

This section first deals with several basic conceptual questions about synthesizers. While we have distilled the information as much as possible, some topics have philosophical or complex origins that do not lend themselves to simple explanations. The balance of the section provides an overview of how the CS-series synthesizers operate, much of which can also apply to other synthesizers.

#### What is a Synthesizer?

A synthesizer is an audio processor that has a built-in sound generator (oscillator), and that alters the envelope of the sound with voltage controlled circuitry.

Synthesizers can produce familiar sounds and serve as musical instruments, or they can create many unique sounds and effects of their own. The synthesizer operates by creating each basic element of sound and then providing you with separate controls for each element.

You don't have to use all the many controls on the synthesizer to create a complete sound. In fact, often only a handful of the available controls need be used, depending on the sound you wish to achieve.

#### What is the Difference Between Synthesizers & Electric Organs?

An electric organ offers a wide variety of preset sounds at the touch of a finger. Synthesizers usually offer no presets, or very few of them, instead providing an infinite variety of adjustable sounds. The CS-50 and CS-60 offer many presets and infinitely adjustable sounds as well.

Organs utilize different means to generate sound than do synthesizers. Because of this, most organs are polyphonic, meaning that you can play many notes simultaneously, whereas most conventional synthesizers allow you to play only one note at a time. The CS-Synthesizers, however, incorporate additional circuitry that allows you to play several notes at a time (4 on the CS-50 and 8 on the CS-60).

#### Why Use a Synthesizer?

Many of the sounds that can be created with a synthesizer would be either impossible or highly impractical to create with acoustic instruments. Also, the synthesizer can give you common acoustical sounds with much greater convenience than would otherwise be possible. For instance, you can adjust the controls to "stretch" a common instrument, like gradually transforming a piccolo to a Bass flute, or even to a 20' long flute, if there were such a thing. Similarly, the synthesizer allows instant or gradual transitions from the sound of one instrument to another.

#### What Are the Elements of a Synthesizer?

One section, the VCO, establishes the pitch or frequency of the note, as well as the basic tone (timbre). Another section, the VCF, shapes the tone or emphasizes portions of it. Another section, the VCA, affects the loudness of the notes. Either the VCF, the VCA, or both may be used to "turn on" and "turn off" the sound in a controlled pattern, forming the notes as you play the keyboard. The control that forms the notes is provided by Envelope Generators (EG), one for the VCA and one for the VCF. The synthesizer also houses many other functions to modify the basic sounds for a variety of effects.

Yamaha CS-series synthesizers, because they are polyphonic, are actually equipped with several VCO's, VCF's, VCA's and EG's: 8 sets on the CS-60 for creating each of the 8 notes that can be played simultaneously, and 4 sets on the CS-50 for creating each of the 4 notes that can be played simultaneously.

#### Why Are Voltage Controlled Circuits Used in Synthesizers & How Do They Work?

You can set up voltage controlled circuits to make changes automatically. Suppose you have a sub oscillator that produces a continuously changing voltage (AC), such as the slow sine wave from the synthesizer's Sub Oscillator. If you apply that voltage to the control input of a Voltage Controlled Amplifier, the sound passing through that amplifier will go up and down in level—creating a tremolo effect. (This is exactly what happens when you move down the VCA lever in the Sub Oscillator section.) At this point you are listening to one sound source that is being **modulated** or controlled by something else, a sine wave. If you increase the SPEED of the Sub Oscillator, the rapid changes in control voltage will make the sound level change so fast that beating occurs, producing secondary tones.

You can also adjust a voltage controlled circuit manually, if you wish, just like any conventionally controlled circuit. For example, you might achieve the same slow-speed tremolo effect by continuously moving a Volume control up and down, if you had the fingers free to do it. However, you could not possibly move that volume control fast enough or smoothly enough by hand to produce secondary tones. Thus, voltage controlled circuits enable you to do things that could not be readily accomplished with purely manually controlled circuits.

Amplifiers (VCA's) are not the only voltage controlled circuits in a synthesizer; filters and oscillators may also be voltage controlled. In all instances, the amount of change in the sound is proportional to the voltage applied to the control circuit. The same sine-wave voltage from the Sub Oscillator that created tremolo in the VCA when applied to the control input of a VCF would create wah-wah, or when applied to a VCO would create vibrato.

It is not at all important for a player to understand about voltages and control circuits to program and play the synthesizer. When you set the controls and levers so the sound is "right," you are probably adjusting control voltages.

The synthesizer consists of sound producing and sound modifying circuits, all related by a number of signal paths and control circuits. Oscillators and Noise Generators produce the raw ingredients for sounds. Wave Shape Converters, Filters, Amplifiers, a Ring Modulator, and Sub Oscillators further modify the sound (the audio signals). These circuits, plus the distinction between audio and control functions, are detailed below. While voltages are discussed, it is not really necessary to understand how voltages work; when you move the controls and knobs, you are adjusting voltages inside the synthesizer.

**Audio Signals & Control Voltages**

Electric currents that flow through synthesizers can be thought of in two categories: audio signals and control voltages. The audio signals constitute the actual sound as it is generated, modified, and ultimately fed to the output. The control voltages themselves are never heard, but are instead used to adjust the circuits which process the audio.

Audio signals are alternating currents (AC) with frequencies in the audible range which, as you probably know, covers about 10 octaves from 20 cycles per second (Hz) to 20,000 cycles per second (Hz). Audio signal voltages vary at different points in the synthesizer, but they average about 0.775 volts at the output when the rear panel HIGH/LOW switch is at HIGH position (0dBm into 600 ohms).

Control voltages are usually 10 volts or less, and may be DC (direct current) or AC (alternating current). AC control voltages vary in frequency from very low, sub-audio frequencies (1/2Hz) up to the audio frequency range (as high as 500Hz or more). The effect produced by a voltage controlled circuit will vary in proportion to the control voltage applied. For example, a VCA (voltage controlled amplifier) will cause the **audio signal** to be higher in volume when the **control voltage** is higher in level. If a steady DC control voltage is applied to the VCA, the volume of sound coming out of the VCA will increase by a proportionate amount and will remain at that level. If an AC control voltage is applied to the same VCA, then the volume will vary up and down, corresponding to the variations of the AC voltage; this is AM, or amplitude modulation.

When a DC voltage is applied to a VCO (voltage controlled oscillator), the oscillator increases its frequency. When an AC control voltage is applied to a VCO, the frequency varies up and down, producing an effect known as vibrato or FM (frequency modulation). Similarly, when AC or DC voltages are applied to VCF's (voltage controlled filters) the filter characteris-

tics change; the cutoff points move up or down.

Refer to the programming block diagram on which represents the programmable panel's functions. This is the same diagram appearing on the synthesizer front panel, and is often helpful as a reminder of how the panel functions are related to one another. A key to the block diagram symbols is shown below the diagram. Audio signal paths run from left to right, as shown by the horizontal lines that join the blocks (colored lines). All vertical lines that point to the blocks represent control voltage paths. The block diagram is divided into three sections which correspond to the VCO, VCF and VCA sections of the panel.

A more complete block diagram of the full synthesizer is shown on the following page. Like the programming block diagram, audio signal flows from left to right. However, unlike the programming block diagram, vertical and horizontal lines do not distinguish control and audio signals; audio signals are still shown by the colored lines and control signals are shown by the black lines.

**Oscillators**

An **oscillator** is a circuit that produces AC voltage, generating voltages which go up and down in level according to some regular, defined pattern (waveform) and at some defined rate (frequency). There are many types of oscillators, some for very low frequencies and others for audio frequencies. Oscillators that operate in the audio frequency range are generally used as sources of sound.

The **VCO** is a voltage controlled oscillator. The CS-60 has eight main VCO's, one VCO for each of 8 notes (the CS-50 has four main VCO's). Any main VCO is capable of producing all the notes, but only one note at a time. When you play the keyboard, special digital circuitry assigns different control voltages to the available VCO's so that the desired notes are produced.

**Wave Shape Converters**

The synthesizer's main VCO's produce sawtooth waves. These waves may be used, unaltered, as the sound source, but they can also be processed by the wave shape converter (WSC) to form square waves or sine waves, as desired. The WSC's are considered to be part of the VCO's.

**Noise Generator**

A **noise generator** is like an oscillator that is constantly and rapidly changing its frequency and its waveform so that the output appears to be a random

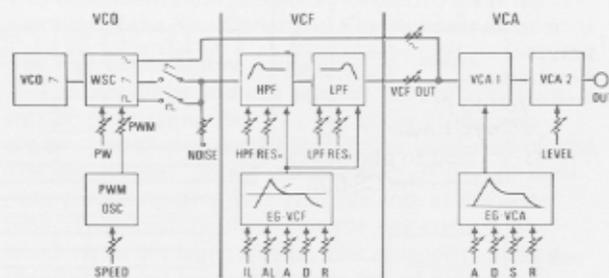
mixture of all sounds simultaneously. White noise is a type of noise that has equal level, on the average, across the full audio spectrum. The noise generator is not voltage controlled, but is included in the VCO section of the programmable panels because it introduces noise at the same point in the circuit as the VCO's: just before the filters.

**Filters**

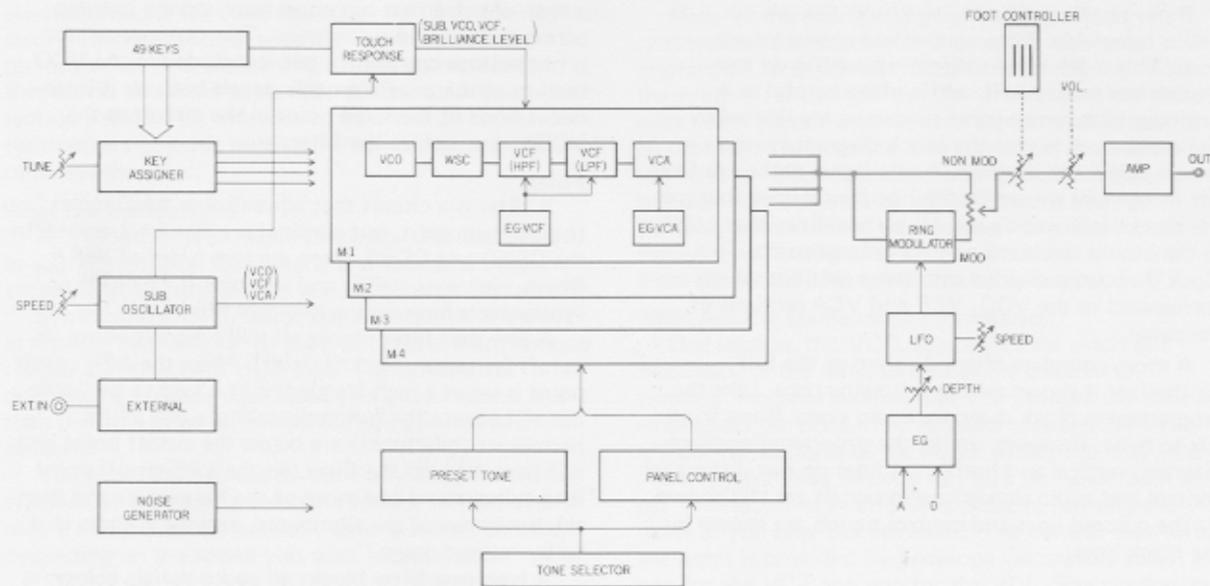
A **filter** is a circuit that allows some frequencies to pass through it, but eliminates other frequencies. In the CS-50 and CS-60, there are two types of audio filters, high pass (HPF) and low pass (LPF). (Many synthesizers have only a low pass filter.)

A **low pass filter** blocks all audio signals above its cutoff frequency (cutoff point). When the LPF cutoff point is set at a high frequency, it is said to be "wide open" because the fundamental note and all its harmonics (overtones) are below the cutoff point and will pass through the filter. As the LPF cutoff point is lowered, more and more of the harmonics and then the fundamental are eliminated, and the filter is said to be "closed down."

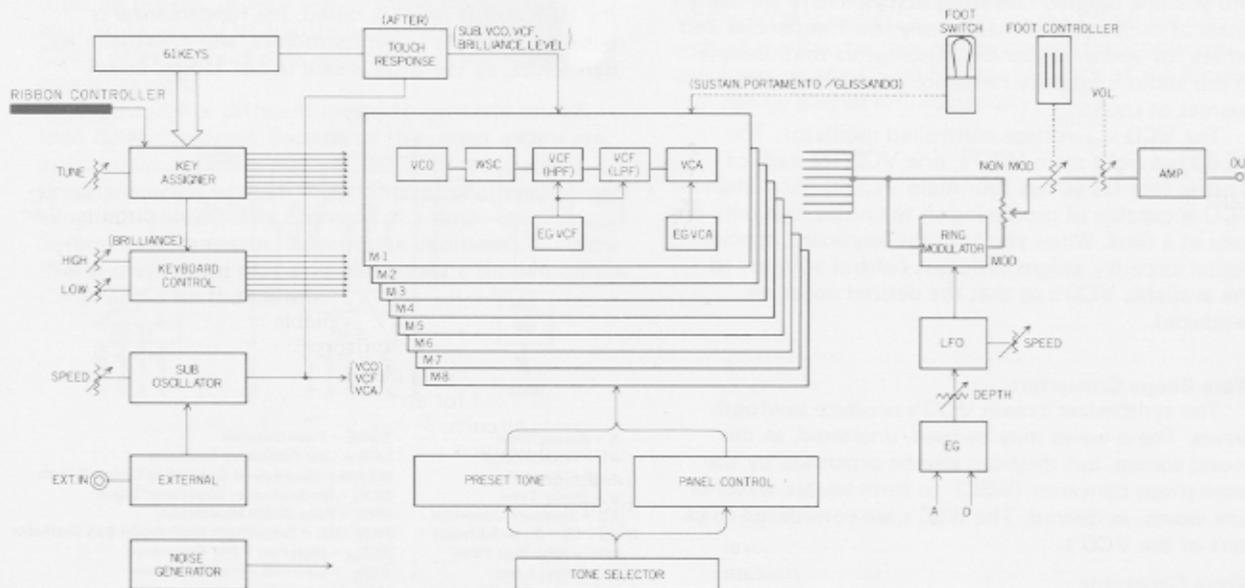
A **high pass filter** blocks all audio signals below its cutoff frequency. When the HPF cutoff point is set at a low frequency, it is said to be "wide open" because the fundamental note and all its harmonics are above the cutoff point and will pass through the filter. As the HPF cutoff point is raised, the fundamental is blocked, then the lower harmonics, and eventually all harmonics, so the filter is said to be "closed down."



- A = Attack Time
- AL = Attack Level
- AMP = Amplifier
- D = Decay Time
- EG = Envelope Generator
- EXT IN = External Input
- HPF = High Pass Filter
- IL = Initial Level
- LPF = Low Pass Filter
- PW = Pulse Width
- R = Release Time
- S = Sustain Level
- TUNE = Pitch Controls
- LFO = Low Frequency Oscillator
- M1-MB = Main Sound Generating Circuit Boards
- MOD = Modulation or Modulated Signal
- PWM = Pulse Width Modulation
- PWM OSC = Pulse Width Modulation Sub Oscillator
- RES<sub>H</sub> = High Pass Filter Resonance
- RES<sub>L</sub> = Low Pass Filter Resonance
- VCA = Voltage Controlled Amplifier
- VCF = Voltage Controlled Filter
- VCO = Voltage Controlled Oscillator
- WSC = Wave Shape Converter (Part of VCO)



CS-50



CS-60

A VCF is a voltage controlled filter. It can be an HPF or and LPF. In fact, the CS-50 and CS-60 VCF's actually consist of two filter sections each, an HPF and an LPF, as described above. Thus, the CS-50 has 4 VCF's (8 filter sections), one for each of its 4 main VCO's, and the CS-60 has 8 VCF's (16 filter sections), one for each of its 8 main VCO's. The cutoffs can be changed automatically by the filter envelope (IL-AL-A-D-R) or manually by moving a filter slider (HPF or LPF).

When you play a note on the keyboard, the sound generated by a VCO goes through the HPF section of the VCF, then through the LPF section of the VCF. The VCF cutoff frequencies "track" the note played, moving up in frequency as you move up the keyboard, so that the tonal spectrum of the notes remains consistent. Recall that the LPF is wide open when its cutoff point is high, yet the HPF is wide open when its cutoff point is low.

Together, the HPF and LPF sections of the VCF may be considered to be a **bandpass filter** because a defined band of frequencies is allowed to pass between the two filter cutoff points. As the HPF cutoff point is raised and/or the LPF cutoff is lowered, the width of the bandpass is decreased until there is no bandpass (no sound). \* Thus, we can speak of the VCF as being a bandpass filter, even though no such label appears on the panels. If either of the two filter sections is completely closed down, then it will block all sound, and the position of the other filter section makes no difference because you won't hear anything.

The HPF and LPF filters each have a **resonance** slider. These RESH and RESL controls only have an effect if their corresponding HPF or LPF slider is partially closed. As the resonance of a given filter is increased, a narrow range of frequencies are boosted (increased in level)—the frequencies centered just at the cutoff point—because the cutoff point is resonating.

Resonance has no effect when a filter is wide open because the cutoff point is well beyond the limit of the fundamental or overtones, so the boost falls in an area where no signal is present. However, as a filter is closed down, the effect of resonance becomes more noticeable; resonance will tend to emphasize a given harmonic or the fundamental, depending on the filter cutoff (HPF or LPF setting). Resonance also causes additional phase shift which can be heard if the filter cutoff point is changed while a note is being played.

\*While the HPF lever [21] may be lowered, the actual High Pass Filter will not be completely closed unless the overall Brilliance control [5] is set at minimum (up).

## Amplifiers

An amplifier is a device that increases the volume or the power of a signal. Some amplifiers, especially VCA's, also can be used to decrease the power or volume. When an amplifier decreases the volume to inaudibility, it is turning the sound OFF; conversely, when an amplifier increases the volume to audibility, it is turning the sound ON.

Most of the amplifiers in the CS-50 and CS-60 are VCA's (voltage controlled amplifiers), and they generally operate at medium line levels. Thus, external power amplifiers, such as a PA system or guitar amplifier head, are required to boost the power sufficiently to drive loudspeakers.

VCA's offer several advantages for synthesizers in addition to their ability to attenuate (lower) the volume as well as increase it. With conventional type amplifiers, audio signals must be routed through complex paths and it may be necessary to have a separate amplifier to achieve each effect—volume control, tremolo, note definition by an envelope, and so forth. With a VCA, on the other hand, numerous control voltages can be mixed together and fed to one amplifier, producing all the desired effects with a minimum of amplifiers. Thus, VCA's enable the circuitry to be simplified while reducing the potential for noise and distortion.

There are two VCA's for each of the main VCO/VCF sound sources. These VCA's are used to "define" notes—to turn them on, vary their volume, and turn them off—as each note is played; this is done by a control signal from the amplitude envelope generator, as described in subsequent text. The VCA's will also vary the volume in a regularly modulated fashion when they are provided with an AC control signal from the sub oscillator.

## Sub Oscillators

A **sub oscillator** generates AC voltages which are used to modify existing audio signals. The CS-50 and CS-60 both have an overall SUB OSCILLATOR [8] and several other sub oscillators. For example, the PULSE WIDTH MODULATION (PWM) [16] available on the programmable panel (and CS-60 memory) is produced by sub oscillators. The RING MODULATOR [12] also includes a sub oscillator.

To understand how a sub oscillator is used, one should recognize that AC and DC control voltages are often mixed (summed) for combined functions. For example, the VCA's level (volume) control input is fed by several sources of AC and DC voltages. The level can be varied up and down for a tremolo effect by applying an AC control voltage which is produced by the SUB OSCILLATOR section [8]. The depth of

the tremolo effect would be adjusted by applying more or less of the AC voltage produced by the sub oscillator to the VCA. The speed of the effect would be adjusted by changing the sub oscillator's frequency. The average volume around which the tremolo is centered is adjusted by changing the DC control voltage, using the LEVEL slider [36].

Pulse width refers to the amount of time a square wave is OFF, and is also known as "duty cycle." A perfectly symmetrical square wave would have a 50% duty cycle (OFF as much as ON), and a narrow pulse width square wave might have a 90% duty cycle (which sounds the same as 10% duty cycle)—ON 90% of the time. The PW control [17] applies a DC control voltage to the WSC circuit which sets the basic pulse width (duty cycle) of the square wave at any point between 50% and 90%. The PWM control [16] applies an AC control voltage to the same point in the WSC (wave shape control) circuit, thereby varying (modulating) the pulse width. That PWM signal is created by a sub oscillator, and the SPEED [15] of pulse width modulation is actually changed by adjusting the frequency of the PWM sub oscillator.

The sub oscillator in the RING MODULATOR section functions similarly to the main SUB OSCILLATOR and the PWM sub oscillators described above. Changing the amount of AC voltage applied varies the depth of the effect, and changing the frequency of the sub oscillator varies the speed of the effect.

## Envelope Generators

An envelope generator is a circuit which produces a single, carefully defined waveform, a one-shot voltage pattern, when the generator is stimulated by a pulse (trigger impulse) from the keyboard. The envelope itself is a changing dc voltage which rises from zero (no voltage) to some maximum point, and eventually falls back to zero in a pattern which is varied by using the envelope generator's controls.

No sound goes through the envelope generator itself. Instead, the envelope generator's output is fed to the control input of a VCF or a VCA. In the CS-50, there are actually 4 envelope generators for the VCF's and another 4 for the VCA's (8 each in the CS-60).

Envelope generators (EG) which control VCF's are known as filter envelope generators. In the CS-series synthesizers, the filter EG's are unique envelope generators, having 5 sliders: Initial Level (IL), Attack Level (AL), Attack Time (A), Decay Time (D) and Release Time (R). These sliders all change the "shape" of the envelope, which in turn creates changes in HPF and LPF filter cutoff points each time a note is played.

When all the filter EG sliders are set at minimum, there is no output from the EG, hence no change in filter characteristics.

Envelope generators which control the VCA's are known as amplitude envelope generators. The CS-50 and CS-60 amplitude EG's have 4 sliders: Attack Time (A), Decay Time (D), Sustain Level (S) and Release Time (R). These sliders change the "shape" of the envelope, which in turn creates changes in the volume (amplitude) of the sound when you play a note. When all amplitude EG sliders are set at minimum, there is only a very brief pulse of output voltage from the EG, hence only a brief "blip" of sound can be heard.

Conventional synthesizers sometimes have simplified EG's, with only Attack Time (A) and Release Time (R) sliders; the same A-R effect can be achieved on the CS-50 or CS-60 by setting the VCA Decay Time (D) and Sustain Level (S) sliders at maximum, and using only the A and R sliders.

## The Keyboard & Related Circuits—General

As suggested in the preceding paragraphs, the CS-50 has four sets of note-generating circuit components and the CS-60 eight sets, each set consisting of a VCO, WSC, VCF and VCA, and two EG's. When you move any of the panel programming controls, it actually affects all 4 or 8 sets of note-generating components. While the CS-50 has 4 note simultaneous capability, its keyboard has 49 keys, and while the CS-60 has 8 note simultaneous capability, its keyboard has 61 keys. Thus, there must be a special way of assigning the specific keys you play to those 4 to 8 different note generating circuits. This is the function of the Key Coder and Key Assigner circuits.

## The Key Coder & Key Assigner

The key coder and key assigner are digital circuits, a sort of micro-computer. The key coder produces a digital "word" that describes the note (or notes) played. The key assigner "looks" to see which, if any, of the note-generating circuits is available and, at the same time, it continuously monitors the key coder to see which notes are being played. The assigner then feeds the digital word for each note to one of the note-generating circuits. If, on the CS-50, a fifth key is depressed while 4 other keys are already being played, the assigner cannot do anything with that additional information, so no new note will be heard until one of the first 4 keys are released. (Similarly, the CS-60 cannot do anything about a ninth key until one of the first eight keys are released.)

If you play only one key, and play it several times in succession, the key assigner will successively feed the "word" for that note to each of the note-generating

circuits. Since each circuit's VCO, VCF and VCA will differ slightly from the next due to normal component tolerances, the notes will not be identical. This is how the CS-50 and CS-60 produce such natural sound, rather than a mechanical, "too perfect" sound.

#### D-TO-A Converters

The note-generating circuits each have a D-to-A Converter (digital to analog) which changes the digital code for a note into a corresponding DC voltage. That DC voltage level is fed to the VCO, which reacts to set the pitch (frequency) of the note. The voltage is also fed to the VCF, which reacts by moving the HPF and LPF filter cutoff frequencies so they maintain the desired relationship to the frequency of the note (so they track).

#### Trigger Output

The instant a key is depressed, the keyboard produces a trigger output, in addition to the digital word. The trigger is a brief voltage pulse that occurs once, and it is routed to two envelope generators, the filter EG in the VCF section and the amplitude EG in the VCA section. The amplitude EG reacts to the trigger and generates a one-shot waveform to "shape" the volume of the note according to the preset or programmed A-D-S-R characteristics. The filter EG reacts to the trigger and produces a one-shot waveform which changes the tone of the note if the IL-AL-A-D-R controls are appropriately programmed (or if VCF envelope is part of the preset patch).

#### Touch Sensitivity

To understand how the touch sensitivity works, it is necessary to understand the method by which the keyboard itself functions. The keyboard, aside from its basic function of "turning ON a note," which it does by means of a switch on each key, has a secondary system which adds effects when you press harder after the key hits bottom.

A bar runs across the keyboard in front of the keys. When you press a key down hard, after it first touches bottom, the bar is caused to pivot. A flag attached to the end of the bar then moves out from between a light and a photosensor. This increases the voltage passing through the photosensor circuit. The amount of bar movement and the subsequent amount of voltage change are both proportional to the pressure on the key(s). Various effects are produced by that voltage, depending on where it is routed. The TOUCH RESPONSE section applies the keyboard sensor's output voltage to the control input of the appropriate voltage controlled circuits.

#### Keyboard Control (CS-60 Only)

The Keyboard Control Brilliance HIGH and LOW levers affect the upper and lower portions of the keyboard separately, with increasing effect toward the ends of the keyboard. The effect is actually achieved by a digital circuit which interprets the position of each note played on the keyboard and produces an proportional amount of DC voltage. With the HIGH lever, the higher the note, the higher the voltage. With the LOW lever, the lower the note, the higher the voltage. If either lever is pulled down, and a note is played in the keyboard area affected by that lever, the extra, positive voltage is added to the VCF, raising the cutoff point for a more brilliant sound. Pushing up a lever creates a negative voltage, lowering the cutoff point for a more mellow sound.

#### Portamento/Glissando

The glissando effect is produced by a digital circuit which "looks at" the last note played and at the note being played. Instead of allowing the voltage fed to the VCO to jump instantly to the voltage called for by the note being played, the glissando circuit gradually moves the voltage from that of the previous note to the currently played note. A digital circuit causes the voltage to increase or decrease in quantized increments that correspond to half-step increments (a chromatic scale).

The portamento effect is actually produced by the same circuit that produces the glissando, except that an additional circuit element is added. This element "integrates" the steps of voltage, smoothing the transition from one note to the next. Thus, the change is continuous rather than stepped.

#### Ribbon Controller (CS-60 Only)

The ribbon controller is a felt strip beneath which is located a flat resistive pad and a conductive cord. When you press down on the felt, the cord contacts the pad and establishes a given resistance. Voltage passes through the pad and the cord, the value varying in proportion to where the strip is pressed down. The actual voltage produced when the ribbon is first pressed down is not important; it serves only as a reference point. The output from the ribbon circuit then becomes proportional to the difference between the reference point and any other point touched on the ribbon.

A comparator circuit "looks at" the change in voltage and produces a positive DC output when the second point touched on the ribbon is to the right of the reference point. A negative DC output is produced when the second point is to the left of the reference point. The further away the second point from the reference point, the higher the voltage output (positive

or negative). No voltage output is produced if only one point is touched. It is necessary to move a finger along the ribbon, or to hold one finger in a given point and then touch another finger elsewhere on the ribbon in order to achieve an effect.

The voltage output from the ribbon controller is fed to the main VCO's, thus changing the pitch of any note or notes being played; a positive voltage would raise the pitch, and a negative voltage would lower the pitch.

#### Pitch Control

The pitch control adds more or less DC voltage to "bias" the VCO control inputs, thus raising or lowering the frequency produced when a given key is depressed. The coarse pitch control merely produces a greater range of voltage variation than the fine pitch control.

#### Ring Modulator

A Ring Modulator blends two signals together in a special way, "beating" a sub oscillator against whatever input signal is fed to the modulator input. The output does not contain the input signal frequency (or frequencies), but it does contain what are known as sum and difference frequencies. Sum and difference simply means that the sub oscillator frequency is added to the input frequency, and is also subtracted from the input frequency. (Actually, the mathematics that describe the modulation are somewhat more complex because two times the sub oscillator frequency is subtracted from and added to the input, three times the sub oscillator frequency, etc.). The effect may resemble "ringing," although the term "ring modulator" is believed to be derived from the configuration of the diodes which comprise many such modulators; they are wired in a circle.

The sub oscillator frequency is set with the SPEED lever, and the amount of sub oscillator voltage fed to the ring modulator is set with the MODULATION lever. An envelope generator is provided for the sub oscillator, and may be used to change the speed when a note is played. The ATTACK TIME lever and DECAY TIME lever respectively speed up and slow down the effect from whatever speed is set with the SPEED lever to some higher value, and back to the set speed. The amount of change in speed—the amount of envelope voltage fed to the sub oscillator—is set with the DEPTH lever.

#### Panel, Preset Patches (& CS-60 Memory)

The main programmable panel provides a means for the player to adjust the many VCO, VCF and VCA characteristics that together comprise a basic "patch"

or sound. The CS-60 memory is a miniaturized version of the programmable panel, and is used in exactly the same way. The preset patches (PRESET TONES) were all derived from actual settings of the programmable panel. Once a given patch was derived, the resistance value or switch position of each panel control was measured. A fixed component of the same value was then built into the instrument, creating a kind of internal memory that is recalled whenever the corresponding preset patch is selected. You can always duplicate a preset patch by using the programmable panel, as is suggested by some of the patch charts included in this manual. You may wish to do do, and to then vary one or more controls to obtain variations from the presets.

#### Foot Controller Pedal (Both Models) & Foot Switch Pedal (CS-60 Only)

The Foot Controller is an expression pedal that contains a light and a photosensor. As the pedal is rocked back and forth, an aperture varies the amount of light reaching the photosensor. In turn, the photosensor varies its resistance, and hence varies the DC voltage output from the circuit. The voltage from the Foot Controller is applied to the VCA, there by varying the volume.

The CS-60 Foot Switch Pedal is just that—an ON-OFF switch which is housed in an assembly designed for foot actuation. The switch can be used to activate the portamento/glissando effect and/or the sustain, depending on the setting of front-panel assignment switches. When the Foot Switch Pedal is not plugged into the synthesizer, the jack automatically closes the circuit so the unit acts as though the Foot Switch Pedal were pressed down.

The Foot Switch Pedal has a standard (tip/sleeve) phone plug, whereas the Foot Controller, because it contains more circuitry, requires a stereo (tip/ring/sleeve) phone plug.

## 48 WHERE'S THE SOUND?

**A Brief Troubleshooting Guide**

Many times the synthesizer will be connected and basically adjusted properly, yet it may not be audible. The difficulty can be as simple as a playing technique that is inappropriate for a given patch, curable by a change in playing style or by minor adjustment of one or two control settings. Other times, the problem may lie with the sound system to which the synthesizer is connected. This procedure will help you to quickly correct the problem, or at least to isolate it.

1. Be sure all equipment is plugged in and the POWER is ON, and all controls are set at nominal, as shown by the inside cover illustrations.
2. Play one or more notes, and continue to play notes, holding the key(s) down for a few seconds rather than playing staccato.
3. Check the sound system to verify it is properly connected, turned ON, and working. If the rear-panel HIGH/LOW switch is at LOW, try the HIGH position (if that doesn't help, switch HIGH/LOW back to LOW). Check the synthesizer's headphone output; if the synthesizer now appears to be working properly, it will be necessary to check the sound system with a sound source other than the synthesizer.
4. Check the Expression Pedal and VOLUME control settings.
5. Use a preset patch rather than a panel-programmed or memory patch, and play in the middle of the keyboard.
6. If you hear nothing, check the setting of the BRILLIANCE control [5]. If, on the CS-60, sound dies only at the upper and/or lower extremes of the keyboard, center the KEYBOARD CONTROL levers [7].
7. If the sound goes away only with a panel or memory programmed patch, check the following:
  - a. A basic waveform or noise level must be turned ON in the VCO section [18, 19, 20] and VCF level in the VCA section [30] must be up or sine wave [31] in the VCA section must be up.
  - b. If the LPF slider [23] is set at the same height or below the HPF [21] slider, it may be necessary to raise the LPF or lower HPF.
  - c. VCA LEVEL [41] must be up.
  - d. Some envelope must be up (Sustain [34] and/or Decay [33]). If a long Attack Time is used [32], then you may have to hold a key for a second or more before you begin to hear the sound.

**TIPS ON RECORDING**

In any recording situation, the levels are extremely important. The CS-50 and CS-60 have very low inherent noise, high output capability, and hence a large usable dynamic range. If you use a lot of Foot Controller expression and Touch Response LEVEL to create very wide playing dynamics, the recording engineer will be forced to use compression and/or limiting to avoid severe distortion on the tape and, ultimately, on the record. If you want to have the recorded sound be very similar to what you play in the studio, then you can limit your playing dynamics (less Touch Response LEVEL and expression pedal excursion) so that less compression and limiting are needed.

The synthesizer output is capable of driving low impedance studio console or tape machine inputs, even though it is unbalanced. Where long cable runs are required, it may be a good idea to use a balancing transformer or direct box at the synthesizer output, since this will help to reduce susceptibility to hum, noise and radio frequency interference. The LOW/HIGH switch should be set at HIGH and the VOLUME control at 12 o'clock or higher, whenever possible, so that signal levels between the synthesizer and recording equipment are as high as possible. In most cases, the level can then be turned down (attenuated) at the console input.

As you know, with overdubbing the first track recorded is the one against which the rest of the music is played. Therefore, make it clean and rhythmically precise. For large multi-track machines, you might use a click track (metronome) or a rhythm line with a pair of bass and piano tracks. On the other hand, with 4-track machines it is usually better to start with a rhythm sound that is as close to the midrange as possible. This avoids excess high frequency loss or low frequency irregularities that might occur after multiple "sound-on-sound" transfers. (Head bumps, a very common tape machine characteristic, produce irregular low frequency response that would be emphasized more by a bass track than by a midrange track.)

The following suggestions apply to all orchestration, whether you are playing with a large band, overdubbing one synthesizer on multiple tracks of a tape machine, or not using any synthesizer at all. There is sometimes a trade off between clarity of voices and richness of sound, often because too much music is being played in one frequency band. To avoid competition between voices, try to make a sound full and complete as possible, but keep it within a given frequency range. The secret to a richer sounding orchestration is to use a variety of waveforms, counter lines, envelopes and

sub oscillator frequencies for the different voices; try not to layer many voices that are nearly identical. This principle of distinct voices and frequency bands is useful, but it does not mean that frequencies should never be duplicated by two or more voices; it is only a guide line. If two sounds are played in the same register, a slight detuning of one sound can make the mix more dense.

**TIPS ON LIVE PERFORMANCE**

When rehearsing, try to set up a logical progression of patches—logical in that a given patch is changed slightly to achieve the next sound. You never need to start "from scratch" because you can start with a preset patch and adjust the Sub Oscillator, Touch Response, Ring Modulator, etc. to modify that sound. In a live performance, you can then quickly get another sound by selecting a different preset, or by readjusting one or more of the modifying circuits.

Two different approaches can be taken with regard to use of programmed patches. In one instance, you may wish to program a unique and different sound on the panel (and on the CS-60 memory). This would essentially add to the variety of existing preset patches. On the other hand, you may wish to pre-program a patch that is very similar to a preset, differing only slightly but in areas where control settings are critical. Then the sound variations can be pushbutton selected. Of course, you can always program a sound that is completely different from anything available with the presets.

The preset patches make it easy to get different sounds quickly and with excellent repeatability. Also, a very wide range of variation can be achieved within any given preset by merely changing the Brilliance lever [5]. Use of the Sustain [10], Transposition selectors [4], and various Sub Oscillator functions [8] will add even more possibilities to each preset. In fact, instead of switching from preset to preset, it is often more interesting and exciting to explore the full scope available within a single preset patch.

Yamaha polyphonic synthesizers enable you to get a very wide range of keyboard dynamics, plus further dynamic control via the expression pedal. Thus the playing level can change quite dramatically depending on which voices you have programmed and how you play them. Therefore, be sure to check levels for a specific patch ahead of time so that when you come on stage to play the first notes, they are at the right volume level.

If one of your programmed patches doesn't work and you suspect some control(s) was accidentally

moved, don't panic; just go to a preset while you check the panel levers and switches.

### TIPS ON AUXILIARY SIGNAL PROCESSING

Phasers, echo boxes, reverbs, digital delay lines, parametric equalizers, fuzz boxes, wah-wah pedals, graphic equalizers, etc. are all auxiliary signal processing devices that may be used with a synthesizer. The synthesizer output is higher in level than most electric guitar pickups, but it can still be plugged into many guitar-type pedals and boxes if the HIGH/LOW switch is at LOW and the Volume control is set at a moderate level. For optimum headroom and lowest noise, it may be better to use an external attenuation pad to match the level of the synthesizer output to a high-sensitivity (low level) effects device. Signal processing equipment made to interface with studio equipment can usually be driven directly from the synthesizer output with the HIGH/LOW switch in HIGH position. In all cases it is a good idea to check the level (sensitivity) specifications for the auxiliary signal processing unit against the synthesizer specifications.

Many of the sounds you might wish to achieve with an outboard effects device can actually be achieved with controls and circuits that are built into the synthesizer. For example, tremolo, vibrato and wah-wah can all be obtained using the Sub Oscillator [8]. Where practical, use the built-in capability of the synthesizer because the sound will be going through fewer circuits and will therefore have lower noise and better frequency response.

Many patches are greatly enhanced by auxiliary signal processing. The realism of "acoustic" instrument patches can be very much heightened by using reverb.

The synthesizer's External input can afford some interesting effects. To obtain strange "vocal" effects, plug in a source of a very pure, high-frequency sound, such as a 10kHz or higher frequency sine wave oscillator.\* Then engage the VCF (filter) on the Sub Oscillator [8], and add a lot of Resonance [6 and/or 22 & 24]. You might try connecting a sequencer to the External input (applying pre-programmed DC voltages) and engage the Sub Oscillator's VCO lever, thus creating a sequence of different notes when you hold down just one key. The External input is not made for use with guitars or microphones, and even if a preamplified guitar or mic is used, the results could be disappointing. Some preamplified (electric) instrument outputs will produce interesting results when connected to the External input.

\*The purer the sine wave fed to the external input, the better-sounding the result will be.

### DIRECT BOX

A "direct box" is a type of adapter. In some cases, rather than connect the CS-50 or CS-60 directly to a mixer, one could connect the synthesizer to an instrument amp. The direct box would then be used to interface the instrument amplifier's speaker output (guitar amp, P.A. amp, etc.) with the mic or line level mixer input, thus including the amplifier's reverb, tremolo, brightness and other effects in the mix. Another application for a direct box is to achieve grounding isolation between an unbalanced line level output and a balanced mic or line level input.

The CS-50 and CS-60 outputs have a low source impedance so that they will drive a low impedance (600-ohm) or high impedance input without adapters. The synthesizer outputs are unbalanced, meaning that the signal, which flows through a single-conductor shielded cable, is grounded on one side (the shield) and ungrounded on the other side (the center conductor). This arrangement is perfectly suitable for cables of up to 3 m (10') in length. When a longer distance separates the synthesizer output from the mixer input, it is desirable to use a balanced line rather than an unbalanced line for better rejection of potential hum, noise and interference. In a balanced line, the cable shield is grounded, but carries no audio signal; two center conductors, neither of which is grounded, carry the signal. Provided the mixer input is balanced (Transformer isolated), a balanced line will be obtained by connecting a direct box at the synthesizer output.

If the synthesizer output is split and connected to more than input on a mixer, or to any two pieces of equipment wired in the same sound system, it is sometimes helpful to use one or more direct boxes so that the ground to all but one of the inputs can be interrupted without breaking the signal path. This avoids so called "ground loops," multiple grounding

circuits between the mixer and the synthesizer that might otherwise introduce hum.

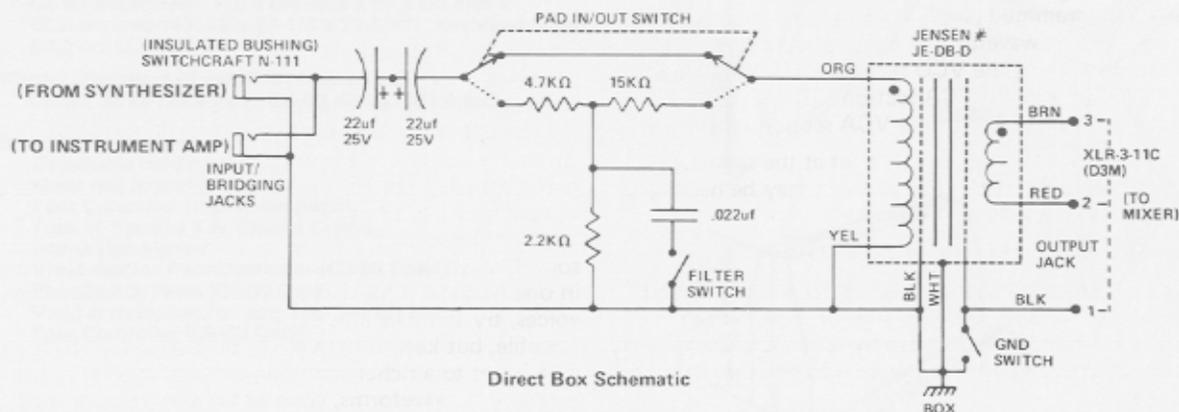
The direct box illustrated can be used in three ways, as described, and its three switches should be set as required (see chart). The **ground** switch breaks the ground (shield connection) in the XLR output, and should be set for minimum hum. The **Pad** drops the signal level so that high level outputs do not overdrive lower level mixer inputs. The **Filter**, which only works when the Pad is switched IN, simulates the high frequency roll off of a typical guitar amp's speaker. Since clipping distortion in a guitar amp often creates high frequency harmonics, the filter switch, by lowering high frequency response, also cuts distortion.

Assemble the unit in a small metal mini-box, and keep the phone jacks isolated from the chassis of the box. Also keep the box away from the chassis of the instrument amplifier or any other grounded object. If you chose a transformer other than the JE-DB-D, it should have similar characteristics: an impedance ratio of 20k-ohms (primary) to 150-ohms (secondary), dual faraday shields, very low capacitance on the primary winding, and full audio spectrum response.

A commercial direct box may be purchased, or a qualified technician can build one from the schematic diagram shown here. The design, courtesy of Deane Jensen (Hollywood, CA), is included in this manual for the benefit of the synthesizer user, and does not represent an endorsement by Yamaha of the specific products mentioned. This direct box also works well with electric guitars, maintaining good high frequency response because the pickup is not loaded.

The JE-DB-D transformer is available directly from:

Jensen Transformers  
1617 North Fuller Avenue  
Hollywood, CA 90046



## Direct Box Use Chart

	PAD*	GROUND†	FILTER
1. Between the CS-50 or CS-60 output and a mixer line input.	IN	IN/OUT	OUT
2. Between the CS-50 or CS-60 output and the input of an instrument amplifier, while also feeding a mixer line input.	IN	IN/OUT	OUT
3. Between the speaker output of an instrument amplifier and a mixer line input.	IN	IN/OUT	IN/OUT

*\*We recommend setting the synthesizer output HIGH/LOW switch to HIGH, and using the direct box pad to reduce the signal level. This protects the transformer from saturation and the mixer input from overdrive. (It is possible to set the HIGH/LOW switch to LOW, and to switch OUT the direct box pad. This does present a much lower impedance to the direct box transformer, causing some transient distortion. While the resulting sound will be brighter and less accurate, there is no harm if you like it.) ALWAYS USE THE PAD WHEN YOU CONNECT A SPEAKER LEVEL OUTPUT TO THE DIRECT BOX.*

*†Set for minimum hum and noise. If in doubt, leave IN.*

## TRAVEL CASE

The CS-50 and CS-60 are built into durable plywood cases with removable covers, and they are suitable for light duty traveling, such as in a station wagon or van. For heavy cartage (i.e., commercial trucking or air freight), we recommend you use an additional travel case. If you buy a custom built case, it should meet "ATA-300" specifications (ATA=Air Transport Authority). The case should be lined with 2-inch thick foam on the large, flat surfaces and 3-inch thick foam on the sides. Consult the specifications for inside case dimensions.

## SPECIFICATIONS

### Keyboard

- CS-50, 49 Keys, c through c<sub>4</sub> (4 octaves).
- CS-60, 61 Keys, C through c<sub>4</sub> (5 octaves).

### Transposition

- Four pushbuttons: normal, 1 octave below normal, 2 octaves below normal and 1 octave above normal.

### Available Fundamental Frequency Range (Harmonics higher than these specified frequencies may be present.)

- CS-50, 32Hz-4kHz; CS-60, 16Hz-4kHz.
- Range is from 2 OCT DOWN and lowest note on keyboard to 1 OCT UP and highest note on keyboard; PITCH controls centered (and no CS-60 Ribbon Controller Effect).

### Pitch Tuning Range

- COARSE TUNE: approximately 1 octave (-500 cents to +700 cents).
- CS-50 FINE TUNE: approximately +14, -11 cents.
- CS-60 FINE TUNE: approximately  $\pm 30$  cents.

### Simultaneous Notes

- CS-50, up to 4 notes; CS-60, up to 8 notes.

### Total Number of Voices

- CS-50, has 13 different presets and 1 panel programmable patch.
- CS-60, has 12 different presets, 1 memory and 1 panel programmable patch.

### Preset Patches (Preset Tones)

- STRING (1 & 2), BRASS (1 & 2), FLUTE, ELECTRIC PIANO, CLAVICHORD, HARPSICHORD, GUITAR (1 & 2), FUNKY (1 & 2); FUNKY 3 on CS-50 only.

### Envelope Generator Time Ranges (VCF-EG & VCA-EG)

- Attack Time: 1 millisecond (min.), 1 second (max.).
- Decay Time: 10 milliseconds (min.), 10 seconds (max.).
- Release Time: 10 milliseconds (min.), 10 seconds (max.).

### Glissando/Portamento Time Range

- 10 seconds maximum to change oscillator frequency from the lowest to the highest note on the keyboard.

### Ring Modulator

- Simultaneous, sine-wave ring modulation of all outputs.
- Variable SPEED, depth of MODULATION. Envelope Generator for varying the speed of the Ring Modulator has variable ATTACK TIME, DECAY TIME, and DEPTH of speed change.

### Sub Oscillator Functions

- Sine wave, sawtooth wave, inverted sawtooth, square wave, white noise, or an external input can be used to modulate any combination of the following: VCO, VCF, VCA. Modulation is applied equally to all notes played. SPEED (frequency) range is adjustable from 0.7Hz to 60Hz.

### Touch Response

- As keys are pressed down harder, there are controls to increase overall BRILLIANCE and LEVEL. In addition, there are controls that introduce VCO or VCF modulation from the Sub Oscillator section (at whatever speed and waveform are set with that section) when the keys are pressed down harder.

### External Input Characteristics

- Unbalanced, standard 1/4" phone jack, 50k-ohm actual impedance (for low or high impedance sources). Nominal sensitivity 10 millivolts rms (30mV peak-to-peak) with EXT IN level at maximum; i.e., 10mV rms sine wave external input would produce the same amount of sub oscillator modulation as the maximum from the built-in sub oscillator.

### Output Characteristics

- HIGH range, 0dBm (0.775 volts rms) or LOW range, -20dBm (77.5 millivolts rms); nominal output when playing four notes, all volume or level controls at maximum. Unbalanced, standard 1/4" phone jacks. Actual 600-ohm output source impedance (will drive low impedance or high impedance loads).

### Headphone Output

- 250 millivolts rms nominal. Unbalanced, Tip/Ring/sleeve 1/4" phone jack for stereo headphones (8-ohm or higher impedance).

### Circuitry

- All solid state; keyboard and note assigning circuitry is digital; all audio circuitry is analog, with voltage controlled oscillators, amplifiers, filters, and envelope generators.

### AC Power

- AC, 50 or 60Hz.
- Power cord stores in covered compartment beneath synthesizer.
- CS-50 draws 55 Watts maximum.
- CS-60 draws 85 Watts maximum.

### Finish

- Black leatherette with metal-reinforced corners; walnut-grained vinyl side panels.

### Dimensions

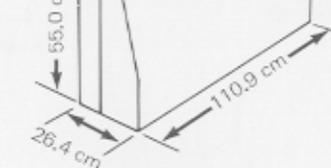
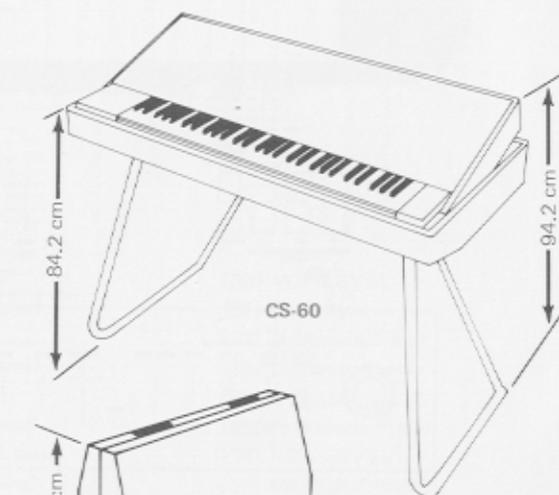
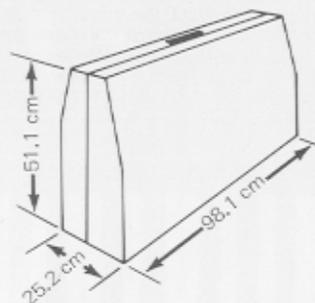
- CS-50 In Case: 98.1 cm wide x 25.2 cm high x 51.1 cm deep. (38-5/8 x 9-7/8 x 20-1/8")
- CS-50 Assembled: 98.1 cm wide x 93.0 cm high x 51.1 cm deep (38-5/8 x 36-5/8 x 20-1/8"); Keyboard height, 84.2cm (33-1/8").
- CS-60 In Case: 110.9 cm wide x 26.4 cm high x 55.0 cm deep. (43-5/8 x 10-3/8 x 21-5/8")
- CS-60 Assembled: 110.9 cm wide x 94.2 cm high x 55.0 cm deep (43-5/8 x 37-1/8 x 21-5/8"); Keyboard height, 84.2 cm (33-1/8").

### Weight (Including all standard accessories.)

- CS-50, 36 kg (79.4 lbs.); CS-60, 46 kg (101.4 lbs.).

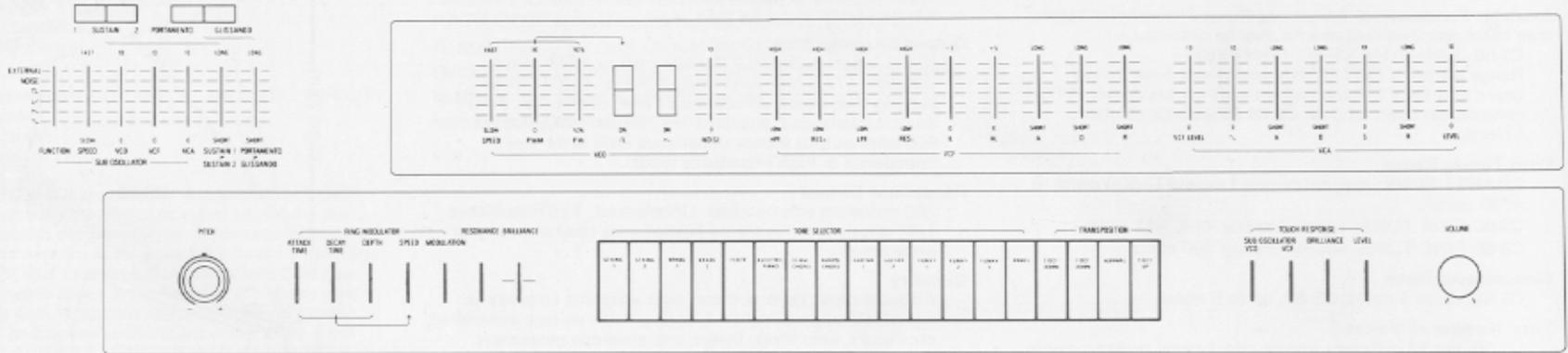
### Standard Accessories

- Detachable hard cover.
- Music rest (stores in cover).
- Foot Controller (expression pedal).
- Tube of Yamaha Key Cleaner Creme.
- Instruction Manual.
- Vinyl case for Foot Controller (CS-50 Only).
- Foot Switch Pedal (CS-60 Only).
- Vinyl carrying bag for legs, Foot Switch and Foot Controller (CS-60 Only).

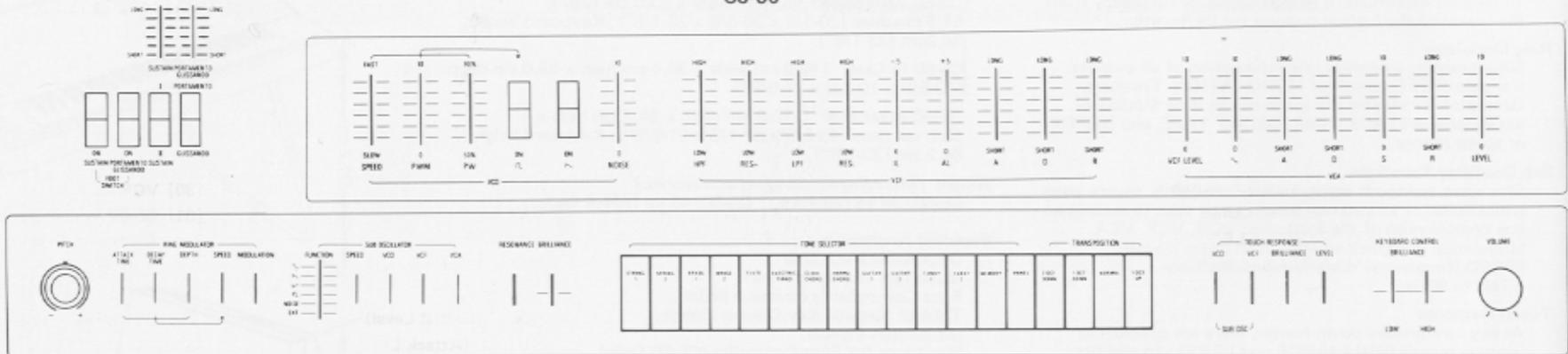


These blank patch diagrams are provided for your convenience. Copies may be made and filled in according to your own requirements. We suggest using a bright-colored felt-tipped pen.

CS-50



CS-60





- |                                                |                                   |                           |                                              |
|------------------------------------------------|-----------------------------------|---------------------------|----------------------------------------------|
| [1] AC POWER switch                            | [10] SUSTAIN                      | [20] White NOISE          | [30] VCF LEVEL                               |
| [2] Main VOLUME                                | [11] PORTAMENTO/GLISSANDO         | [21] HPF filter cutoff    | [31] Sine Wave                               |
| [3] TONE SELECTORS                             | [12] RING MODULATOR               | [22] RES <sub>H</sub> "Q" | [32] A (Attack Time)                         |
| [4] TRANSPOSITION SELECTORS                    | [13] PITCH (tuning)               | [23] LPF filter cutoff    | [33] D (Decay Time)                          |
| [5] Overall BRILLIANCE                         | [14] Ribbon (glide) controller    | [24] RES <sub>L</sub> "Q" | [34] S (Sustain Level)                       |
| [6] Overall RESONANCE                          | [15] Pulse Width Modulation SPEED | [25] IL (Initial Level)   | [35] R (Release Time)                        |
| [7] KEYBOARD CONTROL—<br>BRILLIANCE LOW & HIGH | [16] PWM depth                    | [26] AL (Attack Level)    | [36] VCA LEVEL                               |
| [8] SUB OSCILLATOR                             | [17] PW duty cycle                | [27] A (Attack Time)      | [37] MEMORY PANEL<br>(beneath Block Diagram) |
| [9] TOUCH RESPONSE                             | [18] Square wave ON/OFF           | [28] D (Decay Time)       |                                              |
|                                                | [19] Sawtooth wave ON/OFF         | [29] R (Release Time)     |                                              |

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