

Real Time FM synthesizer implemented in an Altera Cyclone V FPGA

Antoine Alary, Altera

<http://pasde2.com/RTFM>

Introduction

The RTFM is a polyphonic and multitimbral music synthesizer which, as the name suggests uses frequency modulation (FM) to create rich dynamic timbres. The sound generation circuits are similar to what is used in Yamaha's DX family of synthesizers with one main difference: all the sound parameters can be changed dynamically while the notes are sounding.

The following figure shows the various components of the sound generation module and the parameters that control them. For each note up to 8 instances of the circuit illustrated in Figure 1 can be combined to produce a rich and dynamic timbre.

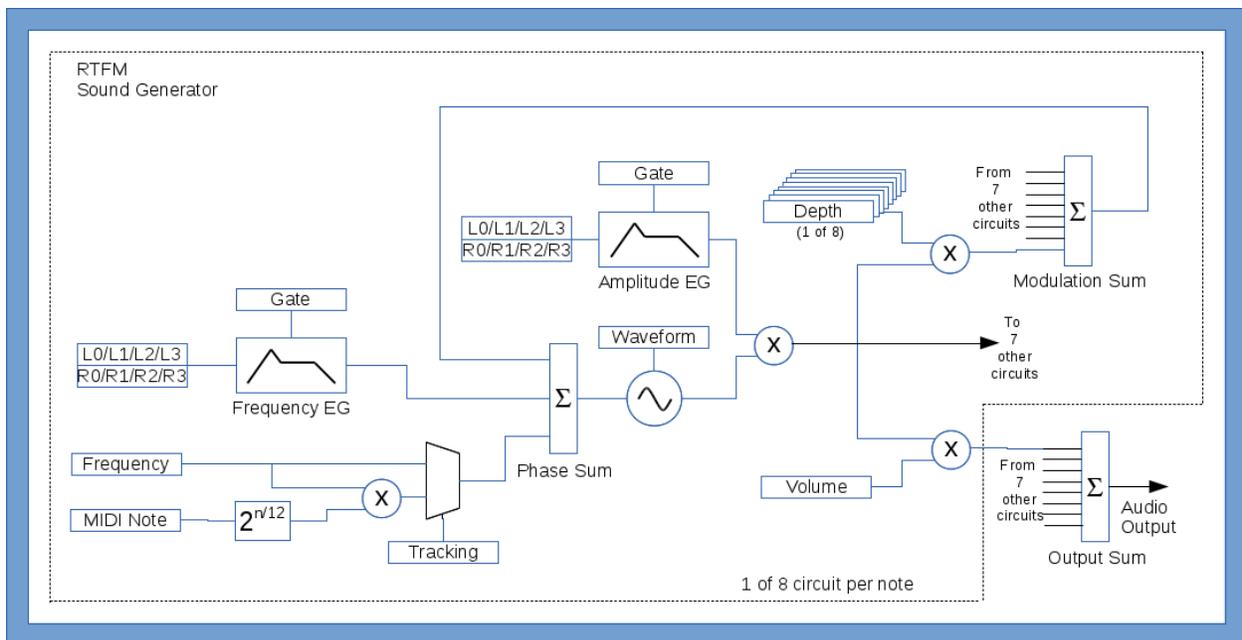


Figure 1: Block Diagram

The RTFM prototype is composed of the following main components:

- The sound generation module (Cyclone V GX Starter Kit board with Arduino MIDI shields.)
- The MIDI controller. (Behringer BCR-2000)
- The MIDI keyboard.
- The amplified speakers.

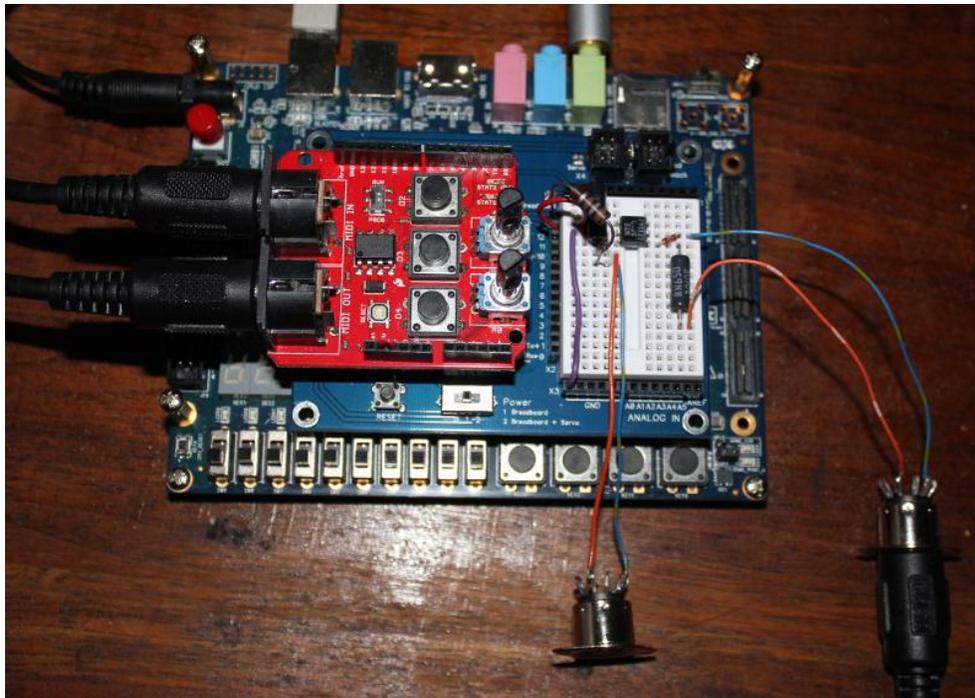


Figure 2: Sound Generation Module.



Figure 3: MIDI controller.

Controls

Oscillators

Each of the columns of control corresponds to one of the 8 oscillators available per note.

Output Volume

The bottom row of knobs controls the volume of the corresponding oscillator in the audio output. Turn clockwise to increase the volume. The range is 0 to 127.

Frequency & Keyboard Tracking

The “Frequency” knobs and the “Keyboard Tracking” switches above them work together to control the pitch of the corresponding oscillator. Turn clockwise to raise the pitch of the note. The range is 0 to 1023. When keyboard tracking is enabled (LED lit) the pitch will vary according to the note pressed on the keyboard. When tracking is disabled (LED dark), the oscillator has a fixed frequency for all notes (useful for modulation). Press the “Keyboard Tracking” switch to toggle between enabling and disabling keyboard tracking for the corresponding oscillator.

Oscillator Select

The “Oscillator Select” switches control which oscillators are affected by the changes to the “Modulation Depth” and envelope generator knobs (Labeled L0 to L3 and R0 to R3). Press a switch to toggle between selecting (LED lit) or de-deselecting (LED dark) the corresponding oscillator. Multiple oscillators can be selected at the same time so that the same changes to the modulation depth or to the envelope generators get applied to them.

Modulation Depth

This is the main control for frequency modulation (FM) synthesis. The “Modulation Depth” knobs control how much the corresponding oscillator affect the frequency of the oscillators selected by the “Oscillator Select” switches. Turn clockwise to increase the amount of modulation. The range is 0 to 1023.

Envelopes

Envelopes are used to dynamically change the character of a note from its beginning to its end. The RTFM contains two envelope generators (EG) for each oscillator; one affects the frequency of the oscillator and the other, its amplitude.

The level knobs Labeled “L0” to “L3” and the rates knobs labeled “R0” to “R3” define the envelopes for each EG. The envelope selection switches on the right, labeled “Frequency” and “Amplitude”, determine which EG is affected by the changes of the “Ln” and “Rn” EG knobs.

The envelopes are defined by for level/rate pairs. The levels are the target values and the rates determine how fast the transition happens.

Amplitude EGs

The amplitude EGs start at a level of 0 (no sound) and increase to level L0 at the rate specified by R0. Once the amplitude reaches the level specified by L0, it starts moving towards level L1 at the rate specified by R1. Similarly, once the amplitude reaches the level specified by L1, it starts moving towards level L2 at the rate specified by R2. Once the amplitude reaches level L2, it stays there until the key is released at which point it starts moving towards level L3 at the rate specified by R3.

The ranges for L0 to L1 and R0 to R3 are 0 to 127. A larger level corresponds to higher amplitude; turn the Ln knobs clockwise to increase the amplitude. For oscillators with a non-zero “Output Amplitude” setting, L3 should be set to 0, otherwise the note will sound forever. A larger rate value corresponds to a longer transition; turn the Rn knobs clockwise to increase the duration of a transition.

Frequency EGs

The frequency EGs behave similarly to the amplitude EGs, but they start at a level of 16 so the pitch can move up if L0 is larger than 16 or move down if L0 is smaller than 16.

Oscillator Select

The “Oscillator Select” switches are used to choose to which oscillator the changes to the EGs apply.

Setup

1. Connect the MIDI OUT port of the MIDI controller to the MIDI IN port of the sound generator on the red Arduino MIDI shield.
2. Connect the MIDI IN port of the MIDI controller to the MIDI OUT port of the sound generator on the red Arduino MIDI shield.
3. Connect the MIDI OUT port of the keyboard to the MIDI IN port of the sound generator on the breadboard.
4. Connect the audio output of the sound generator module (green 1/8” phone jack) to the input of the amplified speaker.
5. (Connect the audio output of the sound generator module (green 1/8” phone jack) to the input of the oscilloscope.)
6. Connect their power cords or power adapter to the MIDI controller, MIDI keyboard, sound generator module, amplified speaker, and oscilloscope.
7. Plug the power cords and power adapters into a power strip.
8. Turn the power strip on.
9. Turn the MIDI keyboard on.
10. Turn the MIDI controller on.
11. Turn the sound generator module on by pressing the red button.
12. Turn the powered speaker on.
13. Turn the oscilloscope on.

Demonstrations

Variety & Presets

To quickly illustrate the variety of sounds that can be generated, cycle through the four “presets” by pressing on the PRESETS buttons 0 to 3 on the MIDI keyboard, and playing a few notes.

First preset: a typical FM bell sound (one note at a time sounds best).

Second preset: an electronic organ sound (chords sound best, sweeps of the keyboard are nice too).

Third and fourth preset: “electronic sound effects”.

MIDI Controller

The following steps in sequence will illustrate the basic functionality of the MIDI controller and the sound generation module.

Presets

- Alternate between presets highlighting the fact that the control panel reflects the parameter setting when switching from one preset to another.
- For the following demonstration we will start with the second preset, the “electronic organ” sound, select it.

Output Volume

- Press and hold a note for the whole duration of the following steps.
 - Turn down the “Output volume” knobs completely to zero one by one starting from the right to hear the harmonic components of the sound disappearing.
 - Turn the volume of the rightmost oscillator back up.

Frequency

- Press and hold a note and turn the rightmost “Frequency” knob to show how it affects the pitch of the note.
- Play various notes on the keyboard to show how the pitch tracks the keyboard.
- Press the rightmost “Keyboard Tracking” button. The red LED in the button should turn off. If the sound becomes too low turn the “Frequency” up.
- Show that the pitch no longer tracks the keyboard by pressing a few keys on the keyboard.
- Turn the “Frequency” down to show 10 on the display (the sound will be too low to be heard).
- Turn the rightmost volume down to 0.

Frequency Modulation

- Turn the third “Output Volume” knob from the left up to hear the fundamental note of the former “electronic organ” sound.
- Press the third “Oscillator Select” button from the left, it should light up.
- Press and hold a key to hear the simple sine sound that is produced by that single oscillator.

- While still holding down a key, slowly turn up the rightmost “Modulation Depth” knob. The pitch of the note should start varying up and down a few times per second. As you increase the modulation depth the pitch will vary in a large range.
- While still holding down a key, slowly increase the frequency of the rightmost oscillator until it is no longer possible to hear each up/down cycle individually. At that point the modulation is not so much perceived as change in pitch but a change in timbre or “texture” of the sound.
- If the oscilloscope is connected, you can see how the waveform changes as the frequency of the modulating oscillator varies with respect to the frequency of the modulated oscillator. (Interesting patterns can be obtained by enabling keyboard tracking on both oscillators and setting the modulator’s frequency to one quarter to one tenth of the modulated oscillator’s frequency, or by setting the modulating frequency to double the modulated frequency.)

Envelopes

- Make sure the amplitude EG is selected by pressing the “Amplitude” envelope switch in the top right area of the MIDI controller.
- Press and release a note a few times and notice how the note starts and ends, then turn the “R0” and “R3” knobs all the way counterclockwise to 0. Press the same note again and notice how the sound now starts and stops instantly when the key is pressed and released.
- Turn the “R3” knob all the way clockwise to 127 and then quick press and release a note and notice how it now takes a long time to die out.