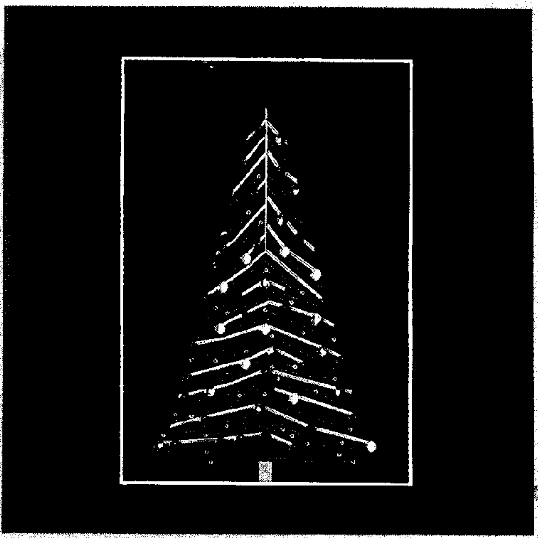
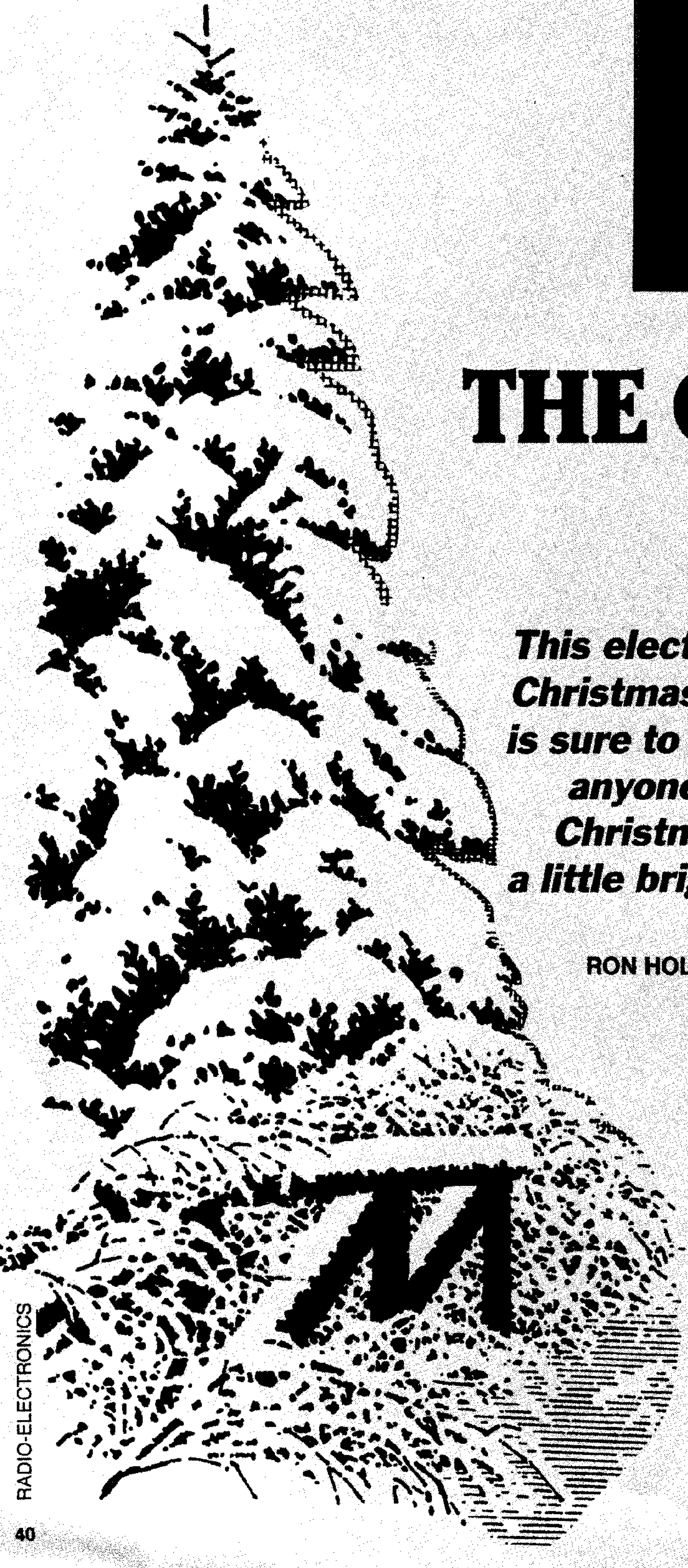




THE CHRISTMAS CARD

This electronic Christmas tree is sure to make anyone's Christmas a little brighter.

RON HOLZWARTH

HERE'S A PROJECT THAT YOU'LL BE happy to display in your front window this Christmas season—it also makes a great gift that anyone else would love to display in his or her window. The electronic Christmas tree is actually made from a printed circuit board with traces that form the branches of the tree. Different colored LED's mounted on the board simulate Christmas-tree lights. A built-in microphone picks up any audio signals—such as Christmas music—and different strings of LED's light according to the spectral distribution of the audio within a frequency band selected by the constructor. When installed in the custom metal frame, all of the electronics and the batteries are hidden behind the black mat and protected by the front glass. The end result is an attractive little Christmas tree whose lights will blink in unison with any kind of audio.

The photographs cannot convey the effect of the flashing lights, nor the vivid impression of seeing sound. Music becomes a quickly moving pattern of dancing lights. In fact, any sound becomes an interesting display as the microphone, which tops the tree, picks up any sound in the room. For the hearing-impaired, it opens up a new window to sound.

The project is also good for those who wish to learn about audio. For example, the tuning fork option only receives frequencies very near A440. But, it is hard to vocalize anything at any pitch without generating a display. In fact, singing notes far lower than A440 generates various displays. In addition, inflections, such as the rise in pitch that usually accompanies the conclusion of a question, are quite visible.

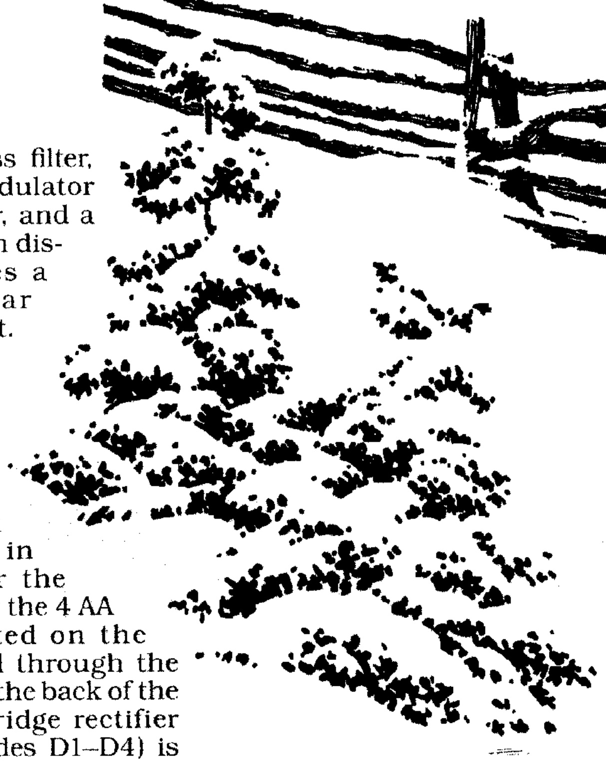
The unit is powered from four AA batteries, although an AC adapter jack is also included so that battery power can be conserved. It is a good idea to use an AC adapter whenever possible, as battery life is limited to about eight hours, depending on the volume level of the audio signal (more or less LED's will light), and the options selected.

The strings of LED's can be more accurately thought of as bar graphs. The device includes an amplitude-discrimination circuit that selects the harmonics of greatest amplitude and displays those harmonics in bar mode, at which time all others are in dot mode.

An interesting experiment would be to interface the board with other circuitry. The outputs of the drivers are TTL- and CMOS-compatible. Since most LED posts can be wire-wrapped, wiring selected outputs to an input port is easy. The device can then function as a front end to allow your computer to monitor sound waves without the complexity of digital filtering. The outputs can also be used to operate relays, allowing lights of any power level to be used.

Circuit operation

Although the circuit may at first seem complicated, it really isn't. Figure 1 shows a block diagram of the circuit. Signals from the microphone are amplified, filtered, and automatically adjusted for gain in the automatic gain control (AGC) section. The sections that follow are duplicated four times. All four sections are identical except for the frequencies that they handle. Each section has a level-adjust potentiometer, a bandpass filter, level shifter, demodulator and discriminator, and a display driver. Each display driver drives a separate LED bar graph at the output. Three of the bar graphs (A–C) contain ten individual LED's, and one of them (D) contains twenty.



Let's take a look at the schematic in Fig. 2. Power for the unit is supplied by the 4 AA batteries mounted on the board or supplied through the power jack (J1) on the back of the board. Since a bridge rectifier (consisting of diodes D1–D4) is used, DC of either polarity can be used, as well as AC. The batteries are disconnected whenever a plug is in the power jack.

Two large electrolytic capacitors, C19 and C20, damp any transients caused by power surges when a large number of LED's are lit. A voltage divider is formed by IC14, an LM336-2.5, which operates much like a Zener diode, but without nearly as much variation in reference voltage. The device has three terminals, and physically looks like a transistor. However, the third terminal is not needed in this application, so the device is drawn in the schematic as a Zener diode. The reference voltage from IC14 is divided and then wired to op-amp IC1-c which is in a buffer configuration. The output of IC1-c (pin 8) then serves as an analog ground for later portions of the circuit.

The output from the electret microphone (MIC1) appears as an AC waveform. It is amplified by IC1-b, which is configured as a non-inverting amplifier with an adjustable gain set by potentiometer R8.

The next stage is a bandpass filter (IC1-a), which selects the frequencies to be used by later portions of the circuit. Following the initial filter is the AGC that limits the signal when the output reaches approximately 1.1 volts peak-to-peak. The gain will increase slowly during periods of silence, reaching maximum sensitivity after approximately three seconds.

The AGC section consists of op-amp IC1-d configured as a non-inverting amplifier. When the output of IC1-d increases, Q2 turns on and allows a small amount of current to flow into C4. That will raise the gate voltage of Q1, effectively lowering the resistance of R12, thus decreasing the gain of the amplifier as a whole. In the rest of the discussion, only one filter (filter A which controls bargraph A) will be described, as the others are identical except for a few resistor values.

A level-adjust potentiometer (R17) is next, followed by a buffer (IC2-a). As the potentiometer setting is increased, the amplitude of the filter output increases, causing more LED's to light at the output.

The stage that follows is nothing more than a summing amplifier. The input signal is summed with a portion of the output from the filter that follows. With a little positive feedback from the filter output, the Q is increased. Within the feedback network is another filter which has a resistive divider attached to it that causes it to act as a unity-gain filter.

The next section is the level shift, which is necessary since the output of the filter appears as an oscillation about the analog ground. The display drivers require an input measured from true ground, hence the level shift section is needed to amplify the output as well as lower the waveform so that it is relative to ground.

The output of the level-shift section, which is a series of half sine waves, goes through D7 to a resistor and capacitor in parallel (R61 and C14). Note that this is similar to a conventional AM demodulator. The resistor values control the rate at which the display falls back to a zero state. Increasing the resistor values will make the display fall back (turn off) at a slower rate.

The output of the demodulator goes to the amplitude discriminator, which is an op-amp configured as a comparator. Germanium diode D11 will conduct whenever one of the filter outputs reaches 0.2 volts. Thus, C18 will charge and remain at 0.2 volts below the highest DC level. That causes the comparator for the filter output of the highest DC level to switch its output to a high state. That output connects to the control input of one section of a 4066 bilateral switch which connects power to pin 9 of the corresponding LED driver putting it in bar mode.

Resistor R65 is of a much larger value than R61–R64. Thus, when the filter output begins to decrease, the driver returns to dot mode and does not go back to bar mode until the output increases. The time constant is set so that the voltage has significantly decreased in about one second, so the rhythm of the music is displayed as the LED's shift to bar mode at each beat. Varying the RC time constant will make the device operate differently.

Bargraph D is driven by two drivers (IC12 and IC13) stacked end-to-end. They are made to function exactly as the others as far as the dot-to-bar mode transition is concerned. The display drivers (IC9–IC13) control the lighting of the LED's according to the input voltage. A databook should be consulted if you wish to know more about the operation of the display drivers.

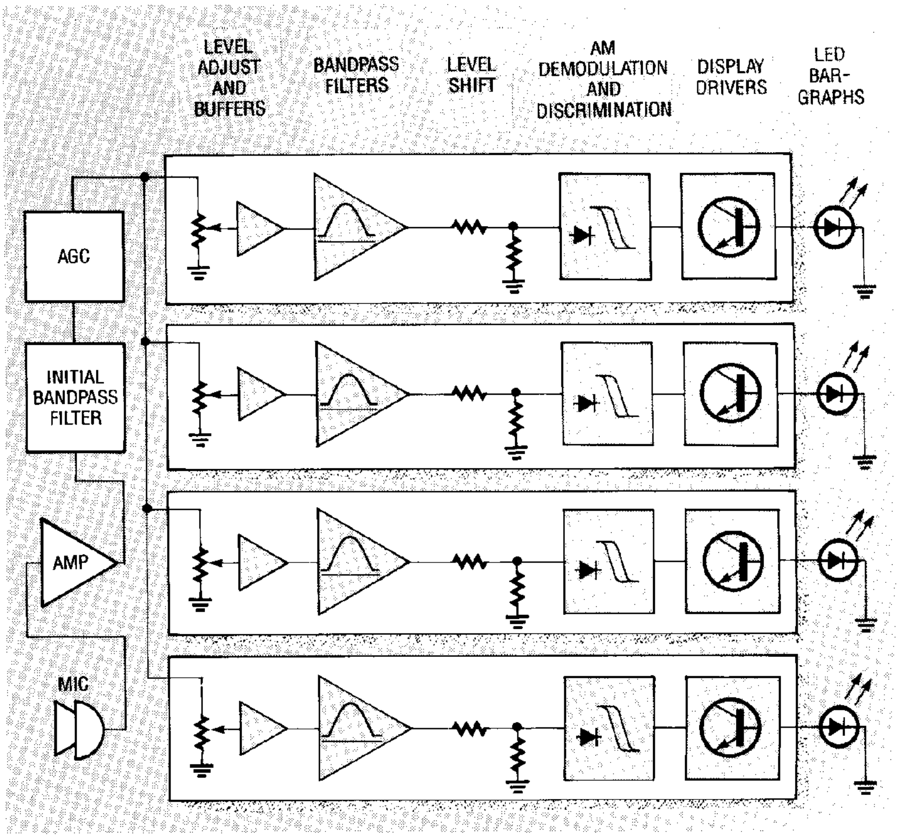


FIG. 1—BLOCK DIAGRAM OF THE CIRCUIT. Signals from the microphone are amplified, filtered, and automatically adjusted for gain.

Filters and Q

The Q of a filter defines how narrow the passband is. It is equal to the center frequency divided by the difference in frequency between the −3-dB points. The −3-dB frequency is the frequency at which the peak-to-peak voltage is attenuated by one half from that at the center frequency, assuming a constant voltage at the input.

Assuming we want a center frequency of 440 Hz, which is the American tuning standard for musical instruments, and we want A flat (415.3 Hz), one half step down, to be a −3-dB frequency, and A sharp (466.16 Hz), for the other −3-dB point, 440/(466.16−415.3) = 8.65. That would be the Q required for an attenuation of one half when stepping up or down one key on a piano.

Interestingly enough, the same Q is required to accomplish that across the entire keyboard. This is a necessary consequence of our tuning scale, which is now defined as the twelfth root of two multiplied repeatedly at each step. A logarithmic scale was thus developed by musicians centuries before mathematicians had opened their eyes, so to speak—$17/18$ has been used for the approximation of this factor, which results in an error of less than one percent. It has been used for the construction of guitars and similar stringed instruments for over three hundred years.

The Delyiannis-Friend bandpass filter (the type used in this project) was first described by T. Delyiannis in 1968. It has a number of advantages over some other filters, such as reduced sensitivity to component tolerances, minimal parts count, and a relatively easy-to-understand design algorithm. It has been described as a bridged-T RC circuit with an op-amp to provide negative feedback.

There are only two parameters needed to design a bandpass filter. They are the center frequency desired for the passband, and the Q, or quality factor. The bandpass filter in its simplest configuration is shown in Fig. 3. That filter has a bandpass center frequency of $1/2\pi$ Hz. The first step in designing is to assign numerical values—that is, substitute the Q required. Assuming a Q of 4, $1/2Q = 0.125$, and $4Q^2 = 64$.

After assigning numerical values for each of the components, the filter is scaled up in frequency by dividing the capacitor values

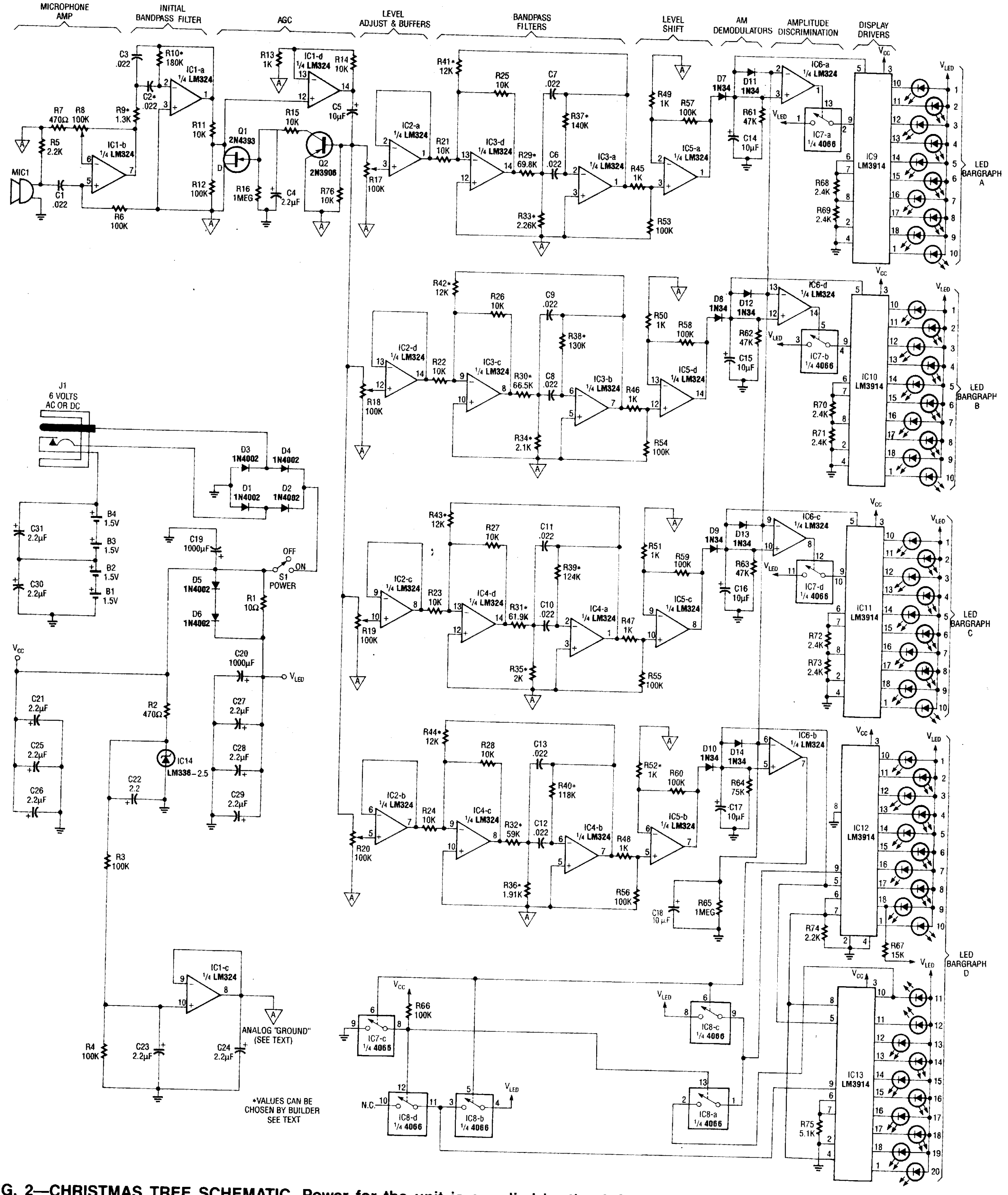


FIG. 2—CHRISTMAS TREE SCHEMATIC. Power for the unit is supplied by the 4 AA batteries or via the power jack on the back of the unit.

by the difference in frequency required. Assume the frequency required is 440 Hz. The difference in frequency required is equal to:

$$f_{NEW}/f_{OLD} = 440/(1/2\pi) = 880\pi$$

The capacitor value (0.125 F) is then divided by this number, giving 4.52×10^{-5}, the new capacitor value for our filter.

The next step, scaling to realistic values, is best described by an analogy. In an RC network, the time constant remains unchanged if the capacitor value is divided by any constant, just as long as the resistor values are multiplied by the same constant.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise indicated.
R1—10 ohms
R2, R7—470 ohms
R3, R4, R6, R12, R53–R60, R66—100,000 ohms
R5, R74—2200 ohms
R8, R17–R20—100,000 ohms, multiturn potentiometer
R9, R10, R29–R44—option dependent, see text and Table 1
R11, R14, R15, R21–R28, R76—10,000 ohms
R13, R45–R52—1000 ohms
R16, R65—1 megohm
R61–R63—47,000 ohms
R64—75,000 ohms
R67—15,000 ohms
R68–R73—2400 ohms
R75—5100 ohms
Capacitors
C1–C3, C6–C13—0.022 µF, 5% metal film
C4, C21–C29—2.2 µF, tantalum
C5, C14–C18—10 µF, tantalum
C19, C20—1000 µF, electrolytic
Semiconductors
IC1–IC6—LM324 quad op-amp
IC7, IC8—CD4066 quad bilateral switch
IC9–IC13—LM3914 bar/dot LED driver
IC14—LM336Z-2.5-volt reference
Q1—2N4393 or 2N3972 MOSFET
Q2—2N3906 PNP transistor
D1–D6—1N4002 rectifier diode
D7–D14—1N34 germanium diode
Bargraph1–Bargraph4—50 LED's, assorted colors (3 groups of 10, 1 group of 20—see text)
Other components
MIC1—1-volt PC-mount electret microphone
J1—coaxial barrel-type power jack (Shogyo SJ-0202)
S1—C&K 7000-series right-angle SPDT switch
B1–B4—AA battery
Miscellaneous: PC board, two battery holders (Keystone 2223), metal frame and cover glass, six ⅝-inch spacers, solder, a bit of Christmas spirit, etc.

Note: The following is available from ART WORKS, Box 753, St. Francis, Kansas 67756: PC board, $35 each (three or more, $30 each); Partial kit, including PC board, all components including S1, J1, battery holders, and all 1% resistors listed (does not include LED's, frame, or spacers), $90 each (three or more, $80 each); Complete kit, including all of the above, plus 50 LED's in four colors, spacers, flat-black metal frame, front glass and mat, $125 each (three or more, $100 each). All prices include shipping and handling. Check or money order only. Please order early—we will do our best, but cannot guarantee delivery in less than 30 days. When making technical inquiries please include a SASE.

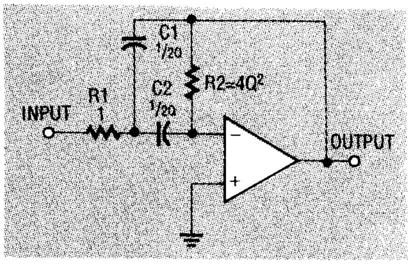


FIG. 3—A BANDPASS FILTER in its simplest configuration. It has a bandpass center frequency of 1/2π Hz.

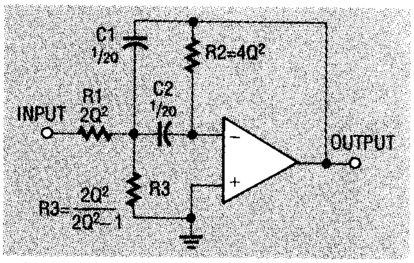


FIG. 4—WHEN DESIGNING a unity-gain filter, a voltage divider must be added to the input.

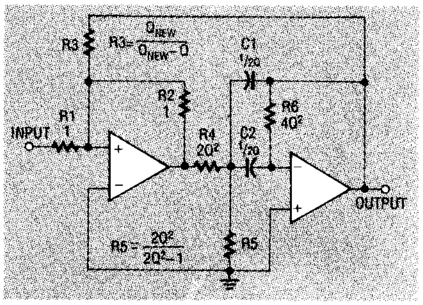


FIG. 5—TO RAISE THE Q, positive feedback is added to the filter input.

The same concept happens to be true in an op-amp filter. That is, the center frequency (and Q) will be unchanged when this step is taken.

A capacitor value of 0.022 µF results in realistic component values across the entire audio band, provided the Q is not too high. So, since the capacitor values will all be 0.022 µF, we can divide 4.52×10^{-5} by 0.022×10^{-6}, resulting in 2,055. Both of the resistor values in Fig. 3 are then multiplied by that constant, resulting in 2,055 and 131,533 kilohms.

At this point, it is a good idea to check your work. The values just obtained should be substituted into the following equation:

$$f = 1/2\pi C\sqrt{R1R2}$$
$$= 1/2\pi(0.022 \times 10^{-6} \times \sqrt{2{,}055K \times 131{,}533K})$$

The result should be the original frequency. That equation can also be used to check the variance in center frequency when standard component values are substituted, or to analyze an already existing filter.

In designing a unity-gain filter, a voltage divider must be added to the input, as shown in Fig. 4. Since the new R1 is one half of R2, that value is easy to calculate. For the new R3, the factor

$$2Q^2/2Q^2 - 1 = 2(16)/2(16) - 1$$
$$= 1.032$$

is then multiplied by the old R1, resulting in 2121.5.

To raise, or enhance the Q, positive feedback is added to the filter input, as in Fig. 5. The values for R1, R2, and R3 of Fig. 5 do not need to have the same scale factor as used before. A fine value for R1 and R2 is 10K; R3 will then be

$$10K(Q_{NEW}/Q_{NEW} - Q)$$

or, for our example,

$$10K(Q_{NEW}/Q_{NEW} - 4)$$

where Q_{NEW} is the desired Q of the complete filter. The last step is to determine the closest standard value for each resistor.

There are four versions of the unit that can be built without having to make any calculations. The four versions are the broadband option, the lower-four-guitar-strings option, the upper-four-guitar-strings option, and the tuning fork option. The tuning fork option is a good general-purpose version that will provide a nice display with most audio inputs.

To use any of those options, you must refer to Table 1; it shows the resistor values you'll need to use for the four filters to achieve the specified frequencies. Also, depending on which option you choose, the initial bandpass filter must be set up accordingly.

To use Table 1, first refer to the top section to determine the resistor values for the initial bandpass filter, the other four bandpass frequencies, and any special provisions for the particular option. Then, from the bottom section, determine the resistor values for the other four filters according to the frequencies listed in the top section. The resistor numbers shown (R29, R33, and R37) are for filter A. For filter B, add 1 to the resistor number (for example, R29 becomes R30, etc.). For filter C, add 2 to the resistor number, and for filter D, add 3.

Although you can assign any of the four frequencies to any of the four filters, the display will be most interesting if you use the lowest frequency for filter A, next highest for B, and so on. Note that where it says to delete a component, you should leave it out but DO NOT jumper the pads on the board. Where it says to jumper a component, you should leave it out and solder a jumper between the pads.

Construction

If you like, you can etch your own PC board since the foil patterns for the double-sided board are provided. However, an etched, drilled, plated-through, and silkscreened board is available from the source mentioned in the parts list. Keep in mind that the cosmetic effect of the green mask, silver branches, and white snow will be lost if you make your own board. Locating the components for installation is also easier using the pre-made silkscreened board. Complete and partial kits for the Christmas tree are also available.

Before beginning construction, you have to decide on how you want your LED's arranged. The author's intention was to make each detected harmonic a separate color. However, you are free to arrange the LED's in any pattern you choose, and you can also use whatever colors you like. In any case, the silk screening on the pre-made board indicates which bar graph each light belongs to; there are short white lines between the LED leads. The lines going up (from left to right) are for bargraph A, the horizontal lines are for bargraph B, and the ones going down (from left to right) are for bargraph C. Bar-

TABLE 1

Lower Four Guitar Strings Option: (E3, A3, D4, G4)
Initial Filter Q = 1.5 Center Frequency = 270 Hz
R9 = 9.1K R10 = 82K R41–R44 = 11K

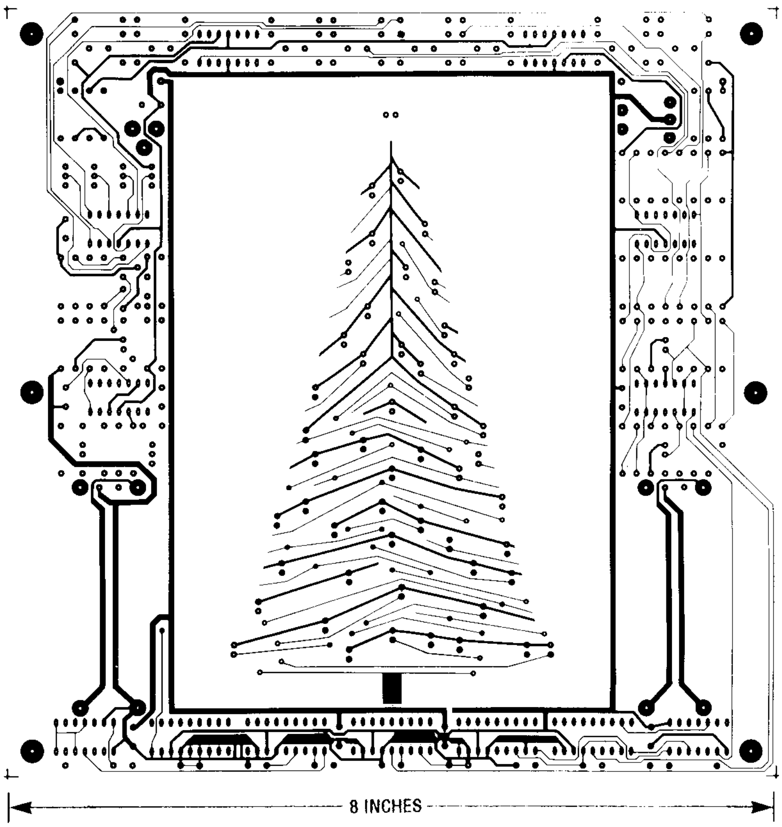
Upper Four Guitar Strings Option: (D4, G4, B4, E5)
Initial Filter Q = 1.5 Center Frequency = 470 Hz
R9 = 5.1K R10 = 47K R41–R44 = 11K

Tuning Fork Option: (A4 flat, A4, A4 sharp, B4)
Initial Filter Q = 5.8 Center Frequency = 470 Hz
R9 = 1.3K R10 = 180K R41–R44 = 12K

Broadband Option: (E2, A3, B4, F6 sharp)
(Jumper C2, delete C3)
R9 = 1K R10 = 100K delete R41–R44

Note	**(frequency)**	**R29**	**R33**	**R37**
E3	(164.81 Hz)	174K	5.62K	348K
A3	(220 Hz)	133K	4.22K	261K
D4	(293.66 Hz)	97.6K	3.16K	196K
G4	(392 Hz)	73.2K	2.37K	147K
A4	flat (415.3 Hz)	69.8K	2.26K	140K
A4	(440 Hz)	66.5K	2.10K	130K
A4	sharp (466.16 Hz)	61.9K	2K	124K
B4	(493.88 Hz)	59K	1.91K	118K
E5	(659.26 Hz)	44.2K	1.40K	88.7K
E2	(82 Hz)	11K	delete	680K
A3	(220 Hz)	4.22K	delete	261K
B4	(493.88 Hz)	1.8K	delete	118K
F6	sharp (1480 Hz)	620 ohms	delete	39K

NOTE: All versions except the broadband option require 1% resistors.



COMPONENT SIDE of the Christmas tree at half the actual size.

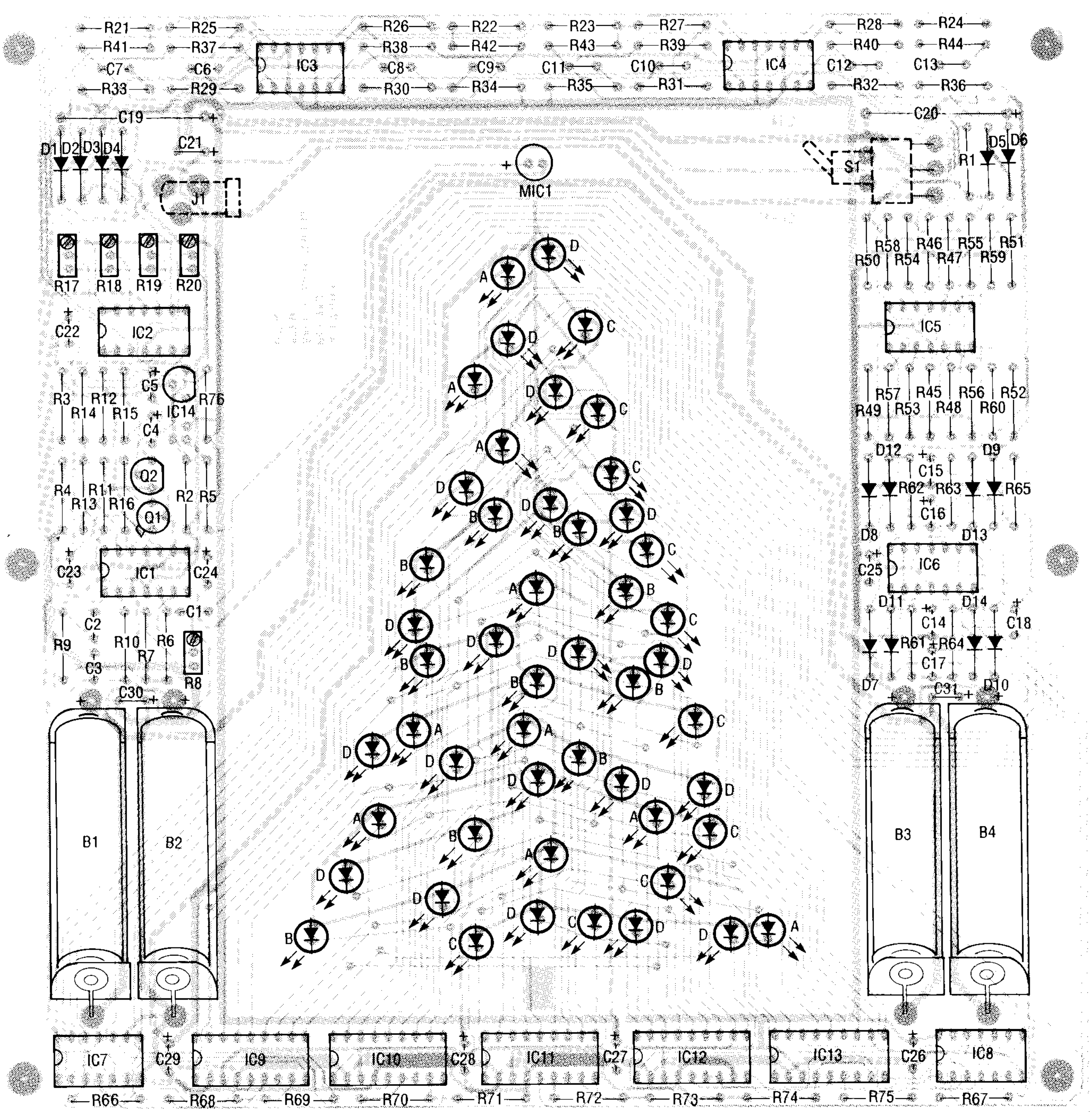


FIG. 6—ALL OF THE COMPONENTS mount on the front of the board, with the exception of J1 and S1; they mount on the solder side. Use a separate color for each LED bargraph.

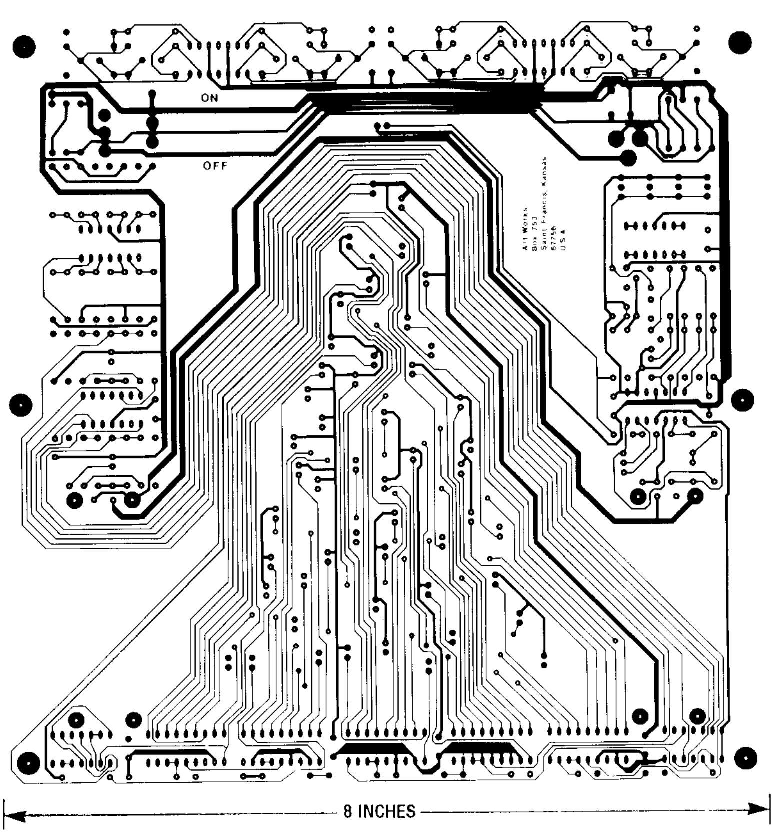
graph D is indicated by the absence of a short white line.

When installing the components, start with the LED's, as shown in the parts-placement diagram of Fig. 6. The letters next to the LED's indicate which bargraph they belong to. You should probably spend a minute or so looking at how the LED's are arranged on the printed circuit board because, once the device is assembled, the pattern becomes very confusing and the short white lines are covered by the LED's.

The LED's are installed with the cathode (the flat side) toward the bottom of the board. It's best to first solder one lead of each LED and then check for uniform positioning. Straighten them out where necessary, and then solder the other leads. Remember, that if you want to interface your tree to other circuitry later on, to leave enough extra lead on the back of the board to allow a wire-wrap connection to be made. Be sure to work carefully, so that you'll be able to bring out this project for many a Christmas to come. If you install all the components properly, it's very likely that the device will operate correctly right off the bat.

From the photo in Fig. 7, you can see the six spacers that are installed on the board to hold it in place within the metal frame. It's a good idea to install the spacers now, since they will protect the LED's from being damaged and can also support the board steadily. Now continue installing the rest of the components on the board.

You must now decide what fre-



SOLDER SIDE of the Christmas tree at half the actual size.

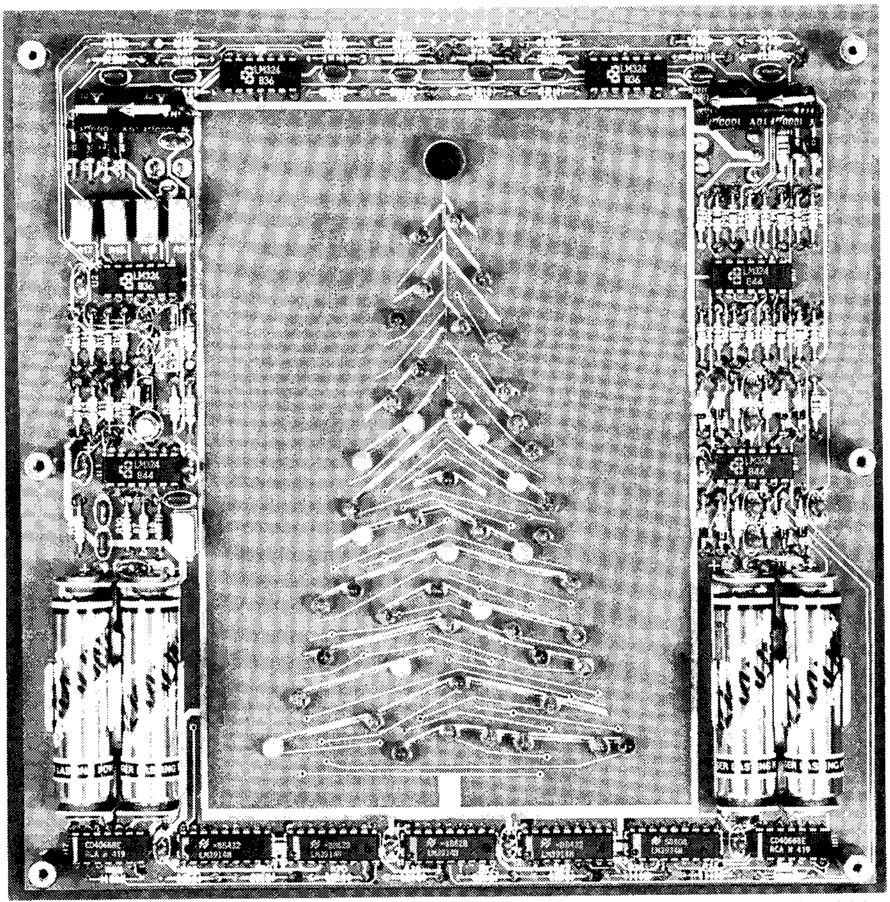


FIG. 7—THE SPACERS THAT HOLD THE BOARD in place in the metal frame should be installed early to prevent damage to soldered components.

quencies your Christmas tree will respond to. If your device is to be an assistance to the hearing-impaired, the broadband option will be the best, as both low frequencies and the high pitch of a police siren will be detected. For a musical version, you will have to make a decision based on your instrument of choice. Perhaps you can consult with a musician friend on this. You can re-tune the device at any time by simply changing a few resistors. All the components required for each suggested version are included in the kit. Remember that the initial filter must be "in harmony" with the other filters. They cannot detect frequencies that the initial filter doesn't pass. Refer to Table 1 when choosing frequency determining resistor values, or you are free to calculate your own values.

A word to the wise: put a set of batteries in the holders before soldering them. If you don't, the contacts on the battery holders are too close together which makes battery changing extremely difficult. Also, remember that the ON/OFF switch and the DC power jack mount on the solder side of the board as indicated by the dashed lines in Fig. 6.

Checkout

After checking for incorrectly installed components, poor solder joints, and shorts, and making sure to correct any problems, install a set of batteries or connect a 6-volt power source to the power jack. Turning the power switch on will cause many of the LED's to light. After which point, they will step down to position one, then go out. This is normal operation as the device approaches steady state. Slowly increase the gain of the initial amplifier by turning R8 clockwise. Go back and forth between one of the level-adjust potentiometers and R8, increasing them a little bit each time until one of the bargraphs responds to the sound of your voice. Make sure that none of the potentiometers are set too high, as troublesome oscillations may occur.

Alternatively, connect a voltmeter to the junction of R15 and R16 and increase the setting of R8 until speaking directly into

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CHRISTMAS CARD

continued from page 47

the microphone causes a voltage to appear. Do not increase the setting until R17 through R20 are adjusted so as to give a complete range through each bargraph. The best bet for making these adjustments is to play a stereo audio source (actually, any source will do) at a normal listening level. Simply adjust the potentiometers for what you consider to be a pleasing or most Christmas-like interpretation of the sound.

If you have any problems with the device, the first thing to do is decrease the setting (counterclockwise) of all the potentiometers. A filter that still oscillates after decreasing the potentiometers most likely has an incorrect component or one that does not meet its tolerance.

For high-Q versions of the circuit, sometimes the component tolerance is such that the filter will begin to oscillate when presented with a large input. If that's the case, all you must do is interchange the two filter capacitors; this old technician's trick usually works, assuming that there aren't any problems with the other components.

If you still have problems, check that the analog ground is stable. A variation on that line will cause serious problems with the operation of the unit. If you cannot find the problem, the best thing to do is to shut off the display by lifting one lead of both R1 and D5. With the load of the display removed, it's easier to locate problems.

The finished, working board can be installed in any kind of housing you like, although the custom black metal frame adds a nice touch, as does the mat that keeps the circuitry from view. After installing the unit in the frame you may want to readjust the potentiometers, since the frame and front glass seem to couple the microphone to the surrounding air. Vibrations picked up by the device will also produce a display; a fan operating nearby is almost always displayed. Have fun, and don't forget to have a merry Christmas, as well! **R-E**