# The Kurzweil 250 Digital Synthesizer
## Version IV

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# Introduction

> In recent years, the world of musical instruments has been divided into two different and distinct approaches to creating music, each with its own strengths and weaknesses, and each with its own history. The world of acoustic instruments has provided rich complex timbres, but relatively limited ability for modification and control. The world of electronic instruments has provided a wide range of flexible methods to provide artistic control over sounds... but traditionally has been unable to achieve the rich and musically satisfying timbres of "natural" acoustic instruments... The primary goal of the Kurzweil 250 is to bridge these two musical worlds, to provide the capabilities of both in a single instrument. For the acoustic world, the goal has been to recreate the rich complex time-varying timbres of the grand piano and other acoustic instruments, as well as the effect of pitch and loudness on these timbres. For the electronic world, the goal has been to provide a state-of-the-art system for modification and control.
>
> [Kurzweil 1984]

In the early 1980's, synthesizers had been in use for some fifteen or twenty years, yet (notwithstanding manufacturers' claims to the contrary) no synthesizer had thus far produced a sound that a careful listener could possibly mistake for a grand piano. One obvious reply to such a statement is, so what? Why not use a real acoustic instrument if you want the sound of a real acoustic instrument? The basic reason is, as the quotation above suggests, that an electronically-produced sound can be modified and controlled in ways that would be impossible with an acoustic one. (The question of control deserves more attention; see "Unplayable by Human Hands" below.) It might also be argued that it is very hard to be sure how well a sound created from scratch will wear; but if you start with a sound that has survived centuries of use, you can expect that most variations on it will keep people's attention. Finally, there is an answer that might motivate synthesizer developers to work specifically on the sound of a piano. This sound (1) is exceptionally complex, resulting as it does from a system with over two hundred strings (many totally undamped, none *perfectly* damped), soundboard, case, and keybed (thump affects the sound significantly); (2) it covers a wider range of pitches than any other major instrument; and (3) it's very familiar to a great many listeners. Hence, if you can do a convincing piano, you should be able to do almost anything. The K250 is widely considered to be the first electronic keyboard to produce a convincing piano sound (see the next section). Incidentally, the apparent complexity of the piano sound is borne out by the experience of Kurzweil Music System's "Soundware Group", of which Byrd has been a member: probably as much effort has been put into the Kurzweil 250's piano sound as into all the other sounds of the original base sound block combined (Keyboard Setups 1 to 40 of the K250 Version I).

## Technology Imitates Reality

The history of technology's attempts to imitate reality, both in music and in other areas, is fascinating. According to [Kurzweil 1984],

> The original commercial Hammond organ was introduced in 1939 at the Industrial Arts Exposition in New York and was favorably received. In promoting his new instrument, Hammond claimed that his "Model A", which sold for $2,600, generated a sound that was equal in quality to a $75,000 pipe organ. When challenged by the Federal Trade Commission to substantiate that claim, a "blind" test was set up to compare the Model A to the Aeolian-Skinner Pipe Organ in the University of Chicago's Rockefeller Chapel. A panel of experts and students were essentially unable to tell the two instruments apart.

It is remarkable that not only students, but also "experts", could not tell the difference. Much more recently, Kurzweil Music Systems performed a similar A-B comparison [Kurzweil 1984]:

> At the June, 1984 NAMM (National Association of Music Merchants) convention in Chicago, between a top of the line 9-foot concert grand piano and a Kurzweil 250, both played through the same very high quality $40,000 sound system. There was general agreement that it was not possible to tell the difference between the piano and the K250.

An earlier and much less sophisticated musical impostor was the Mellotron; it will be described later.

Another anecdote that is remarkable in several respects involves Willis O'Brien, who did the special effects for *King Kong*; Sir Arthur Conan Doyle, the creator of Sherlock Holmes; and Harry Houdini, the great magician. A few years before *King Kong*, a movie called *The Lost World* was made, based on a novel of Doyle's; O'Brien was in charge of special effects, which included extensive scenes of dinosaurs. According to [Schechter and Everitt 1980]:

> In 1922, a test reel O'Brien had made for the film, showing a group of his prehistoric animals in action, was turned over to Doyle, who had been having a running battle with Houdini over the issue of spiritualism. [Doyle] was a devout believer in psychic phenomena, while [Houdini] was a dyed-in-the-wool skeptic... When Houdini invited his esteemed adversary to a meeting of the Society of American Magicians, Doyle decided to play a little prank. He brought along O'Brien's test reel, threaded it through a projector, then gave a brief, introductory speech in which he suggested that the scenes he was about to show were obtained through preternatural means. The audience, which included the publisher of the New York Times, watched the movie in open-mouthed wonder. The next morning an article on the front page of the Times announced the astonishing news that Doyle had somehow managed to get his hands on moving pictures of living prehistoric beasts. Having enjoyed his little joke, Doyle hurried to reveal the source of his movie.

No modern audience would be fooled by 1922 special effects, no matter how good, for more than a few seconds. One last example: one of the current authors (Byrd) created the flute sound for the Kurzweil 250. While working on that sound, he noticed a very peculiar change of timbre going up the scale that he was certain was an artifact of the processing, until he listened to a flute and discovered that it really did change in that way. This in spite of the fact that he is himself a flutist! It is hard to escape the conclusion that our sensitivity to deviations from reality is overwhelmingly influenced by our expectations, and that these expectations are shaped by our experience. Over the course of the 20th century, audiences for both movies and music have been exposed to increasingly accurate simulations of reality, and their sensitivity to the differences has increased tremendously. There is no reason this trend should not continue: as good as the K250's sounds — and current movie special effects — are, there is still room for improvement.

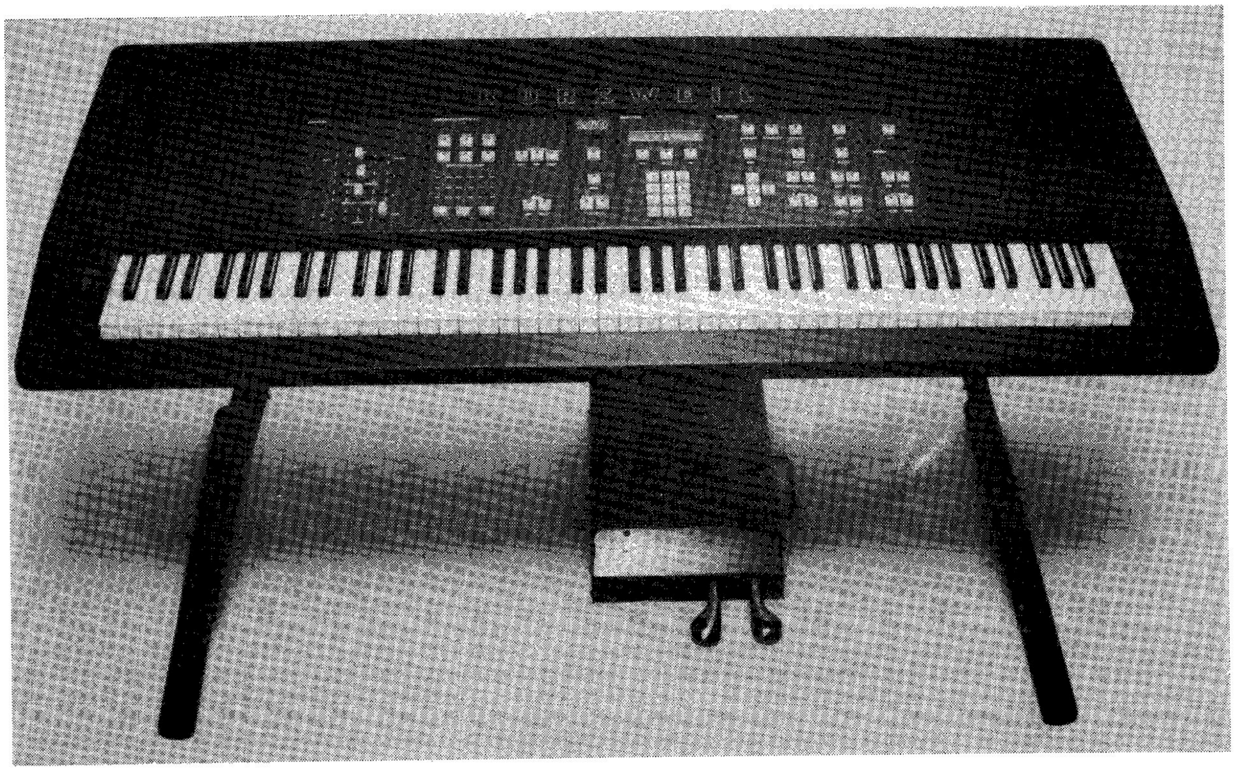
The Kurzweil 250 is a product of Kurzweil Music Systems. What was to become the K250 was conceived and its preliminary design done by Raymond Kurzweil, the company's founder, in late 1982. A development team was then put together. An engineering prototype was exhibited publicly in 1983 and production began in 1984. It is beyond the scope of this article to describe the development process; suffice it to say that the project took enormously more time and effort than was expected. The interested reader should see [Kaplan 1981], which recounts the history of a similar project.

The remainder of this article will assume no prior knowledge of the Kurzweil 250. It will, however, assume an understanding of the basic principles of digital sound synthesis. For background, see [Chamberlin 1980 and Pohlmann 1986]. For a good discussion of the K250 from a rather different viewpoint, see the review by Dominic Milano [Milano 1985].

## Caveat: Audio Bandwidth and Sampling Rate

In this article we will hardly ever mention an audio bandwidth; instead we will give sampling rates. The theoretical maximum bandwidth for a given sampling rate is, of course, one-half the sampling rate, but — if one wants to avoid any risk of aliasing or imaging — this can only be achieved with ideal low-pass filters, not with real ones. Images are spurious copies of the spectrum above one-half the sampling rate (they are often confused with "aliases", which occur when going from a continuous domain to a sampled one, while images occur in the other direction, i.e., sampled to continuous). Most often, the audio bandwidth is around two-fifths of the sampling rate. Again, see [Chamberlin 1980] for more details.

*Fig. 1. The Kurzweil 250.*



# Technical Overview

The Kurzweil 250 is shown in Fig. 1. The main enclosure includes the keyboard (88 full-size, weighted wooden keys with a proprietary action, velocity sensitive), control panel, display (back-lit LCD, two lines of 24 characters each), and electronics. There is also a separate "pod" containing the power supply and two foot pedals. Fig. 2 is a block diagram of the instrument from the standpoint of hardware. There are three main components to the electronics, corresponding to the three main circuit boards: the Central Processing Unit (CPU), the Channel Group Processor (CGP), and the Channel board.

*Fig. 2. Block diagram of the Kurzweil 250.*

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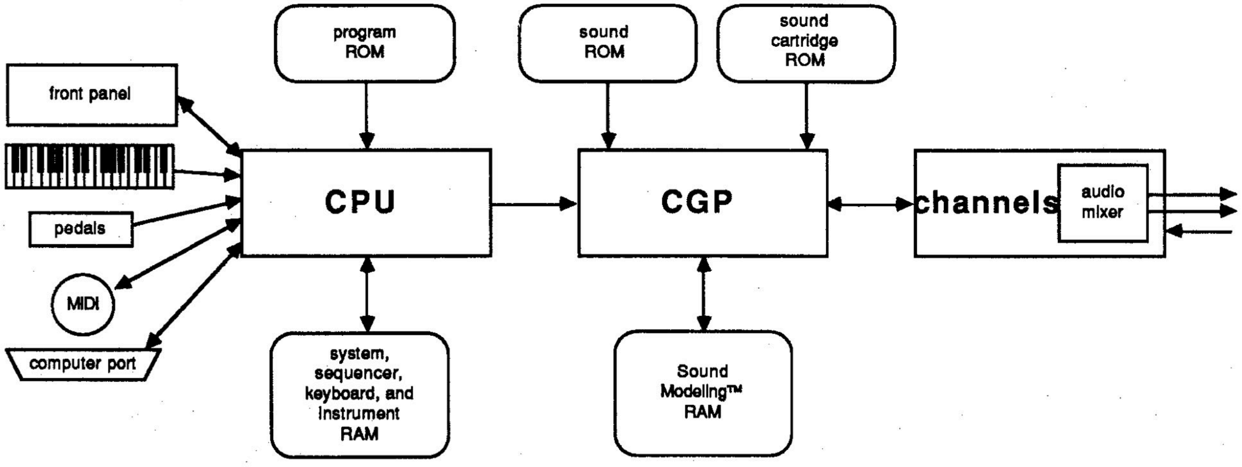


An "expander" version, without keyboard or pedals, but smaller, lighter, and cheaper, is also available. It is called the "250XP", and except for the obvious differences, it is identical to the standard K250. The rack mountable Kurzweil RMX was introduced in 1987 offers all the features of the K250 in a lightweight box measuring 10.5" x 19" x 20".

The entire system is controlled by the CPU, which is built around a Motorola 68000 microprocessor running at 10 MHz. As the diagram shows, the CPU reads data from the keyboard, control panel, and foot pedals; controls the display and front panel lights; talks to the MIDI and computer ports; and controls the other two boards. We'll say more about the MIDI and computer interfaces later. The CPU has 256K bytes of ROM which its programs are stored, and 128K bytes of RAM for sequences, Keyboard Setups (see "Controlling the Kurzweil 250", below), "instrument" definitions (again see "Controlling the Kurzweil 250"), and general system use. The RAM is battery-backed and retains its contents even when the K250's power is turned off.

Generating samples in digital form is the sole job of the CGP. It has, in a condensed form, definitions for all the sounds the instrument can produce — factory-defined, permanent sounds in ROM; user-loaded ones in RAM. The K250 stores samples in a modified floating point format with 18-bit words. In effect, the fractions contain the waveform with its dynamic range compressed as much as possible; most of the dynamic information is in the exponents. For typical musical sounds the K250's separation of the original signal into compressed waveform and exponent uses the sample bits much more efficiently than would be possible through uniform compression systems such as those of dbx or similar companders. The original amplitude information goes into the exponents for later use by the Voltage Controlled Amplifiers (VCAs).

The basic Kurzweil 250 has 2 megasamples of ROM sounds (in the base sound block); sound blocks A, B, C, and D which are optional, each have an additional 1 megasample. The cartridge slot is intended to hold an optional half megasample of sounds in ROM, but no cartridges have yet been released to the public. Finally, K250 has 500K to 2000K samples of RAM; this can be used either to digitize sounds with a microphone or line input to the K250, or to load sounds from a computer connected to the computer port. Naturally, digitized sounds in RAM can also be sent to the computer for safekeeping. A fully loaded K250 contains 8 megasamples. See Fig. 3.

*Fig. 3. K250 sound architecture.*

## ROM

| | | |
|---|---|---|
| **BASE SOUND BLOCK** | = 98 Setups | Such as: Piano, String Section, Acoustic Bass, Trumpet, Horn, Trombone, Organ, Percussion, Guitar, Harpsichord, Sine Wave. |
| **SOUND BLOCK A** | = 86 Setups | Such as: Choir, Flute, Oboe, Clarinet, Chimes, Timpani, Marimba, Vibes, Electric Bass, Conga Drums, Harp Gliss. |
| **SOUND BLOCK B** | = 49 Setups | Such as: 10 Processed Drum Sets, Electric Guitar, Electric Piano, Various MiniMoogs. |
| **SOUND BLOCK C** | = 56 Setups | Such as: Solo Violin, Solo Cello, Pizzacato Strings, Plucked Harp, Handbells, Celeste, Bassoon, Pipe Organs, and Sawtooth wave. |
| **SOUND BLOCK D** | = 53 Setups | Such as: New Trumpets, Trombones, and Tuba (also with various mutes) and the Saxaphones, doublings, and Square wave. |

## RAM

| | | |
|---|---|---|
| **User Keyboard Library** | = 40 Setups | Combinations of RAM & ROM sounds |
| **Digitizer Memory** | = 60 Setups | (400 seconds or 252 Soundfiles) |

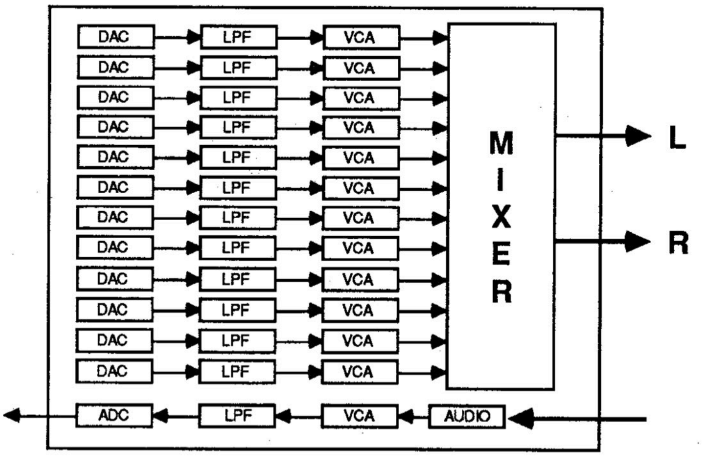
**Total: 442 Setups**

The K250's channel board has 12 channels, each of which can output any sound independently of the others. The K250 is a variable sampling rate machine: each channel can run independently at an (output) sampling rate up to about 60K samples per second. As is well known, the use of variable sampling rate completely eliminates some serious problems of constant (output) sampling rate systems. For example, to raise the pitch of a sound (regardless of the technique), one must output a period of the sound in a shorter time. On a variable-sampling rate device, this can be done simply by outputting the samples more frequently; but with constant-sampling rate hardware, the correct value for each sample time must be computed. This computation cannot be done exactly, although it can be done as accurately as desired; any error is heard as noise. In fact, in most systems, a very substantial amount of computing must be done to make the noise inaudible, and so — besides having the overhead of doing the computation — one ends up tolerating some noise. On the other hand, it is not hard to share a high-speed digital-to-analog converter (DAC) and anti-aliasing low-pass filter (LPF) among several channels if they have a common sampling rate; with different sampling rates, this is prohibitively difficult, so each of the K250's 12 channels has its own DAC and LPF. (In addition, machines equipped with Sound Modeling have a channel that "goes the other way", with an analog-to-digital converter (ADC) instead of the DAC.)

Since channels have a fixed maximum sampling rate, the higher the rate at which a sound was originally sampled, the less it can be transposed up. For example, a sound sampled at 25K samples per second can be transposed up 15 semitones. All sounds can also be transposed down as much as five octaves. The Sound Modeling system offers selectable sampling rates from 5K to 50K. At 50K samples per second, the 500K total samples last for about 10 seconds, while at 5K, they last 100 seconds.

The CGP sends a sample to each channel in each of its sample periods (note that this period need not be the same as any other channel's); the CPU also sends an exponent. The sample is converted by the DAC, then fed to an LPF. This programmable-cutoff low-pass filter is normally set for the greatest bandwidth that will reject images. As might be expected, this bandwidth is nominally two-fifths of the sampling rate. The filter output passes through a VCA, whose gain is controlled by the exponent. The VCA output goes to either Instrument Group A or B, depending on the sound it is playing; the other 11 VCA outputs do likewise. Finally, the A and B signals go to a two-in/two-out mixer controls (stereo audio output is through Hi or Low level 1/4-inch jacks, balanced XLR connectors, or a headphone jack); to independently pan A and B across the outputs appear on the front panel. See Fig. 4.

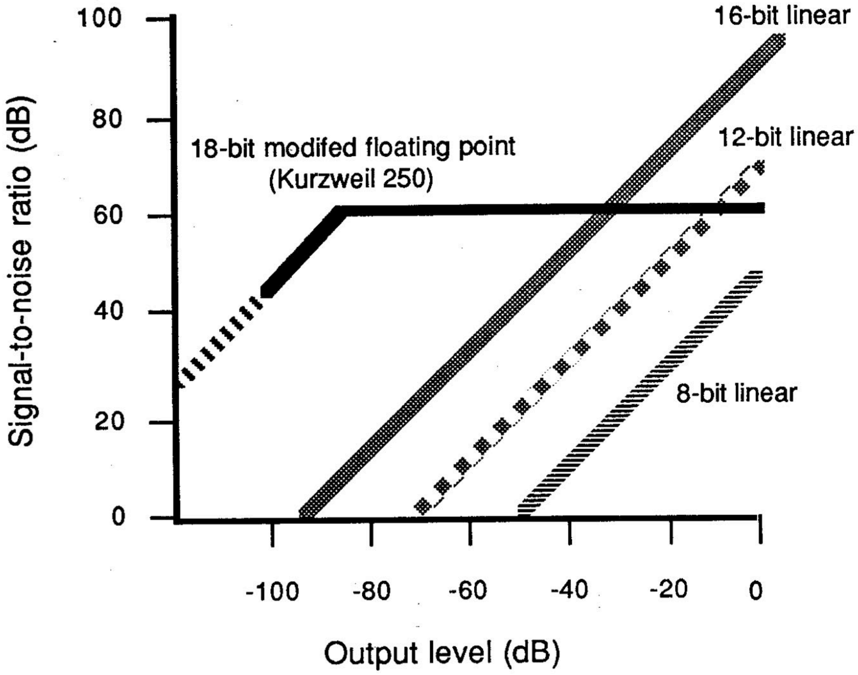
*Fig. 4. Channel Board Details.*



## How Well Does All This Work?

Fig. 5 compares the signal-to-noise ratio and dynamic range of the Kurzweil 250's sample format to more conventional 8-, 12-, and 16-bit linear encodings. There is much confusion about the difference between signal-to-noise ratio and dynamic range. One reason for the confusion is that they are identical on most devices; only with hardware whose noise output varies with the signal can they be different. In the K250's case, as a result of the floating-point format, the noise goes down with the signal. (The signal-to-noise ratio is constant as the signal goes down; therefore, the noise must also be going down.) The K250 has a signal-to-noise ratio of about 60 dB. The exponent controlling the VCA increases the dynamic range to something over 100 dB — great enough that it is difficult to measure.

*Fig. 5. Signal-to-noise ratio as a function of amplitude for various sample formats.*



Aside from considerations of sample format and overall design craftsmanship, perhaps the biggest difference between the K250 and most other sampling instruments is that the K250 has far more high-speed memory — mostly ROM — for sounds definitions. What this means in practice is that the K250, and almost no other instrument, can do a credible impression of an orchestra.

## How Much Memory?

In theory, one could reproduce perfectly any desired sound with a sampling-based digital synthesizer like the Kurzweil 250 simply by recording it and then, when the appropriate key is struck, playing back the recording. Readers may recall the Mellotron, an electro-mechanical instrument that did just this with tape loops, one per key. Timbres could be changed by replacing the tape loops with a new set. The Mellotron was used heavily in the 1960s and '70s by such groups as the Moody Blues, but is now largely obsolete.

In his article [Kurzweil 1984], Raymond Kurzweil points out the practical difficulties of applying the straight "play-back-a-recording" approach to a sound as complex as that of the piano.

> A loud strike on a piano (and other instruments) is not the same as a soft strike amplified. The entire spectral evolution changes along with the loudness... Consider that each of the piano's 88 keys can create an average of approximately 50 distinct distinguishable timbres. Each of these 4,400 sounds lasts an average of about 10 seconds for a total of about 44,000 seconds. If these were recorded using standard digital audio disk techniques (44,100 16-bit samples [per second]), it would require about (44,000x44,100x16) or 30 billion bits. With 256K bit memory chips, that would require over 100,000 memory chips for the piano alone!

One may quibble with some of these numbers, especially the number of distinct timbres per key and the number of seconds per sound. But it is clear that to perfectly reproduce piano sounds in this brute force way is out of the question. The basic K250 in fact squeezes many sounds (of which piano is by far the most memory-hungry) into 60 Megabit chips, using a proprietary data compression technique called Contoured Sound Modeling™. It is capable of capturing changes of timbre with loudness, as a careful audition of the K250's piano sound demonstrates.

## Moorer's Recommendations

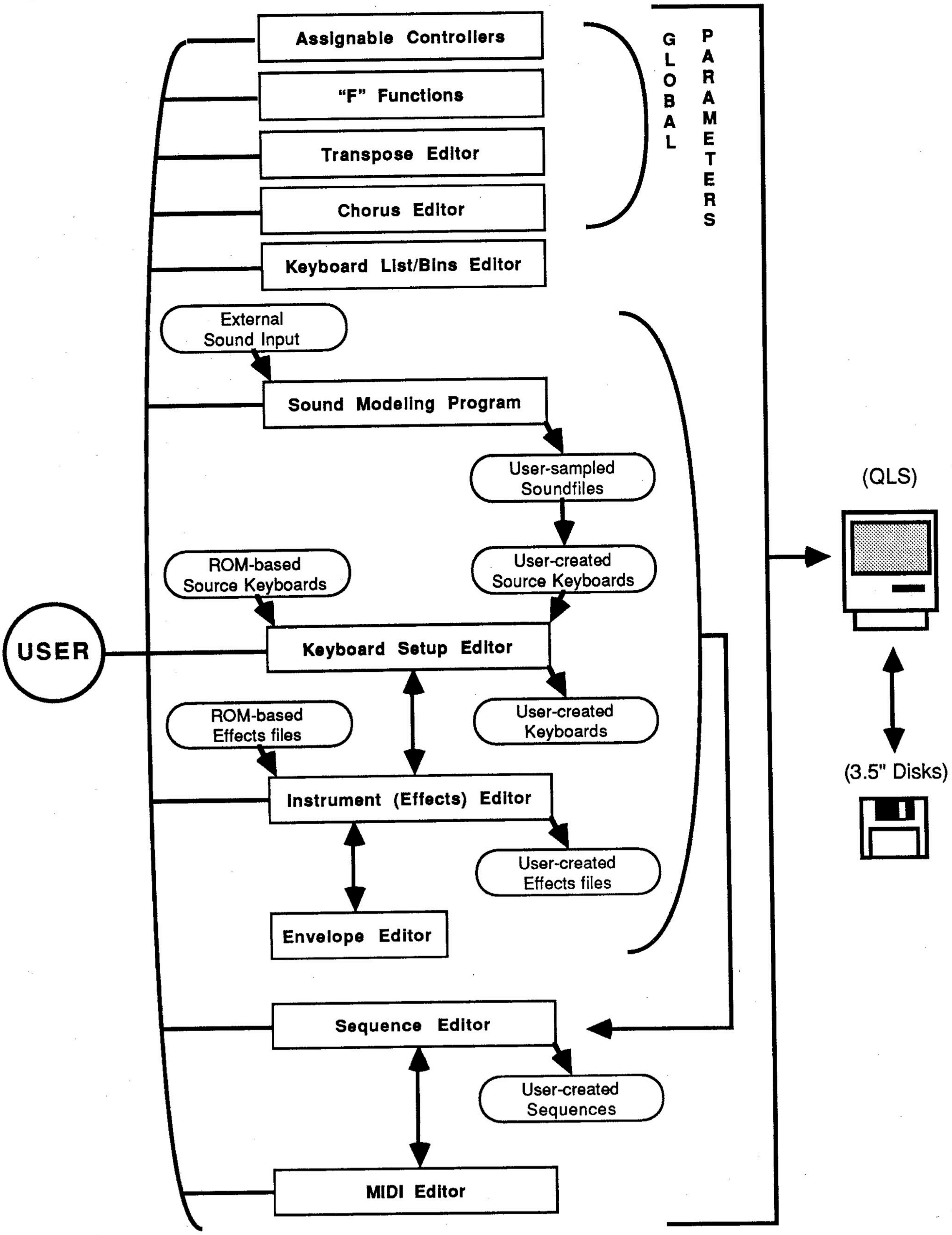
It is interesting to look at the Kurzweil 250 in the light of some recommendations J. A. Moorer made to future synthesizer designers a few years ago [Moorer 1981]. They were: (1) that "the DAC output path or ADC input path should have some amount of buffering... This allows the synthesizer to be momentarily stopped without affecting the flow of data to (or from) the converters. It also removes the restriction that the synthesizer take a constant amount of time to compute each sample"; (2) if real-time control is desired, there must be a direct path to update parameters that bypasses any other update path that contains timing information; and (3) some kind of synchronized sample-data writeback [to a separate computer] should be included, both for diagnostic purposes and to facilitate multiple runs to generate sounds more complex than the machine can produce in real-time. The K250 follows recommendation 1 as a result of its distributed processing: the CGP can generate samples for some time without assistance from the CPU. It follows recommendation 2: the CGP rarely has timing information more than a second or so in advance, and control information that cannot wait that long — vibrato, pitch bend, transpose, and tremolo — is sent from the CPU straight to the appropriate channel, bypassing the CGP. It does not follow recommendation 3. This is unfortunate, but synchronized sample-data writeback would be quite difficult in a variable-sampling rate system where the channels are not synchronized.

# Controlling the K250

The K250 provides the user access to and control of the full sound modification potential of the instrument's Keyboard, Instrument, and Soundfile Libraries as well as the Sequencer and Sound Modeling Program™ (less formally called the Digitizer). Although immediate control to a certain level is utterly simple, relative proficiency with the instrument takes a few weeks. See Fig. 6.

Through the various editors and editing modes, the user has control of a number of aspects of the K250. First and foremost is access to the multitude of ROM-based and user-created RAM-based sounds. In the K250 a sound is a combination of two elements: a soundfile containing the "raw" digital data of a sound; and an "instrument", which, in K250 jargon, means the effects — envelope, vibrato, tremolo, etc. — currently associated with a soundfile. However, the K250 does not play "instruments" directly, it plays mappings of "instruments" onto the keyboard which are referred to as *Keyboard Setups*. A Keyboard Setup may have multiple hardness levels which trigger different soundfiles depending upon the hardness of keyboard strike (notes played on multiple-hardness Keyboard Setups still use only one channel each). A Keyboard Setup consists of

*Fig. 6. User Control.*


Assignable Controllers
"F" Functions
Transpose Editor
Chorus Editor
GLOBAL
PARAMETERS
Keyboard List/Bins Editor
External Sound Input
Sound Modeling Program
User-sampled Soundfiles
(QLS)
ROM-based Source Keyboards
User-created Source Keyboards
USER
Keyboard Setup Editor
ROM-based Effects files
User-created Keyboards
(3.5" Disks)
Instrument (Effects) Editor
User-created Effects files
Envelope Editor
Sequence Editor
User-created Sequences
MIDI Editor

any number of sound/"instrument" configurations (including extremely complex splits and/or up to six layers) on the physical K250 keyboard. The software currently provides room for up to 342 ROM-based Keyboard Setups, 350 or more ROM-based "instruments," 100 user-defined Keyboard Setups (40 created with the Keyboard Setup Editor and 60 created in the Digitizer), 48 user-defined instruments, and, presumably, well over a thousand ROM-based soundfiles. User-defined soundfiles are limited to 252 with the SuperRAM II option.

The K250's internal sequencer acts as a 12-track digital keyboard recorder with a capacity of about 12,000 notes. Each track will record as many simultaneous note events as desired, although, due to the 12-channel output limitation, without the use of an expander, RMX, or some other external device, there is no point to letting the note density on any single track exceed 12 channels, for a maximum total of 144 for the 12 tracks combined. While a single K250 will not directly output these 144 channels simultaneously, it is a relatively simple task to transfer each channel (with all of its 12 voices played) to a multi-track tape-recorder using the Sequencer's built-in sync function. Of course, the Sequencer records keystroke information, not actual samples (the advantages of this methodology will be discussed in "The Sequence Editor" below), so it is possible to record at any tempo between 10 and 600 beats per minute and change the playback speed without affecting pitch.

The optional Sound Modeling Program allows the user to sample (i.e., digitally record) 100 to 400 seconds of any sound or sounds (depending on the amount of SMP RAM) from any source and store these sounds as soundfiles which may be used within Keyboards and Instruments in the same way that the ROM-based soundfiles are used. There is one difference: the SMP provides the user with a number of possibilities for editing user-created soundfile data, whereas ROM-based soundfiles cannot be altered (although their associated "instrument" files can be).

## User Interface

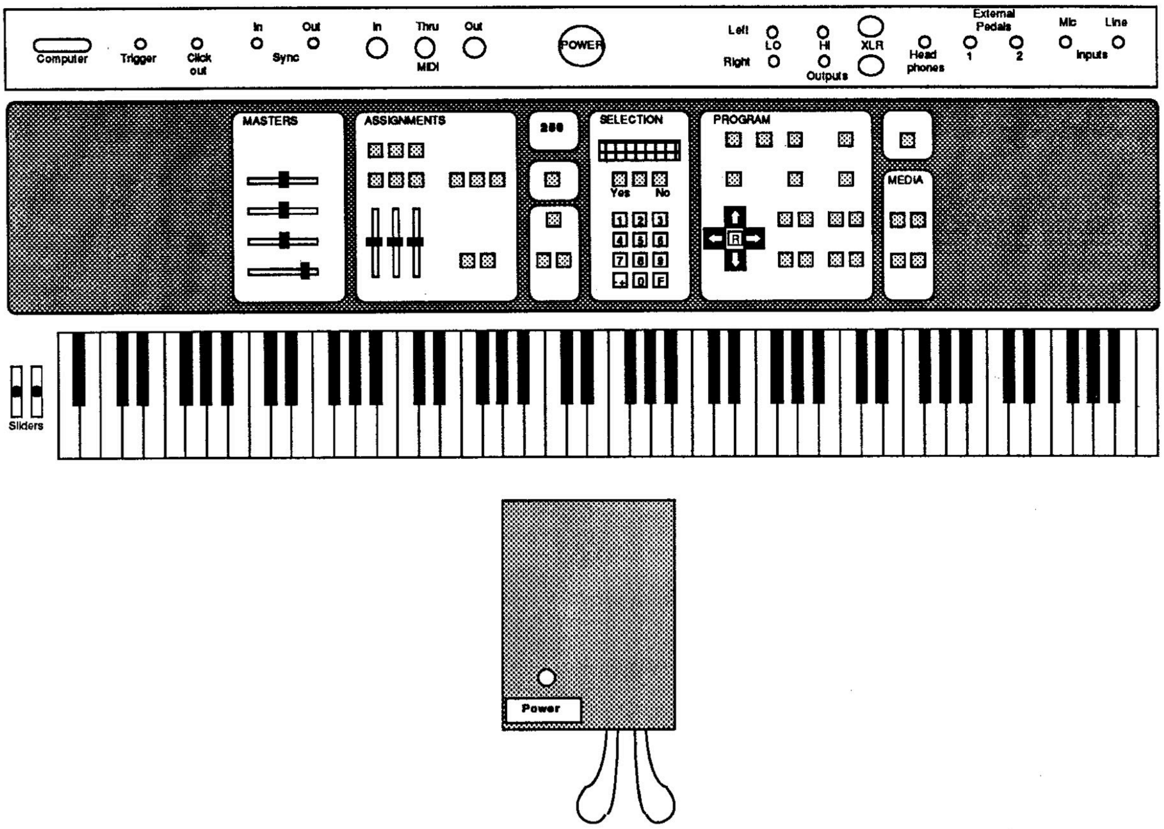
The Kurzweil 250's front panel (shown in Fig. 7) functions in two basic capacities, those of real-time control and editing/sound modification control. The K250's editing and sound modification capabilities are exploited with five basic editors: the Keyboard Setup Editor, the Instrument Editor, The Envelope Editor (accessed through the Instrument Editor), the Sound Modeling Program™, and the Sequence Editor. Seven additional edit modes control the global parameters of the instrument, instrument library manipulation, MIDI, and the mapping of user-assignable levers, sliders, and footpedals. The functions of the various buttons, keypad, and sliders change, within the context of each editor although there is a certain amount of consistency among them.

The user interface employs a front panel with 38 multi-function buttons (all of which light up when in use and some of which blink to indicate further information such as a critical choice, sequencer tempo, etc.), seven sliders, two levers, a five-key multi-function cursor pad, a numeric keypad, and a 48-character back-lit liquid crystal display (LCD). There are also two standard footpedals and jacks for two supplementary footpedals. The functions of the sliders, levers, and footpedals are completely user-definable.

The various menu options are accessed in four ways: (1) stepping through the menu options via the cursor keys (usually, the Left-Right cursor keys will scroll backwards and forwards through the main options menu and the Up-Down cursor keys will switch between main options and sub-options); (2) using the front-panel controls in their current function; (3) using the numeric keypad; or (4) via MIDI. Active options are indicated in the display and values are entered with the numeric keypad, the sliders, cursor pad, or other button currently active for step entry.

One of the nicest aspects of the K250 design and architecture (and perhaps the most striking difference to other commercially available sampling instruments) is the fact that, with the exception of the one-time loading of user-sampled sounds, there is no need ever to access a disk. In fact, the K250 does not have its own disk drive and it is fully operable without one. All software functions and sounds are available instantly and in any simultaneous combination from the ROM or battery-backed RAM. An external computer and disk drive is necessary only for file storage or the use of the various external software packages described below.

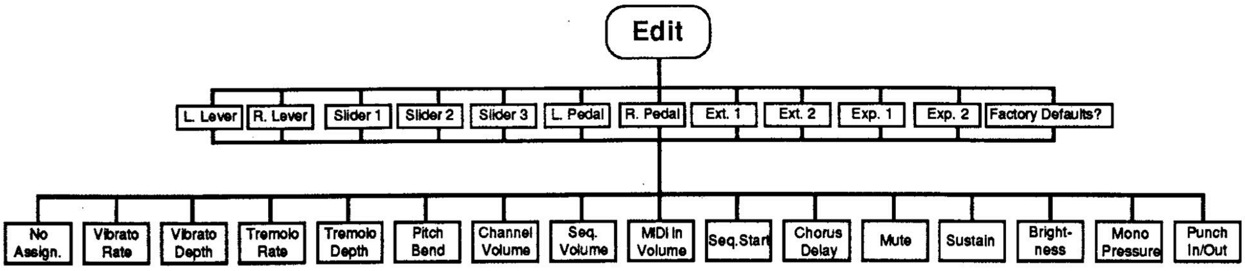
*Fig. 7. The Front and Back Panels.*


Computer
Trigger
Click out
In
Out
Sync
In
Thru
Out
MIDI
POWER
Left
Right
LO
HI
XLR
Outputs
Head phones
External Pedals
1
2
Mic
Line
Inputs
MASTERS
ASSIGNMENTS
250
SELECTION
Yes
No
PROGRAM
MEDIA
R
Sliders
Power

## Fundamental Editing

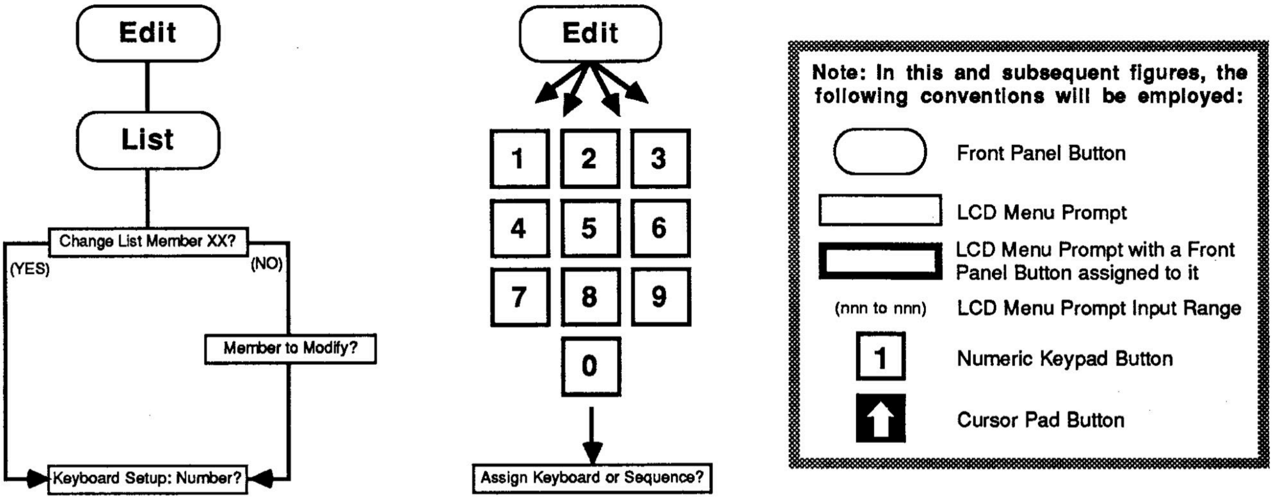
Fundamental editing on the Kurzweil 250 refers to edit functions which do not affect or modify sound output. In addition to the settings of the four far left front panel sliders (master tune, stereo positioning of Instrument Groups A and B, master volume), one of the K250's most fundamental editing consists of assigning functions to the nine assignable levers, sliders, and footpedals. Any of 15 functions may be routed to any control: vibrato and tremolo rate and depth, pitch bend, channel volume, sequence volume, MIDI volume, sequence start, chorus delay, mute, sustain, brightness, mono pressure out, punch in/out and "No Assignment" (see Fig. 8).

*Fig. 8. Editing the Assignable Controllers.*


Edit
L. Lever
R. Lever
Slider 1
Slider 2
Slider 3
L. Pedal
R. Pedal
Ext. 1
Ext. 2
Exp. 1
Exp. 2
Factory Defaults?
No Assign.
Vibrato Rate
Vibrato Depth
Tremolo Rate
Tremolo Depth
Pitch Bend
Channel Volume
Seq. Volume
MIDI In Volume
Seq.Start
Chorus Delay
Mute
Sustain
Bright-ness
Mono Pressure
Punch In/Out

Another editing capability in this category is rearranging the Keyboard Setup Library. The Keyboard Setup Library may be edited on two levels. First, the Setup List" may be edited. Besides providing a way to quickly jump from keyboard to keyboard with a single button, the List allows the user to assign MIDI program change numbers under 65 to K250 Setups numbered 65 to 750. Secondly, the user may assign Keyboard Setups or sequences to the "keypad bins" (30 Keyboard Setups or sequences which are instantly on-line with one or two keystrokes); see Fig. 9. These keypad bins provide another way to jump instantly from instrument to instrument or sequence to sequence making it easy to take advantage of the K250's very large RAM and ROM, particularly in real-time performance.

*Fig. 9. Editing the Instrument List and Keyboard Bins.*


Edit
List
Change List Member XX?
(YES)
(NO)
Member to Modify?
Keyboard Setup: Number?
Edit
1
2
3
4
5
6
7
8
9
0
Assign Keyboard or Sequence?

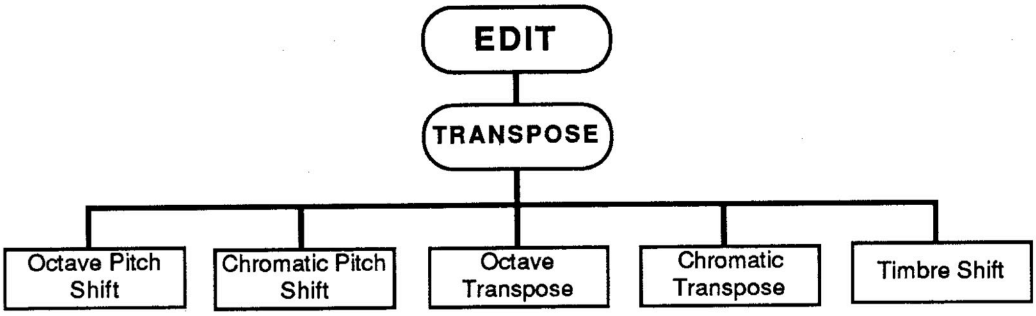
**Note: In this and subsequent figures, the following conventions will be employed:**

Front Panel Button
LCD Menu Prompt
LCD Menu Prompt with a Front Panel Button assigned to it
(nnn to nnn)
LCD Menu Prompt Input Range
1
Numeric Keypad Button
Cursor Pad Button

## Global Parameter Editing

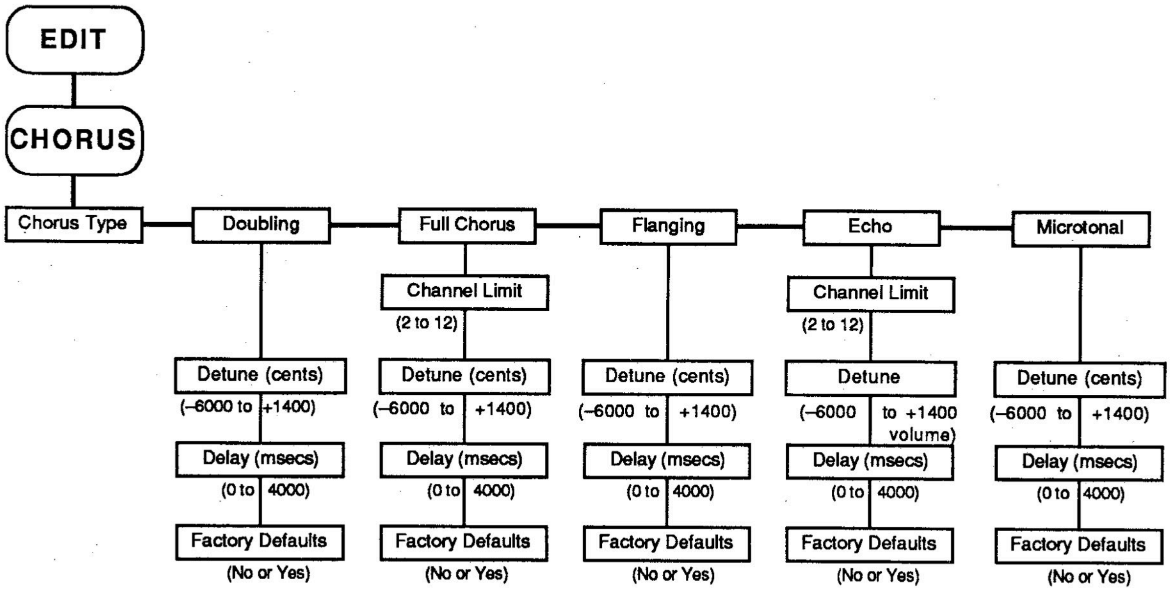
Three edit modes control global output parameters of the Kurzweil 250. Most basic is the selection of which type of transposition will be activated by the transpose buttons: Transpose (by octave or chromatic), Pitch Shift (octave or chromatic), or "Timbre Shift". On the K250 a Transposition alters pitch while preserving the natural timbres of the sounds. Pitch Shift involves sending the data to the DACs at a different rate, so timbre is affected. "Timbre Shift" implies a stepwise shifting of timbre but not of associated pitch, a very interesting effect. [Milano 1985] describes it subjectively: "The effect seems to operate as if the machine is shifting harmonics from the higher notes and then retuning them to fit the actual note you're playing, making the sound brighter or darker depending on the direction of the timbre shift." When any form of transposition is invoked, the LCD displays the relative transposition pitch and/or interval. A very practical aspect of transposition on the K250 is that it may be invoked with a single front-panel button rather than (as on many synthesizers) entering a transpose mode and then striking a key on the keyboard to indicate the interval of transposition. See Fig. 10.

*Fig. 10. Editing the Transposition Modes.*



Slightly more complex are the Chorus functions: Doubling, Full Chorus, Flanging, Echo, and Microtonal Tuning. Unlike most chorus units, which combine a signal with a delayed version of itself, the K250 works by having keystrokes trigger two or more separate channels which are delayed and offset in pitch and/or volume. It is possible to set new default characteristics for the Chorus options. As with Transposition options, modifications to any chorusing option may be done in real time. For each Chorus Type there are four sub-options, namely, the maximum number of channels to activate with the effect; delay time (in milliseconds); detune interval (in cents), or, in the case of Echo, relative volume; and reset to factory defaults. See Fig 11.

*Fig. 11. The Chorus Editor.*


EDIT
CHORUS
Chorus Type
Doubling
Full Chorus
Flanging
Echo
Microtonal
Channel Limit
(2 to 12)
Channel Limit
(2 to 12)
Detune (cents)
(–6000 to +1400)
Detune (cents)
(–6000 to +1400)
Detune (cents)
(–6000 to +1400)
Detune
(–6000 to +1400 volume)
Detune (cents)
(–6000 to +1400)
Delay (msecs)
(0 to 4000)
Delay (msecs)
(0 to 4000)
Delay (msecs)
(0 to 4000)
Delay (msecs)
(0 to 4000)
Delay (msecs)
(0 to 4000)
Factory Defaults
(No or Yes)
Factory Defaults
(No or Yes)
Factory Defaults
(No or Yes)
Factory Defaults
(No or Yes)
Factory Defaults
(No or Yes)

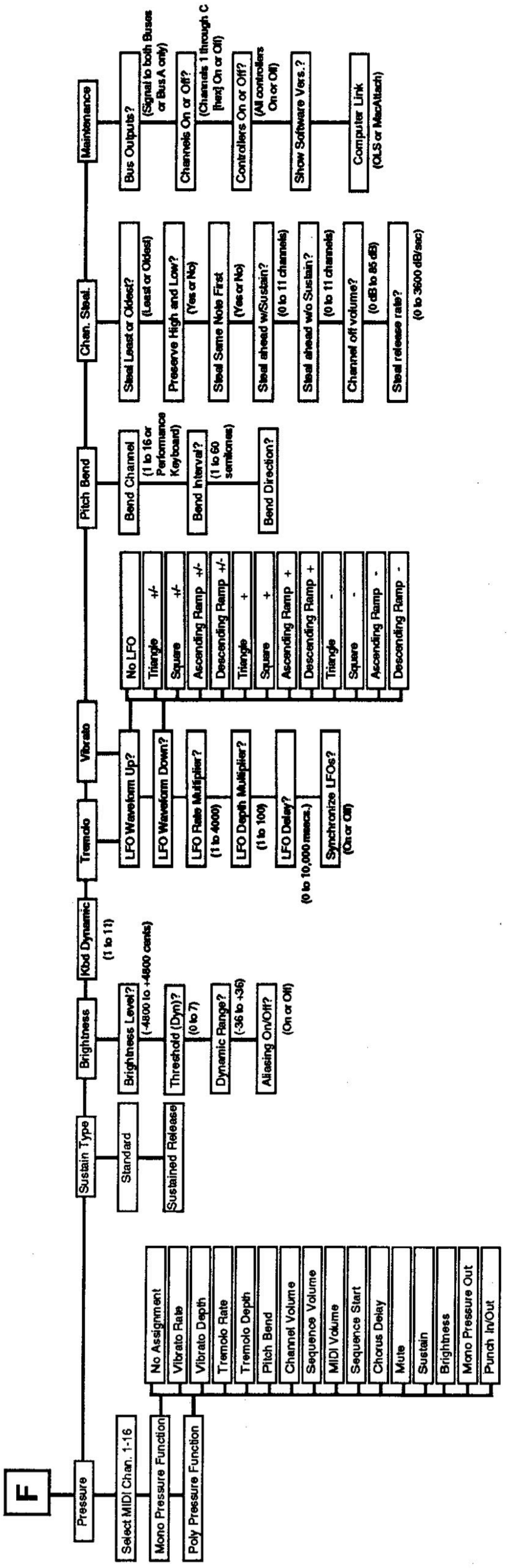
The final set of Global Parameter Editing possibilities is accessed by pressing the /F/ key on the numeric keypad. The nine main options are: Pressure (assignment of function and MIDI channel to mono and/or poly pressure), Sustain Type (sustain or sustain release, the latter allowing for the "catching" of a note in its release segment), Brightness (control of the low-pass filters — opening them wide to produce "aliasing", closing them to make the sound duller), Keyboard Dynamics (degree of velocity sensitivity), Tremolo, Vibrato, Pitch Bend, Channel Stealing, and Maintenance. Selecting any of these options brings the user to a list of sub-options. Here, Brightness may be mapped to keystrike velocity; tremolo and vibrato waveforms and maximum depth may be defined; and pitch bend limits given (up to 60 semitones). The extent and practicality of control of these functions is commendable. One example in detail will suffice. Channel stealing offers the following sub-options: "Steal Least or Oldest?" (least volume or oldest attack), "Preserve High and Low Voices?", "Steal Same Note First?" (for repeated notes), "Steal Ahead with Sustain (0 to 11 channels)?", "Steal Ahead without Sustain (0-11 channels)?", "Channel Off Volume?" (0 dB to 85 dB — indicating at what level a channel will actually be stolen if it meets the requirements for stealing), and "Steal Release Rate?" (0 to 3600 dB/sec — the rate at which a channel that is being stolen will turn off). With such a degree of control over the Channel Stealing algorithm, it should be possible to tailor the K250 to the needs of almost any situation. Refer to Fig. 12 for a complete display of this editor's capabilities.

## Sound Modeling Program

User sampling is available with the Kurzweil 250 through the optional Sound Modeling Program. This "program" (it actually involves slight modification to the K250 hardware as well) provides 10 sampling rates from 5K up to 50K samples per second. Maximum sample time per SMP RAM Bank ranges from 100 seconds at 5K to 10 seconds at 50K and up to four Banks may be installed.

The Sound Modeler compresses sounds in order to take advantage of the K250's floating-point format, described in "Technical Overview" (above). For a sampling instrument to do compression is not, in itself, an unusual feature; what is unusual is that the K250 does it with software and not hardware. In order to get the best possible compression, the algorithm does feature recognition along the lines described in [Strawn 1980].

*Fig. 12. Global Parameter Editing.*


F
Pressure
Select MIDI Chan. 1-16
Mono Pressure Function
Poly Pressure Function
No Assignment
Vibrato Rate
Vibrato Depth
Tremolo Rate
Tremolo Depth
Pitch Bend
Channel Volume
Sequence Volume
MIDI Volume
Sequence Start
Chorus Delay
Mute
Sustain
Brightness
Mono Pressure Out
Punch In/Out
Sustain Type
Standard
Sustained Release
Brightness
Brightness Level?
(-4800 to +4800 cents)
Threshold (Dyn)?
(0 to 7)
Dynamic Range?
(-36 to +36)
Aliasing On/Off?
(On or Off)
Kbd Dynamic
(1 to 11)
Tremolo
Vibrato
LFO Waveform Up?
LFO Waveform Down?
LFO Rate Multiplier?
(1 to 4000)
LFO Depth Multiplier?
(1 to 100)
LFO Delay?
(0 to 10,000 msecs.)
Synchronize LFOs?
(On or Off)
No LFO
Triangle +/-
Square +/-
Ascending Ramp +/-
Descending Ramp +/-
Triangle +
Square +
Ascending Ramp +
Descending Ramp +
Triangle -
Square -
Ascending Ramp -
Descending Ramp -
Pitch Bend
Bend Channel
(1 to 16 or Performance Keyboard)
Bend Interval?
(1 to 60 semitones)
Bend Direction?
Chan. Steal.
Steal Least or Oldest?
(Least or Oldest)
Preserve High and Low?
(Yes or No)
Steal Same Note First
(Yes or No)
Steal ahead w/Sustain?
(0 to 11 channels)
Steal ahead w/o Sustain?
(0 to 11 channels)
Channel off volume?
(0 dB to 85 dB)
Steal release rate?
(0 to 3600 dB/sec)
Maintenance
Bus Outputs?
(Signal to both Buses or Bus A only)
Channels On or Off?
(Channels 1 through C [hex] On or Off)
Controllers On or Off?
(All controllers On or Off)
Show Software Vers.?
Computer Link
(OLS or MacAttach)

Setting the instrument up to sample a sound through the Microphone or Line inputs takes only a few seconds. There are six record modes: Slow Decay, Normal Decay, Fast Decay, Speech, De-Emphasis, and Quick Take. The first four each do high-frequency de-emphasis and compression optimized for a given type of sound. De-Emphasis skips the compression, and Quick Take — for speed — does no processing at all. In all six modes, the user specifies the sample rate (there are fourteen choices ranging from 5K to 50K), the time to sample (in seconds), and the trigger level (in dB). Once these parameters are entered the user may elect to check the level. If he or she so does, the LCD turns into a level meter with peak-hold function, and the gain may be modified with one of the sliders. See Fig. 13.

Once the sound is recorded, the digitizer evaluates the take, and the maximum level or the precise number of samples clipped is displayed. If the take falls within acceptable limits, the user may instruct the SMP to process the sound, after which it may be previewed, then either saved or re-recorded using the same parameter configuration (with different gain) or a new setup. When the sound has been saved, it may be named, then assigned as a "root" on a keyboard with or without a multiple hardness (of keystrike) level. If assigned to a multiple hardness level, the Keyboard Crossover Rate may be set from 0 to 255 to define the exact point hard strike ends and soft strike begins for dual amplitude (i.e., timbre-dynamic) keyboards.

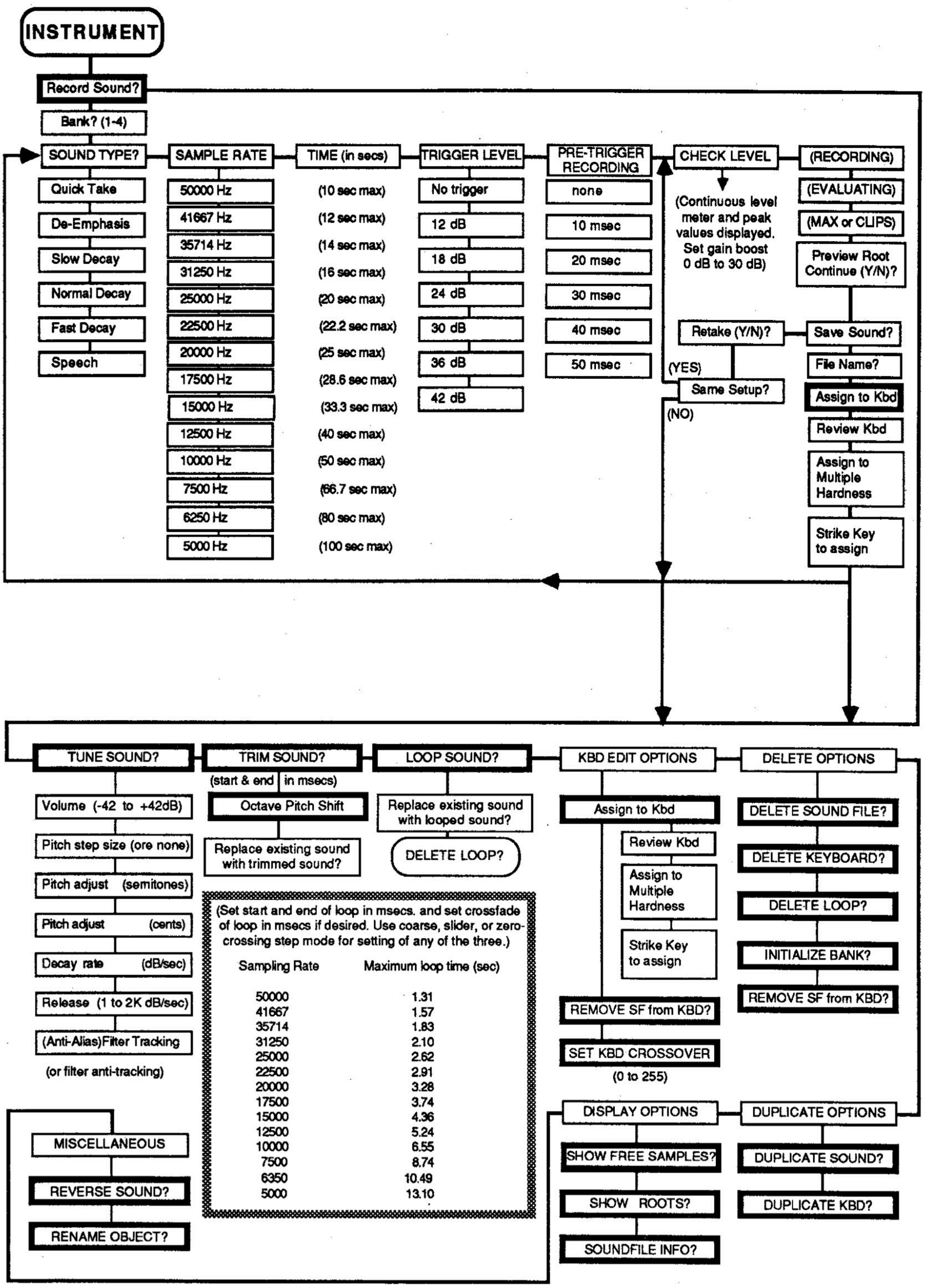
Having saved and assigned a sound, the user may manipulate the soundfile in a number of ways. First, the soundfile may be precisely trimmed at either end; it may be reversed, duplicated, and/or tuned. Tuning involves any or all of adjusting the volume of the sound, setting the pitch step size and adjusting the frequency in cents or semitones (this option provides another way to create a microtonal keyboard rather than using the microtonal option of the Chorus Editor), setting the decay rate and the release rate (both in dB/sec), and/or setting the anti-alias (so-called; actually anti-image) filter "tracking" direction relative to or in an inverse relationship to the direction moved from a specific root tone. You might assume that the low pass filter should always track the sample rate; however, in this case, sudden discontinuities in filter cut-off frequency may be experienced when making stepwise transitions between roots. Finally, the sound may be looped, the loop lasting up to a maximum of 13.10 seconds at 5K. Looping requires setting a beginning and end point for the loop within the soundfile and, if desired, the duration of the crossfade. For some sounds it is possible to automatically step through zero crossings during this operation.

The process of creating sampled soundfiles and assigning them to root pitches on one or more keyboards may continue until all the digitizer RAM (500K samples) is used up or 63 soundfiles (per bank to a maximum of 252) have been created. For musical instruments, sampling sounds at every perfect fifth seems usually, and at every minor third seems always, to be more than adequate for creating convincing transitions between the assigned roots. In the latter case, the K250 has only to transpose a half step in either direction from the original roots to create a complete chromatic.

Sampled sounds in the digitizer memory are not battery-backed but may be saved to disk via *QLS* either as individual soundfiles or as a complete Digitizer Bank memory. When the entire memory of a single bank is used, the file size is 658K (this Macintosh file normally contains several digitizer soundfiles although, in an extreme case, one soundfile might take up the entire digitizer memory) — all four banks will require 2,632K.

With the Sound Modeling Package and *QLS* (see under "External Control" below), it is possible for the user to create a disk-based library of soundfiles equal in quality to many of those supplied on the K250's ROM chips or cartridges. Using the *QLS* utility "SD Convert" individual soundfiles may be converted to Digidesign's "Sound Designer/Softsynth" format for graphic editing on the Macintosh screen. A side effect of this conversion is K250 compatibility with soundfiles created through additive or FM synthesis using Digidesign's "Softsynth" software, as well as with sounds sampled on most other commercially available samplers.

*Fig. 13. The Sound Modeling Program™.*


INSTRUMENT
Record Sound?
Bank? (1-4)
SOUND TYPE?
Quick Take
De-Emphasis
Slow Decay
Normal Decay
Fast Decay
Speech
SAMPLE RATE
50000 Hz
41667 Hz
35714 Hz
31250 Hz
25000 Hz
22500 Hz
20000 Hz
17500 Hz
15000 Hz
12500 Hz
10000 Hz
7500 Hz
6250 Hz
5000 Hz
TIME (in secs)
(10 sec max)
(12 sec max)
(14 sec max)
(16 sec max)
(20 sec max)
(22.2 sec max)
(25 sec max)
(28.6 sec max)
(33.3 sec max)
(40 sec max)
(50 sec max)
(66.7 sec max)
(80 sec max)
(100 sec max)
TRIGGER LEVEL
No trigger
12 dB
18 dB
24 dB
30 dB
36 dB
42 dB
PRE-TRIGGER RECORDING
none
10 msec
20 msec
30 msec
40 msec
50 msec
CHECK LEVEL
(Continuous level meter and peak values displayed. Set gain boost 0 dB to 30 dB)
Retake (Y/N)?
(YES)
Same Setup?
(NO)
(RECORDING)
(EVALUATING)
(MAX or CLIPS)
Preview Root Continue (Y/N)?
Save Sound?
File Name?
Assign to Kbd
Review Kbd
Assign to Multiple Hardness
Strike Key to assign
TUNE SOUND?
Volume (-42 to +42dB)
Pitch step size (ore none)
Pitch adjust (semitones)
Pitch adjust (cents)
Decay rate (dB/sec)
Release (1 to 2K dB/sec)
(Anti-Alias)Filter Tracking
(or filter anti-tracking)
TRIM SOUND?
(start & end in msecs)
Octave Pitch Shift
Replace existing sound with trimmed sound?
LOOP SOUND?
Replace existing sound with looped sound?
DELETE LOOP?
(Set start and end of loop in msecs. and set crossfade of loop in msecs if desired. Use coarse, slider, or zero-crossing step mode for setting of any of the three.)
Sampling Rate
Maximum loop time (sec)
50000 1.31
41667 1.57
35714 1.83
31250 2.10
25000 2.62
22500 2.91
20000 3.28
17500 3.74
15000 4.36
12500 5.24
10000 6.55
7500 8.74
6350 10.49
5000 13.10
KBD EDIT OPTIONS
Assign to Kbd
Review Kbd
Assign to Multiple Hardness
Strike Key to assign
REMOVE SF from KBD?
SET KBD CROSSOVER
(0 to 255)
DELETE OPTIONS
DELETE SOUND FILE?
DELETE KEYBOARD?
DELETE LOOP?
INITIALIZE BANK?
REMOVE SF from KBD?
MISCELLANEOUS
REVERSE SOUND?
RENAME OBJECT?
DISPLAY OPTIONS
SHOW FREE SAMPLES?
SHOW ROOTS?
SOUNDFILE INFO?
DUPLICATE OPTIONS
DUPLICATE SOUND?
DUPLICATE KBD?

## Keyboard Setup Editor

While the Kurzweil 250 comes with up to 342 factory preset Keyboard Setups, the Keyboard Setup Editor provides a powerful tool for the user to create configurations of the keyboard tailored to his or her specific needs. To understand the Keyboard Editor one must remember the distinction between soundfiles and "instruments": soundfiles are the raw data of the sound and "instruments" are the voicings or effects files associated with sets of soundfiles. The user may either modify existing Keyboard Setups or create entirely new ones. The Keyboard Setup Editor manipulates this data in two fundamental ways: splitting and layering. See Fig. 14.

The first capability of the Keyboard Setup Editor is to allow the layering of up to six keyboard configurations on the keyboard. Response to key strike velocity as well as relative volume can be set for each layer. Thus, the keyboard can easily be set up so that striking the same key at different velocities produces radically different sounds.

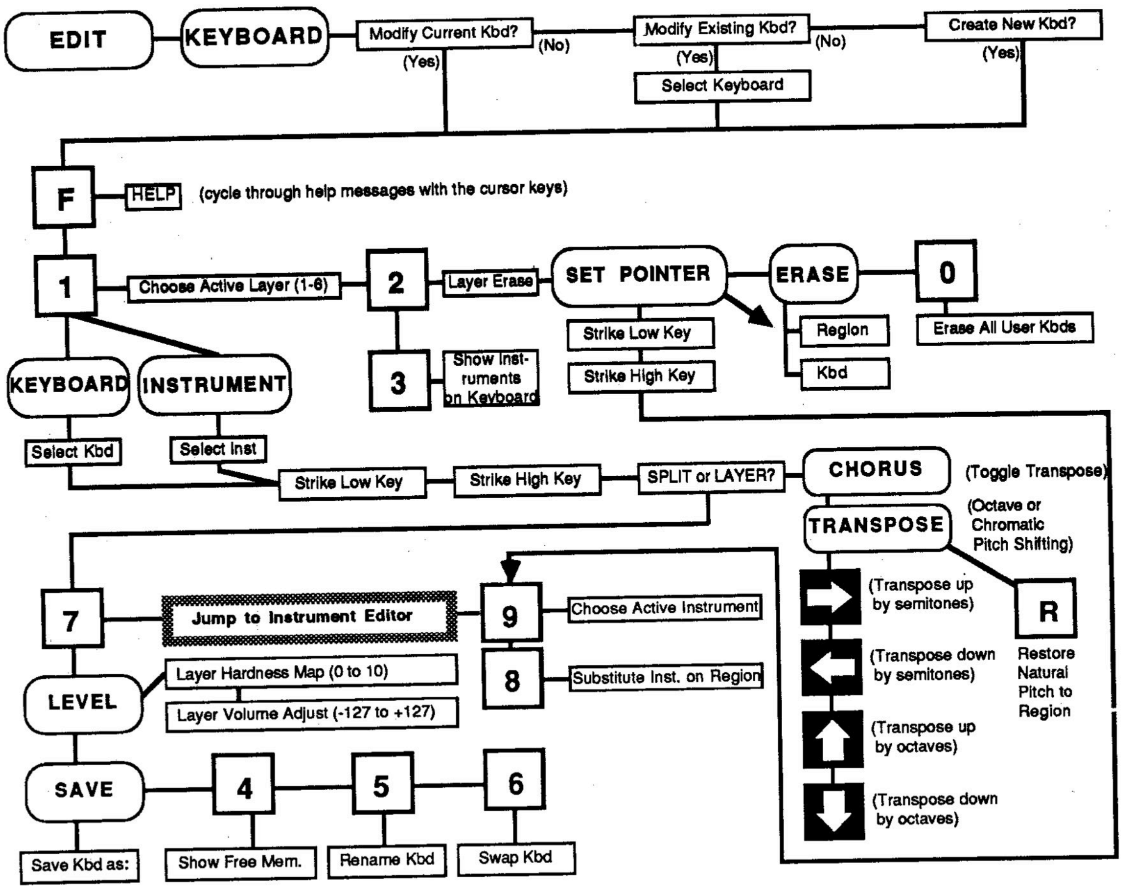
Second, any layer of a Keyboard Setup may be split into any number of regions defined by up to 87 split points. Each of these regions (soundfiles associated with a note or group of notes) may have a different "instrument" (effects, voicing, envelope) associated with it and a different user-definable transposition, which may include Timbre Shift. This means that a different sound may be assigned to any single key or set of keys anywhere on the keyboard. The number of possibilities that this produces, especially when the up to six multiple layers are also considered, is truly astronomical. It is also possible to jump directly from the Keyboard Setup Editor to the Instrument Editor to create new effects files without leaving the Keyboard Editor. Since it is possible to have keyboard splits in which certain regions have no soundfile associated with them, the splits may consist of regions of variable numbers of layers across the keyboard.

After a Keyboard Setup is created, whether layered or not, the user may name it and save it in the User Keyboard Library which holds up to 40 user-defined Setups. Since this is in the battery-backed RAM, these Setups are instantly accessible at any time. The library may also be saved to or restored from a Macintosh disk with *QLS*. A utility program of *QLS* called "Keyboard Mover" permits keyboard setups in different library files to be freely interchanged.

Through the Keyboard Setup Editor the user gradually comes to a new perception of the keyboard: that of programmable trigger device, instead of fixed instrument interface. Rather than producing pitches and registers always in a fixed relationship, the K250 Keyboard Setup Editor can produce keyboards whose pitches are in complete reverse order (from highest to lowest instead of lowest to highest), keyboards in which every succeeding octave covers the same register as the previous one but with a new timbre, keyboards where every key is the same pitch played by a different instrument, keyboards where every key is a different *chord* played by different combinations of instruments, and keyboards of any tuning system or microtonality. By tuning each key to the appropriate pitches Yavelow has created keyboards which, when a chromatic scale is played, produce whole pieces such as Chopin's first *Etude* in C major.

The speed and ease with which the Keyboard Setup Editor interface operates coupled with the fact that the effects of modifications to the keyboard along the way are instantly heard (without having to save anything or enter a preview mode), produce a powerful tool for orchestration and creativity.

*Fig. 14. The Keyboard Setup Editor.*


EDIT
KEYBOARD
Modify Current Kbd?
(Yes)
(No)
Modify Existing Kbd?
(Yes)
Select Keyboard
(No)
Create New Kbd?
(Yes)
F
HELP
(cycle through help messages with the cursor keys)
1
Choose Active Layer (1-6)
2
Layer Erase
SET POINTER
ERASE
0
Erase All User Kbds
Region
Kbd
Strike Low Key
Strike High Key
3
Show Inst-ruments on Keyboard
KEYBOARD
INSTRUMENT
Select Kbd
Select Inst
Strike Low Key
Strike High Key
SPLIT or LAYER?
CHORUS
(Toggle Transpose)
TRANSPOSE
(Octave or Chromatic Pitch Shifting)
(Transpose up by semitones)
(Transpose down by semitones)
(Transpose up by octaves)
(Transpose down by octaves)
R
Restore Natural Pitch to Region
7
Jump to Instrument Editor
9
Choose Active Instrument
8
Substitute Inst. on Region
LEVEL
Layer Hardness Map (0 to 10)
Layer Volume Adjust (-127 to +127)
SAVE
4
5
6
Save Kbd as:
Show Free Mem.
Rename Kbd
Swap Kbd

## Instrument Editor

The Instrument Editor may be accessed directly or through the Keyboard Setup Editor. Nested within the Instrument Editor and accessible only through it is the Envelope Editor. Recall that in K250 terminology, an "instrument" refers to a set of effects, optionally including an envelope. Although most of the ROM-based "instruments" are "attached" through software to ROM-based soundfiles, it is an easy process to disconnect them so the "instrument" can be used with other soundfiles. As in the Keyboard Editor, the user has the option of modifying the current "instrument," an existing "instrument," or creating a new "instrument" altogether. See Fig. 15.

The types of effects that may be stored in an "instrument" include voicing effects, chorusing effects, vibrato effects, tremolo effects, an envelope of up to 256 segments, and a set of "miscellaneous effects": response to global parameters, brightness level, "sustain decay rate" (an alternate decay rate used when the sustain pedal is down), monophonic or polyphonic mode, and whether it should ignore release and play all soundfiles to their ends. Other voicing options let the user (1) set the output group to A or B (essentially the output buses) for the purpose of creating stereo instruments, (2) create an output gain window delineated by user-defined minimum and maximum attenuation limits ranging from 0 to 85 dB in steps of 1/3 dB, (3) remove or add touch sensitivity, and (4) set keyboard attack velocity "tracking" or "anti-tracking" (not to be confused with the filter tracking/anti-tracking option in the Digitizer, this determines whether a sound will get louder or softer as the key velocity increases). Another option, which can save much effort, is the ability to capture current front panel effects settings and write them *en masse* to the effects file.

A number of effects may be flagged in the Instrument Editor as "local," so that an "instrument" will override the global settings of those effects. "Instruments" may have their own chorusing effects (doubling, full chorus, flanging, echo, microtonal tuning), vibrato effects, tremolo effects, and brightness setting. All of these are edited and assigned in the same way and with the same degree of precision as the global parameters. An "instrument" may be set to ignore or receive pitch bend, pedal information, or key release information being passed to it in real-time (or from the Sequencer or an external MIDI device). Finally, an instrument may be set to monophonic mode and the note priority in monophonic mode may be set to highest note, lowest note, first note, or last note.

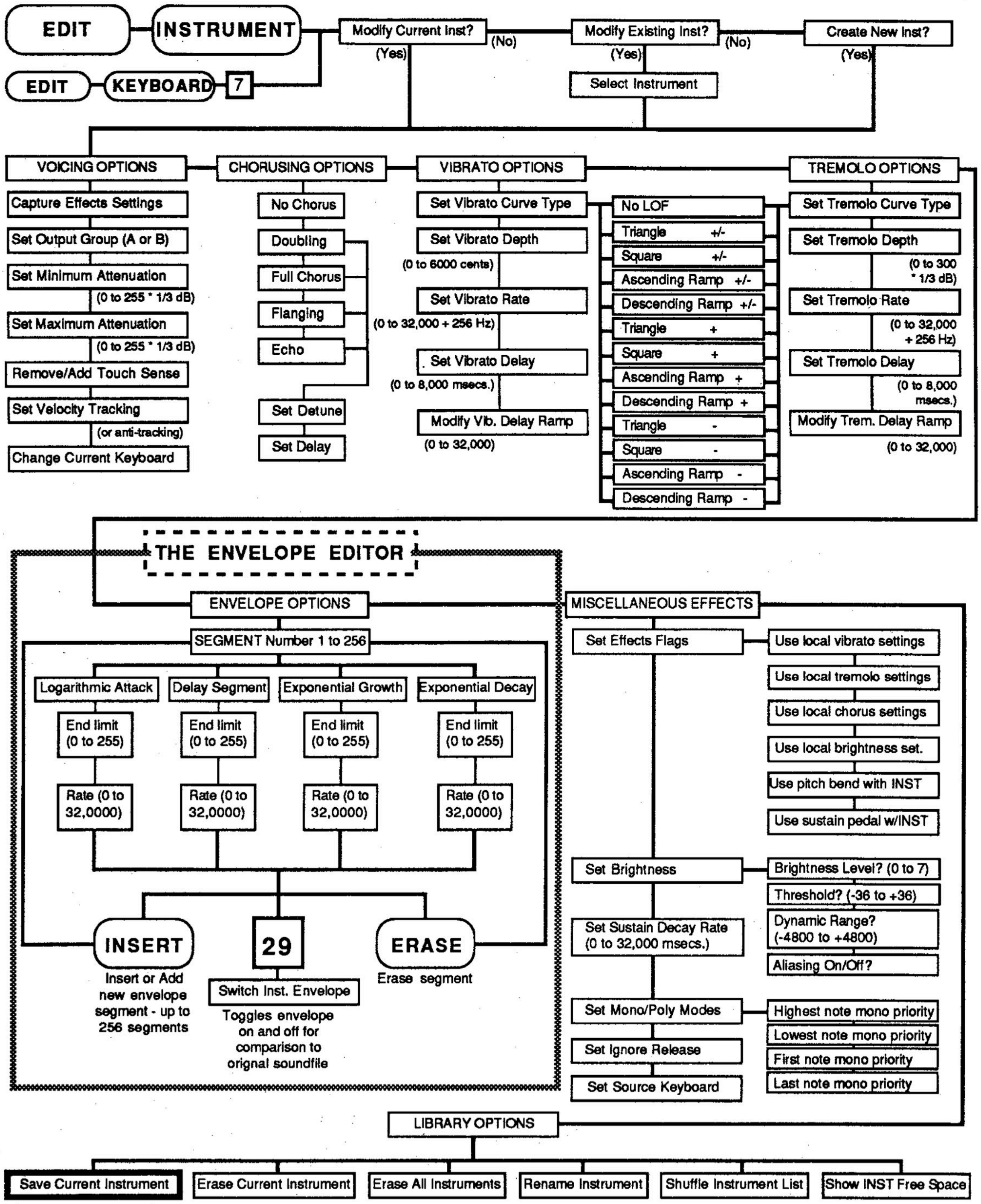
Instruments may be saved to Macintosh disks using *QLS* and the utility program "Kbd/Inst Mover" provides features for examining the settings of effects parameters and rearranging the user-defined Instrument Library.

## Envelope Editor

Although the Envelope Editor is accessed through the Instrument Editor, it is possible to use it alone, bypassing all the other instrument editing capabilities and thus creating an "instrument" (i.e., effects file) which consists of only an envelope.

The control offered by the Envelope Editor is extensive. An envelope may have up to 255 segments, each of which (with minor restrictions) may be any of the following: logarithmic attack, exponential growth, delay segment, or exponential decay (see Fig. 15). A delay segment keeps the sound at its present volume for a specified length of time, up to 32,000 milliseconds. The other three types have: (1) an End Limit on a scale of 0 to 255 (1/3 dB units) which indicates the volume level that segment will reach; and (2) a Rate which controls how quickly the segment will reach its End Limit. At very slow rates, this may take a minute or more. Thus, the user may construct envelopes up to several hours long and modify them in steps as small as a millisecond. The last segment is always considered the release segment: if the key is released before the last segment has been reached, the K250 will jump ahead and use that segment. While editing the envelope, the user can scroll through the various segments, inserting, deleting, or modifying them at any point.

*Fig. 15. The Instrument and Envelope Editors.*


EDIT
INSTRUMENT
EDIT
KEYBOARD
7
Modify Current Inst?
(Yes)
(No)
Modify Existing Inst?
(Yes)
(No)
Select Instrument
Create New Inst?
(Yes)
VOICING OPTIONS
Capture Effects Settings
Set Output Group (A or B)
Set Minimum Attenuation
(0 to 255 * 1/3 dB)
Set Maximum Attenuation
(0 to 255 * 1/3 dB)
Remove/Add Touch Sense
Set Velocity Tracking
(or anti-tracking)
Change Current Keyboard
CHORUSING OPTIONS
No Chorus
Doubling
Full Chorus
Flanging
Echo
Set Detune
Set Delay
VIBRATO OPTIONS
Set Vibrato Curve Type
Set Vibrato Depth
(0 to 6000 cents)
Set Vibrato Rate
(0 to 32,000 + 256 Hz)
Set Vibrato Delay
(0 to 8,000 msecs.)
Modify Vib. Delay Ramp
(0 to 32,000)
No LOF
Triangle +/-
Square +/-
Ascending Ramp +/-
Descending Ramp +/-
Triangle +
Square +
Ascending Ramp +
Descending Ramp +
Triangle -
Square -
Ascending Ramp -
Descending Ramp -
TREMOLO OPTIONS
Set Tremolo Curve Type
Set Tremolo Depth
(0 to 300 * 1/3 dB)
Set Tremolo Rate
(0 to 32,000 + 256 Hz)
Set Tremolo Delay
(0 to 8,000 msecs.)
Modify Trem. Delay Ramp
(0 to 32,000)
THE ENVELOPE EDITOR
ENVELOPE OPTIONS
SEGMENT Number 1 to 256
Logarithmic Attack
Delay Segment
Exponential Growth
Exponential Decay
End limit (0 to 255)
End limit (0 to 255)
End limit (0 to 255)
End limit (0 to 255)
Rate (0 to 32,0000)
Rate (0 to 32,0000)
Rate (0 to 32,0000)
Rate (0 to 32,0000)
INSERT
Insert or Add new envelope segment - up to 256 segments
29
Switch Inst. Envelope
Toggles envelope on and off for comparison to orignal soundfile
ERASE
Erase segment
MISCELLANEOUS EFFECTS
Set Effects Flags
Use local vibrato settings
Use local tremolo settings
Use local chorus settings
Use local brightness set.
Use pitch bend with INST
Use sustain pedal w/INST
Set Brightness
Brightness Level? (0 to 7)
Threshold? (-36 to +36)
Dynamic Range? (-4800 to +4800)
Aliasing On/Off?
Set Sustain Decay Rate (0 to 32,000 msecs.)
Set Mono/Poly Modes
Highest note mono priority
Lowest note mono priority
First note mono priority
Last note mono priority
Set Ignore Release
Set Source Keyboard
LIBRARY OPTIONS
Save Current Instrument
Erase Current Instrument
Erase All Instruments
Rename Instrument
Shuffle Instrument List
Show INST Free Space

To quote the K250 manual [Kurzweil Music Systems 1985]: "Returning to our artist analogy for a moment — the soundfiles resident in the K250's memory and the instrument voicings you combine with them are your paints; the Instrument Voicing Editor is your palette, where you blend and perfect the balance of warm and cool, of hue and shade and tint; the Keyboard Setup Editor is your brush; and the pictures you paint when you play your K250 will play directly to the mind's own eye."

## Sequence Editor

The Kurzweil 250 Sequencer can act as the "conductor" of the K250 orchestra and the Sequencer's associated editor can provide the power of a true orchestral sketchpad. This is a unique feature of the K250 brought about by the large number of sounds in ROM or RAM. Any or all resident sounds may be accessed simultaneously within the Sequencer. This type of freedom for a composer may be compared to a visual artist suddenly having a magic pencil that could sketch and selectively modify all colors on a magic sketchpad whose dimensions and perspective could be altered at will. Other analogies that come to mind are a choreographer having a personal corps of robot dancers; a sculptor having a sophisticated holographic design system; or a playwright having a voice-activated wordprocessor with the capability of providing both hard-copy feedback and instantaneous audible realization of the performance of a play.

The Kurzweil 250's Sequencer has a 12,000 note capacity, enough memory to store the first movement of the Bartók *Concerto for Orchestra* and then some — up to 40 sequences per library. Recording a new sequence and adding new tracks to an existing one are very easy. A "metronome" (click track) is standard; it provides both audio and visible (flashing light) tempo indications. "Punch In" is available in two forms: the first merges new information with the track and the second corresponds to its analog counterpart erasing everything on the track after the punch. Although some stand-alone sequencers provide more on-line event storage than this, the built-in Sequence Editor provides considerable editing power. See Fig. 16.

Once a sequence has been loaded into the Edit buffer, the Edit pointer may be set at any measure or a specific track may be searched for any of 17 types of events: note attack, note release, sustain change, keyboard change, instrument change, transpose change, volume adjust, tempo change, rhythm change, beat number change, section loop, call section start, call section end, section call, sequence chain, silence track, or track end. Any of these events may be modified, deleted, or inserted at any point on any of the 12 tracks. While one is stepping through a track, the LCD indicates the measure and beat numbers, fraction of the beat, event type, and other information associated with the event.

Each event has two types of information associated with it: timing (beat and fraction of beat, in 256ths of a beat) and "specifics" (varies with type of event; for example, "Note Attack" has two "specifics" associated with it: pitch and velocity — the latter with 256 possible values). All of this information is easily modified with the Sequence Editor.

Fig. 17 provides an example of typical LCD displays in Edit mode. Cursor keys allow one to step through the main menus in either direction, and note attacks are sounded during the process. Both specifics and timing information may be modified at any point in the procedure.

In addition to the local control just described, there are several global default parameters. Some of these parameters override individual event modifications, while others modify the frame of reference. All may be set for each track and modified anywhere and any number of times within a track, except for tempo and meter signature — these may also be modified anywhere and any number of times but affect all tracks. The parameters are listed on page 27.

*Fig. 16. The Sequence Editor.*
*Note: Menu prompts in thicker boxes have front panel buttons assigned to them.*

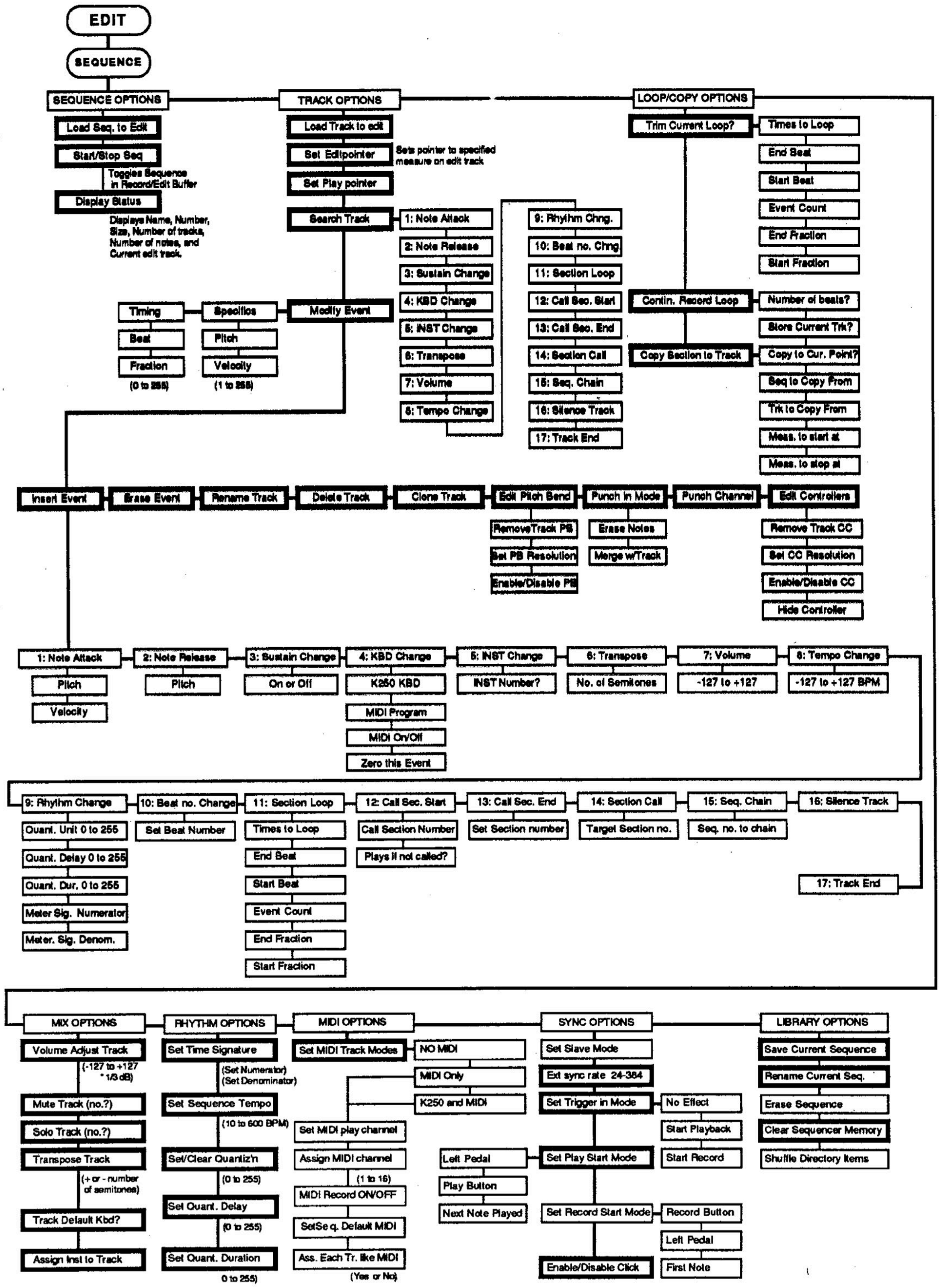
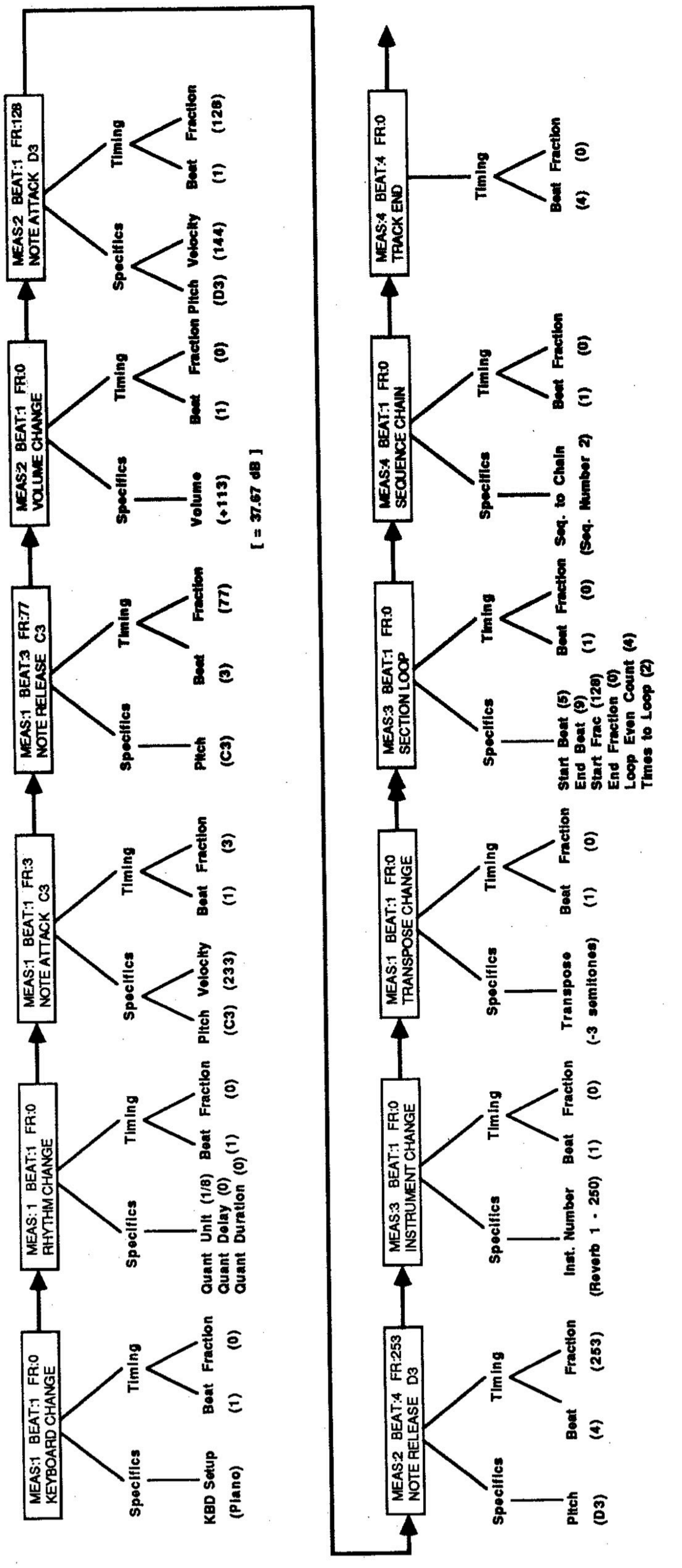
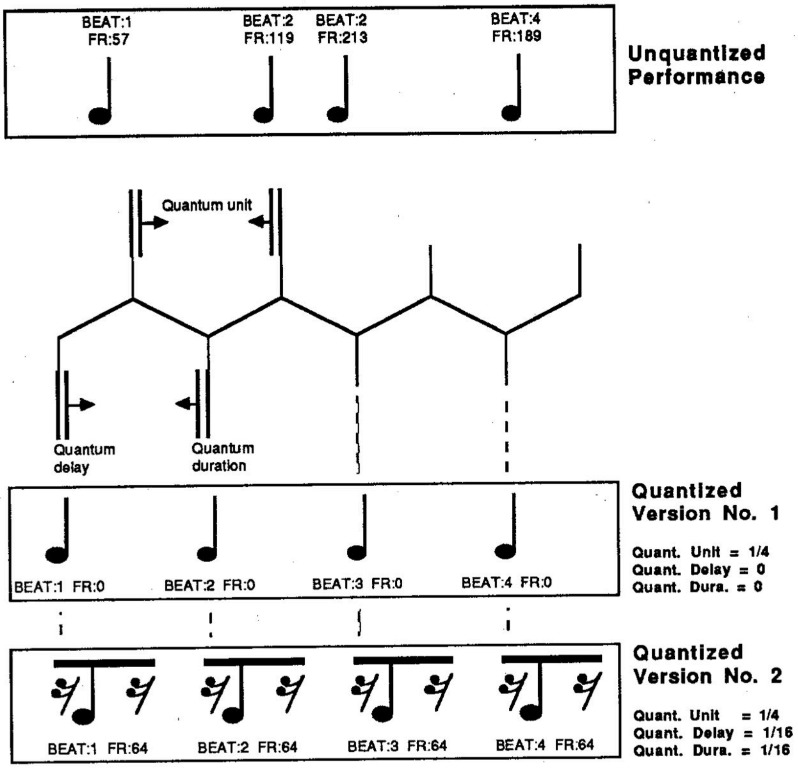

EDIT
SEQUENCE
SEQUENCE OPTIONS
Load Seq. to Edit
Start/Stop Seq
Toggles Sequence in Record/Edit Buffer
Display Status
Displays Name, Number, Size, Number of tracks, Number of notes, and Current edit track.
TRACK OPTIONS
Load Track to edit
Set Editpointer
Sets pointer to specified measure on edit track
Set Play pointer
Search Track
1: Note Attack
2: Note Release
3: Sustain Change
4: KBD Change
5: INST Change
6: Transpose
7: Volume
8: Tempo Change
9: Rhythm Chng.
10: Beat no. Chng.
11: Section Loop
12: Call Sec. Start
13: Call Sec. End
14: Section Call
15: Seq. Chain
16: Silence Track
17: Track End
Modify Event
Timing
Beat
Fraction
(0 to 255)
Specifics
Pitch
Velocity
(1 to 255)
LOOP/COPY OPTIONS
Trim Current Loop?
Times to Loop
End Beat
Start Beat
Event Count
End Fraction
Start Fraction
Contin. Record Loop
Number of beats?
Store Current Trk?
Copy Section to Track
Copy to Cur. Point?
Seq to Copy From
Trk to Copy From
Meas. to start at
Meas. to stop at
Insert Event
Erase Event
Rename Track
Delete Track
Clone Track
Edit Pitch Bend
RemoveTrack PB
Set PB Resolution
Enable/Disable PB
Punch In Mode
Erase Notes
Merge w/Track
Punch Channel
Edit Controllers
Remove Track CC
Set CC Resolution
Enable/Disable CC
Hide Controller
1: Note Attack
Pitch
Velocity
2: Note Release
Pitch
3: Sustain Change
On or Off
4: KBD Change
K250 KBD
MIDI Program
MIDI On/Off
Zero this Event
5: INST Change
INST Number?
6: Transpose
No. of Semitones
7: Volume
-127 to +127
8: Tempo Change
-127 to +127 BPM
9: Rhythm Change
Quant. Unit 0 to 255
Quant. Delay 0 to 255
Quant. Dur. 0 to 255
Meter Sig. Numerator
Meter. Sig. Denom.
10: Beat no. Change
Set Beat Number
11: Section Loop
Times to Loop
End Beat
Start Beat
Event Count
End Fraction
Start Fraction
12: Call Sec. Start
Call Section Number
Plays if not called?
13: Call Sec. End
Set Section number
14: Section Call
Target Section no.
15: Seq. Chain
Seq. no. to chain
16: Silence Track
17: Track End
MIX OPTIONS
Volume Adjust Track
(-127 to +127 * 1/3 dB)
Mute Track (no.?)
Solo Track (no.?)
Transpose Track
(+ or - number of semitones)
Track Default Kbd?
Assign Inst to Track
RHYTHM OPTIONS
Set Time Signature
(Set Numerator)
(Set Denominator)
Set Sequence Tempo
(10 to 600 BPM)
Set/Clear Quantiz'n
(0 to 255)
Set Quant. Delay
(0 to 255)
Set Quant. Duration
0 to 255)
MIDI OPTIONS
Set MIDI Track Modes
NO MIDI
MIDI Only
K250 and MIDI
Set MIDI play channel
Assign MIDI channel
(1 to 16)
MIDI Record ON/OFF
SetSe q. Default MIDI
Ass. Each Tr. like MIDI
(Yes or No)
Left Pedal
Play Button
Next Note Played
SYNC OPTIONS
Set Slave Mode
Ext sync rate 24-384
Set Trigger in Mode
No Effect
Start Playback
Start Record
Set Play Start Mode
Set Record Start Mode
Record Button
Left Pedal
First Note
Enable/Disable Click
LIBRARY OPTIONS
Save Current Sequence
Rename Current Seq.
Erase Sequence
Clear Sequencer Memory
Shuffle Directory Items

*Fig. 17. Typical LCD display information within the K250 Sequence Editor.*


MEAS:1 BEAT:1 FR:0
KEYBOARD CHANGE
Specifics
Timing
KBD Setup
(Piano)
Beat
Fraction
(1)
(0)
MEAS:1 BEAT:1 FR:0
RHYTHM CHANGE
Specifics
Timing
Quant Unit (1/8)
Quant Delay (0)
Quant Duration (0)
Beat
Fraction
(1)
(0)
MEAS:1 BEAT:1 FR:3
NOTE ATTACK C3
Specifics
Timing
Pitch
Velocity
(C3)
(233)
Beat
Fraction
(1)
(3)
MEAS:1 BEAT:3 FR:77
NOTE RELEASE C3
Specifics
Timing
Pitch
(C3)
Beat
Fraction
(3)
(77)
MEAS:2 BEAT:1 FR:0
VOLUME CHANGE
Specifics
Timing
Volume
(+113)
[ = 37.67 dB ]
Beat
Fraction
(1)
(0)
MEAS:2 BEAT:1 FR:128
NOTE ATTACK D3
Specifics
Timing
Pitch
Velocity
(D3)
(144)
Beat
Fraction
(1)
(128)
MEAS:2 BEAT:4 FR:253
NOTE RELEASE D3
Specifics
Timing
Pitch
(D3)
Beat
Fraction
(4)
(253)
MEAS:3 BEAT:1 FR:0
INSTRUMENT CHANGE
Specifics
Timing
Inst. Number
(Reverb 1 - 250)
Beat
Fraction
(1)
(0)
MEAS:1 BEAT:1 FR:0
TRANSPOSE CHANGE
Specifics
Timing
Transpose
(-3 semitones)
Beat
Fraction
(1)
(0)
MEAS:3 BEAT:1 FR:0
SECTION LOOP
Specifics
Timing
Start Beat (5)
End Beat (9)
Start Frac (128)
End Fraction (0)
Loop Even Count (4)
Times to Loop (2)
Beat
Fraction
(1)
(0)
MEAS:4 BEAT:1 FR:0
SEQUENCE CHAIN
Specifics
Timing
Seq. to Chain
(Seq. Number 2)
Beat
Fraction
(1)
(0)
MEAS:4 BEAT:4 FR:0
TRACK END
Timing
Beat
Fraction
(4)
(0)

(1) Meter signature (global for sequence): may be anything from 1/1 to 254/128. It is interesting that one is not constrained to powers-of-two note durations: the user may choose fifth-notes, eleventh-notes, or anything up to 128th-notes for the meter signature denominator.
(2) Tempo: 10 to 600 beats per minute (global for sequence).
(3) Quantization (local or global for track): as with any sequencer, quantization assumes that the music was recorded with a click track (the K250 has a separate click track 1/4-inch output). N.B. Quantization on the K250 affects output only and does not alter timing information on the track. As a result, the quantization unit, delay, or duration may be modified at any time or the track restored to its original, unquantized state. See Fig. 18.

*Fig. 18. Quantization Parameters of the Sequence Editor.*


BEAT:1 FR:57
BEAT:2 FR:119
BEAT:2 FR:213
BEAT:4 FR:189
Unquantized Performance
Quantum unit
Quantum delay
Quantum duration
BEAT:1 FR:0
BEAT:2 FR:0
BEAT:3 FR:0
BEAT:4 FR:0
Quantized Version No. 1
Quant. Unit = 1/4
Quant. Delay = 0
Quant. Dura. = 0
BEAT:1 FR:64
BEAT:2 FR:64
BEAT:3 FR:64
BEAT:4 FR:64
Quantized Version No. 2
Quant. Unit = 1/4
Quant. Delay = 1/16
Quant. Dura. = 1/16

(a) The Quantization Unit is expressed in fractions of a whole-note, up to 1/255. Thus, quantizing (i.e., rhythmic "rounding off") to quarter-notes would require setting the denominator to 4. Quantizing to triplet eighth-notes would require 12, and to 11-tuplet eighths, 11.
(b) Quantization Delay, expressed in the same units, controls how far after the beat each note will sound.
(c) Quantization Duration, expressed in the same units, sets a constant that is subtracted from each quantized note's duration. At its maximum setting, notes will be forced to play staccato, whereas if it is left off, notes will be played more legato.

(4) Keyboard Setup Number (local).
(5) Instrument Number (local).
(6) Transposition in semitones (local).
(7) Volume in steps of 1/3 dB (local).
(8) Continuous Controllers (local).

Other sequence editing functions include *looping* sections, *calling* sections, *copying* sections, and the *chaining* together of entire sequences. Looping parameters include: the number of times to loop, start and end beat and fraction of the loop, as well as the number of events within the loop. Calling a section is similar to calling a subroutine. This requires specifying the start and end of a section within the current sequence to be called and whether or not the section will play even if it is not called. A single track may have up to 127 sections marked off in this fashion for calling; each section may be called up to 255 times, and each call to a target section may include any modification of keyboard, instrument, transposition, volume, tempo, or quantization. In contrast to section calling, sequence chaining causes a one-way jump to any other sequence in the library of up to 40 sequences. This is intended for linking separate portions of larger works together.

With the Sequence Editor it is possible to copy any portion of any other track of any sequence in the sequence library (including the sequence currently being edited) to any portion of the current sequence by defining the sequence to copy from, the track to copy from, and the measures which begin and end the section to be copied.

Output capabilities of the sequencer include syncing to tape, syncing to an external device, and, through MIDI, controlling an external device alone or simultaneously with the K250. Each Sequencer track can be assigned to a separate MIDI channel. When syncing to an external device via the Sync Output (K250 in master or slave mode), the clock rate can be set to any value between 24 and 384 to accommodate the rate of the external device. The K250 also can sync itself to tape. After a sync track has been recorded on the tape, any number or combination of sequencer tracks may be synced to any number or combination of analog tape tracks. This provides a number of advantages. First, while the K250 can only *output* 12 channels at once (unless, of course, it is connected to other K250s or K250 expanders), each track in the sequencer will record every note played. Therefore, if the tracks are sent out to a tape recorder one at a time or in any combination which does not exceed 12 channels, it is quite possible to get 144 synchronized channels with a single K250. Second, one might want to isolate the different tracks or combinations of tracks in a sequence onto separate tape tracks for further equalization or to add different effects to the final mixdown. When the K250 is synced through MIDI-SYNC to an external device (such as a SMPTE Synchronizer, or a software-based sequencer) it can lock together with the other device using the MIDI commands START, STOP, and CONTINUE. Finally, when the K250 is being used as a MIDI controller, external MIDI synthesizers may be synced to tape with or without the K250.

The Sequencer RAM is battery-backed and, like all other RAM-based aspects of the K250, it may be saved via *QLS*. Using the *QLS* utility "Sequence Mover," sequences may be freely interchanged between different library files. "Sequence Mover" provides a limited form of sequence editing on the Macintosh screen.

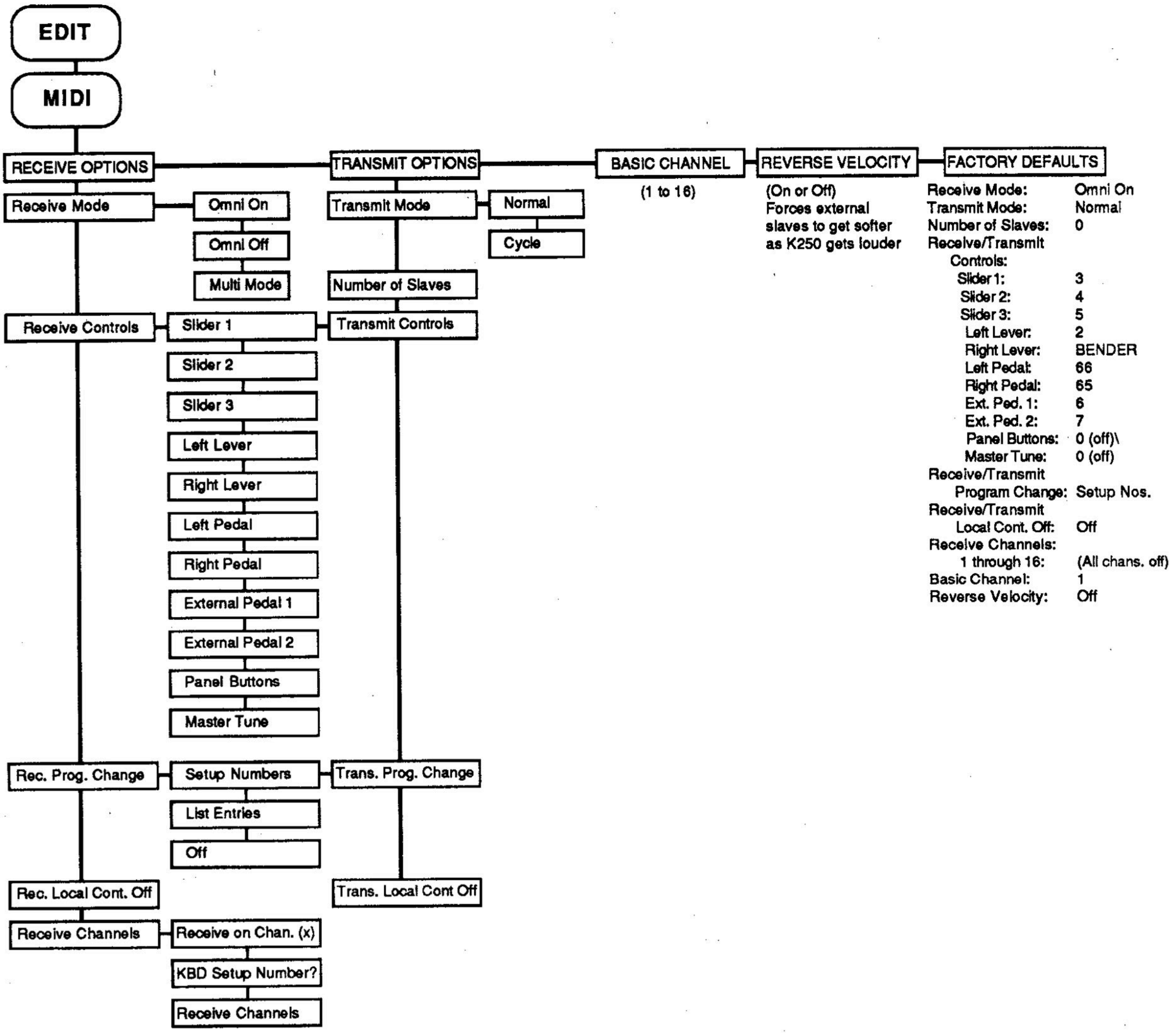
## MIDI Editor

MIDI (Musical Instrument Digital Interface) is, of course, the hardware and software standard for transferring data between devices (musical instruments or computers) which have built-in microprocessors. It should not be confused with the K250's computer port, which sends and receives data in a format unique to the K250.

The Kurzweil 250 is equipped with MIDI-in, MIDI-out, and MIDI-through jacks and can interact with MIDI in a variety of ways. The MIDI Editor permits the user to set all MIDI parameters of the K250. See Fig. 19.

There are three MIDI Receive Modes: Omni-on (K250 responds to data coming in any or all of the 16 MIDI channels), Omni-off (K250 responds to data coming in over a pre-selected MIDI channel), and the nonstandard Multi Mode (K250 will receive over channels other than the basic channel but only if the channels have keyboards assigned to them). In Omni Off or Multi mode, it is possible to select the channels through which MIDI information will be received. In addition, there is a special MIDI mode ("Cycle Mode" described below) for slaving additional K250's, expanders, or RMXs to a master. Although the K250 can normally only have one Keyboard Setup turned on at a time (although this may consist of up to 6 layers, and up to 12 Keyboard Setups may be "stacked" in standard play mode, only the current setup will accept additional note attacks), MIDI allows up to 16 Keyboard Setups to be turned on at once.

*Fig. 19. The MIDI Editor.*


EDIT
MIDI
RECEIVE OPTIONS
Receive Mode
Omni On
Omni Off
Multi Mode
Receive Controls
Slider 1
Slider 2
Slider 3
Left Lever
Right Lever
Left Pedal
Right Pedal
External Pedal 1
External Pedal 2
Panel Buttons
Master Tune
Rec. Prog. Change
Setup Numbers
List Entries
Off
Rec. Local Cont. Off
Receive Channels
Receive on Chan. (x)
KBD Setup Number?
Receive Channels
TRANSMIT OPTIONS
Transmit Mode
Normal
Cycle
Number of Slaves
Transmit Controls
Trans. Prog. Change
Trans. Local Cont Off
BASIC CHANNEL
(1 to 16)
REVERSE VELOCITY
(On or Off)
Forces external
slaves to get softer
as K250 gets louder
FACTORY DEFAULTS
Receive Mode: Omni On
Transmit Mode: Normal
Number of Slaves: 0
Receive/Transmit
Controls:
Slider 1: 3
Slider 2: 4
Slider 3: 5
Left Lever: 2
Right Lever: BENDER
Left Pedal: 66
Right Pedal: 65
Ext. Ped. 1: 6
Ext. Ped. 2: 7
Panel Buttons: 0 (off)\
Master Tune: 0 (off)
Receive/Transmit
Program Change: Setup Nos.
Receive/Transmit
Local Cont. Off: Off
Receive Channels:
1 through 16: (All chans. off)
Basic Channel: 1
Reverse Velocity: Off

Using the MIDI Editor, one can choose which assignable controllers will handle which received data, how program changes will be treated, and whether or not and when the K250 will have a live keyboard while it is receiving MIDI data. Note that even while the K250's keyboard is separated from its sound-generating capabilities, it can still be set to act as a MIDI controller, sending note events out over the hookup. Similarly, the K250 can disable and enable other slave synthesizers if they support the MIDI Local Control Off and On commands.

MIDI Transmit Mode on the K250 has two options: Normal or Cycle. In Normal Mode, MIDI information is transmitted over the Basic Channel. In Cycle Mode, notes played on the K250 regularly cycle among channels out to a string of different MIDI devices, so that each note is played on a different instrument in turn. Variations on Cycle Mode include sending the cycled information back to the original K250 so that it will play two or three notes in a row before passing information on to the real slave devices, and permitting the original K250 to play more than one Keyboard Setup at once. Literally every channel can be set to receive control information from an external MIDI device, and each of those channels can control a different Keyboard Setup.

In Transmit Mode, analogously to Receive Mode, the MIDI Editor allows flexible assignment of how the K250 will send controller information as well as program change information to the other devices. The Basic Channel (over which the K250 normally sends and receives all MIDI data) may be set here. Activating "Reverse Velocity" causes slave synthesizers to play softer as the K250 keyboard is played harder.

Every MIDI-equipped synthesizer sends and receives some information other than keystrokes, pitch bend at the very least. The Kurzweil 250, like many recent synthesizers, goes much further. Through the previously mentioned "special MIDI mode," it is possible to control *any* of its functions externally through MIDI, that is, any sequence of keystrokes, front panel button pushes, and pedal, slider and lever movements can be received over MIDI. It can also send out the equivalent information, though much of it will not be useful unless another K250 or an appropriately-programmed computer is listening. Transmission and receipt of the MIDI status codes for these controls may be selectively enabled and disabled with the MIDI Editor.

The K250's MIDI implementation is very flexible — much more so than that of most other MIDIable devices. See "The Sequence Editor" (above) and "Commercial MIDI Applications Supporting the K250" (below).

## External Control

The K250 has two very different facilities that allow it to control external equipment or vice-versa, namely its computer port, and MIDI. There are advantages to both: the computer port is faster, but MIDI is far more standardized. Also, as has already been stated, it is possible to control any of the K250's functions externally through MIDI. See [Loy 1985] and [Yavelow 1986a] for a thorough discussion of MIDI. See Fig. 20.

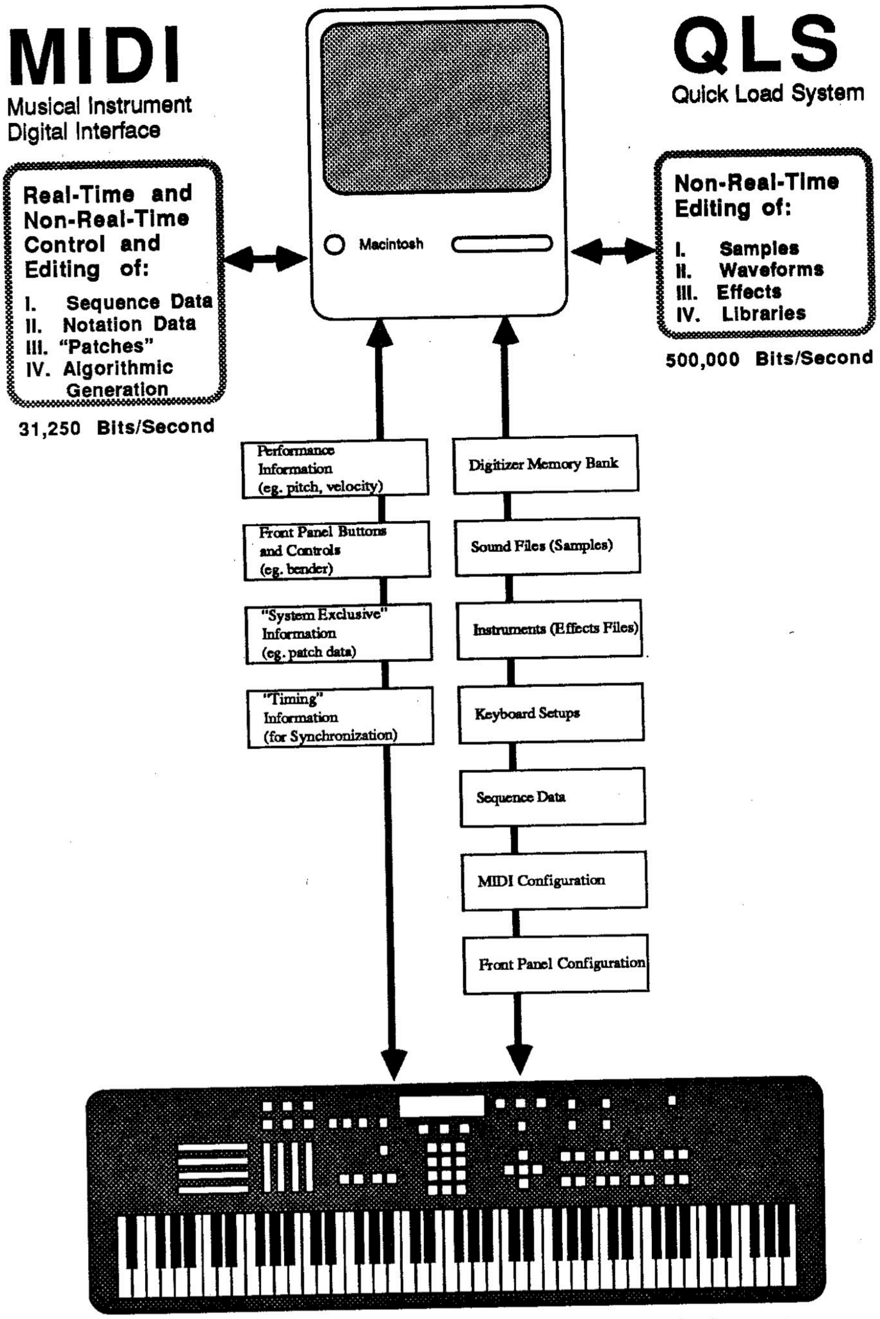
The only application available thus far that communicates with the K250 through its computer port is Kurzweil Music Systems' own *QLS* (the successor to an earlier package call *MacAttach*). Of course, numerous commercially-available MIDI applications can be used with the K250.

**QLS.** Kurzweil Music Systems' own computer interface package, entitled *QLS*, consists of a cable to connect the Macintosh computer (either the 128K, 512K, or Mac+ version), and a disk containing four applications (QLS, Sequence Mover, Keyboard/Instrument Mover, SD to SF Convert) and some demo files. Data transfer is at 50,000 bytes per second.

*QLS* supports saving files from the K250 to Macintosh disks and loading files back to the K250 from the Mac. One may save or load any K250 user-defined file: the entire Sequence Library of up to 40 sequences, the Keyboard Library of up to 40 Keyboards, the Instrument Library of up to 48 "instruments", one to four Digitizer RAM Banks, each of up to 100 seconds of user sampled sounds distributed upon up to 15 additional Keyboard Setups, the current Keypad Bins, Setup List, MIDI configuration, or a file containing all the setting of the assignable controllers. Some of these files may be saved and loaded in various combinations (for example, the Keyboard, Instrument, and Sequencer Libraries may be saved and loaded as one file).

Because digitizer soundfiles can be stored on convenient Macintosh diskettes, creating a library of new sounds for the K250 is a simple and inexpensive process. Public-domain soundfile disks, many made by the owners themselves and others provided by Kurzweil Music Systems, are readily circulated amongst K250 owners.

*Fig. 20 QLS and MIDI Interface the K250 with the Apple Macintosh.*


MIDI
Musical Instrument Digital Interface
Real-Time and Non-Real-Time Control and Editing of:
I. Sequence Data
II. Notation Data
III. "Patches"
IV. Algorithmic Generation
31,250 Bits/Second
Macintosh
QLS
Quick Load System
Non-Real-Time Editing of:
I. Samples
II. Waveforms
III. Effects
IV. Libraries
500,000 Bits/Second
Performance Information (eg. pitch, velocity)
Front Panel Buttons and Controls (eg. bender)
"System Exclusive" Information (eg. patch data)
"Timing" Information (for Synchronization)
Digitizer Memory Bank
Sound Files (Samples)
Instruments (Effects Files)
Keyboard Setups
Sequence Data
MIDI Configuration
Front Panel Configuration

**The Performing Artists' Network (PAN).** Kurzweil owners are given a free account on PAN, a large international telecommunications network dedicated to music and technology with well over a gigabyte (a million megabytes) of storage. Local telephone numbers worldwide provide users with access to many different electronic mail services (including TELEX), a variety of SIGs (Special Interest Groups), and subnetworks. Practically every facet of the music industry is represented: recording, publishing, touring, booking, promoting, hardware and software development, synthesizer techniques, MIDI, online shopping, and classified ads. Participation in international real-time "conferences" can be extremely educational. PAN is the home of the large and growing Kurzweil Users Group. Here one can "download" (transfer files from PAN to your computer) from a library of the latest Kurzweil utility software, soundfiles, keyboard libraries, and entire digitizer memory banks. Participation in an ongoing colloquy with other users in the public forum is also instructive.

**Other Kurzweil Community.** Kurzweil Music Systems maintains a quarterly newsletter, *The Kurzweil Generation* (formerly called: "4-5-Select") which contains user profiles, new products, tips, and user group news, etc. There is also a Kurzweil 250 users group in the Los Angeles area which meets about every 6 weeks. Another users group via mail has been organized by Sweetwater Sound in Ft. Wayne, Indiana. Sweetwater maintains a large collection of disk-based K250 sounds that is available to members and a newsletter is circulated every few months.

**Commercial Applications Requiring QLS.** Both of Digidesign's popular sound laboratory applications, *Sound Designer* and *Sofsynth* become compatible with through the Kurzweil utility "SD Convert." This program, supplied with *QLS*, permits the conversion of *QLS* created soundfiles into Digidesign's file format and vice versa.

*Sound Designer* displays sampled soundfiles in any magnification desired. The Macintosh screen may show an entire soundfile of hundreds of thousands of samples or zoom into the level of individual samples for the purpose of "drawing" new samples into the file with a mouse-controlled pencil. A five mode digital equalizer is provided along with the capability of cutting, copying, pasting, mixing, and merging features to operate on separate parts of soundfiles or several entire soundfiles simultaneously. In this way, the gradual changing the sound of a jet plane into that of a violin is possible. *Sound Designer* permits synthesis using the Karplus-Strong plucked string algorithm and also provides for a three-dimensional spectral analysis display (FFT — Fast Fourier Transform). Creating loops with *Sound Designer* is particularly easy because there is a feature for displaying and tweaking the crucial loop seam.

*Softsynth*, also from Digidesign, allows sounds generated by additive or FM synthesis to be saved as 16-bit linear sample files. The Macintosh's graphic capabilities are a great advantage to this kind of sound manipulation which provides 32 pseudo digital oscillators simulated by the software or 32 FM operators. Each individual partial has a 40-segment amplitude envelope and a 15-segment frequency envelope. Soundfiles created by *Softsynth* may be edited by *Sound Designer* and both applications offer a "preview through the Macintosh speaker" option.

**Commercial MIDI Applications Supporting the K250.** Many commercially available applications that support the Kurzweil 250 via MIDI are currently available or in stages of imminent release. The most effective of these packages run on the Macintosh and we will concentrate on these (IBM users have essentially a single option for serious sequencing with the intent of obtaining conventional music notation: *Personal Composer*. See [Miller 1985].)

At present, the types of external software which will run with the K250 fall into three basic categories: sequencer software, notation software, and interactive composition software. Naturally, many applications combine the first two functions with varying degrees of edit and control capabilities; some also have file conversion utilities to transform data from one company's format to another's. Some packages currently offer MIDI out only, while others combine MIDI in and out.

Since MIDI is not hardware-compatible with the Macintosh's RS-422 port, a hardware interface is necessary. A number of MIDI adapters for the Macintosh are available, namely those of Opcode (*MIDIMAC*), Passport Designs, Musicworks Inc. (*MacMIDI Star* and *MacMIDI 32*), and Southworth Music Systems (*Total Music* MIDI adapter).

**MIDI Sequencing.** MIDI sequencer software offered by the above companies typically provides between 50,000 and 100,000 note event capacity and increases the number of channels and tracks available considerably. Most of the programs offer inputting of sequencer data from the K250's keyboard, sequencer, or by use of the Macintosh mouse and/or keyboard. With the Macintosh computer's "user friendly" interface (it is generally accepted as the most user friendly operating system on any widely available computer in history), sophisticated editing of sequences displayed in graphic or notated formats on the Macintosh screen becomes a matter of point, click, and drag with the Macintosh mouse.

All of the companies which market MIDI interfaces also provide Macintosh sequencer software for use in conjunction with their hardware, namely Southworth (*Total Music and MIDI-Paint*), Musicworks Inc. (*MegaTrack*), and Opcode (*MIDIMAC Sequencer* ). In addition, a number of companies are marketing or are about to market software, specifically: Mark of the Unicorn (*Performer*), Electronic Arts (*Deluxe Music Construction Set*), Creative Solutions (*Studio Mac*), Great Wave Software (*Concertware+ MIDI*), and Passport Designs (*Master Tracks*). Since MIDI is an international standard, any MIDI adapter should work with any software package; however, in practice, there are some exceptions. For further information see [Yavelow 1986a, 1987a, & 1987b].

**Notation.** Several of the programs convert sequencer data into genuine music notation for printing or editing — notably Kimball Stickney's *High Score* (being marketed by Southworth), Mark of the Unicorn's *Professional Composer* and *Performer*, Electronic Arts' *Deluxe Music Construction Set*, and soon to be released, Advanced Music Notation Systems (*Nightingale*). With some of these packages, conversion of traditional music notation back to MIDI format is also possible. The degree of sophistication offered by some of these products (full score editing, multiple quantization modes, text linked to note positions, automatic instrumental range and rhythmic checking, part extraction), when used in conjunction with a high-end synthesizer like the K250, is of a level which, only one year ago, would have cost a vast amount of money and could have been considered by only the largest computer music facilities in the world. Considering that the K250 owner will likely have a Macintosh already for the storage of user data files, getting into serious computer control and computer notation can be arranged for a mere $500 or so.

Many of the available notation programs also support the Apple Laserwriter, which offers much higher resolution printing than any dot-matrix impact printer. The recent release of the Adobe Systems' PostScript music font, "Sonata" has finally fulfilled the promise of obtaining publishers' quality music notation by microcomputer. Because PostScript is "device-independent" the same files which can be printed at 600 dots-per-inch using an Apple Laserwriter can be printed on higher-end laser printers such as the Linotronics 100, at 1270 or even 2540 dpi. For a detailed discussion of the problems of notating music with a computer, see [Byrd 1984], [Miller 1985], and [Yavelow 1986b].

**Interactive Composition.** Computers have had a profound impact on the concepts of improvisation and composition, engendering a sort of hybrid creative activity referred to as interactive composition. Software opening these new artistic doors has finally become available commercially. When these tools are combined with a Kurzweil their true power can be realized. Laurie Spiegle's *Music Mouse* (being marketed by Opcode Systems), is an expert system (that is, it allows non-experts to function as experts) that turns the Macintosh mouse into a MIDI controller which interacts with "intelligent"software running on the Macintosh to derive accompanimental music for music described by mouse motions. Intelligent Computer Music Systems' (ICMS) *Jam Factory*, provides four sequencer modules which generate probabilistic variations on material input by the user (using a process called "Markov Chains") — essentially, it is like jamming with four "clones" of yourself. ICMS' other product, *M*, allows the user to define transformational processes and configurations of parameters, both of which may be controlled in real-time by the user — the feeling is something like conducting an orchestra of your ideas rather than instruments. See [Yavelow 1987b].

**File Conversion.** At the time of this writing, there are no utilities which convert data captured from one company's program into another's. However, Opcode's *MIDIMAC Sequencer* offers a way for many different program's files to communicate with each other. It includes options to convert MIDI performance data it captures into either Professional Composer files or Deluxe Music Construction Set files for conventional music notation. The conversion process is two-way: Opcode's sequencer can read files from either format as well. Finally, data generated by ICMS' *M* or *Jam Factory* can be saved in a file format which can be read by Opcode's *MIDIMAC Sequencer* and subsequently converted into notation within *Professional Composer* or *Deluxe Music Construction Set.* There is considerable discussion between manufacturers regarding the adoption of the Opcode/Electronic Arts/ICMS file format as a standard for Macintosh MIDI applications.

## Unplayable by Human Hands

In the Introduction, we claimed that electronically-produced sounds could be modified and controlled more easily than acoustic sounds. This is certainly a common view, and (we think) the "modification" aspect is unassailable. The "control" aspect is less clear-cut. Composers like Conlin Nancarrow and Richard Teitelbaum have found ways to get very precisely controlled, and tremendously complex, music out of acoustic pianos. For many years Nancarrow has been creating "unplayable" piano music of incredible density by directly punching player piano rolls. Teitelbaum's recent system depends on the Marantz Pianocorder, an electro-mechanical apparatus that interfaces to the piano sound-producing mechanism for output (with solenoids as actuators), and (in some models) the piano keyboard for input. Its main limitation seems to be that it provides only monophonic velocity sensing. Teitelbaum's system "interfaces three Marantz Pianocorder-equipped grand pianos and three microcomputers to create a real-time, multi-instrumental, composition/performance system: musical material played on one keyboard by the composer-performer is instantly read into computer memory, where it can be processed, stored, and/or simultaneously output for playback by two [Pianocorders] attached to the two additional grands." [Teitelbaum 1984] Thus, Teitelbaum can improvise music that would be far beyond the capabilities of a single unaided performer.

Neither the player-piano tape nor the Pianocorder captures the subtlest details a piano is capable of, but a recently developed mechanism — the Stahnke Bösendorfer — does. This is a modification to a Bösendorfer grand piano, developed by Wayne Stahnke and apparently to be marketed by Kimball International, that is in principle similar to the Pianocorder, but has extremely high-resolution polyphonic velocity sensing on the keyboard and position sensing on the pedals, etc. On the other hand, the Stahnke mechanism has a different drawback: it is quite expensive. It seems likely that very precise electronic control of acoustic instruments will always be expensive and, therefore, not easily available. Furthermore, all of these systems — Nancarrow's, Teitelbaum's, and Stahnke's — produce piano sounds only.

For all practical purposes, we believe our original statement stands up.

# The Future

Kurzweil Music Systems' official position is that they are committed to supporting the K250. Given this, what in particular can one expect? The basic design of the K250 allows improvements in a variety of ways. The software "engine" and SMP continue to be improved and new features added in response to users requests and experiences. Kurzweil releases these new versions on a set of eight chips for plugging into CPU board sockets about every 8 months or so for a nominal upgrade fee.

Since the address space of the Motorola 68000 is 16 megabytes, and a fully-configured K250 originally consisted of 2 megabytes, one might guess that it would not be hard to increase ROM and RAM. In fact, ROM and RAM have increased with practically each new software release to the current over 8 megabytes. Upgrades to the basic sounds were released in 1986 — in particular, the piano sound has been worked on extensively.

The soundware group has continued to add new ROM sounds as fast as these can be sampled, cleaned up, and burned onto chips. To date four additional sound blocks have been added: "Sound block A" (meant to complement those sounds on the standard base block); "Sound Block B" (the "rock" block); "Sound block C" (the "classical "block); and "Sound Block D" (the brass and sax block).

The Kurzweil 250 provides, within one instrument, capabilities of sound modification and control which would be difficult to obtain in any other way. These capabilities give the K250 significant value as a creative tool for the composer, an academic tool for the pedagogue, or a research tool for the psychoacoustician.

One experienced user said, "If you can imagine it, the Kurzweil 250 can probably do it." Although it won't do the dishes, it will allow the user to manipulate the sound of dishes being washed in ways that have been hitherto unimaginable. In the words of Raymond Kurzweil [Kurzweil 1984]:

> The Kurzweil 250 is a new type of musical instrument and many of the persons who have been involved in its creation have expressed the feeling that the new things it allows a musician to do will probably end up being of greater importance than the K250's ability to play acoustic sounds. Piano sonatas were not created before there was a piano, and similarly, we anticipate new forms of music developing for this new musical technology.

# Appendix I: Applications

## Pedagogic Applications

The Kurzweil 250, barely three years old, is much too new to have had all of its academic possibilities thoroughly explored. Nonetheless, a number of colleges and universities have already put the instrument to serious use.

The K250 has obvious applications in the teaching of orchestration, theory, ear-training, composition, and electronic studio. Some institutions are also finding it valuable for research into music perception and psychoacoustics.

Samuel Adler's recent text *The Study of Orchestration* provides the student with tape recordings of every example in the text (often with various alternate instrument configurations); Yavelow has called this "Fourth Generation Orchestration Pedagogy." New approaches to the teaching of orchestration like this indicate that the teaching of orchestration is becoming more and more "ear-oriented." Using the K250 as an orchestration tool carries this idea one step further. The K250's sounds are so realistic and the Sequencer Editor so easy to use that students with access to one are able to experiment with various doublings, instrumental combinations and textures and hear immediately how their orchestration will sound. It is as if each student has access to their own personal orchestra, ready to perform at their beck and call at any time. Naturally, basic knowledge of instrumental ranges, idiosyncrasies, and articulation effects must still be learned the hard way.

The teaching of theory and especially ear-training is undergoing a radical change through the application of the K250 at a number of institutions. Suddenly, it is possible with little effort to present ear-training and dictation examples played with absolute rhythmic accuracy and with various instrumental or vocal combinations. The benefits of teaching harmony and ear-training this way are uncontestable.

The advantages of the K250 used as an adjunct to the teaching of composition and arranging are so obvious that we will refrain from commenting on them here — likewise its role in the college or university electronic studio and courses revolving around that department.

Finally, when the K250 is used in conjunction with *QLS*, it is distinctly suited for multiple users. The fact that each user can save all of their work to disk in minutes to be reloaded at a later time and continued from exactly the point they left off makes use practical in an academic community in which many users might have to share a limited number of K250s.

There is a wealth of opportunities for the K250 to transform the face of music education. It has already been used to provide the orchestra part in the learning of piano concerti, the K250's sequencer playing the orchestra part while the piano part is simultaneously performed on the same K250 — slow practice with an orchestra is no problem here. The following examples illustrate more of the possibilities.

**Berklee College of Music.** David Mash is using no less than three Kurzweil 250s and nine K250 expanders in Berklee's new Digital Synthesis Department. These are each a component in fully self-contained digital music workstations which provide students with a variety of equipment. All the workstations are interconnected in three ways: via MIDI, through an audio net, and via a 3COM Local Area Network to a file server.

**Boston University.** Samuel Headrick will uses BU's K250 in three courses starting with his "Introduction to Electronic Music," The advanced electronic music course for graduate students uses the K250 in its capacity as a live performance instrument. The jazz-arranging course uses the it for the realization of student works. Finally, the theater department has expressed much interest in using the K250 as an accompaniment to theatrical productions. The obvious applications to the orchestration curricula is being explored as well as plans for bringing MUSIC-11 files from the VAX through the Macintosh to the K250.

**New England Conservatory.** From the moment they acquired the K250, the theory department of NEC has it to produce a series of ear-training tapes intended to cover a multi-semester ear-training curricula. The tapes present the "Gallon" and "Philiba" dictation series of 1-, 2-, 3-, and 4-voice exercises using the mixture of instrumental timbres available through the K250. Another factor favoring the choice of the K250 for the production of the ear-training tapes is the degree of rhythmic precision permitted by it's quantization capabilities. In fact, the acquisition of the K250 made possible a radical change in the entire solfege curriculum, hitherto impractical due to the expense of producing multi-timbral ear-training cassettes. The dictation exercises are downloaded directly from the K250 to cassette. It is planned that they will eventually be made available to the students on Macintosh disks for playback through the K250's sequencer rather than cassette recordings.

**Skidmore College.** Anthony Holland uses the Kurzweil 250 extensively in a two-semester Electronic Music course sequence. The course design has been considerably influenced by the K250. The first semester introduces the students to studio techniques and culminates in an introduction to the K250, which the department has had since early 1985. The second semester revolves around a series of compositional "etudes" requiring the students to use the K250. Assignments like these are typical: (a) The students are given a sequence on the K250 upon which one track has some deliberately wrong notes recorded. Their task is to isolate the track in question and correct the mistakes, thus learning to use the sequence editor; (b) Other assignments involve creating pieces which connect everything in the studio together either via MIDI or computer; (c) Looping, trimming, and sampling assignments will follow. Prof. Holland feels that the students are less creatively inhibited this year and attributes this to the K250.

The K250 is also used in the theory courses at Skidmore for the creation of weekly dictation cassettes in many varied timbres (as at NEC, these are recorded directly onto cassette from the K250). Quantization and the availability of a variety of percussion timbres are considered to be a strong point, especially for the creation of rhythmic dictation examples.

The K250 is used in live performance in several ways at Skidmore College. First, the students of the Electronic Studio course present a live concert with the Kurzweil each semester, and secondly, the K250 is used to "pad" the orchestra during semesters when certain instruments are missing from the student body (a common problem at small private liberal arts colleges such as Skidmore). It is already affecting repertoire planning for the coming year. For example, when there are only two horn players enrolled in the college, works involving three horns will no longer have to be excluded from the repertoire.

**SUNY-Buffalo.** The well-known computer music pioneer Lejaren Hiller sees the Kurzweil 250 becoming one of the central devices in his computer music studio at SUNY–AB. He anticipates extensive use of the instrument as soon as their K250 returns from Japan, where it has been resident in the United States pavilion at EXPO 85. At the U.S. pavilion, the K250 was in constant use performing DEC VAX–11/780 algorithmic compositions (programming by Charles Ames). The K250 is also featured on Hiller's latest record, *Lejaren Hiller: Computer Music Retrospective*, which is being released on Wergo Records in Europe and Harmonia Mundi in the United States this fall.

## Music Perception/Psychoacoustic Research

One application of the Kurzweil 250 that came as a surprise to its developers is applying the instrument to research in psychology, psychoacoustics, and performance. For example, it is well suited for studies in rhythmic interpretation. The performance of a work for piano which is recorded into the K250's sequencer may be examined very closely. Minute, and sometimes shocking, details about the actual performance rhythm are displayed in the LCD when one goes back and steps through the sequence in the Sequence Editor — remember, the K250 displays the timing information by beat *and* fraction of the beat to an accuracy of 1/256th of a *beat* (not to be confused with a 256th-note: if the denominator were a 128th-note, the resolution would be the relatively uncommon 32,768th-note). The study of rubato should benefit greatly from the ease of obtaining this information (see "Wesleyan University" below). Furthermore, it is possible to scrutinize attack velocity with equal precision (there are 256 values); crescendo and decrescendo curves of a performance can be studied with this information, as can articulation and performance of accents.

**Harvard University.** The department of Psychology and Social Relations at Harvard University recently purchased a K250 to be made available as a resource for research in psychoacoustics. Initial studies include research into rhythmic interpretation.

At Project Zero, a research division of Harvard University's Graduate School of Education, Lyle Davidson, Chairman of the Theory Department at NEC, and Lawrence Scripp, are engaged in a study entitled "The Perception of Invariance in Themes and Variations". All examples for this psychological study were made with the Kurzweil 250, downloading directly to cassettes. Prof. Davidson feels that, due to the K250, the examples are of "studio quality" and "make most psychological tests [examples] look like child's play". The tests consisted of a group of about sixteen trials, each in three parts: one of several themes (from Mozart) followed by two variations. Only one of the variations was actually a variation of the particular theme being used for the trial. The various themes and their variations were subsequently altered (using the Sequence Editor) through transposition, tempo and rhythmic quantization in ways which would have been difficult, if not impossible, without the K250.

## Compositional and Performance Applications

Such varied ensembles as the Boston Pops Orchestra, the Composers in Red Sneakers, and the New York City Ballet have used Kurzweil 250s in recent performances. Alan Howarth, who created the special sound effects for the widely acclaimed films, *Poltergeist* and *Star Trek: The Motion Picture,* is using the K250 to create music and sound effects for motion pictures and television. His latest endeavor using the K250 is the Disney film: *My Science Project.* Other film music composers have used the K250 in such films as *The Falcon and the Snowman* and *The Woman in Red.*

Patrick Moraz created the soundtrack of the 1987 film *The Stepfather* using the Kurzweil exclusively. An interesting twist to this application is the fact that all the sequences were mixed *inside* the Kurzweil's own sequencer and transferred directly to stereo tape rather than being "peeled off" in layers onto a multi-track recording for later analog mixdown.

# Appendix II: Product Specifications

## The Advanced Sampling Kurzweil 250

**Keyboard:** 88 notes, velocity sensitive (256 increments), wooden keys.

**Pedal Pod:** Two piano-type pedals, power cord, fuse, power switch.

**Channels:** 12

**Dimensions:** Keyboard: 57-inch (L) x 27-inch (W) x 9-inch (H)
Pod: 17 3/4-inch (L) x 11 1/8-inch (W) x 4 1/8-inch (H)

**Weight:** Keyboard: 95 lbs.
Pod: 22 lbs.

**Power Consumption:** AC 110V, 50/60 Hz, 380W (220V option available).

**MIDI:** In, Out, Thru. 16 channels, user assignable. Each sequencer track can be assigned to a separate MIDI channel. Normal, Omni, Multi, and Cycle modes. Special MIDI mode slaves one Kurzweil 250 or Expander to another.

**Inputs:** Mic/Line input (user sampling option); two 1/4-inch assignable volume type pedal jacks; external synchronization; computer port.

**Stereo Audio Output Levels:** Balanced XLR 600 ohm, 10V peak-to-peak nominal. High level, 10V peak-to-peak nominal. Low level, 1/4-inch 600 ohm, 1V peak-to-peak nominal. Headphone, stereo 1/4-inch 8 to 600 ohm.

**Dynamic Range:** Over 100 dB.

**Additional Outputs:** Click Track Out; Sync Out.

**Resident Voices:** Concert Grand Piano, Violin Section, Viola Section, Cello Section, Bass Section, Plucked Acoustic Bass, Snare Drum, Bass Drum, Tom-Tom (2 octave chromatic), Hi-hat open, Hi-hat closing, Hi-hat closed, Crash Cymbal, Ride Cymbals, Cowbell, Sandpaper, Hammond* B-3 Organ (3 settings without percussion, 1 setting with percussion), Trumpet, Baritone Horn, Valve Trombone, Sine Wave, "Endless Glissando," Nylon-stringed Acoustic Guitar, Hand Claps, Finger Snaps, Temple Blocks, Grater up, Grater down, Guiro, Ratchet, Sleigh Bells, Sandpaper, Harpsichord, White Noise

**Sound Block A:** Choir, Flute, Electric Bass (open), Electric Bass (slap), Clarinet, Oboe, Harp arpeggios, Harp glissando, Conga (open), Conga (slap), Conga (ringing), Chimes, Marimba, Vibes, Timpanis

**Sound Block B:** Rock Drums (a large variety of processed drums), Fender Rhodes™ (A variety), Analog Synths (including one based upon the Mini Moog™) Electric Guitar, Guitar Harmonics, Guitar Mutes,

**Sound Block C:** Solo Violin, Solo Cello, Pizzicato Strings, Plucked Harp, Celeste, Hand Bells, Bassoon, Sawtooth Wave, Cathedral Pipe Organ, Church Pipe Organ

**Sound Block D:** Solo Trumpet, Muted Trumpet, Solo Trombone, Growl Sax, Tenor Sax, Dual Hardness Sax, Soft Tenor Sax, Falls (Stabs), Square Wave, Digital Waveform

**Keyboard Setups:** The base unit contains 98 factory-installed keyboard setups, with up to 40 user-definable keyboard setups. Sound Block A adds 86 new factory-installed keyboard setups. Sound Block B adds 49 setups. Sound Block C adds 56 setups. Sound Block D adds 53 setups. All configurations provide room for up to 48 user-definable "instruments" ("effects files").

**Sound Sample Memory:** Over 8 Megasamples (includes SuperRAM II: 2 megasamples).

**Programmable Functions:** Eleven editing modes (menu-driven); variable 256-segment envelope generator; 88-way keyboard split (up to 87 split points) with up to 6 instrumental layers; 24 LFOs; 4 wave shapes (ramp up, ramp down, square, and triangle); continuously variable tremolo/vibrato/amplitude parameters; variable brightness levels including velocity-to-brightness mapping; velocity-to-layer mapping; variable output group; attenuation window definition; variable pitch modulation; 5 modes of transposition (octave or chromatic pitch shift or transpose, and timbre shift); stereo chorus parameters: doubling, flanging, echo, full chorusing, microtonal tuning; variable delay time (up to 30 seconds); variable detuning (+1200 cents to -6000 cents); bend interval (to 60 semitones); variable sustain decay rate; effects flag setting; keyboard dynamics table with up to 11 different settings; 7 parameter channel stealing algorithm; saving of up to 48 "instruments" to disk or battery-backed RAM.

**Assignable Controls:** 2 assignable levers, 3 assignable sliders, 2 assignable on-off foot switches (pod), 2 assignable external pedal jacks, 16 assignable functions.

**Front Panel:** 38 multi-function LED buttons, seven sliders, 2 levers, 5-key multi-function cursor pad, numeric keypad, 48-character back-lit Liquid Crystal Display.

**Sequencer:** 12-track, polyphonic, 12000 note storage capability (battery-backed RAM). Complete software includes: punch in (merge and erase modes); sequence editing; individual track editing; individual track volume control, looping, quantization on playback, individual note and event editing/insertion/deletion; call section; section copy; sequence chaining; continuous record looping; variable rate external synchronization, MIDI synchronization; click track output; simultaneous access to all on-board sounds. Practical limit of 12 channels per track (144 total) without external device.

**Sound Modeling Program™:** Variable sampling rate (14 sampling rates ranging from 5 to 50 kHz); total sampling 10 to 100 seconds per Digitizer RAM bank (up to four banks), depending upon sample rate; compression; adjustable loop decay and release rates; automatic natural amplitude envelope extraction and artificial envelope generation; VU level check meter with peak hold function; clip indicator; trimming and looping functions; multiple samples on each key with layer hardness mapping; multiple-key and single-key multi-sampling; internal storage (63 soundfiles, 15 keyboard setups in volatile, non-battery-backed memory per bank — fully configured: 252 soundfiles, 60 keyboard setups); external storage capability on Apple** Macintosh*** diskettes via QLS™.

**SMP RAM Options:** (CGP RAM of 500,000 samples is standard — 1 bank); SuperRAM I = 1,000,000 samples (2 banks); SuperRAM II = 2,000,000 samples (4 banks)

**QLS™:** Quick Load System. Off-line storage and editing of sampled soundfiles, complete digitizer RAM banks, keyboard setups, "instruments" (envelope and effects files), sequences, MIDI configurations, front panel button assignments, etc. Macintosh interconnection cable. 3.5-inch hardcase disk. Transfer rate: 500,000 bits/sec.

**Documentation:** "Player's Guide to the Kurzweil 250,"

**Adjustable Performance Stand**

**Plexiglass Music Rack**

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**All specifications subject to change without notification.**

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# References

Byrd, Donald. 1984. *Music Notation by Computer*. Ph.D. Dissertation, Indiana University. Ann Arbor: University Microfilms.

Chamberlin, Hal. 1980. *Musical Applications of Microprocessors*. Rochelle Park, N.J.: Hayden Book Co.

Kaplan, S. Jerrold. 1981. "Developing a Commercial Digital Sound Synthesizer." *Computer Music Journal* 5: 62–73.

Kurzweil Music Systems. 1985. *A Player's Guide to the Kurzweil 250*. Waltham: Kurzweil Music Systems.

Kurzweil, Raymond. 1984. "The Goals of the Kurzweil 250." Waltham: Kurzweil Music Systems.

Loy, Gareth. 1985. "Musicians Make a Standard: The MIDI Phenomenon." To appear in *Computer Music Journal*. 9(4): 8-26.

Milano, Dominic. 1985. "Keyboard Report: Kurzweil 250 Digital Sampling Keyboard." *Keyboard* 11:82—90.

Miller, Jim. 1985. "Personal Composer." *Computer Music Journal*. 9(4): 27-37.

Moorer, J. A. 1981. "Synthesizers I Have Known and Loved." *Computer Music Journal* 5: 4—13.

Pohlmann, Ken C. 1986. *Principles of Digital Audio*. Indianapolis: Howard W. Sams & Co.

Schechter, Harold, and Everitt, David. 1980. *Film Tricks: Special Effects in the Movies*. New York: Harlan Quist Books (distributed by Dial/Delacorte Sales).

Strawn, John. 1980. "Approximation and Syntactic Analysis of Amplitude and Frequency Functions for Digital Sound Synthesis." *Computer Music Journal* 4:3—24.

Teitelbaum, Richard. 1984. "The Digital Piano and the Patch Control Language." Paper delivered at the International Computer Music Conference, Paris.

Yavelow, Christopher. 1985. "Music Software for the Apple Macintosh." *Computer Music Journal* 9(3): 52-67.

Yavelow, Christopher. 1986a. "MIDI and the Apple Macintosh."*Computer Music Journal*. 10(3): 11-48.

Yavelow, Christopher. 1986b. "From Keyboard to Score." *Macworld*. 3(12): 108-117.

Yavelow, Christopher. 1987a. "Microcomputers and Music — The State of the Art." *Journal of the Audio Engineering Society*. March/1987.

Yavelow, Christopher. 1987b. "Composition or Improvisation? Only the Computer Knows! *Proceedings of the Audio Engineering Society's Fifth International Conference: Music and Digital Technology*.