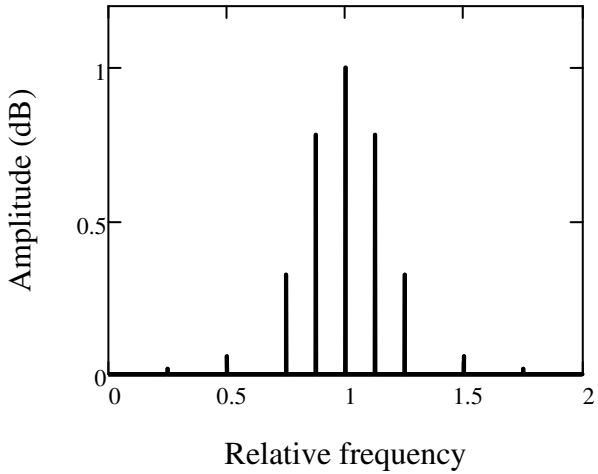


Figure 1.13 (e) and (f)