HARALD BODE

Frequency Shifters For Professionals

Integrated into electronic synthesizers, frequency shifters increase the possibilities of tone interplay and innovation.

IN CONTRAST to transposing devices, frequency shifters change the harmonic structure of any natural or synthesized sound received at the input, thus creating new sounds for the innovative user. Among the different types of frequency shifters known, the model 735 Bode Frequency Shifter and its counterpart, made by Moog Music, Inc. are the most versatile. In these devices, the amount of frequency shift is voltage-controlled according to one of two control modes.

In the linear mode, the amount of shift is continuously variable from +5 kHz, through zero, to −5 kHz. In this mode of operation, an alternating control voltage introduces additional sidebands into the shifted outputs without actually changing the average amount of shift. In the exponential mode, the amount of frequency shift doubles for each one-volt increase in control voltage, thereby producing changes in the amount of frequency shift that run parallel to the frequencies of synthesizer oscillators and filters that are being controlled from the same voltage. The resulting effects and some interesting applications will be described in this article.

Frequency shifters have been built for a number of purposes, such as the reduction of acoustical feedback (howl) in sound reinforcement systems and, in a multiple single sideband configuration, for the simulation of a choral tone effect. Whereas instruments of this kind use small frequency changes to achieve the desired results, there is an apparatus used for substantial changes of musical frequencies. This is known in the German broadcasting system under the name *Klangumwandler,* which, directly translated, means *sound converter.* This device operates through double heterodyning and single sideband production through the use of a single sideband filter.

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The techniques employed for frequency shifting are basically the same as known for single sideband production—heterodyning and the use of the phase shifting principle. I used a combination of both principles in a special frequency shifter built for the Electronic Music Centers of Columbia and Princeton universities in 1963.[6]

Since the introduction of this rather specialized instrument, I have developed a number of different models. Among these is a carrier injection model of 1964, which subsequently was manufactured by Moog. In a more recent joint effort by Moog and myself, a versatile frequency shifter was developed and presented at the AES Spring convention in Los Angeles in 1972.[7] This model has, among other features, a built-in beat frequency quadrature oscillator (patented in 1974), which is voltage controllable, including a linear-to-exponential interface, making this frequency shifter compatible with voltage controlled synthesizer modules and functions.

BEAT FREQUENCY QUADRATURE OSCILLATOR

A basic (simplified) block schematic diagram of this frequency shifter is shown in FIGURE 1. Through the input terminal, the program signal is entered into two phase shifting networks, ϕ_1 and ϕ_2, which produce two output signals with a 90 degree phase difference relative to each other[8]. These phase-shifted signals are then fed to the first inputs of two four quadrant multipliers. The second inputs of the same multipliers reecive two 90 degree out-of-phase signals from a beat frequency oscillator, which is composed of a fixed (20 kHz) and a variable (15-25 kHz) oscillator. The fixed oscillator is followed by a gate, a low-pass filter (or resonance circuit) to secure pure sine waves, and by two phase shifters ϕ_3 and ϕ_4, which produce two 90 degree out-of-phase outputs (sine/cosine relationship). After mixing these two components of the fixed frequency with the variable frequency, two beat frequencies are obtained at the outputs of mixers 1 and 2, which again are in sine/cosine relationship. At the mixer outputs, the 10 kHz low pass fil-

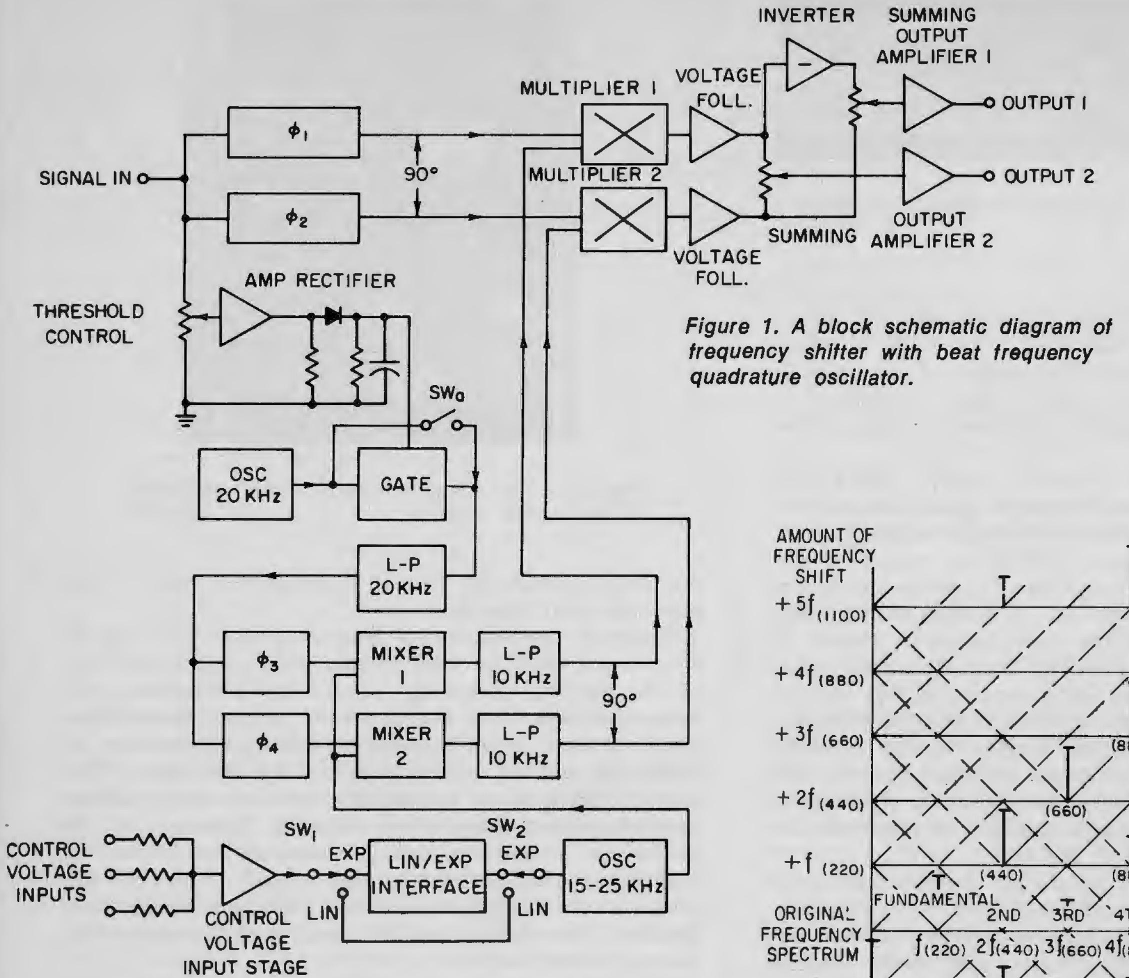

Figure 1. A block schematic diagram of frequency shifter with beat frequency quadrature oscillator.

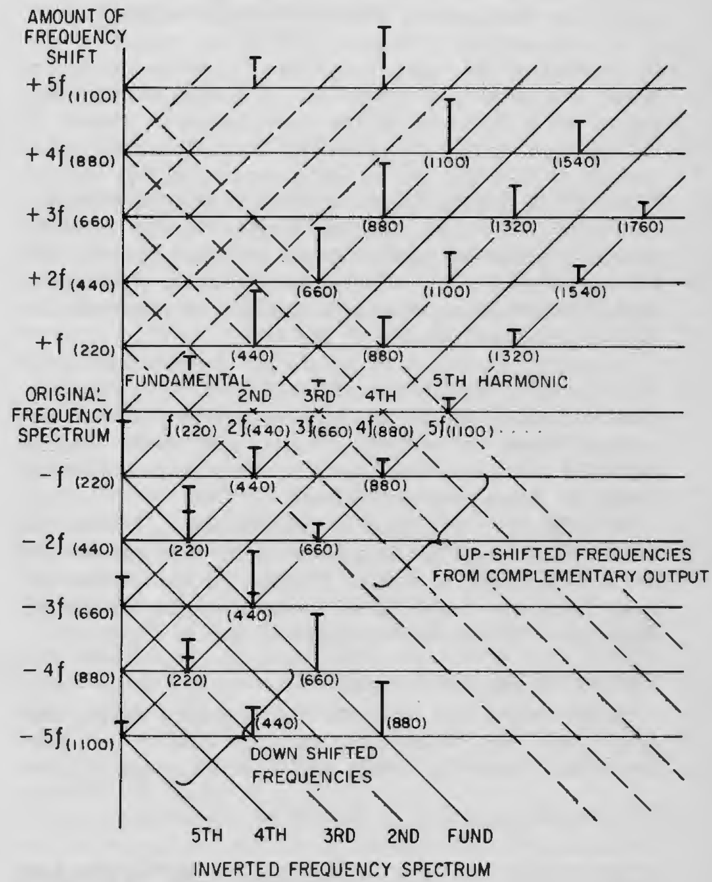

Figure 2. The change of harmonics through frequency shift.

ters are provided to eliminate the high frequency components of the beat frequency oscillators. Through the use of direct-coupled circuitry, this oscillator operates with a constant amplitude from d.c. to the highest beat frequency.

When displaying the two output components on the X and Y axis of an oscilloscope, a clean circle appears, which reverses its rotation when going through zero beats.

Going back now to the four quadrant multipliers 1 and 2: These produce two sidebands each with a suppressed carrier. The sidebands are made up of the beat frequency plus and minus the program frequencies received at the input. Due to the phase relationship between the two multiplier outputs, one of the sidebands is cancelled when combining the two output signals (at the voltage follower outputs) through summing. When combining the inverted output signal of multiplier 1 with that of multiplier 2, the other sideband is cancelled. Thus the two opposite sidebands appear at outputs 1 and 2, which means that one output produces an up-detuned signal and the other a down-detuned signal.

FREQUENCY-SHIFTED SIGNAL

So far, I have discussed the basic performance of frequency shifting functions. Before going into a description of some of the other features of this instrument it may be of interest to see what the analysis of a frequency-shifted signal looks like.

As an example, Figure 2 gives a graphical display of the first five harmonics of a sound before shifting (original frequency spectrum) on the horizontal center line, and after shifting above and below this center line. The approximate amplitude values are chosen for a square wave, a waveform which has a hollow, clarinet-like quality because it has only odd harmonics.

Let's assume for the sake of illustration that the fundamental frequency f equals 220 Hz. Then the harmonic frequencies will be 2f = 440 Hz, 3f = 660 Hz, 4f = 880 Hz, and 5f = 1,100 Hz. If we now shift the frequency up by +f, or +220 Hz (seen on the vertical scale), then all of the harmonics go up in frequency and the new, shifted frequencies can be found at the intersection of the solid diagonal lines and the horizontal line identified by $+f$. In this case, the fundamental of the original sound has changed to 440 Hz, the third har-

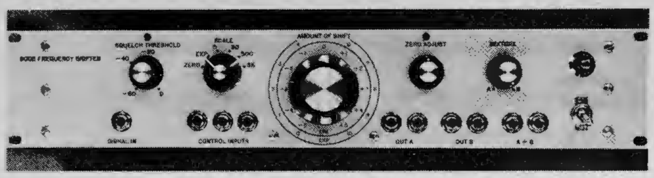

Fig. 3. The front panel layout of the Model 735 Bode frequency shifter.

Figure 4. The Moog version of Bode frequency shifter (Model 1630).

monic to 880 Hz, and the fifth harmonic to 1,320 Hz.

It can be recognized immediately that these new frequencies are the first three harmonics of a sawtooth wave (or stringlike quality), or, if not extended, of a flute tone, with a fundamental one octave higher than that of the original.

This is of course a very special example, which happens to represent a frequency change by an amount that equals the fundamental frequency of the original sound. If, in contrast, the frequency shift is not related to the frequencies of the original spectrum, a new sound is produced, the partials of which are no longer harmonically related. For instance, if the tone spectrum shown in FIGURE 2 is shifted by +50 Hz, then the fundamental changes to 270 Hz, the second harmonic to 490 Hz, the third to 710 Hz, the fourth to 930 Hz, and the fifth harmonic to 1,150 Hz, and the original sound loses its identity. Sounds of bells, chimes, carillons, and the like fall into the category of tones with non-harmonic structures. The frequency shifter is capable of producing an endless variety of sounds of this type.

From the discussion of up-shifted sounds, the reader may derive as well the structure of down-shifted sounds. One interesting feature of the down-shifting is that, depending upon the amount of shift, part of the original spectrum or all of it is inverted, which leads to another family of interesting new sounds.

In addition to the group of partials obtained from one of the outputs of the frequency shifter and represented by the solid lines in FIGURE 2, there are the partials derived from the complementary output of the instrument, represented by the dashed diagonal lines.

EXPONENTIAL SHIFT CONTROL

So far only a few examples for frequency shifting one single note have been discussed. But what if we have found an interesting sound and want to repeat it over the entire keyboard? This is accomplished with an exponential shift control.

Evidently the amount of frequency shift will need to be changed with the fundamental pitch so that the ratio of the shifting frequency *versus* the fundamental remains the same over the keyboard range. This will become obvious when considering the first example, in which the amount of shift equalled the fundamental frequency. From this it follows that the amount of shift or the b.f.o. (beat frequency oscillator) frequency of the shifter has to move in the same musical intervals as the audio frequency fed to the signal input. Since the frequencies of the keyboard scale follow an exponential function, the same has to be true for the oscillator frequency of the shifter.

For this reason, the linear voltage intervals of the keyboard controller (or ribbon controller) of a synthesizer have to be translated into exponential intervals for the local oscillator of the frequency shifter, as shown in the diagram of FIGURE 1 (linear to exponential interface), just as it is done on voltage-controlled oscillators and other keyboard-controlled synthesizer modules. Through the inclusion of the exponential mode, the frequency shifter becomes a real-time performance instrument within a synthesizer installation.

Another important feature is the variable sensitivity carrier squelch circuit, which eliminates the almost inaudible carrier feedthrough when the audio signal level at the input is below a preset threshold level.

FIGURE 3 shows the front panel layout. The threshold control for the squelch circuit is seen on the left hand side. A light emitting diode above the control knob lights up when the incoming signal is above the preset threshold level. A mode selector and scale switch, under the heading, *Scale,* facilitates the selection of the exponential mode and the ranges from +5 to −5 Hz detuning through +5 kHz to −5 kHz detuning (linear), as well as calibration mode, which operates in conjunction with the *zero adjust* control. With this control, the instrument is initially calibrated to zero beat, indicated on the l.e.d. above the control knob.

Using the main tuning knob (*amount of shift* control in the center of the instrument), the built-in beat frequency oscillator is either detuned in linear increments in accordance with the range selected on the *scale* switch or in exponential increments. In the latter case, the change by one dial increment corresponds to a one-octave frequency change.

The *mixture* control facilitates the mixing of the two up and down detuned signals in any desired proportion.

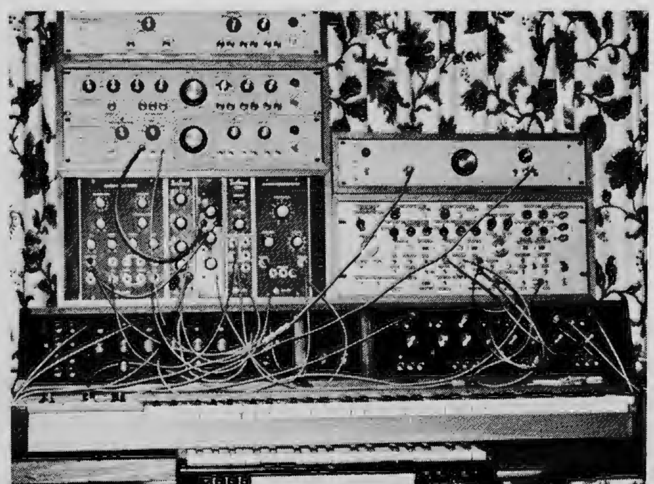

Figure 5. The author's synthesizer, using frequency shifters.

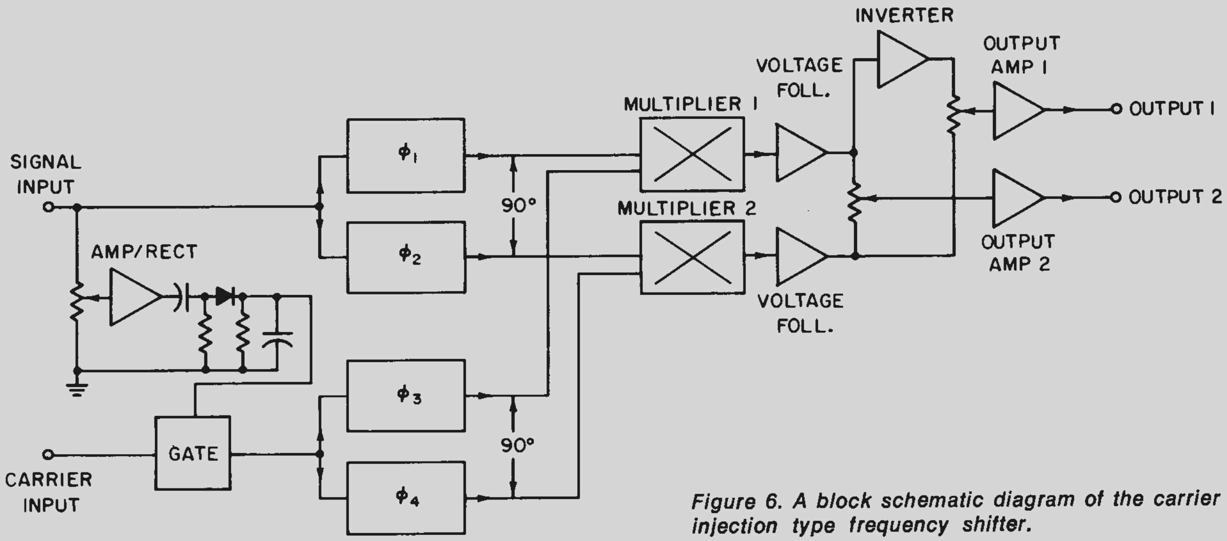

Figure 6. A block schematic diagram of the carrier injection type frequency shifter.

In the center position, the output A + B equals the performance of a ring modulator.

The inputs of the frequency shifter include one input jack for the program signal, *signal in,* and three input jacks for control voltages, *control inputs.* The outputs feed into two jacks each for one of the sidebands, *Out A,* two jacks each for the other sideband, *Out B,* and two jacks each for the mixture of both sidebands.

On the right hand side, the line switch and the pilot light is shown on this particular model, which is equipped with a built-in power supply.

FIGURE 4 shows the Moog version of the Bode frequency shifter, which fits into the modular assembly of the Moog synthesizers. All of the controls just explained (with the exception of the power switch and pilot light) can be found on the 1630 Moog model in a different geometric arrangement. Electrically both models are identical.

A limited size custom synthesizer is shown in FIGURE 5. Here the model 735 frequency shifter is in a case on the left hand side directly above the case with the Moog modules.

OTHER TYPES OF FREQUENCY SHIFTERS

Other types of frequency shifters include the heterodyning model, the carrier injection model, and models with a built-in quadrature oscillator. Of these, the latter two will be described briefly.

A block schematic diagram for the carrier injection model (Bode model 750) is shown in FIGURE 6. Here the incoming signal is fed to two phase-shifting networks, ϕ_1 and ϕ_2, the output signals of which are 90 degrees out of phase relative to each other over the audio range (35 Hz to 16 kHz). The outputs of these networks are connected to the first inputs of multipliers 1 and 2, the second inputs of which receive their signals from two phase shifting networks, ϕ_3 and ϕ_4, the basic circuit of which is identical to that of ϕ_1 and ϕ_2 with the exception that they cover a frequency range from 8 Hz to 4 kHz. This latter range is more meaningful for frequency shifting carrier frequencies.

The phase filters ϕ_3 and ϕ_4 receive the carrier (usually a sine wave) through a gate, which is opened at a preset level of the program signal, so that there is no carrier feedthrough in the quiescent state.

The output signals of multipliers 1 and 2 are summed at the voltage follower outputs to produce a frequency-shifted signal at output 2 in much the same way as it was described for the system in FIGURE 1. A signal of opposite shift direction is produced at output 1 by summing the inverted signal of multiplier 1 with the non-inverted signal of multiplier 2.

FIGURE 7 shows the front panel layout of the Bode model 750 carrier injection frequency shifter. The controls are, from left to right, the squelch threshold control with the l.e.d. above the control knob, the sideband switch, which facilitates sideband reversal, and the mixture control for mixing of the up-detuned and the down-detuned signal in any desired proportion. If the proportions are equal, the signal at the A + B output equals the performance of a ring modulator.

The inputs of this frequency shifter include one input jack each for the program signal (audio in) and for the carrier signal (sine wave, + 2 dBm nominal level). The outputs feed into two jacks each for the upper sideband (*A Out,* up-shifted signal), two jacks for the lower sideband (*B Out,* down-shifted signal), and two jacks for a mixture of both (*A + B*).

In the installation of FIGURE 5, this frequency shifter can be recognized on top of the instruments on the left hand side.

The block schematic diagram of a further frequency shifter type with a quadrature oscillator for producing the frequency shifting sine/cosine signals is shown in FIGURE 8. From the preceding descriptions, this schematic should be self-explanatory. The Bode model 741 frequency shifter uses this system for feedback suppression in sound reinforcement systems. In this application, the

Figure 7. The front panel layout of the carrier injection-type Bode frequency shifter.

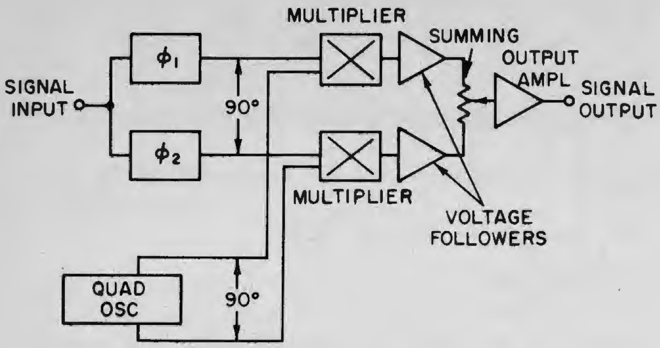

Figure 8. A block schematic diagram of frequency shifter with built-in quadrature oscillator.

quadrature oscillator provides a frequency shifting carrier in the range from 0.5 to 5.0 Hz. The front panel layout of this feedback suppressor is shown in FIGURE 9.

This instrument has also other interesting studio applications. For instance it can be used as a pseudo stereo and ambience effect enhancement device, supplying a complementary signal for a second channel when fed with monophonic program material at its input. In FIGURE 5, the frequency shifter is shown on top of the right hand equipment assembly.

A FEW TYPICAL APPLICATIONS

The typical applications of the model 735 can be put into four basic categories:

1. The simple up- and down-detuning of sounds, including passes through zero shift and production of "mirror image."
2. Frequency shift modulation around zero (or any other center frequency).
3. In-step detuning with voltage controlled synthesizer modules.
4. Repetitive detuning in tape loop. (Iteration effect).

Here are some typical effects which can be obtained. Triggering an envelope follower in conjunction with an envelope generator from a drum sound source (which also connects to the signal input) and feeding the voltage contour obtained from the envelope generator to the control input of the shifter will result in a varying frequency shift contour at the individual drum tone bursts (at a speed depending upon the decay time set at the envelope generator) and will yield a whole new class of sounds.

By setting the main tuning control to zero and applying a subsonic square wave to the control voltage input (linear mode), the up- and down-detuned outputs will switch places, resulting in a new type of special effect when heard over two channels. When this square-wave frequency is raised and enters the audio range, a completely new effect is obtained. In addition, a number of other effects will be produced with different types of wave shapes applied to the control input. A sine wave in the order of 5-6 Hz will result in a stereo vibrato. A sawtooth wave around 1 to 2 Hz will produce a somewhat dramatic effect. With pink noise applied to the control input, the program material will assume a hoarse quality which can be remixed with the original program signal.

By selecting the exponential mode and feeding the control voltage of the keyboard controller of a synthesizer into the control input of the frequency shifter, an infinite variety of new harmonic and non-harmonic sounds can be obtained when feeding the synthesizer tone signal into the signal input of the shifter. In this mode, the shifter becomes an integral part of the synthesizer, capable of being programmed into a large number of systems configurations.

A further special category of sounds obtained with the frequency shifter is the *iteration* effect, also referred to as the spiraling echo effect, which is produced by inserting the shifter in the line between the output of a recorder to its input. In this setup, the delayed sound received at the playback head is frequency shifted, then rerecorded, played back and frequency shifted again and again. An increasingly detuned sound is created, the character of which is determined by the amount of tape delay and the amount and sign of detuning. Evidently other delay devices can be used, such as digital delay lines, acoustical delay lines and the like.

The effects achieved with simple detuning of quasi-pitched sounds, such as drums, bells, and chimes cannot be overlooked; a frequency shifter can be a rather useful instrument with a drum section. Further applications include the processing of the human voice and many other natural as well as synthesized sounds.

The carrier injection model 750 can also be made into a rather versatile instrument by using a voltage-controlled oscillator (such as the Moog 921) for the carrier input. Almost all of the complex functions just described can be performed, with the exception of the frequency shifts through zero and modulation around zero shift. In the *exponential mode,* obtained through the Moog 921, which is controlled by the keyboard controller and which supplies the carrier frequency, very rich sounds can be obtained when using outputs other than sine waves, such as the triangle, square wave or sawtooth waves.

From these limited examples and from the preceding description it will become quite clear that a frequency shifter can be a most powerful tool for the production of new sounds. ■

Figure 9. A front panel layout of anti-feedback frequency shifter.

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