IMITATING MUSICAL INSTRUMENTS

WITH SYNTHESIZED SOUND

How the sounds of traditional instruments can be produced electronically

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IN A previous article ("Timbre and and Voicing Circuits for Electronic Music," June 1975), we discussed techniques for altering the tonal quality of a basic waveform to produce the desired musical effects. Now, we can consider specific ways of synthesizing the sounds of given traditional musical instruments. Once we know how to accomplish this, we can go on to designing our own "voices" for the instruments. (Imitating an instrument is called "voicing." Proper voicing can make an electronic instrument, while improper voicing will break it.)

As a gross and crude approximation to classes of instruments, you can use sine waves with slight amounts of second-harmonic content to imitate flutes, piccolos, and bland tibia organ pipes. Sawtooth waveforms, with either additional high-pass filtering for brightening or low-pass filtering for softening or mellowing, produce string-like tones. The same sawtooth waveforms passed through a fixed resonant bandpass filter circuit or two will produce a horn-like resonance.

Square waves with some softening and perhaps some even-harmonic content added are useful as a source of "hollow" or "woody" tones, such as those produced by the clarinet and other woodwinds and some stopped organ pipes. Lower piano notes and some organ pipes, or diapasons, have strong second harmonics, obtained by adding extra energy (usually more than is available in an unmodified sawtooth) at twice the fundamental frequency. Filtered noise forms the basis for many of the percussion instruments, particularly drums.

While any of these techniques is a good place to start and can produce a "clarinet-like" or a "trumpet-like" tone, they will all sound less than real. So, let us look at some basic voicing principles to find out what is needed in synthesized voices to make them sound more realistic.

Principles of Voicing. Successful voicing schemes must customize both the envelope and the timbre to the instrument. Having a fixed envelope shape and changing only the timbre is just as bad as having a fixed timbre and changing only the attack, sustain, and decay characteristics of the voice. Admittedly, some instrument limitations are somewhat tolerant of variations in envelope and timbre, but to do the job properly both envelope *and* timbre must be controlled, in addition to adding special effects.

Successful voicing cannot be accomplished with resistors and capacitors alone. Active electronic filters or inductors are usually needed. The formant or fixed-filter method (or a voltage-controlled filter with a fixed input reference) is normally best for synthesizing traditional musical instrument sounds, although a tracking filter or vcf is useful for changing harmonic content during note decay and for sympathetic resonance effects.

Precise control of many harmonics, preferably the first 30 or so involved, is required for successful voicing. Synthesis techniques that use or build up only the first few harmonics are doomed to failure. Harmonics 30 dB and more down from the fundamental can have a significant effect on overall tone quality.

Voicing must be accomplished in register to be successful. If a trumpet has a certain acoustical range, the filtering to imitate that range should handle only those notes a trumpet would normally cover. Extensions out of register on the high or low end will sound too bright or too shallow to be realistic.

Voicing must not be spread too thin if it is to be successful. With modern low-cost operational-amplifier active filters, there is no reason to use only one active filter for an entire voice register. By customizing the filtering to one-third or one-half octave steps and using multiple filters, a much better

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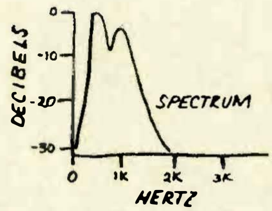
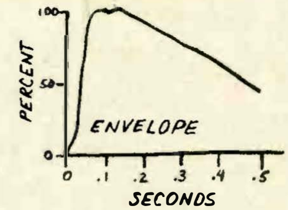
CHARACTERISTICS OF MUSICAL INSTRUMENTS

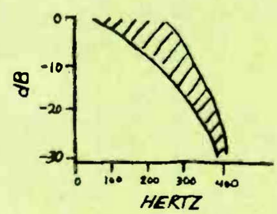
(Numbers in parentheses give the instrument's range, indicated by note and octave on the piano keyboard.)

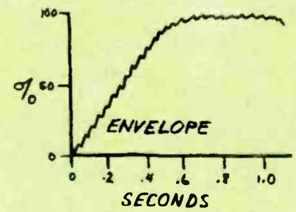
Bassoon (A#1-D#5): Typical of the bassoon are its moderate Q resonances at 550 and 1150 Hz. Dropoff of higher harmonics is very rapid above the second peak. The blip-free attack lasts 50 ms and sustain is 60 ms in duration, followed by a gradual noise-free decay.



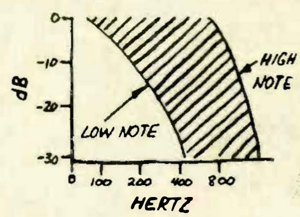


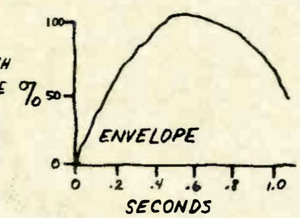
Bass Violin (E1-E3): Characteristic of the bass violin is its range through an almost pure sawtooth wave on the low end (50 Hz) through a steeply low-pass-filtered sawtooth on the high end (250 Hz). The rise and decay times are both 0.5 s in duration. A slight low-frequency noise modulation appears on the envelope.



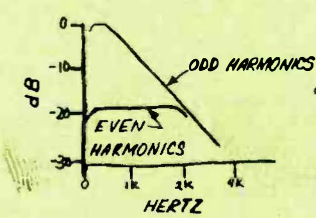


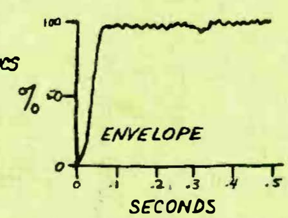
Cello (C2-E3): The sound from the cello is obtained by a predominantly sawtooth waveform that is moderately low-pass-filtered. Filter cut-off becomes steeper and must move up with increasing frequency. Very gradual attack and decay, with decay becoming more abrupt on the higher notes. characterizes the envelope.



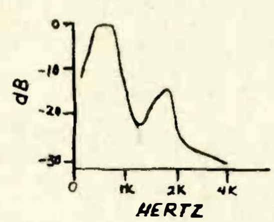


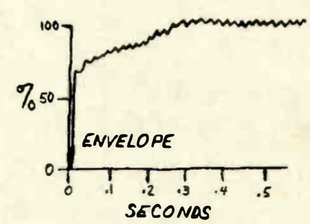
Clarinet (D3-F6): The sound of the clarinet consists predominantly of odd harmonics, although a low level of even-harmonic content must also be provided. Even harmonics are somewhat stronger for the upper notes. The rise time is about 50 ms, and a 10% modulation of low-frequency random noise adds to tone character.



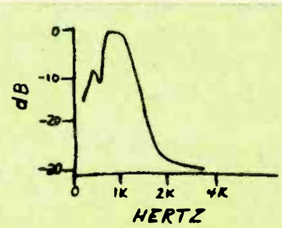


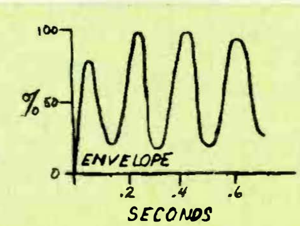
English Horn (G#3-C#6): A high, flat-topped resonance at 600 Hz and a narrower resonance at 1900 Hz are characteristic of the English horn. The dip between the two resonance peaks, located at 1300 Hz is some 26 dB down from the lower-frequency resonance peak. The two-step rise time is 5 ms to 60% amplitude and then more gradually to maximum at 400 ms. The final attack and sustain have a characteristic 10% random-noise amplitude modulation.



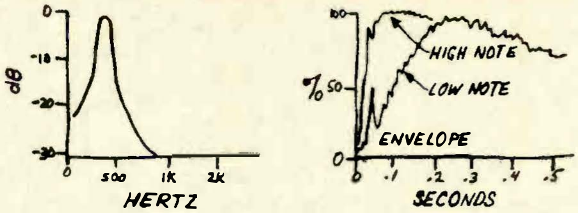


Flute (C4-C7): The flute is another double-resonance instrument with a minor resonance peak located at 300 Hz and a stronger peak at 600 Hz. Harmonics are very weak. The rise time is about 50 ms. A very pronounced (50-75% of maximum) tremolo of 5 to 7 Hz is present.

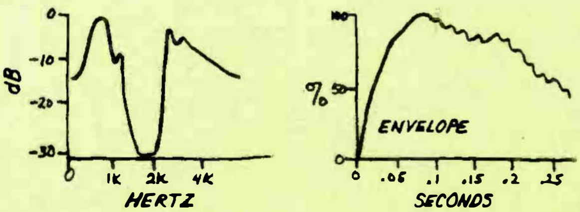




French Horn (B1-F5): Has a single resonance at 500 Hz and much narrower bandpass than the trombone. Risetime varies between 100 and 20 ms, with an attack blip on lower notes.

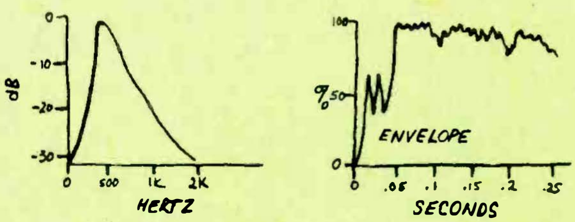


Oboe (A3-G6): A very complex spectrum structure is characteristic of the oboe. It has a 1050-Hz resonance peak, a 30-dB dip at 200 Hz, and a final high-pass resonance at 3000 Hz. Much more harmonic energy is in the oboe's sound than in other instruments. The rise time is 60 ms, sustain time is zero, and decay begins 100 ms after the start of the note. The envelope starts out relatively clean but then takes on a 10% noise modulation during the decay period.

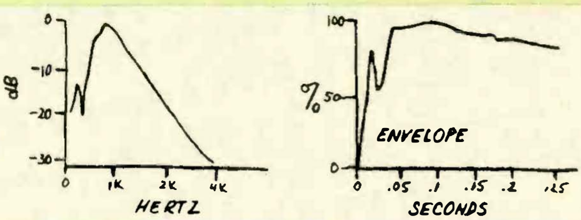


Piano (A0-C8): The absolute minimum needed to create a piano voice is three tone sources with non-harmonic overtones, combined with sympathetic-resonance buildups and interactions of harmonic overtones with time for each note. The waveform structure for the piano note is too complex to be shown here.

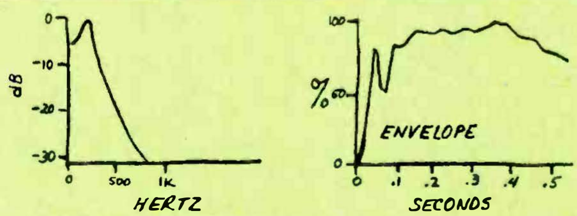
Trombone (E2-B4): The trombone's frequency spectrum curve shows a single resonance peak at 475 Hz whose rise time is on the order of 60 ms. The envelope has a very pronounced double blip on the leading edge. Portamento or frequency modulation is needed for slide effects.



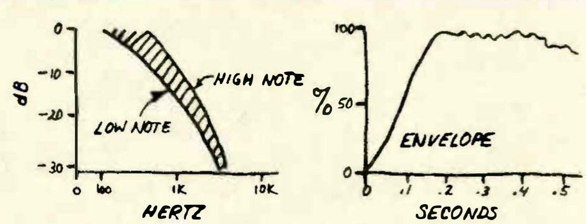
Trumpet (E3-A#5): The trumpet's single resonance peak falls at 1150 Hz. Its envelope displays a characteristic horn blip or impulse change in amplitude. The rise time is 50 ms.



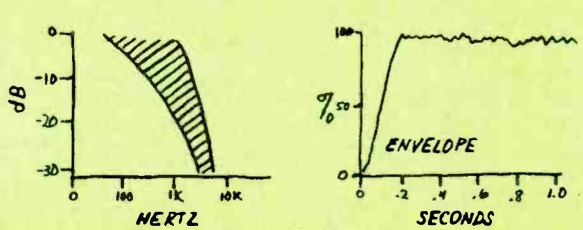
Tuba (F1-F4): The tuba's voice has a single resonance peak located at 275 Hz. A very pronounced horn blip is on the attack edge of the envelope. Rise time is 400 ms.



Viola (C3-E4): The voice of the viola ranges from a brightened, high-pass-emphasized sawtooth on the low end at 140 Hz through a slightly low-pass-filtered sawtooth on the high end at 750 Hz. The attack time is 150 ms, followed by a 150-to-300-ms decay time. The envelope exhibits some low-frequency noise modulation.



Violin (G3-C6); The violin's voice ranges from a brightened high-pass-emphasized sawtooth on the low end at 200 Hz through a slightly low-pass-filtered sawtooth on the high end at 1500 Hz. The attack time varies between 80 and 200 ms, and a 6- to 8-Hz frequency-modulation vibrato is optionally present.



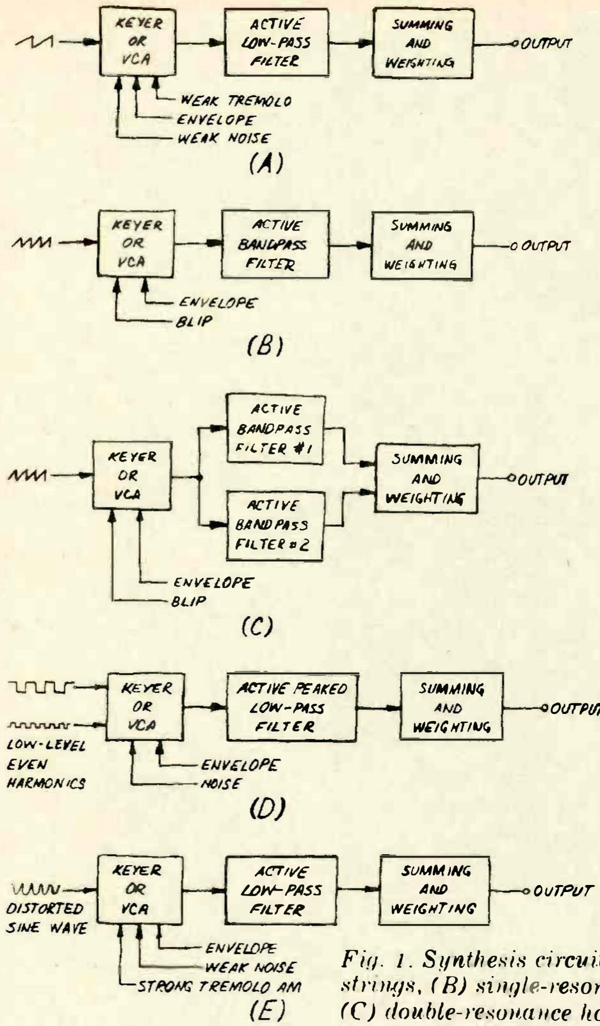


Fig. 1. Synthesis circuits: (A) strings, (B) single-resonance horn, (C) double-resonance horn, (D) woodwind, (E) flute or piccolo.

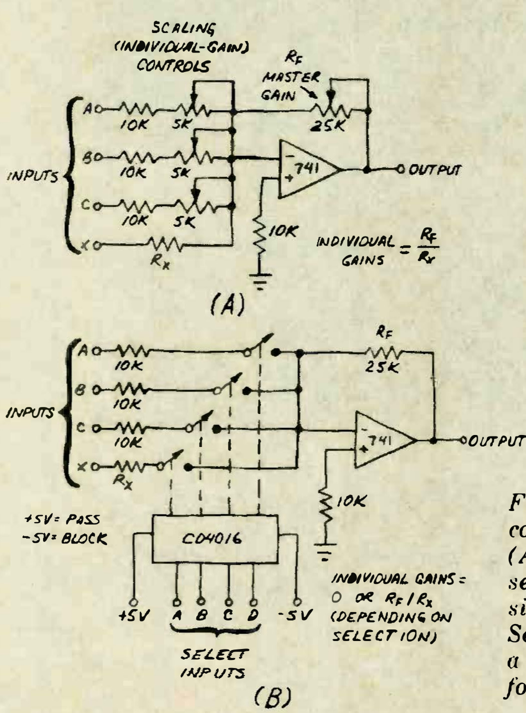


Fig. 2. Mixing and combining voice outputs: (A) Summing and scaling several sources to a single output. (B) Selecting voices with a CMOS analog switch for stops or presets.

job can be done at negligible additional cost. An alternate approach in monophonic instruments is to use a bank of vcf's and shift their parameters as needed to get the desired effect. Multiple or movable filters greatly ease the loudness balancing (scaling) problem from note to note.

One must recognize that instrument sounds are norms and not absolutes. A bass violin sounds quite different when played in a tiled room than it does in a concert hall. It sounds even more different in an anechoic, or acoustically "dead," room. Furthermore, the model and age of the instrument, its quality, the ambient temperature and humidity, mood of the performer, and context in which the instrument is used all combine to produce the final effect of the sound heard.

Finally, successful voicing cannot be accomplished by an engineer alone. Nor can the musician alone do the job properly. It must be done by both people contributing their best efforts.

Instrument Sound Synthesis. The accompanying box illustrates some of the characteristics essential to a number of popular traditional musical instruments. Bear in mind that the information given in the box is only a starting point in designing a system capable of realistic instrument voicing.

For most of the instruments listed, you can use a system setup like one of those shown in Fig. 1. In general, start with a sawtooth waveform and pass the signal through a suitable active filter or two. Use similar circuits for each octave or, better yet, each half- or third-octave increment. This permits each portion of the register to be weighted for optimum voicing and volume level. Where a clarinet voice is needed, a square wave or two sawtooths are used as an input. (A fundamental-frequency and minus one-half of the second harmonic-frequency sawtooths can be summed to obtain a square wave. Filtering then takes over.)

You can combine and mix various instrument voices, either in the preset form of the synthesizer or in the stoptablet form of an electronic organ, with the aid of one of the circuits shown in Fig. 2. The CMOS analog switch in (B) is ideal for voice switching because it draws essentially zero control-line power. ◈