FM Synthesis V, subaudio carrier, carrier 0Hz/wave shaping and audio signals as carrier and modulator

phase modulation vs linear frequency modulation

In Yamaha's FM implementation actually phase modulation is applied. This means that if the value at the modulation input changes, carrier frequency changes. If the value at the input changes positive then the phase is modulated upwards. Lower modulating values results in less upward phase modulation. (This phase modulation results in side band generation: sum and difference frequencies of carrier and modulator.)

When the modulation signal level is going negative, the carrier phase again is shifted upwards, but with opposite phase sign. This is called 'through zero FM'. The modulation depth in Yamaha's phase modulation is thus determined by the *speed* at which the modulation amplitude changes.

In true linear frequency modulation, such as in the Clavia Nord Modular Classic and NMG2 oscillators, it is not the speed of amplitude changing in the modulation signal that causes modulation of the carrier frequency. Here it it the actual *amplitude value* of the modulating signal wich is responsible for the carrier frequency.

A constant value applied to the phase modulation input leads to nothing, the carrier remains on the set frequency. A constant applied on a real linear FM input indeed results: the frequency is linear related to the amplitude value of the FM modulation input signal.

For sub audio carrier frequencies we hear in the output signal cyclical changes. Thus these beatings take place in the time domain. Carrier frequencies higher than 20 Hz cause changes, modulations, which are so fast that they manifest themselves in the pitch domain. These changes becoming now manifest as a tmbre change. Here follow some examples of sub audio and FM carrier 0Hz/waveshaping.

sub audio carrier

```
c  :  m = 1 Hz (fixed freq.) : 440Hz (A4)

| n  ±  nm |
upper side bands (Hz): 441, 881, 1321, 1761, 2201, 2641
lower side bands (Hz): 439,-879, 1319,-1759, 2199,-2639
```

In this example, two spectra are generated, an upper side band spectrum and a lower side band spectrum. Now there occurs beating between the upper side band and lower side band frequencies, due to a frequency difference of 2Hz between all the upper and lower side bands. The auditory sensations stemming from sub audio carrier settings depends on the speed of beating. Think of illusions like phasing and Leslie effects. (Reminder: The lowest adjustable fixed frequency on the DX7 is 1 Hz)

0Hz carrier

```
 c : m = 0 Hz : Ratio 1

| c ± nm | for c = sine

upper side bands: 1, 2, 3, 4, 5, 6, 7, 8, 9, ...
lower side bands: 1,-2, 3,-4, 5,-6, 7,-8, 9, ...


| c ± nm | for c = cosine

upper side bands: 1, 2, 3, 4, 5, 6, 7, 8, -9, ...
lower side bands:-1, 2,-3, 4,-5, 6,-7, 8, -9, ...
```

In this example we we obtain an output signal with only odd harmonics, because the the phase of the even lower side band frequencies is negative. Thus the even upper side band frequencies cancel against the even lower side band frequencies due to their opposite phase.

waveshaping synthesis/0Hz carrier

A carrier frequency fixed at `0Hz` seems to be rather strange. There's no output signal whatsoever. Well, that is true if there is a constant signal value at the frequency modulation input. However when the modulatior amplitude changes in positive direction the carrier frequency is modulated upwards. If the modulation input changes in negative direction the carrier frequency is also modulated upwards but with opposite phase (through zero FM). Again the changing speed of the modulator amplitude controls the modulation depth.
With a carrier fixed at `0Hz` thus we can consider the carrier waveform, as a waveshape function, a distortion curve. In the `SY77/TG77/SY99` synthesizers waveshaping synthesis can be realized by setting the carrier at `0Hz`. Not only we can set the carrier frequency at `0Hz`, we also can shift the starting point of the waveshape function in 127 steps between sine and cosine.

In case the carrier waveshape is a cosine wave all odd lower side band

frequncies must be multiplied by -1. All odd upper and lower side band freqencies are canceling now because of opposite phase.
There only remain the even harmonics on: `2, 4, 6, 8, 10, ...` For our perception `'2'is` the lowest frequency. This acts thus as a fundamental, `'1'`. Therefore all numbers must be divided by 2.
And now we get the compact harmonic series: `1, 2, 3, 4, 5, ...`
Note that this sequence is one octave higher than the odd series of harmonics in the case the carrier wave shapefunction is a sine.

With the phase setting of the carrier any desired balance can be made between the even and the odd harmonics.
In each operator in the SY/TG77/99 instruments a choice may be made between 16 different waveforms/waveshapes (one sine/cosine and 15 additional complex waveforms/waveshapes. This yields a virtual unlimmited waveshaping synthesis power.

FM FX, audio signals as a modulator and/or carrier

So far we only discussed internal operators as carrier and modulator signals. However, it is also possible to apply external audio sources as carrier or modulator. In the SY77/99/TG77 instruments, for instance, AWM waveforms can be used as modulation signals. (**A**dvanced **W**ave **M**emory is Yamaha speak for PCM samples.) Actually, FM synthesis is a special case of *side band generation synthesis*. Side band generation however can be realized in various different ways. For instance, by true linear frequency modulation (Clavia, NI Reaktor), by phase modulation (Yamaha), by filter cutoff modulation and by time-delay modulation. With a filter the side bands arise by modulating the cutoff frequency at audio rate. The delay line forms side bands by modulating the delay time. If the modulation frequency is at audio rate, likwise here sidebands occur.

the sample patches

The following patch examples are all implementations for the `Clavia Nord Modular G2`. In case of generating side bands with a delay line we must introduce a latency delay time as a bias adjustment. This because the audio signal in the delay must be modulated up and down The patch `Mod-to-ExtCar` is based on a delay time of 2.68 milliseconds. The modulation signal modulates the delay time: reducing delay time (frequency increasing) and increasing delay time (frequency decreasing).

`ExtMod-Car` is based on an audio signal that serves as a modulator for a carrier, an `OscPM`, a Yamaha-style carrier with *phase* modulation input. The audio input can be edited in a high and low pass filter in series. For instance, the input can be adapted before applying as a modulation signal. In addition to these filters, the input signal is also sent to an envelope follower. The output of the envelope follower can additionally be used for pitch modulation on OscPM (exponential frequency modulation).

In a cross-fade module, a balance can be adjusted between maximum tracking the volume of the audio input and the other extreme, always maximum carrier amplitude. Finally, in a second crossfade module, a dry/wet balance may be made between input and FX signal.

Mod-to-ExtCar include patch variations that are based on external audio acting as a carrier signal. The object in which the modulation takes place is formed by a delay line, a filter or an OscString, depending on one of the eight patch variations.
The eight patch variations allow you to choose different modulation techniques. With Switch 4.1 you may choose between time delay, cutoff frequency and pitch modulation, respectively, in a DlySingleB, FltLP and OscString. With a dynamic modulation signal subtle to heavy dynamic distortion on external audio can be realized.

Reminder!
ExtMod-Car and Mod-to-ExtCar can only be used with the Clavia G2 hardware. All other patches can also be loaded into the Clavia NMG2Demo software.