Modulation

Definition

One signal (carrier) varies according to the changes in another signal (modulator)

Either amplitude modulation (AM) or frequency modulation (FM).

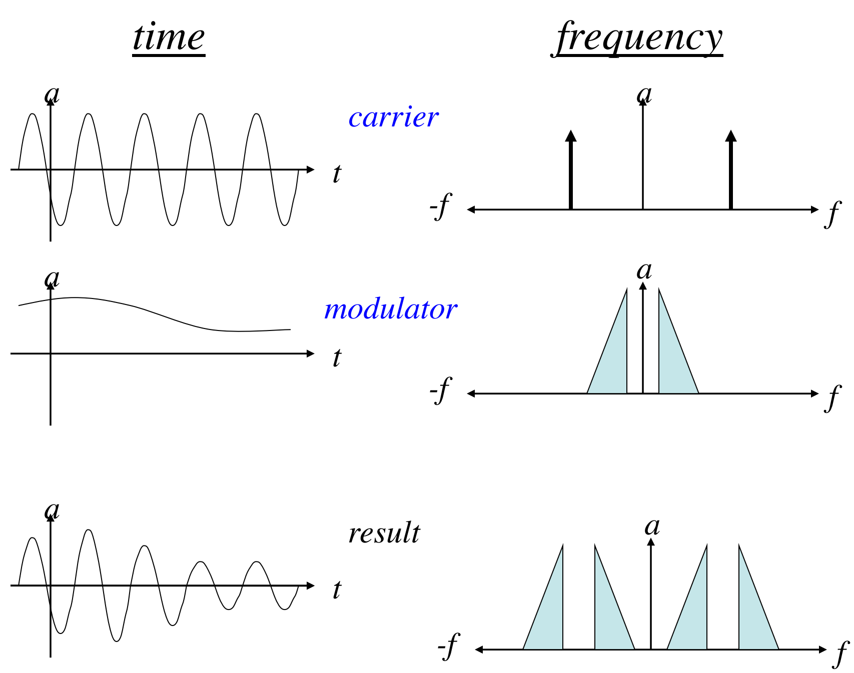
Amplitude Modulation

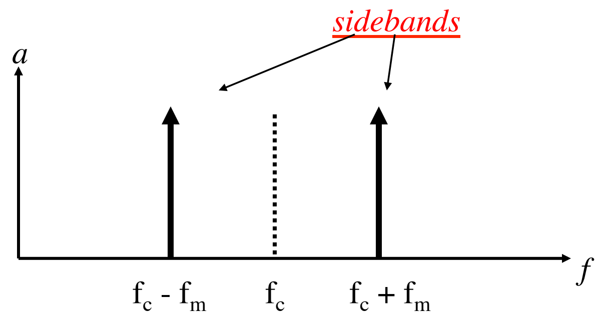
Type #1

balanced/ring/double-sideband suppressed carrier

amplitude modulation

$f_1(t) * f_2(t)$





sum and difference frequencies

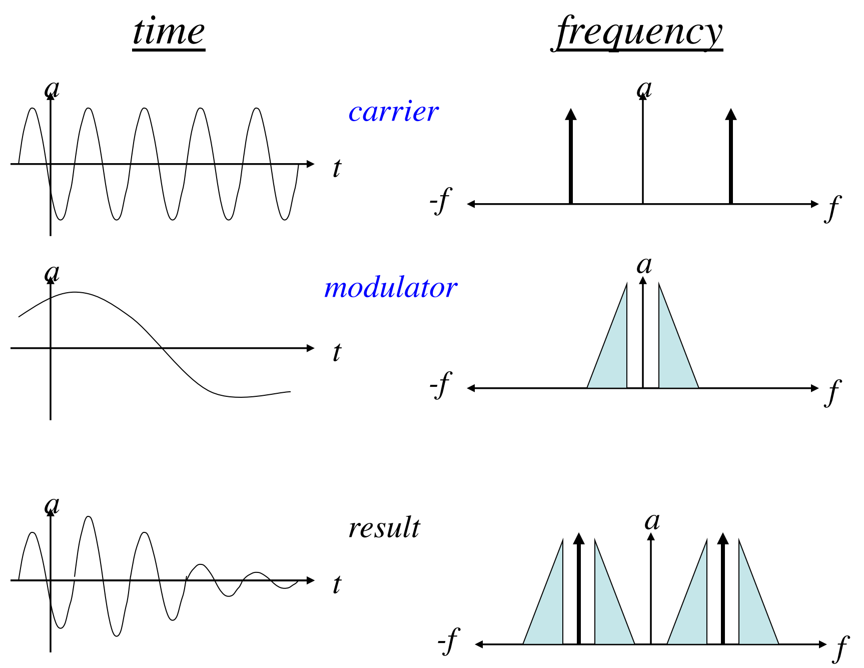
carrier $\sin(2\pi f_c t)$
modulator $\sin(2\pi f_m t)$

Amplitude Modulation

Type #2
double-sideband
amplitude modulation

$0.5 * (1.0 + f_1(t)) * f_2(t)$

f_1 is offset to range between 0.0 and 1.0

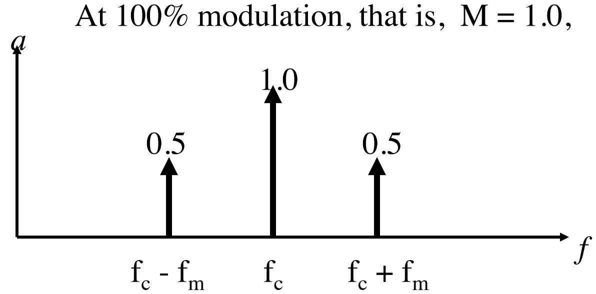


alternatively,

$$0.5 * (1.0 + M\, f_1(t)) * f_2(t)$$

where M is the modulation index

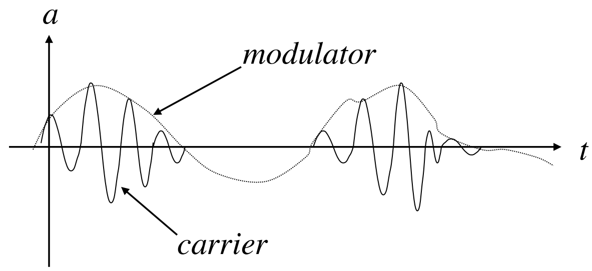
At 100% modulation, that is, M = 1.0,



Overmodulation occurs when M > 1.0

the f_1 part ranges below zero
and greater than 1.0

If [0.5 * (1.0 + M $f_1(t)$)] < 0.0,
then replace with 0.0.



Amplitude Modulation

Type #3
single-sideband, suppressed carrier
amplitude modulation

Pretty hard to do digitally!

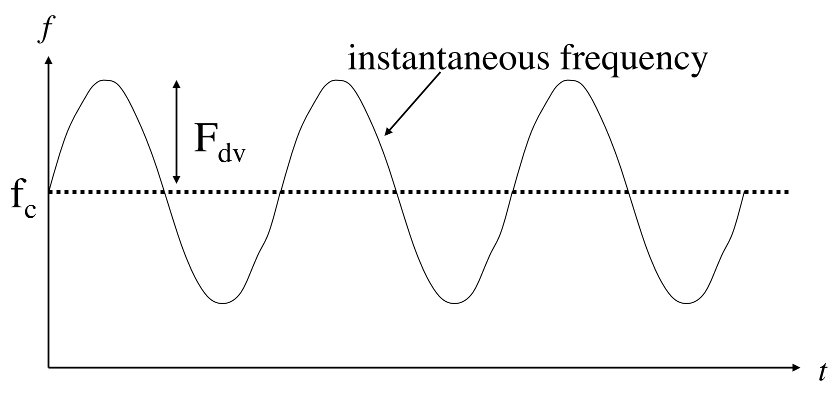
Frequency Modulation

$$f_{inst} = f_c + F_{dv} * \sin(2\pi\ f_m\ t)$$

$$amp * \sin(2\pi\ f_{inst}\ t)$$

where f_c is the carrier frequency,
f_m is the modulator frequency and
f_{inst} is the instantaneous frequency

Frequency Modulation



$$f_{inst} = f_c + F_{dv} * \sin(2\pi\ f_m\ t)$$

Frequency Modulation Index

$$M = F_{dv} / f_m$$

$$F_{dv} = f_m * M$$

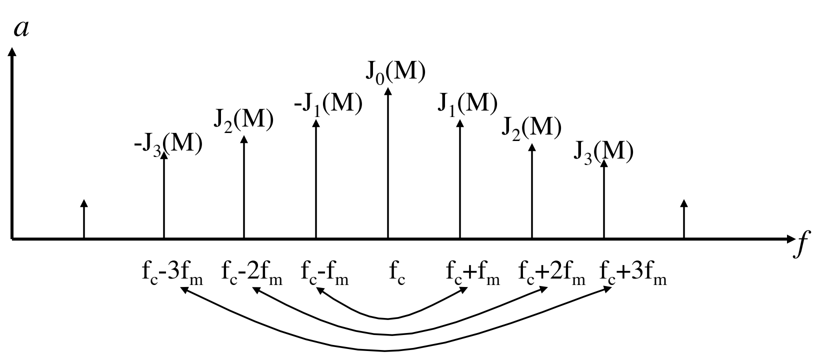
$$f_{inst} = f_c + f_m * M * \sin(2\pi f_m t)$$

$$amp * \sin(2\pi f_{inst} t)$$

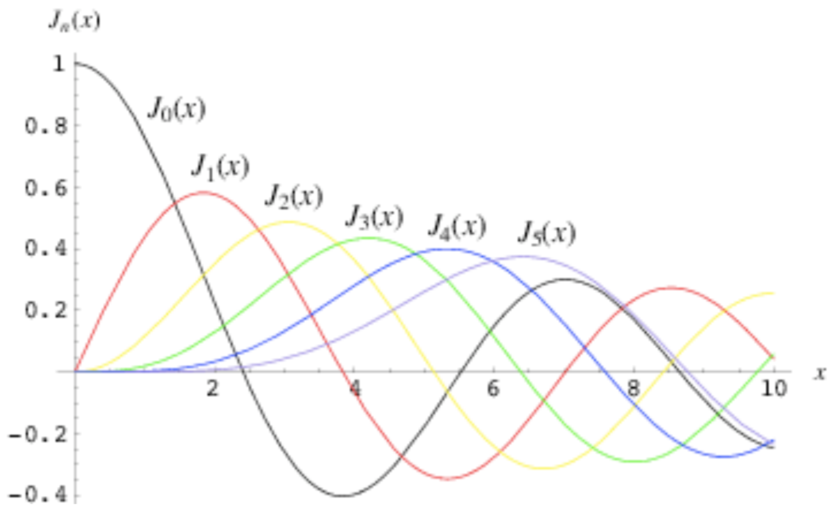
Sidebands at $(f_c \text{ +/- } n f_m)$

Amplitudes at $J_n(M)$ where J_n is a Bessel function of the nth order

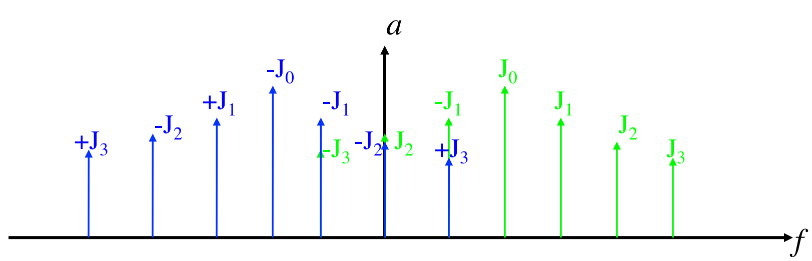
n=0 --- carrier
n=1 --- first sideband pair
etc.



Bessel Functions

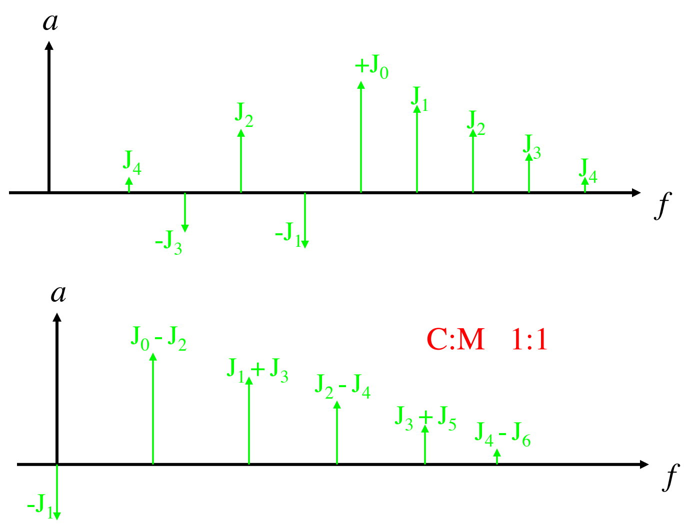


Folding Around 0 Hz

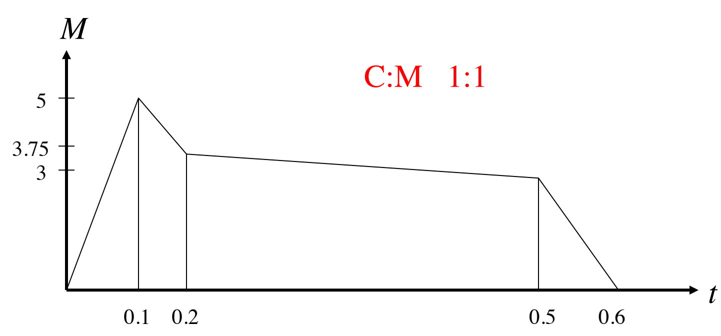


Components appear to fold around zero with reversed sign

Chowning FM

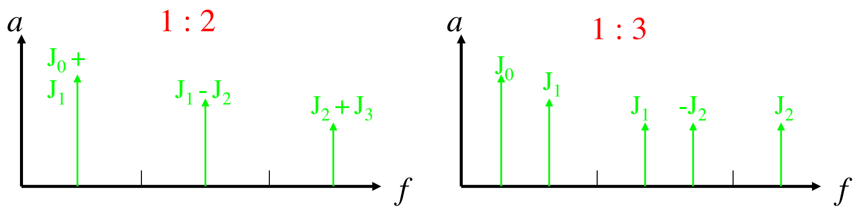


Chowning FM Trumpet



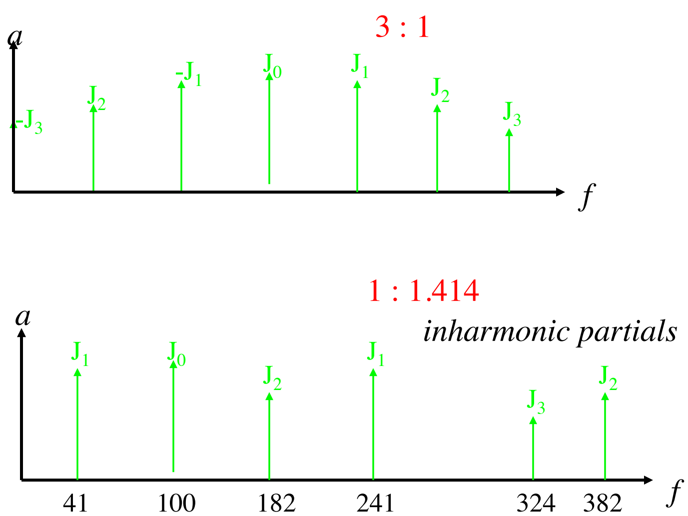
Amplitude envelope shape also serves to control the frequency modulation index

C:M Ratios



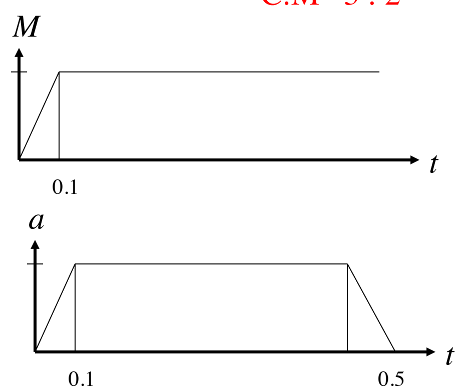
Every Mth harmonic is missing.

C:M Ratios



Chowning FM Clarinet

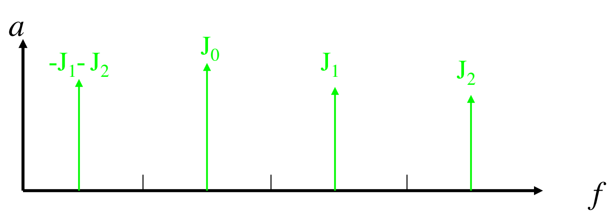
C:M 3 : 2



Amplitude envelope must be separated from the frequency modulation index

Chowning FM Clarinet

C:M 3 : 2

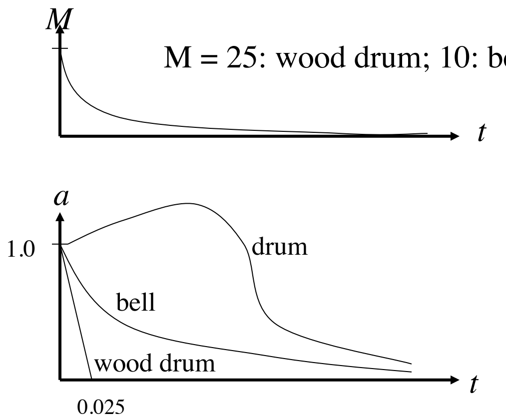


Energy starts in the 3rd harmonic. Every 2nd harmonic is missing.

Chowning FM Percussion

C:M   1: 1.414

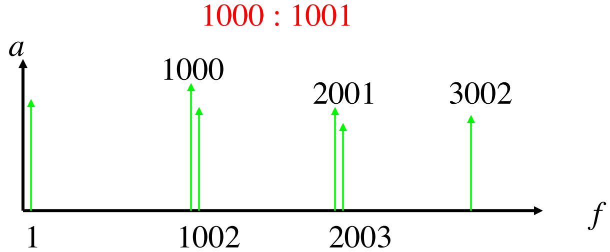
M = 25: wood drum; 10: bell; 2 drum



FM detuning

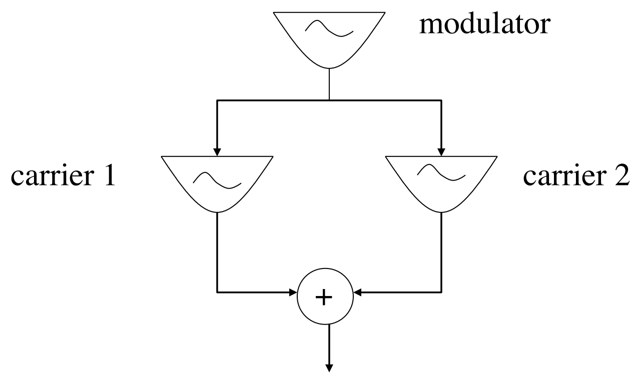
1 : 1 +/- X Hz

1000 : 1001

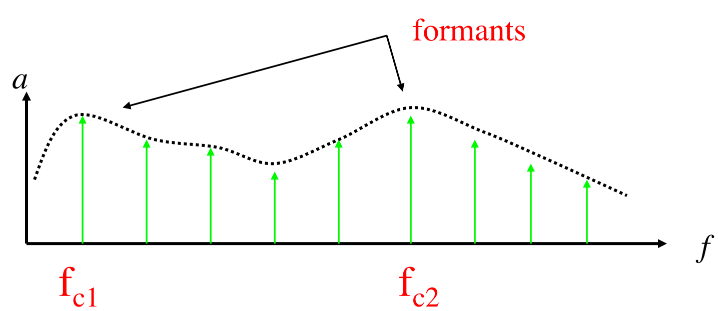


Detuning produces beats at 2 X*

Extensions to FM: Multiple carriers

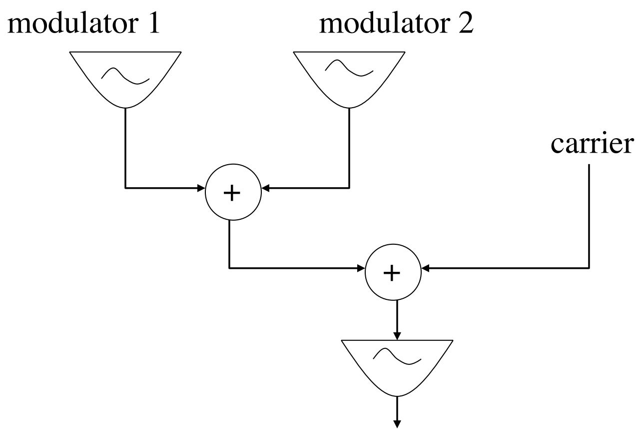


Multiple Carriers



voice synthesis

Extensions to FM: Complex Modulating Wave



Multiple Modulator Sidebands

Multiple Modulator FM
produces sidebands at

$f_c \;\; +/- \;\; i\, f_{m1} \;\; +/- \;\; k\, f_{m2}$

like one FM pair is modulated by the other

$(f_c \;\; +/- \;\; i\, f_{m1}) \;\; +/- \;\; k\, f_{m2}$

Multiple Modulator Sidebands

Example

C: M1 : M2 1 : 1: 4 $M_1 = 1, M_2 = 0.2$

All cross combinations are formed

	1:1	1:4
J_0	.77	.98
J_1	.44	.10
J_2	.12	.005
J_3	.02	

Spreads energy out and limits the influence of dynamic M

Example: String Synthesis

- 1 : 1 : 3 : 4
- Each M dependent on frequency
- 5-6 Hz Vibrato
- 10-20 Hz random fluctuations
- Attack noise: 20% to 0% in .2 sec
- M +1 for .2 sec
- Detuning 1.5 to 4 Hz