FM Synthesis I, global and simple

acoustic vibrations

In the traditional acoustic musical instruments, sound is generated by means of a vibrating mechanism. Overall we can distinguish two different ways.

Firstly resonators, such as strings, stretched sheets and rods, which spontaneously get into a damped oscillation when we hit them with an energy boost. The hammer striking a piano string is one example.

On the other hand, we find complex composite systems as in string and wind instruments. Under certain conditions these systems become to vibrate, to oscillate. Each musician knows from experience that it spends time and effort to realize these conditions by doing and discovering.

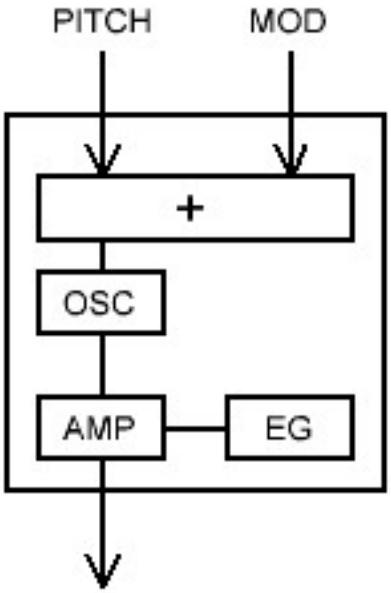
oscillator

In the electronic musical instruments, a periodic vibration is generated by means of an electronic circuit. That vibration is finally converted by the speaker back into an acoustic signal. Such an electronic circuit that serves as the basic tone generation is called an oscillator.

operator

In the first FM synthesizers from Yamaha, as with the well-known DX7, sound generation was completely formed in the digital domain in what was called in Yamaha speak, the operator.

an operator, a schematic representation



Each operator, both carrier and modulator comprises an input mixer where pitch data PITCH, the keys, and modulation data MOD, are mixed. The mixer output is now the control input of the oscillator OSC. By means of the envelope generator, EG, the amplitude of the oscillator can be controlled dynamically in the AMP.

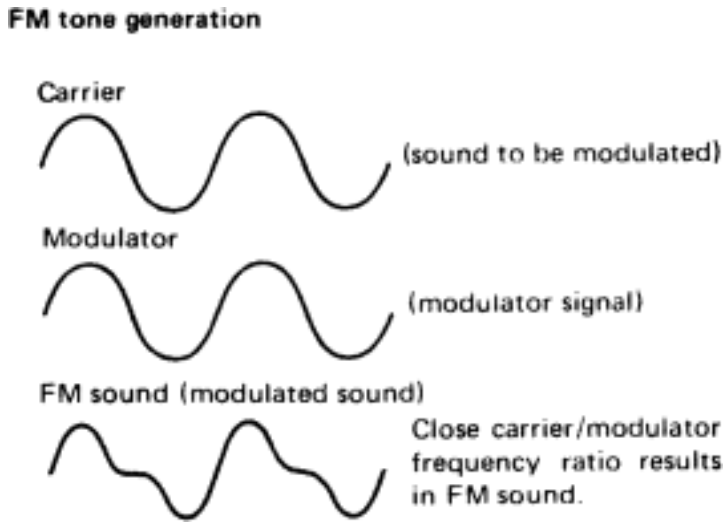
one carrier and one modulator, 'simple FM'

In the basic principle of Chowning's FM one such operator acts as a carrier wave which is connected via an amplifier to the speaker. This carrier frequency is controlled by the modulator wave. This cyclic variation of the carrier frequency takes place at audio rate. It is so fast that we experience this a new hearing sensation, a change of timbre.

'1 + 1' = many

In this `'simple FM'` model the two operators generate pure tones (sine waves), without overtones. According to the mathematical theory of Fourier, however, the resulting vibration consists of a fundamental frequency with harmonics. Herein lies the real power and elegance of

the FM model: With only two pure sine waves a new complex waveform is obtained which consist of many newly formed sinusoidal vibrations, caused by the modulation principle (see figure below from the DX7 manual).



The importance of this is further underlined by the fact that every conceivable sound is made up of a plurality of sinusoidal vibrations, with corresponding frequency, amplitude and phase. The sinusoidal vibration with the lowest frequency is the first harmonic or fundamental. The higher frequencies are called overtones or harmonics. One such pair of operators with sinusoidal waveforms, the carrier and the modulator is in the electronic and computer music language is called `simple FM`.

timbre

the frequency ratio between carrier and modulator: determines which overtones can be obtained.

In musical terms: the pitch interval between the modulator and carrier controls which harmonics or overtones can be formed.

In a way we may compare the `c : m ratio` in FM synthesis with the type of oscillator waveform in subtractive synthesis

the amount of frequency modulation determines the amount and strength of the overtones

The degree of frequency change controls how many of harmonics will emerge. The quantity of the frequency change of the carrier is controlled by the amplitude change of the modulator waveform. In Yamaha FM synthesizer the amount of FM depth is set by the modulator `output level`.

To a certain degree we may compare the FM modulator output level with the frequency setting of a filter in subtractive synthesis.

complex FM, FM with more than two operators

In the Yamaha FM synthesizers we can distinguish three different instruments according to the number of operators that may be used.
4-operator synths like FB01, TX81Z, DX11, DX100 and V50.
6-Operator instruments like DX7/DX7II/TX7/TX802, SY77/99 and TG77.
There are also a few 8-operator instruments like the HX1 electone and the FS1R. In these multiple operator instruments there are several ways to combine the operators.

various combinations of operators

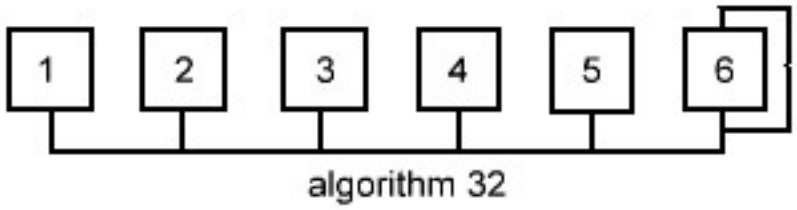
It is now possible, for example, that the carrier wave is modulated by two or more operators that serve as a modulator. These different ways of linking together, can be seen as an imprint on the DX7 synthesizer. These are numbered configurations of rectangular blocks. The bottom blocks represent the carriers, the modulators are indicated by the blocks above. There is always a connection represented by a line. From top to bottom between the blocks standing one above the other. This symbolizes the connection between the output of the modulator and the frequency control input of the carrier. The lower horizontal line represents de mixing of the carriers.
Under each block diagram one can find a number that indicates the appropriate configuration. The block diagrams must be read from top to bottom, an analogy with the diagrammatic representations in the world of computer music.

algorithms, configurations of multiple operators

The various modes of linking multiple operators are called in Yamaha jargon, algorithm. In Algorithm 5 and 6 on the DX7 we find three pairs simple FM which are mixed. It will be clear that through the use of more than two operators synthesis possibilities significantly increase.

additive algorithm

An example of an additive algorithm can be found in algorithm 32 on the DX7.



algorithm 32

In this configuration we see all six operators coexist. Their outputs are simply added together (mixed). In this example, we basically obtain the additive synthesis model. Additive means literally add, mixing. All operators now function as carriers. Modulators are missing here completely.

operators with complex waveforms

Some FM synthesizers have besides the pure sine tone per operator also other vibration modes, complex waveforms: instruments like TX81Z, DX11, V50, SY99, SY77,TG77 and FS1R. In the SY77/99/TG77 instruments for each operator we may choose a sine wave and 15 additional complex waveforms. The previously mentioned 4-operator instruments TX81Z etc. provide a sine wave operator and 7 complex waveforms.

feedback

In the diagrams of algorithms we see always one operator from wich it's output is connected back to it's modulation input. (see for instance alg. 32, operator 6). This is called self modulation or feedback. The output signal itself is now applied as a modulation source. At a certain level this provides an output waveform which is virtually identical to the traditional sawtooth vibration.

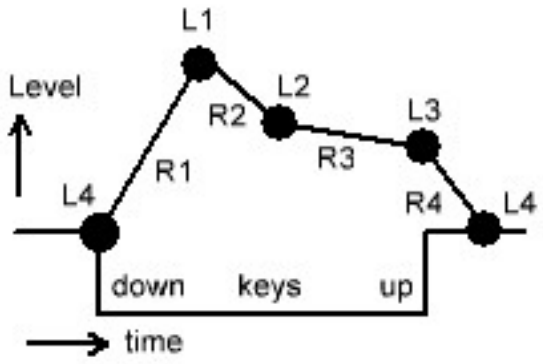
multiple feedback

In some FM instruments there can be several of these feedback connections active. In SY77/TG77 SY99 synthesizers a maximum of 3 of

these feedback links can be utilized in combination with an computer edit program application.

the sound and its dynamics: modulation as a function of time

The time course of the modulation depth, the modulator output level can be precisely determined. This applies equally to the output level, the output level of the carrier. On the Yamaha synthesizers it is shown by means of a diagram how this variable may change over time.



In the picture above we read vertically the modulation depth. We see the horizontal time axis, indicated when a key is pressed and released. The function shown above, which is started when pressing and end when you release a key, indicates a possible variation in time. We thus obtain a better understanding of how the amplitude of the modulator and carrier oscillation changes with time and, thus directly connected, how the resulting sound itself develops over time.
Such a variable in time called an envelope and is formed by the so called envelope generator (EG).

volume and timbre envelope

Each operator contains an envelope generator. The output level, the vibration magnitude (the amplitude, the volume) of each carrier and modulator can be controlled independently. Thus timbre course (modulator envelope) can be completely independent from loudness course (carrier envelope). A similar envelope generator can be used to

pitch course, this is referred to as PITCH EG.

envelope generators, basic building blocks of sound synthesis

Envelope generators are among the essential elements for sound design in a synthesizer. With these tools it is possible to program sounds that exhibit a specific dynamic timbre . The beginning of a sound can thus be given a completely different character than for example the end of that sound.

expression: the 'kneaded' sound

When playing a acoustic musical instrument, we often have the sound literally in hand. We can, for example hitting a string on a guitar, soft or hard. The finger that shortens a violin string can slightly move in the longitudinal axis of the string in order to achieve a tone with vibrato. With wind instruments literally breath gives expressive life to the sound.

breathing and muscle actions

The player actions on an acoustic instrument can be considered as a low-frequency modulating control of the carrier oscillation, the tone, the sound of the instrument.

external fine structure modulation

The subtle low frequency tone variations obtained in this way are of utmost importance for the vitality and quality of sound perception. This sophisticated modulation is known as external fine structure modulation (Tempelaars), because they are externally realized by the player.

internal fine structure modulation

Dissimilar sophisticated modulations in which the player has no influence are common in acoustic instruments. They stem from and are embedded in the physical model of the instrument. This modulation is known as internal fine structure modulation (Tempelaars).

Internal controls

On the Yamaha FM synthesizers we find various possibilities for real time sound control. For example velocity and aftertouch. These variables can then be assigned for instance to modulation depth, i.e. the output level of the modulator and/or carrier.
In addition, the instruments provide a modulation wheel which can be assigned to various parameters.

external controls: breath controller and foot swell pedals

In almost all Yamaha FM sythesizers we find an additional, very powerful way to influence the tone forming, the use of a `breath controller`. This instrument records the breath pressure of the player. By means of varying the breath the modulator and carrier output levels can be affected. This provides opportunities for a very expressive way of playing.
Also there is the possibility to connect one or two continuous controllers or foot swell pedals. As with the breath controller these controllers may be assigned to various parameters.