IC's for electronic music

Electronic music is a fast-growing field with the synthesizer arousing the most interest among the avant-garde. Regardless of what you want in electronic music, IC's will simplify design and ease construction.

One IC top octave generator

Most music is arranged into twelve-note equally tempered note groupings (take a look at a piano keyboard). As you go up in frequency one octave, you double frequency on the thirteenth note. The note spacing is not linear, it is exponential. Each note is spaced from its neighbor by \sqrt{2} or approximately 69. There is no reasonable way to exactly generate an irrational number such as \sqrt{2}, so you have to approximate it the best way you can. Usually you start with a 1 or 2 megahertz crystal and then divide down by some magic optimum series of numbers (often 299: 253: 268: 244: 301: 319: 338: 358: 402: 426: 451) to get a good enough approximation to the highest octave you care to generate. From here you pick up the rest of the notes with a simple string of binary dividers.

The circuitry that handles the top octave is called a top-octave generator. Many of these circuits had been based on the GEMS and GEM56, a pair of hard-to-get IC's that are now essentially obsolete.

The Mostek MK5024P/A is a one-chip.

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**FIG. 1—SINGLE IC top octave synthesizer.**

single 15-volt supply top-octave generator. Hook it up as in Fig. 1. You input a 2,000,020 megahertz squarewave or sinewave of 15 volts amplitude, obtained from a crystal oscillator (for permanent tuning) or a variable oscillator (for vibrato, glides, or tuning to another instrument). You get seven outputs, appearing as square waves from C8 at 4186.01 hertz to C9 at 8369.2 hertz. Cost is under $12. This is admittedly a bit steep, but it is by far the cheapest route to go if you want all the notes at once.

If you only want one octave at a time, you can place a single binary divider between the oscillator and the top octave generator, rather than using 12 separate dividers.

Seven octaves at once

Once you have the top octave, you add binary dividers to get the rest. Again, there are several 'music-only' divider IC's available, but none is as good, as easy to use, or as cheap as the RCA CD4024 or Motorola MC14024 CMOS 7-stage dividers. Cost is around $3.90. One IC is needed to produce seven octaves of a single note. Thus a top octave generator IC and twelve of the CD4024's will generate simultaneously all eight octaves or a total of 97 notes.

Figure 2 shows the connections. Simply apply a voltage from +1 to +18 (best results with +15) and input the top octave output. You get out seven new notes in octave steps. For instance, input A# (A sharp, 8th octave), and you get out A, A#, A, A, A, A, and A. The outputs will all be square waves. Square waves only have odd harmonics present. You can convert these to sawtooth waveforms with virtually all harmonics present with a few resistors as shown in Fig. 2b. While the stair step may not look quite like a sawtooth, analyze it and you find the first missing harmonic is the 16th, followed by the 32nd and the 48th, etc. . . . Otherwise it is also virtually identical to a linear ramp. Filtering is used to convert either the square or sawtooth outputs into familiar tone colors. For instance, the square waves are often used for clarinet and stopped organ sounds; the sawtooth by itself has a good string sound, while bandpass filtering is easily added to a sawtooth to get a horn or reed output.

A tempo generator

How do you get a stable, cheap, wide-range square wave oscillator that's good enough as a monophonic note generator, but also is useful for rhythm and clucking, and easily drives TTL and CMOS to boot? With the Signetics 555 or Motorola MC1555 of course. This $1 IC can't be beat as a stable oscillator. Figure 3-a shows details. You can vary the resistance from 1k to 3.3 megohms, and make the capacitance anything you want above 500 pF or so. Output is usually a rectangular wave. If you need a square wave, make R2 much bigger than R1 or else add a binary divider to square it up. Figure 3-b shows how you can build a triggerable monostable or pulse generator out of the same circuit. This is useful for synthesizer envelope generation.

A voltage-controlled oscillator

Many synthesizer systems are based on voltage controlled oscillators. Apply an input or control voltage, and you get an output frequency which you use as a tone source. Music VCO's have to be very stable to be useful. They also have to have a wide range. Ideally, they should respond in a logarithmic manner, but a log converter is more often added to the input of the VCO as a separate circuit. VCO's also should be able to put out a good looking sinewave for flute-like tones, as well as a square or triangle output. The fetetril 8038 does the whole job for under $1. A "baseline" circuit is shown in Fig. 4 that should get you started. Control voltage ranges from the positive supply to three volts or so less. The sinewave can be adjusted to below 0.5% distortion easily.

A dual operational amplifier

A good "741" style op-amp is essential for any electronic music circuit. An operational amplifier does at least three good things for you—it gives you controllable gain; it eliminates interaction and coupling between multiple inputs; and it gives you a versatile system gain block for active bandpass filters and things like this. The Motorola MC1458 and the Signetics 5558 are typical dual "741" type circuits. Cost is around a dollar. The 5558 is in an easy-to-use 8-pin minidip package.

Figure 5-a shows the voltage follower connection. It gives you unity gain, a very high input impedance, a low output impedance and does not invert the signal. Figure 5-b is a voltage follower with gain. Figure 5-c shows the inverting amplifier and mixer. The gain of each input is the ratio of its own input resistor to the feedback resistor. The input impedance equals the input resistor for any input, and the summing point may be considered to be a virtual ground. There is no interaction between inputs or crosstalk problems possible in this circuit; further, you can scale or individually adjust each and every input to its own signal level inde-
Six keyers at once

At the very least, music notes must be smoothly turned off and on without any key clicks or thumps. It's even better to be able to instantly vary the gain of the note so you can have complete control of attack, fall-back, sustain, decay, sibilant, and perhaps even a echo. To do this, you need something that will behave as an electrically variable resistor. The circuit is called a "keyer," an analog gate, or a voltage-controlled amplifier.

There are lots of ways to do this job. What you have is some circuit that is essentially transparent to the notes fed through it—it simply varies gain and nothing more. You must control the gain smoothly and do so equally well on the positive and negative portions of the envelope. Above all, you cannot let any portion of the envelope or control signal appear as an output, for this gives you a loud thumping.

Diodes have traditionally been used in organ circuits, but they thump, introduce distortion, and have a limited dynamic range.

An obvious choice is an integrated circuit four-quadrant multiplier—see below—but these are far too expensive to use dozens at a time. Another possibility is an electronically controlled gain block such as the Motorola MFC-040, but it has too much gain for many applications.

The simplest good envelope keyer you can use is a single N-channel MOS transistor with some drain-to-gate feedback resistance. Figure 6-a shows the circuit. This gives you a linearly variable resistor, electronic volume control, and a handle up to 10 volts of analog signal in each direction if the substrate load is floated. Control voltage ranges from 0 to 5 volts full off, up to 8 or more for full on. In between you get a good linear control range. For envelope and audio frequencies, there is absolutely zero feedback into the control signal. As a bonus, the control input looks into a high impedance that lets you use a small capacitor for the decay portion of the cycle.

One typical discrete device is the Motorola 2N-1411-1. At $2 or so, the cost is far cheaper than a multiplier, but still a bit steep if you use 97 of them at once.

Once again, it's digital CMOS logic to the rescue. A very few CMOS IC's can have their supply shorted to ground and thus disabling all P-type transistors in the package. This leaves you with a block of N-channel MOS transistors that are ideal for gain control. You can get two and possibly three in the CD4007 (RCA) or the MC14017 (Motorola) devices in a dual package. Most of the other devices, particularly the CD4009 and CD4010, have protective diodes arranged in such a way that you can't do this. The diodes are differently arranged in a new device—CD4049 (RCA) and MC14049 (Motorola). With this package, you get six voltage controlled amplifiers in a single integrated circuit. Cost now is around $5 per amplifier, but this will drop to around $1 per amplifier shortly.

Figure 6-b shows a full proportional control system with complete, thump free, control of attack, sustain, and decay.

Note that in both circuits, the package ground and positive terminals are tied together and form the output. The traditional inverter "outputs" are the signal or timbre input and the traditional inverter "inputs" receive the envelope commands. 1 volt or less is off, above 6 volts is on, and you get a smooth control range. Best input signals are less than 100 millivolts high and from a 100-ohm or less source impedance. The op-am build this back up to 0.5 volt or two output, eliminates crosstalk, and prevents negative feedback from reaching the gate circuit.

An analog quad switch and sample-hold

While you are looking at CMOS, check out the RCA CD1009 or the Motorola MC14018. Either of these has four separate analog off-on switches that you can apply up to ten volts of peak-to-peak signal to. You use the same circuit digitally, forwards as a one line to four line distributor, backwards as a four line to one line selector on four separate switches. Unlike virtually all other IC logic families, the signals can go through the switch in either direction.

Figure 7-a shows the IC. Figure 7-b is a digital or analog one-to-four distributor. Figure 7-c is a digital analog four-to-one selector. Finally, Fig. 7-d shows how you can build a sample-hold amplifier with one quarter of this package, a good Mylar capacitor, and an operational amplifier. Sample-holds are useful in synthesizers for remembering what frequency a note was after a key is released so the decay cycle can...
Now, there're bunches of phase-lock loops available and you probably have already tried a few. The hangup here is that the IC you use must have at least a 1000:1 voltage controlled frequency range and must not be harmonic sensitive. This leaves out everybody but the MC 4046. (The usual "565" type of PLL has only a 3:1 frequency range and is harmonic sensitive.)

One experimental circuit is shown in Fig. 8. Your input frequency can be a sine, square, or triangle or sawtooth wave. If you

A tracker or gliding VCO

One of the biggest problems in any synthesizer is doing glides, sweeps, and tritone effects on a keyboard instrument. A circuit originally used by Olsen in the pioneer RCA synthesizer work to do this was called a glider. Today, it's called a phase-lock-loop tracker, and it is available as the RCA CD4046 or Motorola MC14046.

What the circuit does is this. You send it a frequency. It grabs onto that frequency from the one it is already at. You can control how fast the grabbing takes place. It can be nearly instantaneous, or it can provide a glide or sweep.

The circuit has an internal oscillator that compares its frequency against an input and then provides an error correction signal. You add a capacitor to slow down the response time to "errors".

And some others...

Let's take a quick look at a bunch of other devices that you may want to use in music circuits. These are a bit more specialized but can solve some unusual music problems fast.


American Microsystems Inc. has a whole line of MOS music products. These include older octave synthesizers, rhythm generators, rhythm counters, and newer devices that combine functions. The $2566 Rhym Generator provides a complete handbag-on-a-chip when combined with a counter. Around $18.

Analog Multipliers. Analog multipliers are true four quadrant multipliers. They can be used for precision keys and VCA applications or for ring modulators, where you combine two sounds and get only the sum and difference out, or where you shift the frequency of a tone to compress or expand its harmonic spectra. These are still a bit steep in price to use on each and every note, but in a synthesizer system, one or two of them is certainly worth the price. Costs run from $15 upwards. Typical devices are the Motorola MC1494 and MC1495, the Signetics 5596, and the Analog Devices AD532J.

Besides the CMOS we've talked about, check out the old CD4011 (MC14011) quad gate. What better way to expand the contacts on a keyboard for coupling, translation, and transposition. It takes three IC's per new contact per octave, or 36th of an IC per contact per key. It's the cheapest CMOS device, well under a dollar surplus.

—Don Lancaster

**TABLE 1**

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<tr>
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<td>(Be sure and specify specific devices; the majority of these circuits were designed for non-music applications.)</td>
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**AMERICAN MICROSYSTEMS INC.**  
3800 Homestead Road  
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**ANALOG DEVICES**  
Norwood, Mass. 02062

**INTERSIL MEMORY CORPORATION**  
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