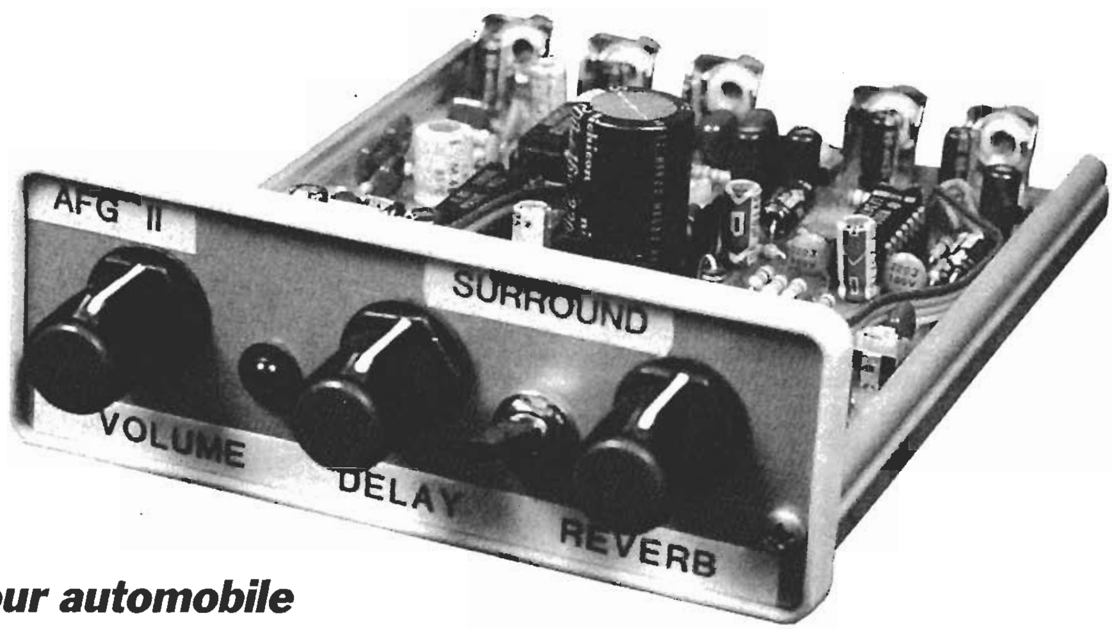
BUILD THE AFGII



Turn your automobile into a concert hall on wheels with the Acoustic Field Generator II.

TOD T. TEMPLIN

WAY BACK IN JANUARY 1990, WE PUBlished plans describing the construction of the Acoustic Field Generator. That circuit, the AFG for short, will recover natural ambience and reflections hidden within any stereo audio signal. In other words, it will reconstruct a three-dimensional acoustic field by reproducing both direct and delayed indirect sound waves through a set of four speakers surrounding the listener. The AFG can also decode specially encoded surround sound material, and thus was intended primarily for use in a home theater system.

Many builders of the AFG where so impressed with it that they requested information on how to modify the circuit to operate from a 12-volt power supply for use in their automobiles. It seems that a good number of audiophiles are looking for a circuit to enhance the acoustic properties of their automotive sound systems.

The circuitry of the original AFG included a bipolar power supply and was not readily adaptable to 12-volt operation. For that reason, an entirely new circuit, the AFG II, has been designed for use in a car. However, the AFG II can also be powered from a 12-volt DC wall transformer, and can therefore become part of any audio system.

Description

The AFG II is a true stereo circuit. It's designed to be placed in the line-level signal path of your car's audio system between the output of the receiver and the input of the equalizer or power amplifier, which drives the rear speakers of your vehicle. Figure 1 is a block diagram of a typical system. The AFG II uses a pair of bucket-brigade devices to delay the sound that is fed to the rear speakers. The delay (in relation to the front speakers) can be adjusted from about 5 to 35 milliseconds. A feedback control adds variable reverberation (echo) to the delayed signals.

In addition to its simple delay mode, the AFG II has a differential mode in which it decodes any surround-sound or ambience signals present. Volume and reverberation level are controlled by an electronic volume control IC. As in the original AFG, an electronic crossover is provided to drive an external power amplifier for a subwoofer system.

The entire unit is built on a single-sided 4- by 5-inch PC board with all controls and input/output jacks mounted on it. The completed PC board slides into an attractive commercial enclosure, so the finished project is quite compact, looks professional, and is easily mounted in most vehicles.

Circuitry

Figure 2 shows a block diagram of the AFG II circuit. Note that the circuit consists of two identical audio channels which share a common power supply and bucket-brigade clock generator. Next refer to the schematic

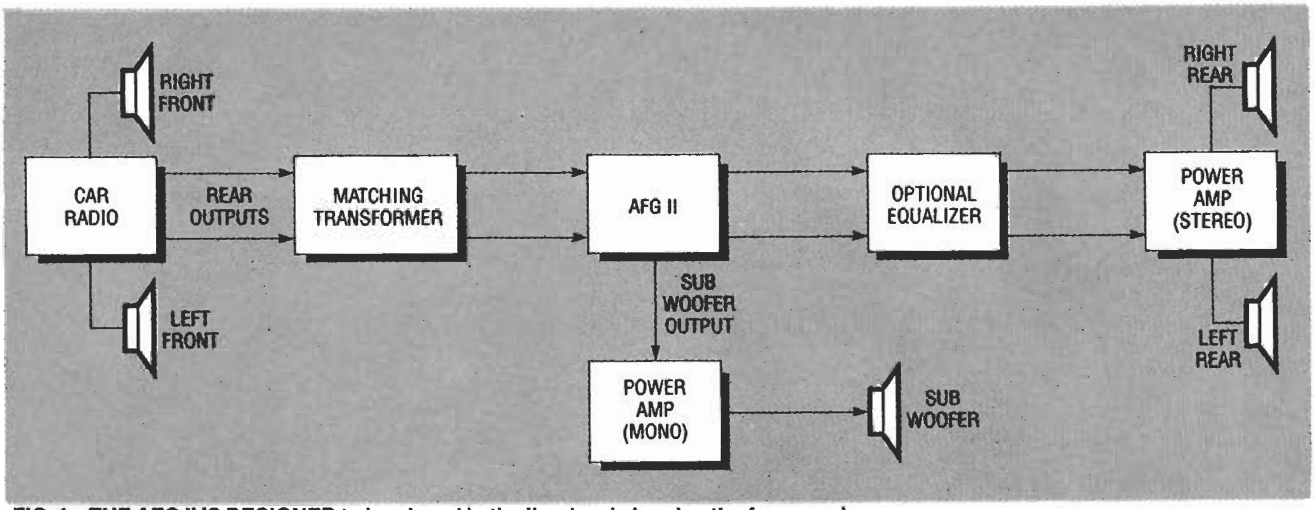


FIG. 1—THE AFG II IS DESIGNED to be placed in the line-level signal path of your car's audio system between the outputs of the receiver and the inputs of the equalizer or power amplifier, which drives the rear speakers.

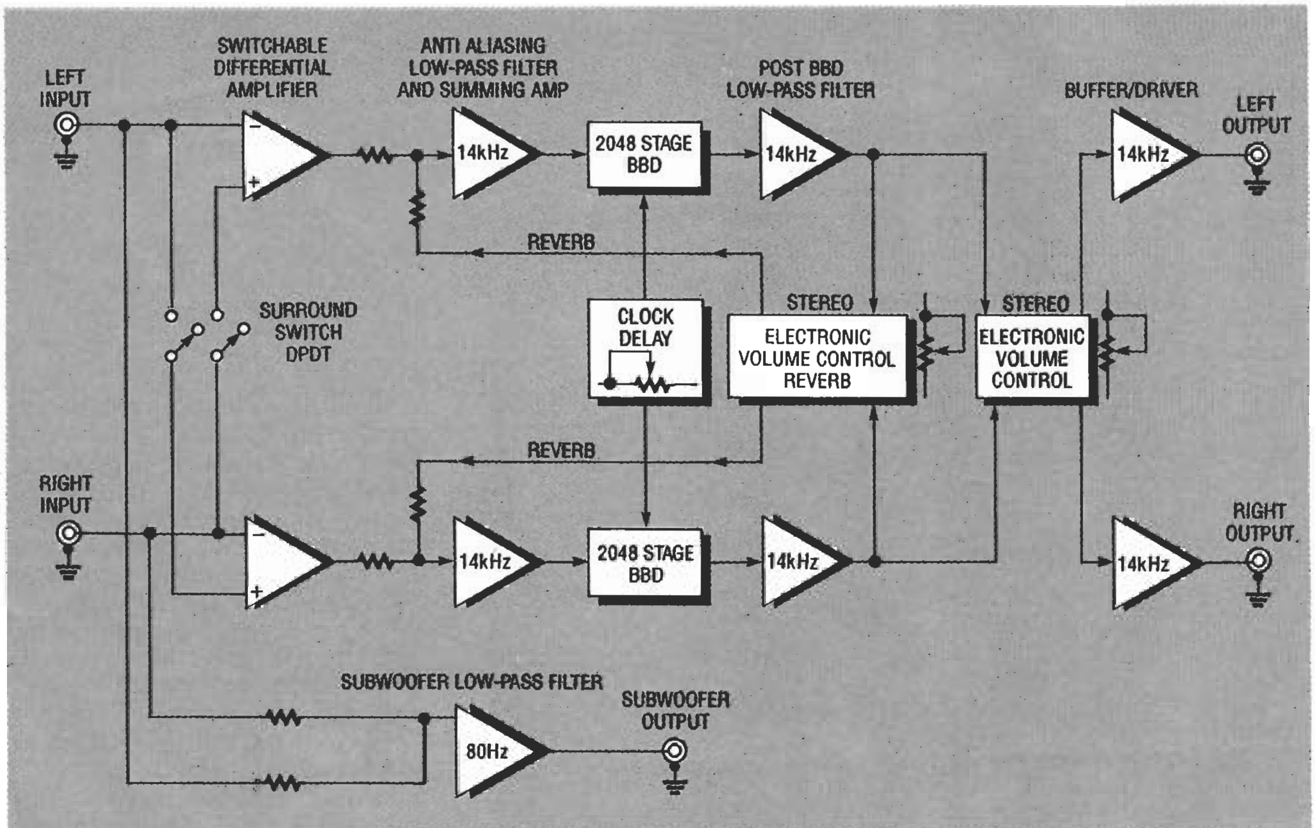


FIG. 2—AFG II BLOCK DIAGRAM. The circuit consists of two identical audio channels that share a common power supply and bucket brigade clock generator.

diagram shown in Fig. 3. An input buffer amplifier is made up of IC1-a and IC1-d. With SURROUND SELECT switch S1 open, IC1-a and -d act as simple inverting amplifiers, and have no effect on the input signal other than providing some gain and a low source impedance for driving the filter section of the following stage.

When S1 is closed, each op-amp becomes a differential amplifier because its non-inverting input is cross-connected, via R3-C6 and R4-C5, to the opposite audio channel of its inverting input. When operating in the differential mode, any audio information that is common to both channels (i.e., mono) is canceled from the output. Only the difference component (L – R and R – L) of the original signal remains. Operating the input amplifier stage in the differential mode decodes any ambience or surround information present in the incoming signal. Trimmers R73 and R74 provide a means for adjusting the overall circuit gain, thus compensating for the varying source signal levels of different components likely to be used with the AFG II.

When op-amps are operated from a single-ended power supply, their non-inverting inputs should be biased at the same DC voltage as the inverting inputs; usually one half the supply voltage. To satisfy that requirement in our circuit, resistors R21 and R22 form a fixed voltage divider. Because the resistors have equal value, the divider splits the supply voltage in half. Capacitor C17 acts as a filter and ensures that no audio signal or noise is coupled to the non-inverting inputs of the op-amps. All of the op-amps in the entire circuit are biased in this manner. Op-amps IC1-b and IC1-c form a pair of anti-aliasing filters for the delay section (see Fig. 4).

The heart of the AFG II delay section consists of a pair of Panasonic MN3008 2048-stage analog bucket-brigade devices, or BBD (one for each channel), and a shared MN3101 two-phase variable-frequency clock-pulse generator. Each element in the BBD is one of 2048 series-connected stages. Each stage consists of a small capacitor that stores an electric charge, and a tetrode transistor switches that charge from one capacitor to the next. Consider each of the 2048 capacitors to be a bucket in a fireman's brigade. A signal presented at the input to the BBD is transferred down the line of capacitors in the same manner in which firemen in a bucket brigade transfer a pail of water from one man to the next. The speed at which the signal is transferred down the line of buckets is controlled by the frequency of the clock signal applied. The more slowly the clock runs, the longer it takes for the signal to travel through the circuit and reach the far end.

When using delay lines, one must contend with a nasty property known as "aliasing." In this case, aliasing means "false signal." When the frequency of a signal applied to the input of a BBD is allowed to become higher (i.e., shorter) than one half of the clock pulse frequency, the sample time duration becomes longer than the actual frequency being sampled. Put another way, the amplitude of that high-frequency signal has a value that changes during the sample time; thus the value stored in the capacitor is not an accurate representation of that instant in time, and the output of the BBD is not "true." To avoid aliasing and the resulting distortion, a low-pass filter is placed ahead of the BBD to limit the input-signal frequency to one half or less of the lowest clock frequency used. The low-pass filter used for this purpose is referred to as an anti-aliasing filter.

Another property of BBD's is that clock phase one drives all of the odd number stages, and clock phase two drives the even number stages. When the signal reaches the end of the line, the output of the last odd stage must be combined with the output of the last even stage to

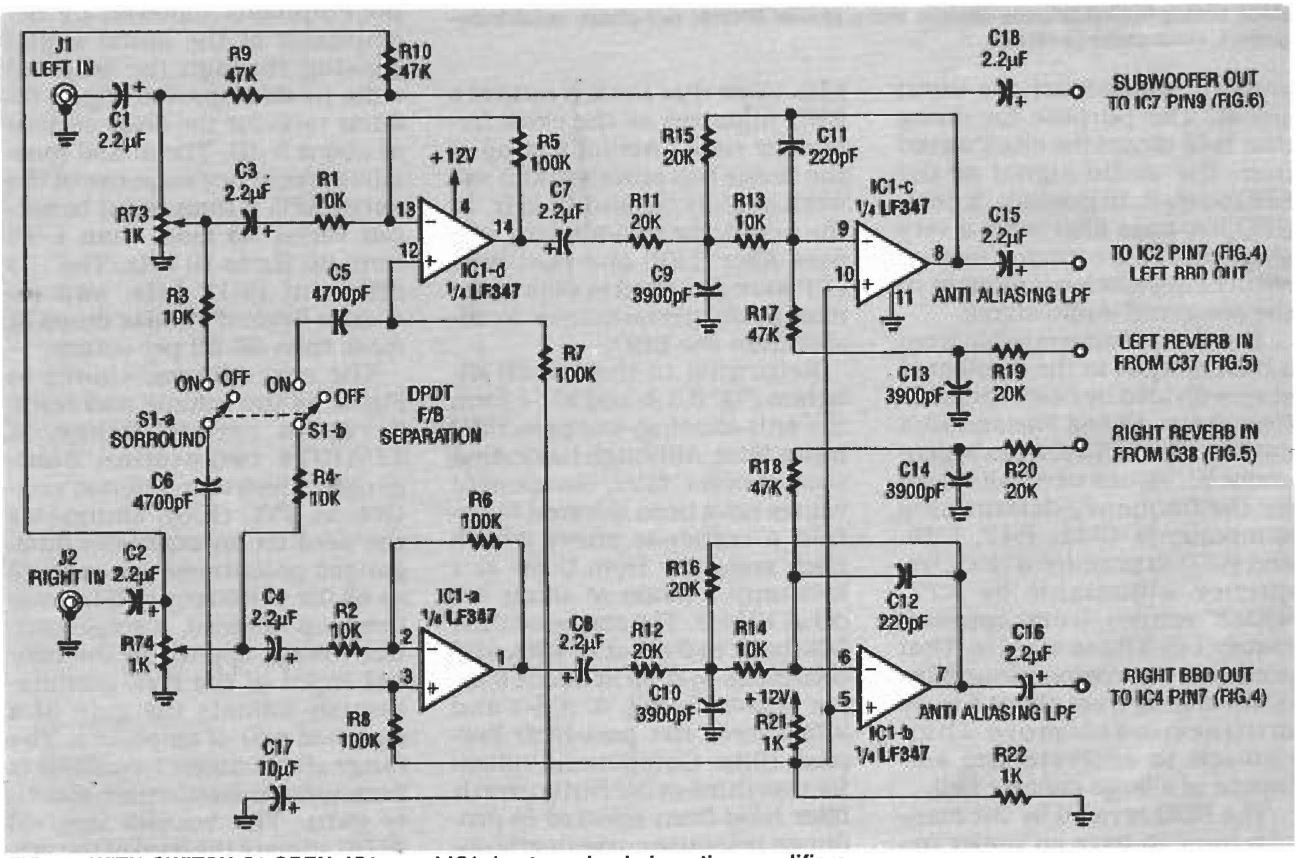


FIG. 3—WITH SWITCH S1 OPEN, IC1-a and IC1-d act as simple inverting amplifiers. With S1 closed, each op-amp becomes a differential amplifier because its non-inverting input is cross-connected to the opposite audio channel of its inverting input. The differential mode "decodes" any ambience or surround information.

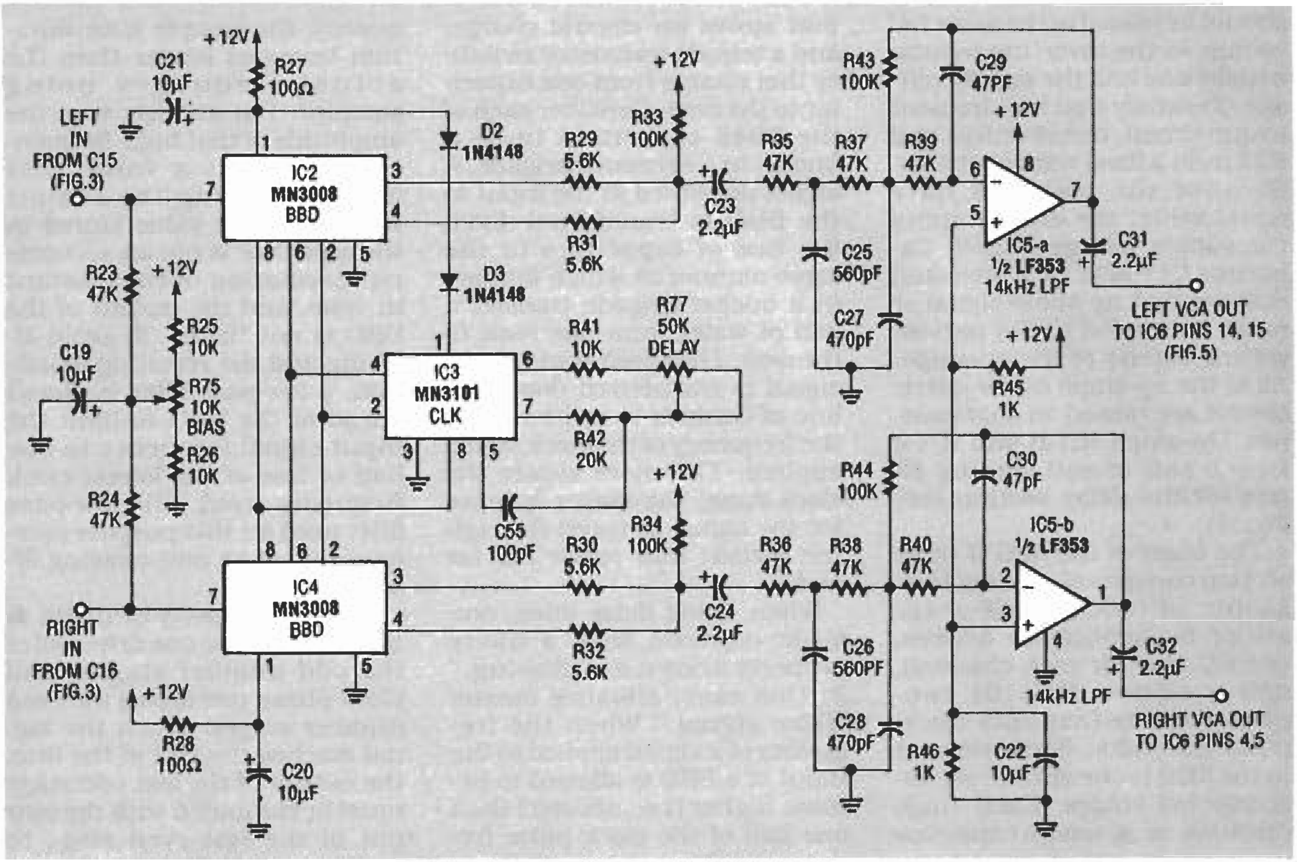


FIG. 4—THE AFG II DELAY SECTION consists of a pair of Panasonic MN3008 2048-stage analog bucket-brigade devices and a shared MN3101 two-phase variable-frequency, clock-pulse generator.

properly reconstruct the input signal. The purpose for doing that is to cancel the clock signal from the audio signal at the BBD output. In practice, a post-BBD low-pass filter with a very sharp cutoff frequency further reduces any clock component in the recovered audio signal.

The delay time available from a BBD is equal to the number of stages divided by twice the clock frequency. Using Panasonic's data for the MN3101 clock generator IC, values were calculated for the frequency-determining components (R41, R42, C55, and R77) to produce a clock frequency, adjustable by R77, which ranges from approximately 145 kHz to 40 kHz. That produces a corresponding delay time ranging from about 5 to 30 milliseconds—more than enough to recreate the ambience of a large concert hall.

The BBD is rated by the manufacturer to have an upper frequency response limit of 10 kHz and a signal-to-noise ratio of 55 dB at a clock frequency of 40 kHz. (Note that the S/N ratio of a BBD improves as the clock frequency rises.) Actual testing of the device has proven that it will work slightly beyond 12 kHz. In the AFG II, the anti-aliasing low-pass filter (LPF) and post-BBD LPF were designed to obtain the maximum performance available from the BBD.

Returning to the circuit diagram Fig. IC1-b and IC1-c form the anti-aliasing, low-pass BBD input filter. Although basically a second-order filter, component values have been selected to obtain a response curve which rises smoothly from 0 dB at 1 kHz until it peaks at about +5 dB at 10 kHz. The response then falls back to 0 dB at 14 kHz, and continues to drop at about 6 dB per octave. In Fig. 4, IC5-a and IC5-b form the post-BBD low-pass filter. Component values for this third-order Butterworth filter have been selected to produce a response curve nearly opposite that of the input filter circuit. This method of high-frequency pre-emphasis followed by de-emphasis of the audio signal passing through the BBD results in an improved signal-to-noise ratio for the delay section of about 5 dB. The actual measured frequency response of the entire AFG II from input to output varies no more than 1 dB from 20 Hz to 10 kHz. The −3 dB point is 12 kHz, and response beyond 12 kHz drops at more than 36 dB per octave.

The next section, shown in Fig. 5, is the volume and reverberation control stage. A TDA1074 two-section dual-ganged electronic volume control, or EVC (IC6), eliminates the need for an expensive dual-ganged potentiometers, as well as all the wires required to hook them up. Instead, a single control voltage applied to the control input of the EVC simultaneously adjusts the gain of a matched pair of amplifiers. The range of adjustment available is from infinite attenuation to unity gain. The VOLUME control (R78) adjusts the level of the signal being sent to the final output filter stage. The REVERB control (R79) adjusts the level of

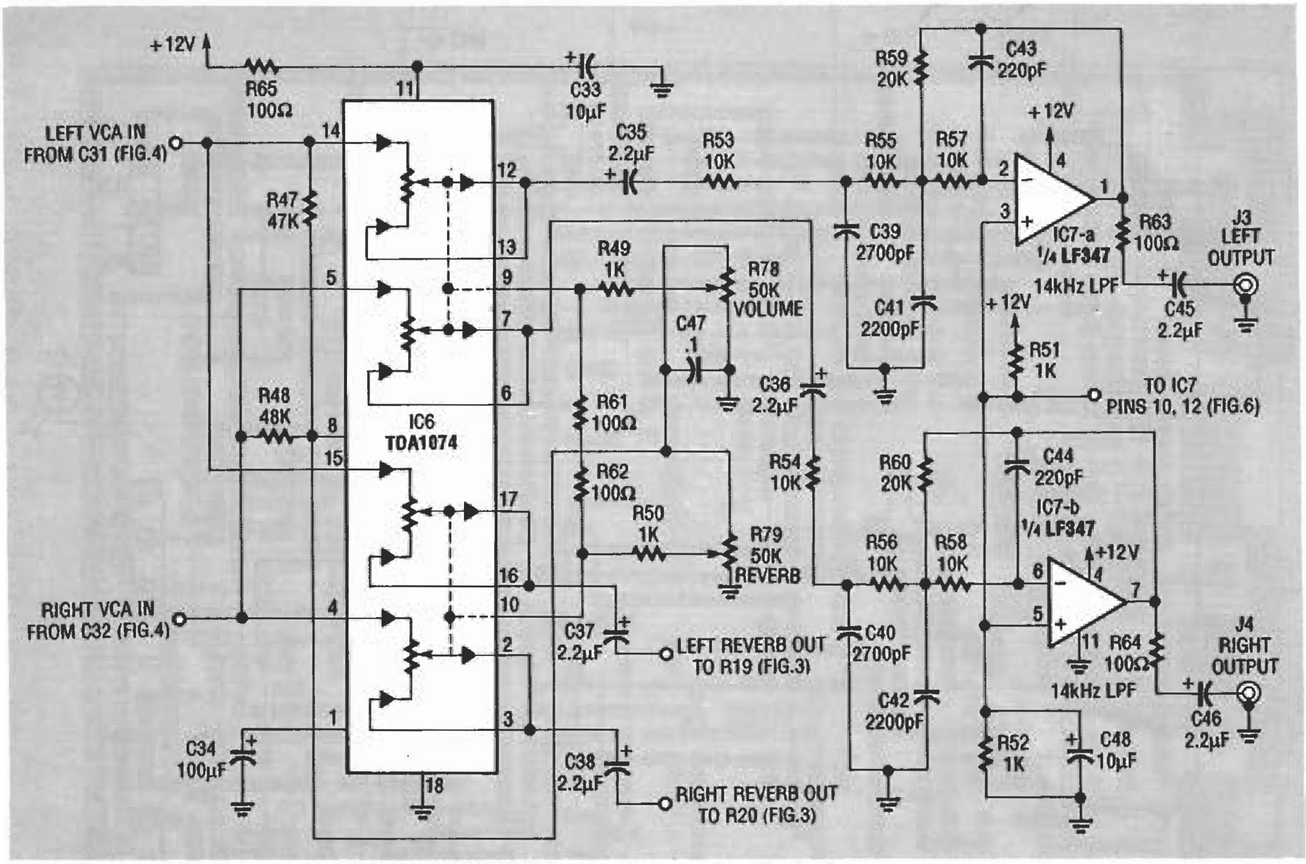


FIG. 5—A TDA1074 ELECTRONIC VOLUME CONTROL simultaneously adjusts the gain of a matched pair of amplifiers (IC7-a and -b). The volume control (R78) adjusts the level of the signal being sent to the final output filter stage, and the reverberation control (R79) adjusts the level of the delayed signal being added back to the input.

the delayed signal being fed back to IC1-b and IC1-c where it is added back to the input signal to produce the reverberation effect. Components R17, R19, and C13, and R18, R20, and C14 form a pair of first-order LPF's to prevent ringing and match levels of the feedback signal. The output stage, IC7-a and IC7-b, is another pair of third-order LPF's with a corner frequency of 14 kHz. They provide for additional reduction of clock noise from the output signal as well as providing a low output-source impedance.

The other half of IC7 (IC7-c and IC7-d) forms an active crossover network for driving a subwoofer system; IC7-c sums the left and right channel inputs, inverts the summed signals by 180°, and provides a low driving impedance for the following low-pass filter stage (see Fig. 6). Potentiometer R76 adjusts the gain of this stage from unity to 3 times unity value. Op-amp IC7-d and its associated

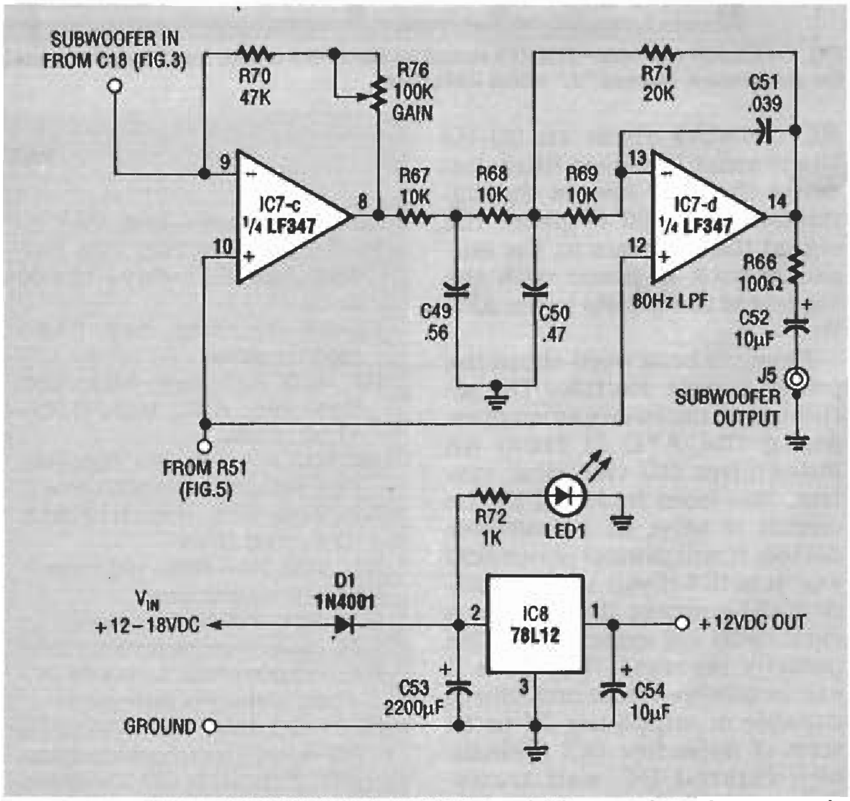


FIG. 6—AN ACTIVE CROSSOVER NETWORK for driving a subwoofer system is formed by IC7-c and -d. Potentiometer R76 adjusts the gain of this stage.

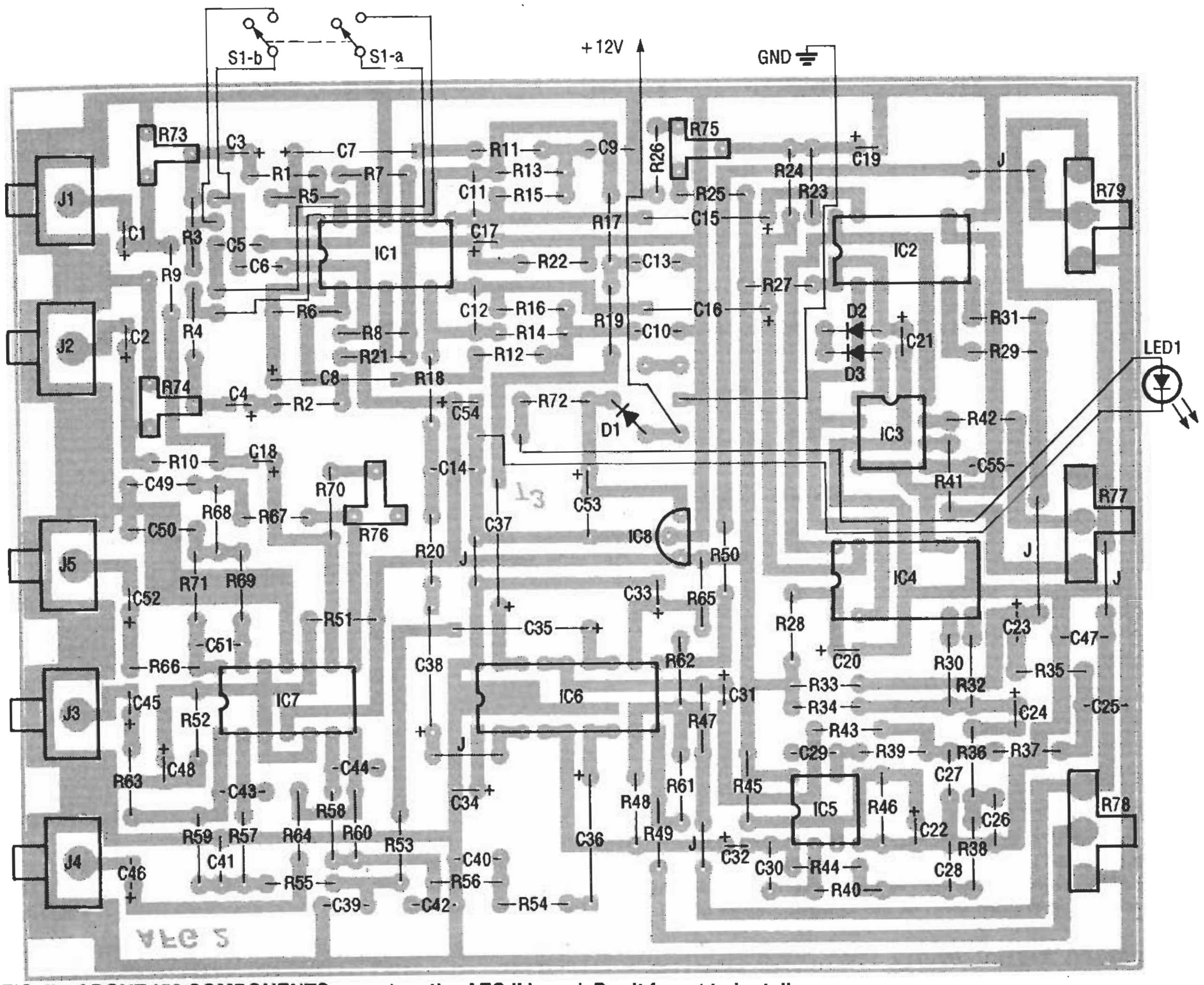


FIG. 7—ABOUT 150 COMPONENTS mount on the AFG II board. Don't forget to install the six jumpers, marked "J," where indicated.

RC network form an 80-Hz third-order low-pass filter. Because the filter inverts the signal another 180 degrees, the signal that appears at the output is back in phase with the signals at the inputs to the AFG II.

Finally, a brief word about the power supply. Rectifier D1, although unnecessary when operating the AFG II from an automotive DC electrical system, has been included in the circuit to serve as a protective device; it will protect about $50 worth of IC's if you should accidentally connect the unit to a car's electrical system with the polarity reversed. The AFG II can be powered from any source capable of supplying 14 to 18 volts of noise-free DC. A small, well-filtered DC wall transformer is all that's required to bench test the AFG II, or adapt it

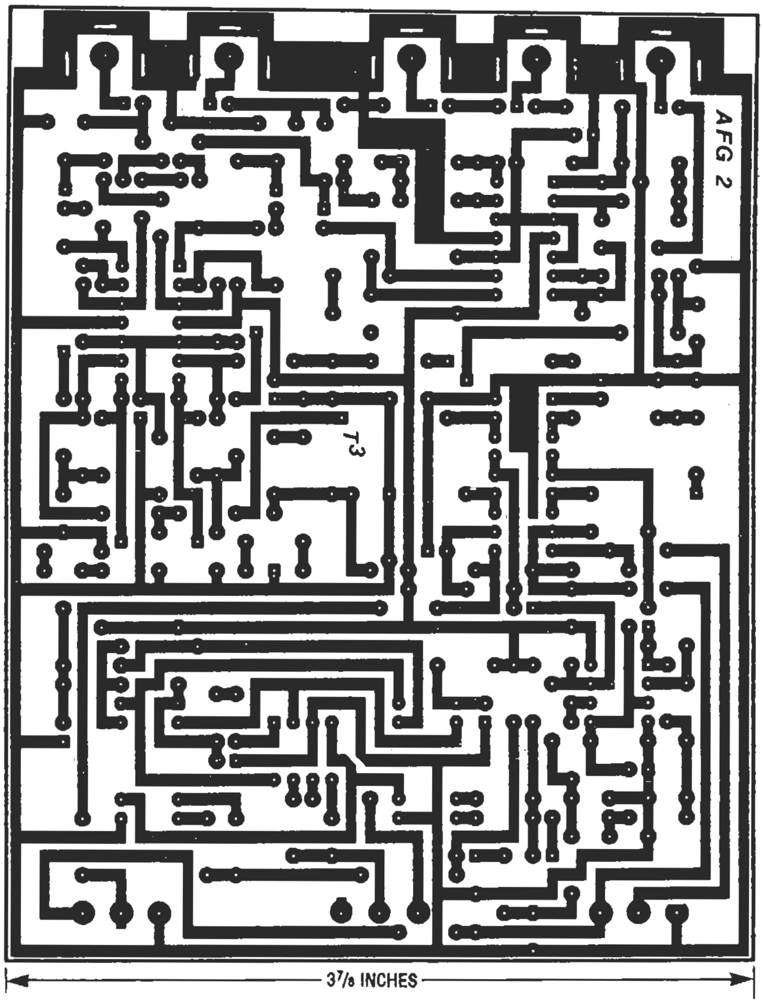
PARTS LIST

All resistors are ¼-watt, 5%.

R1–R4, R13, R14, R25, R26, R41, R53–R58, R67–R69—10,000 ohms
R5–R8, R33, R34, R43, R44—100,000 ohms
R9, R10, R17, R18, R23, R24, R35–R40, R47, R48, R70—47,000 ohms
R11, R12, R15, R16, R19, R20, R42, R59, R60, R71—20,000 ohms
R21, R22, R45, R46, R49–R52, R72—1000 ohms
R27, R28, R61–R66—100 ohms
R29–R32—5600 ohms
R73, R74—1000 ohms, horizontal PC-mount trimmer potentiometer
R75—10,000 ohms, horizontal PC-mount trimmer potentiometer
R76—100,000 ohms, horizontal PC-mount trimmer potentiometer
R77, R78, R79—50,000 ohms, PC-mount potentiometer

Capacitors

C1–C4, C18, C23, C24, C31, C32, C45, C46—2.2 µF, 50 volts, radial electrolytic
C5, C6—4700 pF, 50 volts, Mylar or metal film, 5%
C7, C8, C15, C16, C35–C38—2.2 µF, 63 volts, axial electrolytic
C9, C10, C13, C14—3900 pF, 50 volts, Mylar or metal film, 5%
C11, C12, C43, C44—220 pF, ceramic disc, 5%
C17, C19, C20–C22, C33, C48, C52, C54—10 µF, 35 volts, radial electrolytic
C25, C26—560 pF, ceramic disc, 5%
C27, C28—470 pF, ceramic disc
C29, C30—47 pF, ceramic disc, 5%
C34—100 µF, 16 volts, radial electrolytic
C39, C40—2700 pF, 50 volts, Mylar or metal film, 5%



FOIL PATTERN FOR THE AFG II.

C41, C42—2200 pF, 50 volts, Mylar or metal film, 5%
C47—0.1 µF, 50 volts, Mylar or metal film, 5%
C49—0.56 µF, 50 volts, Mylar or metal film, 5%
C50—0.47 µF, 50 volts, Mylar or metal film, 5%
C51—0.039 µF, 50 volts, Mylar or metal film, 5%
C53—2200 µF, 16 volts, radial electrolytic
C55—100 pF, ceramic disc, 5%

Semiconductors
IC1, IC7—LF347N quad op-amp
IC2, IC4—MN3008N 2048-stage BBD (Panasonic)
IC3—MN3101N clock generator (Panasonic)
IC5—LF353 dual op-amp
IC6—TDA1074 voltage-controled amplifier
IC8—78L12 12-volt regulator
D1—1N4001 diode
D2, D3—1N4148 diode
LED1—red light-emitting diode

Other components
S1—DPDT toggle switch
J1–J5—PC-mount RCA jack

Miscellaneous: four 14-pin IC sockets, one 8-pin IC socket, one 18-pin IC socket, project case, knobs for R77–R79, wire, solder

Note: The following items are available from T3 Research, Inc. 5329 N. Navajo Ave., Glendale, WI.53217-5036:
- **AFG II PC board only—$12.00 + $1.50 S&H**
- **Complete AFG II kit (includes all parts, PC board, and case)—$95.00 + $4.00 S&H**
- **A pair of 4096-stage MN3005 BBD's can be substituted for the MN3008's included in the standard kit—Add $30.00 to kit price**

Wisconsin residents must add 5½% sales tax to total amount before adding shipping charge.

for use with your home stereo system.

Construction

The AFG II is built entirely on one single-sided PC board. To make construction as easy and fast as possible, all of the components, including the input and output jacks, mount directly on the circuit board. Only the SURROUND SELECT switch and the power LED are mounted off the board; they are connected by short lengths of hookup wire. You can make the PC board yourself from the foil pattern provided, or you can order a finished board from the source listed in the Parts List. A complete kit of parts, including the custom case shown, is also available.

The printed-circuit board has many narrow foil paths and small pads which could be damaged by excessive heat during soldering. Use a low-wattage soldering pencil with a fine tip. And, be certain that you use *rosin core* solder.

The AFG II has about 150 electronic components mounted on its circuit board. To avoid errors, work slowly, and double check component values and polarity. Don't try to rush the project and build it in one night. Refer to the parts-placement diagram shown in Fig. 7, and begin construction by inserting the resistors on the circuit board first. Then, using some of the clipped resistor leads, install the six short jumpers (J) where indicated.

Two of the 14-pin IC sockets must be modified to match the unusual pin arrangement of the BBD IC's. Locate pin 1 of the socket, usually indicated by a notch or other unique indication at one corner. Referencing from pin 1, locate and carefully pry out or clip off pins 3–5 and 10–12 of both sockets. Examine the actual BBD IC if you are unsure of which pins to remove. Mount these and the remaining IC sockets next. Align pin 1 with the square-shaped pad on the circuit board. Don't install the IC's now; leave them in their protective shipping sleeve until called for later.

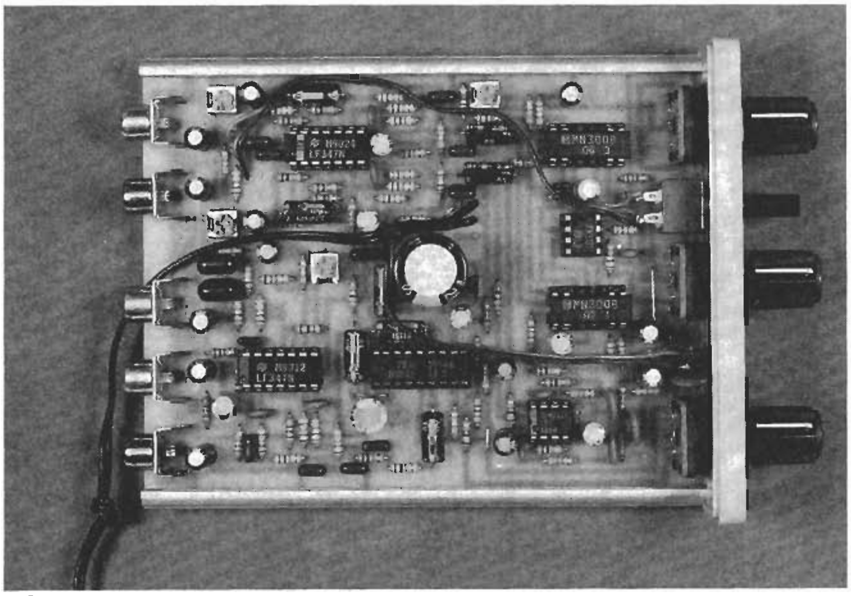


FIG. 8—Inspect the completed board for bridged foil paths and missed solder connections before you slide it into the guide rails of the case.

TABLE 1
SUBWOOFER CROSSOVER FREQUENCY

Corner Frequency	C49	C50	C51
50 Hz	.82 μF	.68 μF	.056 μF
80 Hz	.56 μF	.47 μF	.039 μF
100 Hz	.39 μF	.33 μF	.033 μF
120 Hz	.33 μF	.27 μF	.027 μF

All capacitors are 5% tolerance.

Continue by mounting the four trimmer potentiometers and the electrolytic capacitors. Match the negative lead of each capacitor to the square pad on the circuit board. Follow this by mounting the remaining disc and Mylar capacitors, then IC8, and diode D1. Finally, mount the five phono jacks (J1–J5) at the rear of the board and the three large potentiometers at the front of the board. Note: If the shafts of the potentiometers are too long for your application, cut them off *before* you mount them on the circuit board.

Use some insulated 26 to 28 AWG hook-up wire to make six jumper leads, each about five inches long. Solder these wires to the SURROUND switch and power LED first, then solder the other ends to the circuit board, being careful to match each lead to the proper pad. If you are using a wall transformer to power the AFG II, determine the polarity of its leads, and solder them to the board with the polarity indicated in Fig. 7. If you will be using the unit in your car, cut an appropriate length of 26 to 28 AWG hook-up wire to run between the AFG II and the power source in your vehicle. Solder the wires to the PC board first, and mark the positive lead for later reference.

All of the IC's in the AFG II are CMOS and, although they are rugged, handle them carefully to avoid ESD damage. If possible, try to keep one hand grounded while handling the IC's. Carefully place each IC in its socket as shown in Fig. 7. Make sure that none of the pins have become folded underneath the body of the IC. Figure 8 shows the inside of the completed prototype.

Setup

Use shielded patch cables to interconnect the AFG II to your audio system as shown in Fig. 1. If your auto radio does not have line-level outputs, you will need a matching transformer to go between the radio's rear speaker outputs and the AFG II inputs. These can be purchased at electronic supply stores which sell automobile audio equipment. Connect the positive lead of the AFG II's power input to the switched power output of the radio (if present). If your radio doesn't have a switched power lead, you might have to connect directly to the car's fuse block. Connect the negative lead to ground, preferably at the same point at which the radio is grounded.

Although there are no critical adjustments in the AFG II, trimmers have been provided to calibrate the signal levels of the unit to the requirements of your particular system. Begin by setting each trimmer to the center of its range. Next, turn everything on.

If all is well, you should hear sound coming from your surround (rear) speakers. Check that the VOLUME, DELAY, and REVERB controls of the AFG II operate properly. Set the SURROUND SELECT switch to off and set the VOLUME control to about the center of its rotation. Now adjust R73 and R74 (input sensitivity) in equal amounts to get the level from the surround speakers about equal to the level from the front speakers. If you have a subwoofer in your system, adjust R76 for proper drive to the subwoofer amplifier. Potentiometer R75 adjusts the bias voltage to the bucket brigade devices; set it for minimum distortion, which is usually at the exact center of its range.

Each component in your finished audio system will probably have its own volume control. There will be one on the radio, one on an equalizer, if used, one on your power amplifier, and, of course, one on the AFG II. To get the best possible signal-to-noise ratio from the AFG II, the audio level fed into it should be at the highest possible level that does not cause any distortion. Since you will most likely want to use only the volume control on the radio to control the entire system volume, it might be necessary to perform

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some experiments with audio levels at various lcations in the system to achieve optimum results.

Other considerations

Capacitors C49–C51 (surrounding IC7-d in Fig. 6) tune the crossover frequency of the subwoofer low-pass filter. The values indicated in the Parts List and Fig. 6 produce a filter that has its −3 dB point (corner frequency) at approximately 80 hertz, which is a good frequency for most automobile subwoofer systems. However, if you experience excessive resonance or "boominess", you can move the crossover point up or down by changing the values of the filter-tuning capacitors as indicated in Table 1. All three capacitors must be changed as a set, and they should have a tolerance of 5 percent.

The AFG II, as described here, is capable of providing ample amounts of delay and reverberation for most listening situations. However, it is possible to double the available delay by substituting MN3005 4096-stage bucket-brigade devices for the MN3008 2048-stage devices used in the prototype. The pinouts of the two IC's are identical, and no other changes to the circuit are necessary if you choose to use the 4096-stage devices.

Actual delay and reverberation adjustments are, of course, a matter of individual taste, but note that in live listening situations, the amount of delay and reverberation reaching the listener are a small percentage of the overall sound field. Also, using the AFG II in the surround mode will highlight any reverberation and delay which might exist in the original audio signal. To achieve the most realistic listening environment, judicious and sparing use of reverberation and delay are recommended. If you add too much, the sound becomes artificial and even annoying to some people. Ω