FH MMA SALZBURG – SOUND SYNTHESIS

SOUND SYNTHESIS 01

1. SYNTHESIZER TYPES

ANALOG SUBTRACTIVE SYNTHESIZER

Figure 1: Minimoog Model D (left), Sequential Circuits Prophet-5 (right)

Analog Subtractive Synthesizers use one or more VCOs (Voltage Controlled Oscillators) to generate waveforms rich of partials/overtones (such as sawtooth, pulse, square); a noise generator (pink or white noise) may also be available. The output of the VCOs is modified in timbre by a VCF (Voltage Controlled Filter) with variable cutoff frequency and (usually) adjustable resonance/emphasis.

Standard filters are Low Pass, however some synths offer “multimode filters” that can be set to Low Pass, Band Pass or High Pass. The slope (or “steepness” of the filter) may also be fixed, or variable (12/18/24 dB /oct). The output of the filter is then processed by a VCA (Voltage Controlled Amplifier).

Envelopes applied to the filter and amplifier can further modify the character of the sound (percussive, sustain-type, decay-type, etc.), while LFOs can add modulation effects (vibrato, wah-wah, tremolo).

Examples (monophonic): Minimoog Model D, KORG MS10/20, ARP 2600, Arturia Mini V3 (software), NI Reaktor Monark (software)

Examples (polyphonic): Oberheim OB-8, Roland Jupiter 8, Sequential Circuits Prophet-5, Korg Poly 6, Korg Poly 800

DWG HYBRID (DIGITAL/ANALOG) SUBTRACTIVE SYNTHESIZER

Figure 2: OSCar (left), KORG DW-8000 (right)

The signal path of a DWG Hybrid Subtractive Synth is similar to an Analog Subtractive Synth (oscillators, filter, amplifier), however the VCOs are here replaced by DWGs (Digital Waveform Generators) based on periodic (single-cycle) digital waveforms. This provides a wider choice for the basic sound spectrum compared to a regular subtractive synth.

The output of the DWG is converted by a DAC into an analog signal and is then further processed by analog filters and amplifiers.

Examples: KORG DW6000, KORG DW8000, OSCar
impOSCar (software), Steinberg Prologue (software), Logic ES2 (software)

WAVETABLE SYNTHESIZER

Figure 3: KORG Wavestation (left), Waldorf WAVE (right)

The signal path of a Wavetable Synthesizer is similar to a DWG Hybrid Subtractive Synth, additionally the system can “scan” and interpolate through several single-cycle waveforms stored in a “Wavetable” (PPG), “Wavesequence” (KORG) or “Transwave” (Ensoniq) to create interesting and unusual timbre variations over time (morphing).

Some systems (like the PPG Wave 2.2 in combination with the Waveterm computer) could also play back actual sound samples, allow you to create your own waveforms and offer limited resynthesis options.

Examples: PPG Wave, Waldorf Microwave/WAVE, KORG Wavestation, Ensoniq VFX-SD, NI Massive (software)

VECTOR SYNTHESIZER

Figure 4: Sequential Circuits Prophet VS

The signal path of a Vector Synthesizer is similar to a DWG Hybrid Subtractive Synth (oscillators, filter, amplifier); additionally, it offers real-time blending between 2 to 4 oscillators/DWGs using a joystick, the movements of which can be recorded and played back. Each oscillator can be based on a digital single-cycle waveform (Prophet VS), or on a wavetable (Wavestation).

Examples: Sequential Circuits Prophet VS, KORG Wavestation, Logic ES2 (software)

FM SYNTHESIZER

Figure 5: Yamaha DX7 II (left), Yamaha SY-99 (right)

The basic principle of FM is to generate complex sound spectra using a digital oscillator (the Modulator) to modulate the phase of another digital oscillator (the Carrier) at very high frequency (like a vibrato, but much faster than an LFO), changing the wave shape and hence the timbre (sound color) of the Carrier.

A standard FM Synthesizer uses 6 or more Operators (= digital oscillators + EG) connected in different schematics, called Algorithms. Depending on their position in the algorithm, Operators can work as Modulators (modulating the phase of other Operators, thus affecting the generation of harmonics and the timbre), as Carriers (at the end of the chain, defining the basic pitch and volume of the sound) or as a combination of both.

FM synths can generate both harmonic sounds (when the ratio between modulator and carrier is an integer number, like 2:1) as well as inharmonic sounds (when the ratio is a non-integer number, like 3,71:1) like bells, metallophones, drum membranes, etc.

Examples: Yamaha DX7, Yamaha SY-77/99, Native Instruments FM7/FM8 (software)

2. ENVELOPES AND LFOS

An Envelope Generator (EG) can control several synthesis parameters, changing the dynamic level or sound color of the sound over time. For example, it can:

- modify the timbre over time, when applied to the filter cutoff (filter sweep)
- change the character of the sound from percussive to non-percussive, sustain-type or decay-type, when applied to the amplifier level
- create a pitch sweep, when applied to the oscillators pitch.

The main parameters of an Envelope Generator are:

- Attack (starting when the "note on" command is received): the Time required for the parameter value to go from 0 to maximum
- Decay: the Time required for the parameter value to go from maximum down to the defined Sustain Level
- Sustain: the Level at which the parameter settles after the Attack and Decay segments are completed (until the "note off" command is received)
- Release (starting when the "note off" command is received): the Time required for the parameter to go from the Sustain Level back down to 0

Additionally, these parameters may be available:

- Keyboard Tracking: defines how the key position affects the speed of the envelope, for example to create shorter decay for higher notes)
- Velocity Response: defines how the envelope reacts to keyboard velocity, for example to create brighter/louder sounds at higher velocity levels

Carefully programming the times and levels of the available envelopes is essential to create a great sounding patch. For example, if you are programming an E-Piano patch, the settings for EG decay and release times, as well as the defined parameters for keyboard tracking and velocity response are critical in adding realism, as well as making the E-Piano inspiring for the performance and easier to play and fit in your arrangement. Tweaking these parameters can also reduce the amount of post processing required in the mix (particularly EQ and compression).

An LFO can apply cyclic modulations to several synthesis parameters, creating a wide range of modulation effects:

- vibrato (modulating the oscillator pitch)
- wah-wah (modulating the filter cutoff)
- tremolo (modulating the amplitude)
- pulse width modulation (modulation the VCO pulse width)

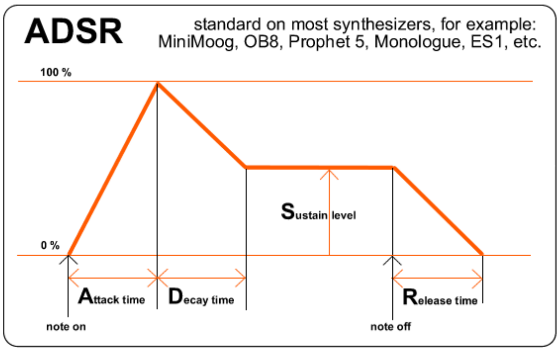
Typical LFO Parameters are:

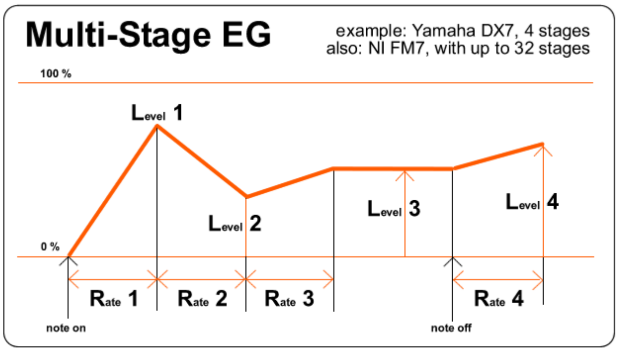
- waveform type (sine, triangle, sawtooth, square, sample&hold)
- frequency (usually a value under 20 Hz, so infrasonic)
- modulation amount
- delay

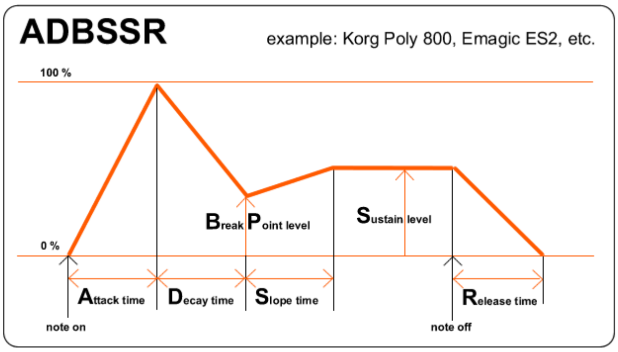
The LFO "sample&hold" waveform creates a quasi-random modulation. If applied to the pitch of a sine wave, or to the cutoff of a filter with very high resonance, S&H can produce the iconic blips and sweeps of the *R2-D2* Star Wars Droid.

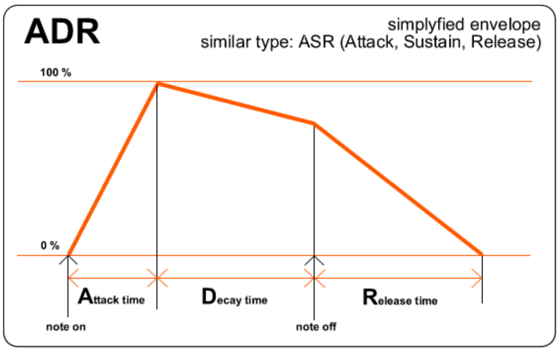
Varying the speed of an LFO (through automation, or specific programming, depending on the synth) that controls the filter cutoff and/or the wavetable position (scan) of a characteristic formant wavetable, it is possible to create the typical "wobble bass" sounds used in Dub Step and other related music styles.

While traditional analogue subtractive synthesizers offer simple ADR or ADSR Envelopes, some hybrid (digitally controlled) and digital synthesizer offer Multi-Stage Envelope Generators. Here a few examples:









3. ANALOG SUBTRACTIVE SYNTHESIS

The basic sound modules in a typical Analog Subtractive Synthesizer are one or more VCOs (Voltage Controlled Oscillators), a VCF (Voltage Controlled Filter) and a VCA (Voltage Controller Amplifier).

The VCO, VCF and VCA parameters can be modified by ADSR envelopes and LFOs (Low Frequency Oscillators).

Typical parameters in a VCO are the waveform type (sawtooth, square, triangle, pulse), pitch (octave, coarse, fine), pulse width (when selecting pulse as a waveform) and level. Optional features in the VCO section are the oscillator sync (with another VCO) and the ring modulation. Some synths might also offer limited FM capabilities.

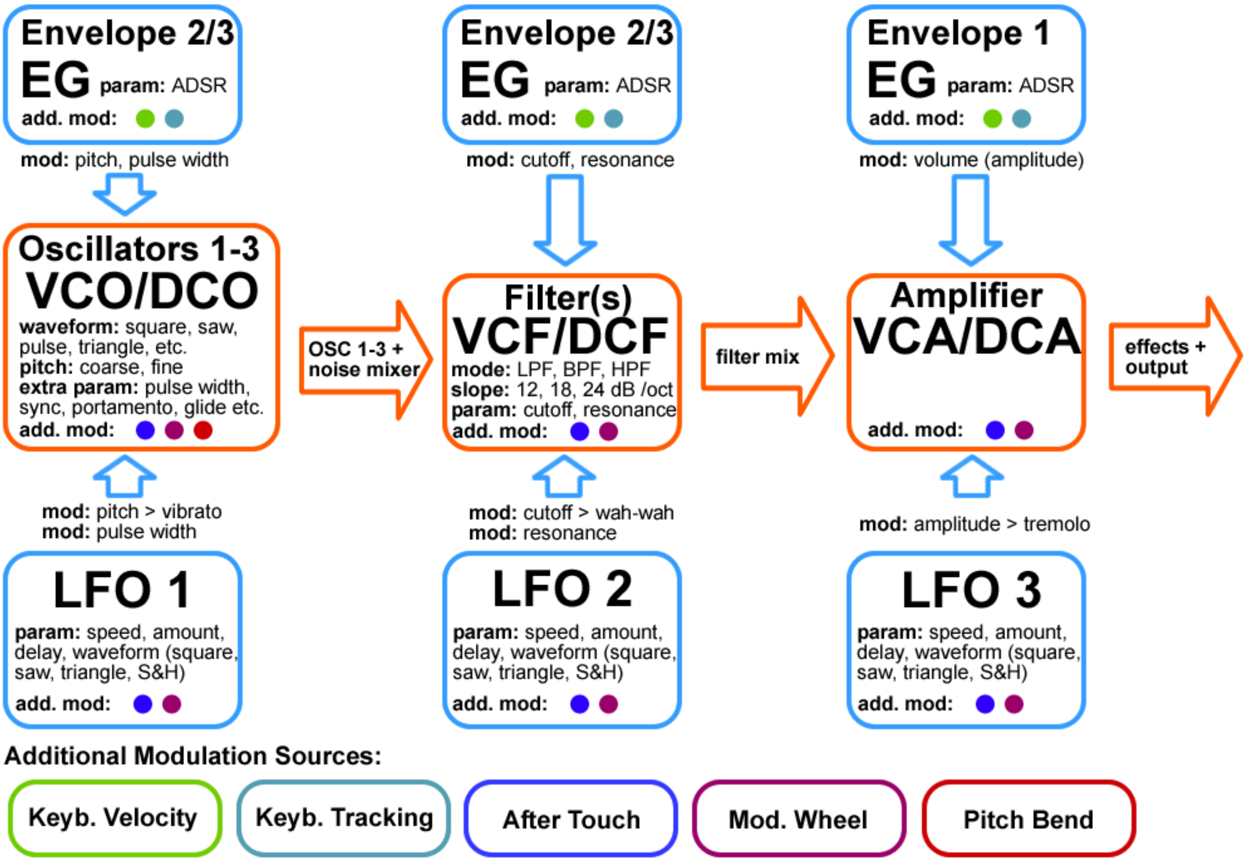
Typical parameters in a VCF are the cutoff frequency, resonance (or emphasis), envelope amount and keyboard tracking. Filters are classified by type or mode: LP (Low Pass), BP (Band Pass), and HP (High Pass). Some synthesizers offer additional filter types, such as Comb Filters, complex Formant Filters, etc. The filter slope (steepness) can also vary: 6/12/18/24 dB /oct (also called a 1-/2-/3-/4-pole filter, where each pole corresponds to 6 dB /oct).

To change the basic character of a sound, it is required to first choose the waveform type (sawtooth, triangle, square, pulse) for each VCO, then set the pitch using the “octave”, “coarse” (interval in half-tones) and “fine” (detuning in cents) parameters, finally adjust the mix levels for each VCO and the noise generator.

To change the “brightness” of a sound (make it brighter, duller, fatter, thinner), it is required to first choose a filter type (LP/BP/HP), then modify the filter cutoff frequency, resonance, envelope amount, etc.

Additional options to create very characteristic timbres are the Oscillator Sync (like in Jean-Michel Jarre’s *Laser Harp*), where the frequency of one oscillator controls the waveform cycle start of another, and the Ring Modulation.

Analog Subtractive Synthesizers are not particularly good at emulating "real" acoustic or electro-acoustic instruments, however they have a very distinctive and lively sound character of their own and are often described as "fat" and "warm" sounding instruments.



4. FM SYNTHESIS

The basic sound modules in a typical FM Synthesizer are Operators organized in Algorithms. An FM-Operator includes a digital oscillator, a multistage EG (envelope generator), a modulation input and output, and an audio output. FM-Algorithms (also called "Operator Schematics") affect the logical relations between operators and define whether they function as carrier, as modulator, or as a combination of both.

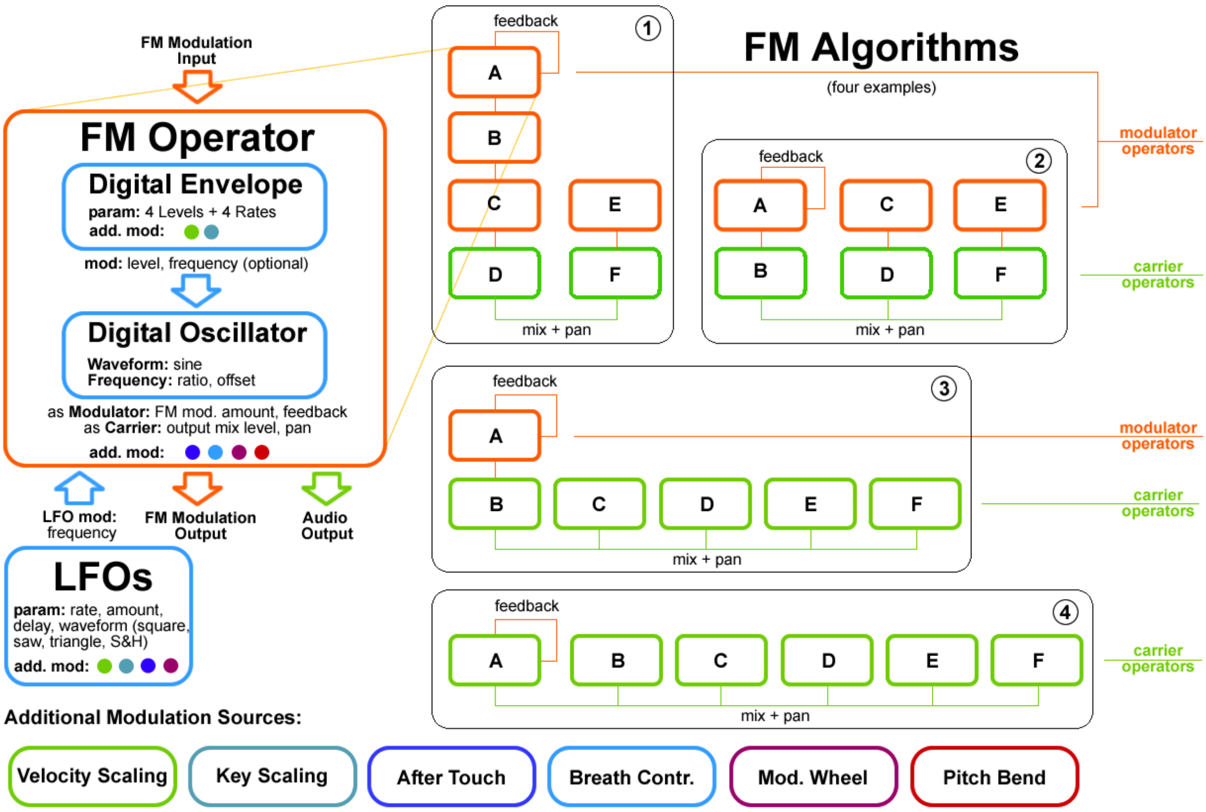
Modulators influence the timbre/spectrum, while Carriers define the basic pitch and level of the sound. The basic wave spectrum of a Modulator/Carrier pair is defined by the frequency ratio and modulation amount between Modulator and Carrier.

To generate a harmonic sound spectrum, like that of a string or wind instrument, the frequency ratio between the Modulator and Carrier must be set to an integer number, for example 1:1 (sawtooth-like) or 2:1 (square-like).
To generate an inharmonic sound spectrum, like that of a bell or a gong, the frequency ratio between the Modulator and Carrier must be set to a non-integer number, for example 5,17:1.

In "Classic FM Synthesis", as used by John Chowning in his computer-generated tracks back in the '70s (and as implemented by Yamaha in the DX series of synthesizer from 1983), all Operators could only output a sine wave waveform (a pure tone, with no harmonics). Complex sound spectra, rich of harmonics, could still be generated through the frequency/phase modulation process.

However, in more recent FM Synthesizers (including Native Instruments FM7 and FM8), other waveform types are also available to offer a wider range of programming capabilities.

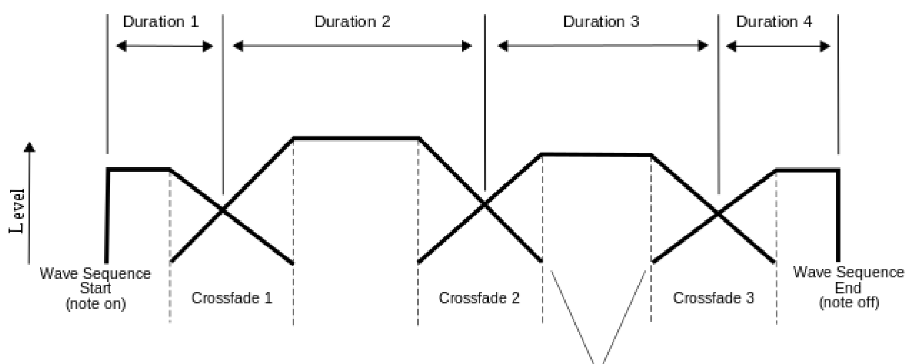
FM Synthesizers can emulate quite realistically certain categories of instruments, such as E-pianos, bells, gongs, mallets, e-bass, brass, etc. Many of these sounds, while retaining a distinct FM “digital” character, can be much more interesting to perform than sample-based sounds, as they can react very lively to the real-time modifications of sound parameters (through dynamics, aftertouch, pedal and breath-controller, etc.).



5. WAVETABLE SYNTHESIS

Basic sound modules in a Wavetable/Wavesequencing synthesizer are special DWGs (Digital Waveform Generators): these can play back single-cycle waveforms, as well as interpolate through several single-cycle waveforms stored in a “Wavetable” (PPG), “Wavesequence” (KORG) or “Transwave” (Ensoniq) to create interesting and unusual timbre variations over time (wavetable scanning / morphing). The sound is further processed by DCFs (Digitally Controlled Filters) or full Digital Filters, and by a DCA (Digitally Controlled Amplifier).

The parameters of these modules can be controlled by ADSR or multi-stage Envelopes and LFOs, sometimes implemented through a “modulation matrix” to offer maximum flexibility in choosing the mod. source and destination.



Four Step Wave Sequence with Crossfades

6. SUBTRACTIVE VS FM SYNTHESIS PROGRAMMING TIPS

PROGRAMMING ACTION	SUBTRACTIVE SYNTHESIS	FM SYNTHESIS
define the basic sound color (spectrum) of your sound patch	▪ select VCO waveform (square, pulse, saw, triangle) ▪ set pulse width ▪ select the interval between oscillators ▪ set volume mix between oscillators	▪ select FM algorithm type ▪ select frequency ratio between modulators and carriers ▪ set amount of modulation (modulator output level) ▪ select the frequency interval between carriers ▪ set volume mix between carriers
set the spectrum to all partial tones: 1-2-3-4-5-6-7 ... (like a trumpet or trombone)	▪ set the VCO waveform to sawtooth	▪ set the ratio between modulator and carrier to 1:1
set spectrum to only odd partial tones: 1-3-5-7-9-11 ... (like a clarinet)	▪ set the VCO waveform to square	▪ set the ratio between modulator and carrier to 2:1
create an inharmonic wave spectrum	▪ set a dissonant interval and detune value between oscillators ▪ note: on standard subtractive synths, a completely inharmonic spectrum cannot be created	▪ set a non-integer value for the modulator to carrier frequency ratio ▪ set a dissonant interval and detune value between carriers
create a harmonic wave spectrum	▪ set a pure interval (octave, fifth) for the coarse pitch of the VCOs ▪ set very little or no detune between oscillators	▪ set an integer value for the modulator to carrier frequency ratio ▪ set a pure interval (octave, fifth) across carriers
add noise	▪ set one of the VCOs to "noise", or add "noise" to the mix stage	▪ set one of the modulators feedback to a high value ▪ on NI FM8, add "noise" from operator X
make the sound color "brighter" (richer in harmonics)	▪ if using a LPF or BPF type filter, open the cutoff	▪ increase the amount of modulation between modulators and carriers (= increase modulator output level)
make the sound color "darker" (poorer in harmonics)	▪ if using a LPF or BPF type filter, close the cutoff	▪ decrease the amount of modulation between modulators and carriers (= decrease modulator output level) ▪ on NI FM8, you can also close the cutoff of the LPF filter in operator Y
change the dynamic character over time (percussive, sustain-like, pad-like, etc.)	▪ modify the parameters of the VCA envelope ▪ set the attack and decay/release to slow values for a pad-like character ▪ set the attack to shortest, decay to 5-10 sec and release to 1-10 sec for guitar or piano-like character	▪ modify the parameters of the carrier envelopes ▪ set the attack and decay/slope/release to slow values for a pad-like character ▪ set the attack to shortest, decay/slope to 5-10 sec and release to 1-10 sec for guitar or piano-like character
change the sound color over time	▪ apply an envelope to the VCF cutoff ▪ set the attack and decay/release to slow values for a pad-like character ▪ set the attack to shortest, decay to 5-10 sec and release to 1-10 sec for guitar or piano-like character	▪ modify the parameters of the modulator envelopes ▪ set the attack and decay/slope/release to slow values for a pad-like character ▪ set the attack to shortest, decay/slope to 5-10 sec and release to 1-10 sec for guitar or piano-like character
create complex sound spectra that change over time (morphing type)	▪ if the synthesizer supports wavetables and multiple oscillator, you can control the spectrum dynamically sweeping through the wavetable and mixing the level of oscillators set to different wave spectra	▪ set different ratios and different envelopes times for different modulators, so that they affect the carrier spectrum in different phases
create a "pitch sweep"	▪ apply a modulation envelope to the VCO pitch ▪ set the envelope values as desired	▪ apply a modulation envelope to the carrier pitch ▪ set the envelope values as desired
make the sound volume change with keyboard velocity (stronger = louder)	▪ set the VCA envelope keyboard velocity to a positive value	▪ set the carrier(s) envelope keyboard velocity to a positive value
make the sound spectrum change with keyboard velocity (stronger = brighter)	▪ apply a modulator envelope to the VCF cutoff ▪ set the VCF envelope keyboard velocity to a positive value	▪ set the modulator(s) envelope keyboard velocity to a positive value
create a vibrato	▪ modulate the VCO pitch with an LFO, making sure the modulation amount does not exceed +/- 10-20 cents ▪ set the LFO wave to triangle ▪ set the mod. speed to about 4-6 Hz ▪ set the desired amount of delay	▪ modulate the carrier pitch with an LFO, making sure the modulation amount does not exceed +/- 10-20 cents ▪ set the LFO wave to triangle ▪ set the mod. speed to about 4-6 Hz ▪ set the desired amount of delay

create a wah-wah effect	▪ modulate the VCF cutoff with an LFO ▪ set the LFO wave to triangle or square ▪ set the desired modulation speed and amount	▪ modulate the modulator output level with an LFO ▪ set the LFO wave to triangle or square ▪ set the desired modulation speed and amount
create a tremolo effect	▪ modulate the VCA amplitude with an LFO ▪ set the LFO wave to triangle or square ▪ set the desired modulation speed and amount	▪ modulate the carrier output level with an LFO ▪ set the LFO wave to triangle or square ▪ set the desired modulation speed and amount

LINKS

- Minimoog Programming Examples: https://www.youtube.com/watch?v=bU2RVYHeVEE
- Sequential Circuits Prophet-5 Patches Demo: https://www.youtube.com/watch?v=mvkKJilJqJ4
- KORG DW 8000 + Eventide Timefactor Chillout Demo: https://www.youtube.com/watch?v=ALMms7LRjVs
- impOSCar (software) + Gforce Controller Demo 1: https://www.youtube.com/watch?v=tfvp-R3wzHU
- impOSCar (software) + Gforce Controller Demo 2: https://www.youtube.com/watch?v=3aeZxTAActU
- Yamaha DX7 Original Patches Demo: https://www.youtube.com/watch?v=-0rWZb1xuSE
- PPG Waveterm + Wave 2.2 Wavetable Scanning: https://www.youtube.com/watch?v=wc5orbnQHEw
- PPG Waveterm + Wave 2.2 Sampling and Resynthesis: https://www.youtube.com/watch?v=YvrJTmIPSrI
- Waldorf WAVE Sounds Demo: https://www.youtube.com/watch?v=wRVlQ7nCoa0
- KORG Wavestation *Ambient World* Patches: https://www.youtube.com/watch?v=fyy7vddIOsw

WEBSITE

- http://www.digitalnaturalsound.com/fh--multimediaart/music-production.html
- www.digitalnaturalsound.com or www.dns-studios.com > FH | MultiMediaArt > Music Production