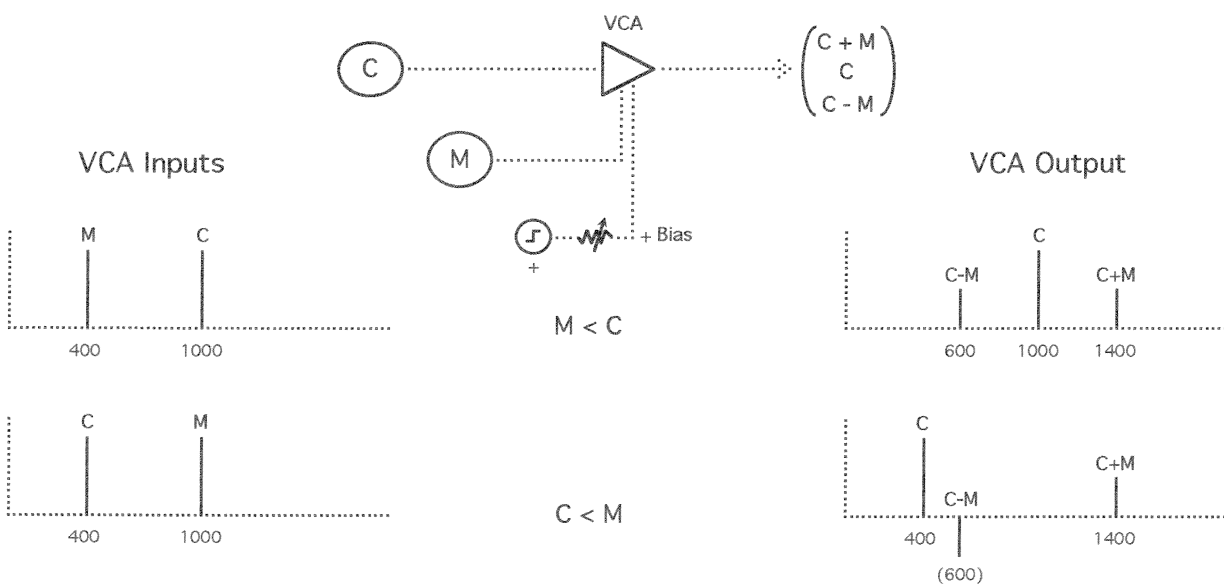
Audio Frequency Amplitude Modulation (AM)

Amplitude Modulation (AM) uses a two quadrant multiplier, e.g. Voltage Controlled Amplifier (VCA) to multiply a bipolar Carrier signal (C) times a unipolar Modulator signal (M).

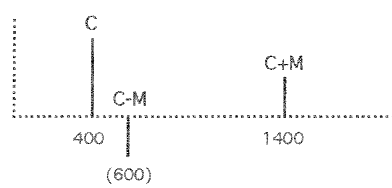
When both C and M are periodic audio frequency signals, classic Amplitude Modulation (AM) occurs as depicted in the frequency domain graphics below. Audible modulation products—an "upper and lower sideband pair" comprising sum (C+M) and difference (C-M) signals are output, as well as the original Carrier (C) signal. The Modulation (M) signal does not appear in the output. Sine wave C and M input signals are shown below. If complex C and/or M wave(s) are used, sum and difference sideband pairs for each partial in C interacting with each partial in M are produced. "Clangorous" sounds may occur due to audio frequency AM, particularly when C and M input frequencies are not harmonically related.

In a two quadrant multiplier (VCA), the M input processes only unipolar positive signals. If a bipolar ± (plus and minus) signal is connected to this M input, "half-wave" AM may occur, since the negative part of the M wave will be ignored. A bipolar M signal may cause extra frequencies to appear in the VCA output, similar to "overmodulated" AM. A positive bias (+ DC) of sufficient level added to input signal M will "normalize" its polarity, making all of its values fall between zero and positive. (See bias shown below). A properly biased M signal is unipolar positive, as required by the M input of a two quadrant multiplier. This VCA is biased "open" to make the largest negative value of a bipolar M signal appear to be zero to the M input of the VCA. This "open" VCA cannot also articulate the carrier.

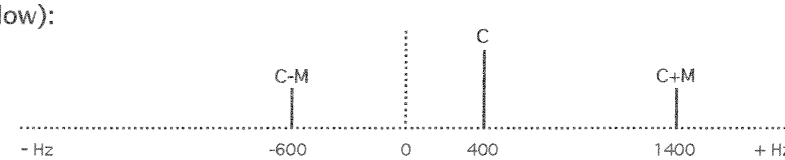


Negative Frequency: a frequency with 180° (degree) phase shift or polarity opposite to a positive frequency. Negative frequency is depicted as negative Hertz (Hz).

Negative frequency may be depicted "below the line" to indicate the change of polarity (see opposite):



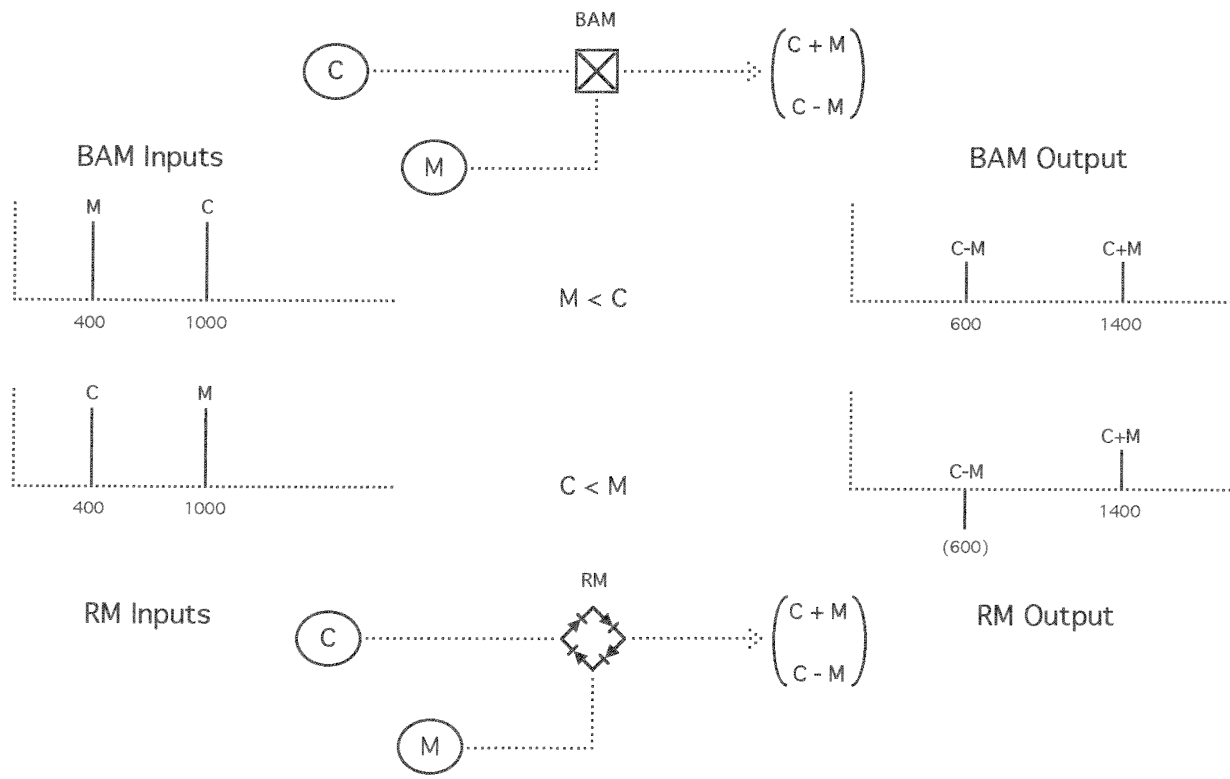
Negative frequency may be depicted on a frequency line that explicitly shows both negative (- Hz) as well as positive (+ Hz) Hertz values (see below):



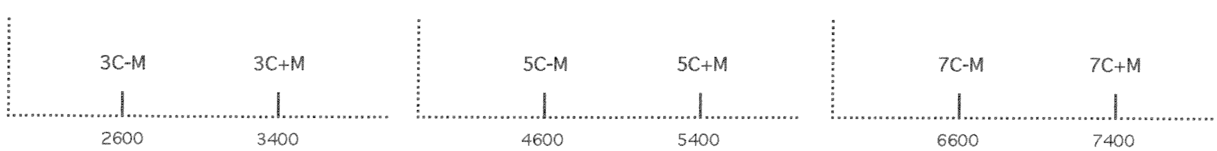
Balanced Amplitude Modulation (BAM) uses a four quadrant multiplier to multiply a bipolar Carrier signal (C) times a bipolar Modulator signal (M). This four quadrant multiplier may be called, variously, a Balanced Amplitude Modulator (BAM), or a Ring Modulator (RM).

When C and M are bipolar periodic audio frequency signals, Balanced Amplitude Modulation (BAM) occurs as depicted in the frequency domain graphics below. Audible modulation products—an "upper and lower sideband pair" comprising sum (C+M) and difference (C-M) signals are output. In typical designs, both the Carrier (C) and the Modulation (M) signals are suppressed, and do not appear in the BAM or RM output. Sine wave C and M input signals are shown below. BAM will produce an upper and lower sideband pair for each C and M partial, typical of AM. The switch of C and M frequencies in BAM (see below) may not be heard, because the ear is relatively insensitive to such phase or polarity differences. But, the phase or polarity of partials in a signal may cause audible effects if the signal is mixed with other signals. Choice of the C or M input relative to the two input frequencies may matter.

AM or BAM sideband amplitude(s) will not exceed half the amplitude of the Carrier signal (C), as indicated graphically. AM or BAM sideband amplitude = Index/2 of C amplitude, where Index ranges from 0 (no mod of C) to 1 (100% mod of C). Sideband amplitude(s) are ≤ 1/2 of Carrier amplitude.

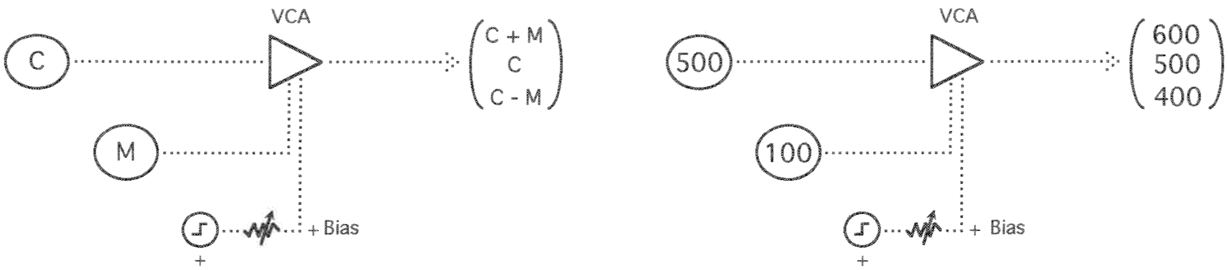


Digital implementations of BAM or RM should produce identical results (see above). But, an analog Ring Modulator may produce additional sidebands. Multiplication of two bipolar signals, e.g. BAM, may be approximated in analog circuitry by including four electronic components called "diodes" arranged in a "ring" configuration, (see RM graphic above). Analog RM may produce sideband pairs (with smaller amplitudes) surrounding odd-number multiples of the carrier frequency, for instance. In addition to the sideband pair shown above when M < C such an analog RM may produce other pairs:



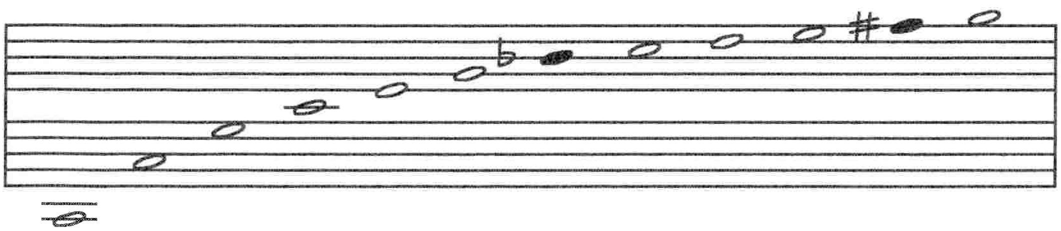
Amplitude Modulation (AM) can produce harmonic spectra, when Carrier (C) and Modulator (M) input frequencies are harmonic to each other (C:M has an integer ratio, or relationship).

When C and M are both single partials, or sine waves, AM output is 3 sine waves, or 3 partials: the C frequency, and upper & lower sidebands (partials) at ± (plus and minus) the M frequency from the C frequency (see below, left). Specific frequencies illustrate these AM relationships (see below, right).

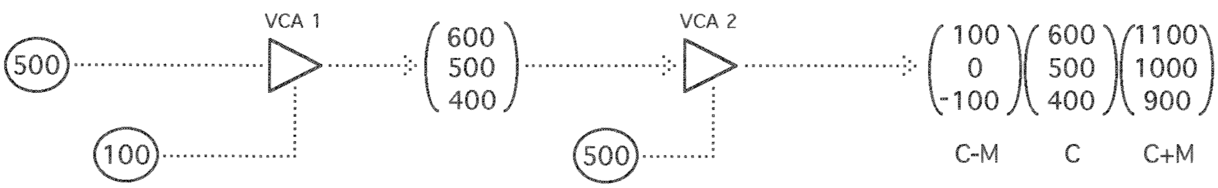


C and M frequencies above comprise an input ratio of C:M (C to M) frequencies 500:100. This reduces to the whole number (integer) ratio of 5:1, which is the musical interval of two octaves and a Major third (see Harmonic Series (HS) below). The resulting AM *output* frequency ratio of 400:500:600 reduces to 4:5:6, a Major chord (see HS below). Given sine wave inputs, any C:M ratio of 5:1 will provide such an AM output. Approximate intervals for the harmonic series for note "C2" are shown:

Harmonic Series (Fundamental C2 = Harmonic1)

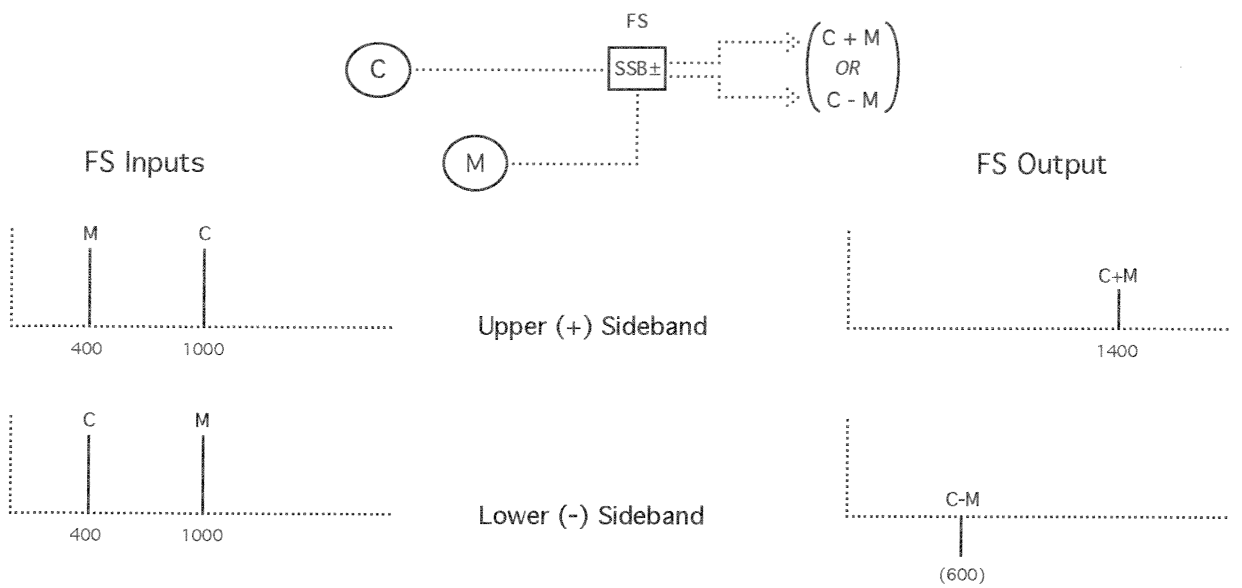


If the output of VCA1 (see below) is used as the Carrier of VCA2, a number of harmonics may result. With respect to VCA2, *all* of the three sine waves 400, 500, and 600 are Carriers, and appear in the VCA2 output (C). *Each* VCA2 Carrier will produce a sideband pair, lower (C-M) and upper (C+M), with the VCA2 Modulation (M) frequency. If 500 Hz, for instance, is selected as (M) for VCA2, a complex output (see below) will result. (Note: VCA biases, though assumed necessary, are not shown below):



Three sine wave oscillators (VCOs) are tuned to the ratio 1:5:5 (heard as "DOH:MI:MI"). VCO output(s) are connected as M & C to VCA1, and as M to VCA2 respectively. VCA2 output is monitored. The VCA2 output spectrum has harmonics spanning 4 through 11, with harmonics 7 and 8 missing. Two partials at 100 Hz have opposing polarities ("phase"), and *cancel* because they have equal (=) amplitudes, identical frequencies, and opposing polarities. VCO(s) detuned from harmonicity (e.g. 101 Hz rather than 100 Hz), may create "stretched harmonics" or chorus effects. If all VCOs track a keyboard and maintain VCO tuning ratios, the same spectrum for any pitch will be produced, making tone color consistent.

A Frequency Shifter (FS) acts like a Ring Modulator (RM) that can suppress either all upper or all lower sidebands. That is, a FS (Frequency Shifter), or SSB (Single Sideband) modulator makes *either* the upper (C+M) *or* the lower (C-M) sidebands available at its output. Some models provide both upper and lower sidebands, with individual (+) upper and (-) lower sideband outputs. Analog units may not reduce the "rejected" (+ or -) sideband(s) completely.



Frequency shifting distorts the signal—unlike "pitch shifting," which maintains the ratios among the partials in the processed signal. ("Harmonizer" is the proprietary name of a well-known Pitch Shifter.) Frequency shifting, like all AM, essentially adds/subtracts the *same number of Hertz* to/from each partial in the input C signal. In the example(s) below, a harmonic "Reference Spectrum" (similar to a square wave) is first pitch shifted (PS), then frequency shifted (FS) for comparison. A Pitch Shifter transposes the existing spectrum (harmonic here). A Frequency Shifter can produce a clangorous, or nonharmonic spectrum. Some FS units have an internal oscillator (M) that can shift any input C signal.