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A project by UNESCO and University of Plymouth
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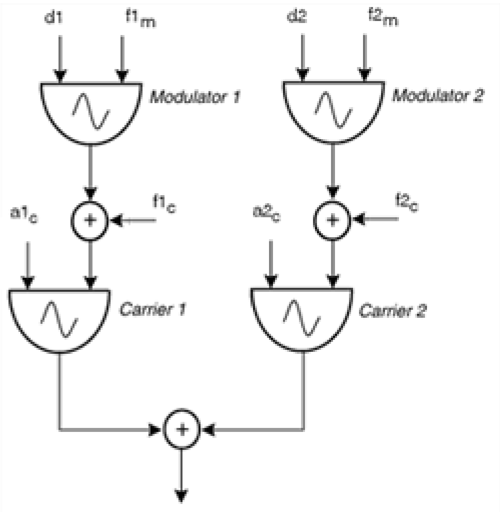
Advanced FM synthesis

Composite frequency modulation

Composite FM involves two or more carrier oscillators and/or two or more modulator oscillators. There are a number of possible combinations and each of them will create different types of spectral compositions.
On the whole, complex FM produces more sidebands but the complexity of the calculations to predict the spectrum also increases. There are at least five basic combinatory schemes for building composite FM instruments:

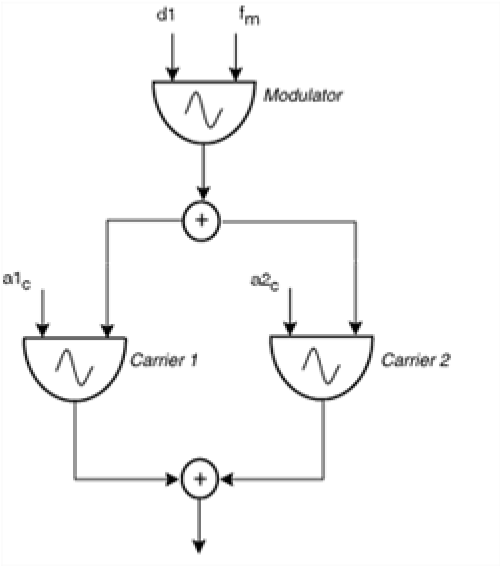
- Additive carriers with independent modulators
- Additive carriers with one modulator
- Single carrier with parallel modulators
- Single carrier with serial modulators
- Self-modulating carrier

Additive carriers with independent modulators



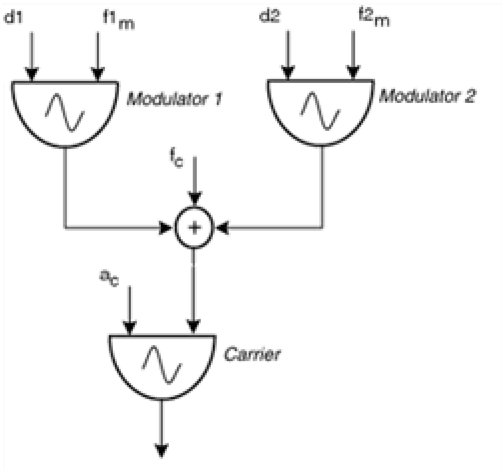
This scheme is composed of two or more simple FM instruments working in parallel. The spectrum is therefore the result of the addition of the outputs from each instrument.

Additive carriers with one modulator



This scheme employs one modulator oscillator to modulate two or more carrier oscillators. The resulting spectrum is the result of the addition of the outputs from each carrier oscillator.

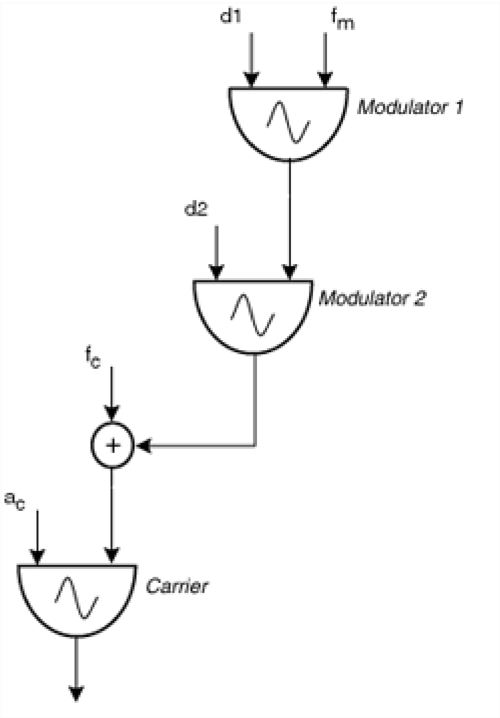
Single carrier with parallel modulators



This scheme employs a more complex signal to modulate a carrier oscillator: the result of two or more sinewaves added together.
In this case, the formula for the calculation of a simple FM spectrum is expanded in order to accommodate multiple modulator frequencies and modulation indices.
For example, in the case of two parallel modulator oscillators, the sideband pairs are calculated as follows:

- $f_c - (k_1 \times f_{m1}) + (k_2 \times f_{m2})$
- $f_c - (k_1 \times f_{m1}) - (k_2 \times f_{m2})$
- $f_c + (k_1 \times f_{m1}) + (k_2 \times f_{m2})$
- $f_c + (k_1 \times f_{m1}) - (k_2 \times f_{m2})$

This formula looks complicated but, in fact, it simply states that each of the partials produced by one modulator oscillator (i.e. $k_1 \times f_{m1}$) forges a 'local carrier' for the other modulator oscillator (i.e. $k_2 \times f_{m2}$). The larger the number of parallel modulators, the greater the amount of nested 'local carriers'. The amplitude scaling factors here result from the multiplication of the respective Bessel functions: B_n



$(i_1) \times B_m(i_2)$.

Single carrier with serial modulators

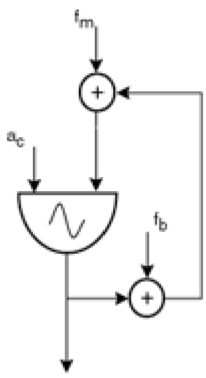
This scheme also employs a complex signal to modulate a carrier oscillator. In this case, however, the modulating signal is a frequency modulated signal. The sideband frequencies are calculated using the same method used above for parallel modulators, but the calculation of the amplitude scaling factors is different. The 'order' of the outermost modulator is used to scale the modulation index of the next modulator:

$B_n(i_1) \times B_m(n \times i_2)$.

The main differences between the spectrum generated by serial modulators and parallel modulators, using the same frequency ratios and index, are that:

1. The former tends to have sidebands with higher amplitude values than the latter
2. No sideband components from Bm(i) are generated around the carrier centre frequency; e.g. $B_0(i_1) \times B_1(0 \times i_2) = 0$.

Self-modulating carrier



The self-modulating carrier scheme employs the output of a single oscillator to modulate its own frequency. The oscillator output signal is multiplied by a *feedback factor* (represented as f_b) and added to a frequency value (f_m) before it is fed back into its own frequency input; f_b may be considered here as a sort of modulation index.
This scheme will always produce a sawtooth-like waveform due to the fact that it works with a 1:1 frequency ratio by default; that is, the modulation frequency is equal to its own frequency. The amplitudes of the partials increase proportionally to f_b.
Beware, however: as this parameter is very sensitive, values higher than $f_b = 2$ may lead to harsh white noise.
The self-modulating carrier scheme is sometimes preferable to a simple 1:1 FM instrument. The problem with simple FM is that the amplitudes of its partials vary according to the Bessel functions, but this variation is not linear. The number of sidebands increases by augmenting the modulation index, but their amplitudes do not rise linearly. This grants an 'unnatural' colouration to the sound which may not always be desirable. The amplitudes of the partials produced by a self-modulating oscillator increase more linearly according to the feedback factor (f_b).