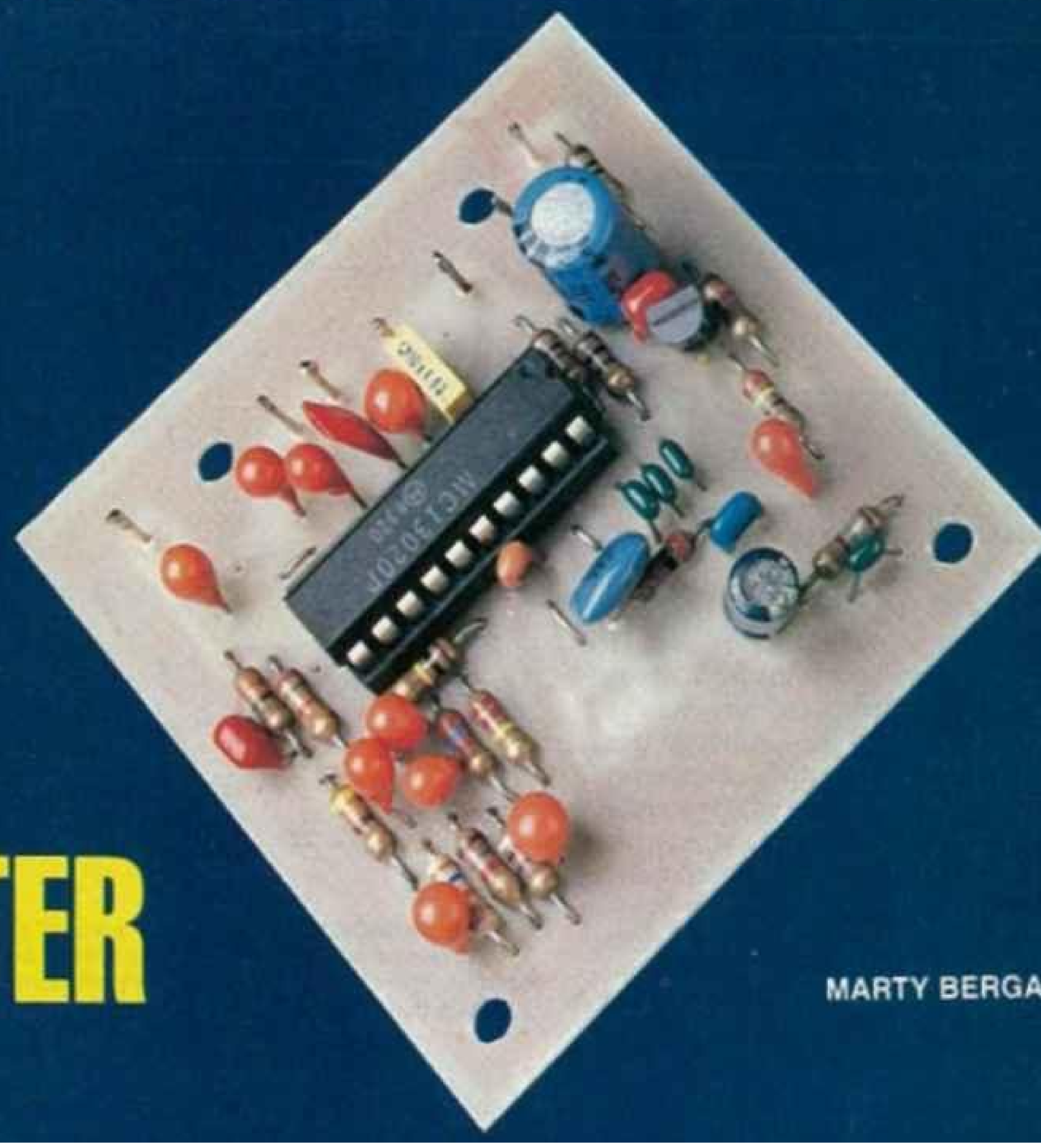
BUILD THIS

C-QUAM AM STEREO CONVERTER



MARTY BERGAN*

AM stereo broadcasting is now well under way and more stations are beginning stereo broadcasts every week. Hear for yourself what all the fuss is about by converting your AM radio to receive C-QUAM stereo broadcasts.

STEREO BROADCASTING BY AM RADIO stations was authorized in March, 1982 by the Federal Communications Commission (FCC). AM broadcasters hoped that the introduction of stereo would help to bring back many of the listeners they lost to FM radio. If you want to find out what AM stereo sounds like, it's easier than you think. You don't have to go out and buy some special receiver—you can convert your present AM radio to receive stereo C-QUAM broadcasts.

The C-QUAM system, designed by Motorola, is one of four systems that the FCC authorized for AM stereo broadcasting. (The Commission declined to determine which of several competing technologies would become the industry standard and instead took a "wait-and-see" attitude. In that way, the marketplace could decide which system would become the standard.) In this article, we will take a look at what the C-QUAM system is and then we'll look at how an AM radio can be converted to decode stereo.

Let's say right from the start, though, that many radios are simply not capable of handling stereo. We'll explain the reasons for that and we'll explain ways around some of the problems. Because AM radios now on the market were not designed to accommodate stereo requirements, you might convert a radio but then be disappointed by the results. We'll give you some pointers on how to choose a good candidate for conversion.

Each of the hundreds of radio designs will probably behave and sound a little different. But each radio's problems can be resolved with the right know-how and test equipment. For those of you who are not equipped to handle such problems, the stereo conversion may be a disappointment, and you might be better off to wait a few months until the AM stereo receivers become available in the marketplace. But if you want to learn about this new system, and you have a good receiver to start with, then the conversion described here should be accomplished easily and successfully.

What is C-QUAM?

C-QUAM is an acronym for Compatible *QU*adrature *A*mplitude *M*odulation. That's certainly a mouthfull—let's see what it means. The most important word there is *compatible*. That means that any ordinary (monaural) AM radio can receive a C-QUAM broadcast and produce the same results as it would if it received a monaural signal. In other words, the C-QUAM system does not make standard radios obsolete—as is necessary to gain FCC approval. C-QUAM is a *quadrature* system. That means that it somehow uses the relationship between two periodic functions that differ in phase by 90°. We'll take a closer look at that shortly. But let's first say that the final term in the acronym indicates that the transmitted signal is amplitude-modulated by each of the two periodic functions that we just mentioned.

A quadrature system combines and transmits two signals that are 90° out-of-phase with each other. Of course, those two signals must be separated again at the receiver, and that's the purpose of this

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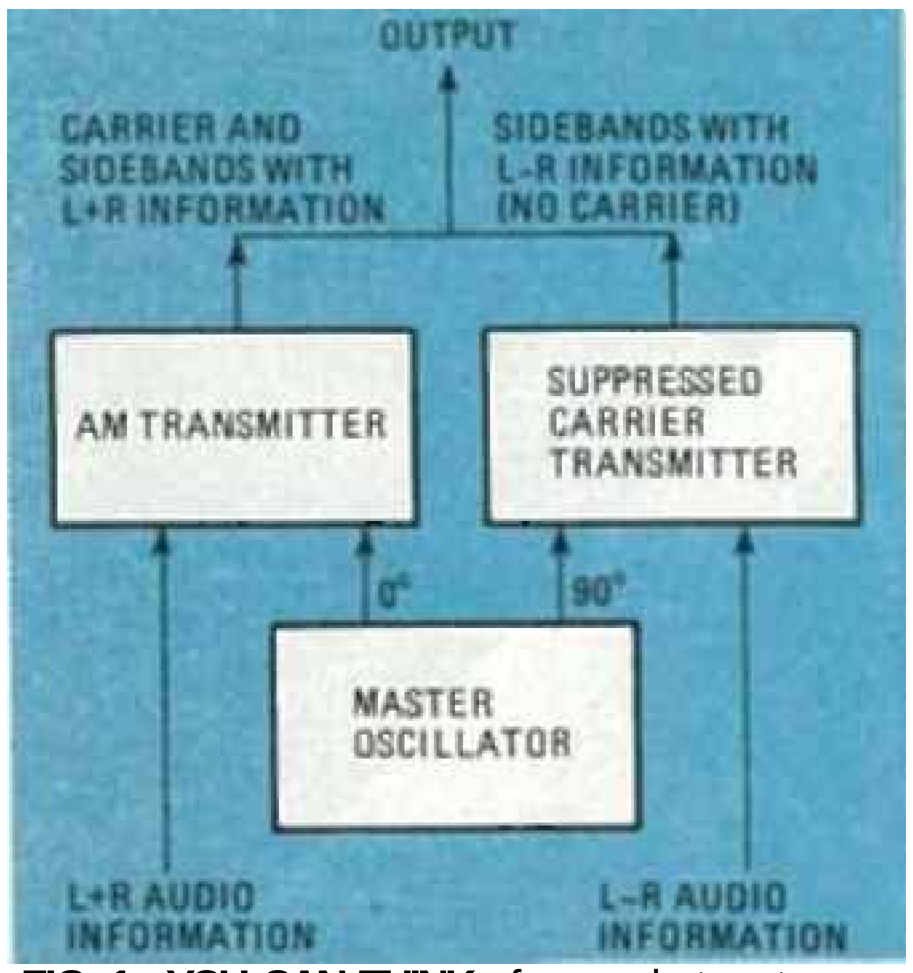

FIG. 1—YOU CAN THINK of a quadrature transmitter as one actually made up of two transmitters that are out of phase by 90°.

decoder. AM stereo is not the only place that quadrature modulation is used. For example, color information for TV broadcasts is transmitted in a similar way.

You can think of the quadrature transmitting system as one with two transmitters, as shown in Fig. 1. One transmitter is a standard AM transmitter at, say, zero phase. It transmits a carrier as well as sidebands that contain audio information (the I sidebands). The second transmitter operates 90° out-of-phase with the other. Because a carrier already exists to provide a phase reference for the receiver, we do not want another to be generated. So the second transmitter cancels out the carrier and produces only sidebands (the Q sidebands). Now, since those Q sidebands are generated from a carrier that is 90° out-of-phase from the original carrier, they are 90° out-of-phase with the I sidebands. In other words, the I and Q sidebands are in quadrature.

What information do the I and Q sidebands contain? The I sidebands contain the sum of the left- and right-channel audio information, or L + R signals. The Q sidebands contain the difference of the information of the two audio channels, or L - R signals.

There is a problem with quadrature-modulated signals, though. They produce distortion in the envelope detectors of normal AM radios. So a quadrature stereo system is not compatible with existing radios. That's because the envelope detectors in normal AM radios don't see the I and Q sidebands separately—they see the sum of the two, as shown in Fig. 2-a. One vector represents the L + R information that is modulated on the carrier (at what we'll call 0°). The other vector is the The L - R information that's modulated on the suppressed carrier (at what we'll call 90°). The magnitude of the sum of those two vectors—which the receiver's envelope detector sees—is:

$$\text{Sqrt.}(1+R+R)^2+(L-R)^2.$$

However, the envelope detector in a standard AM radio expects to see simply the

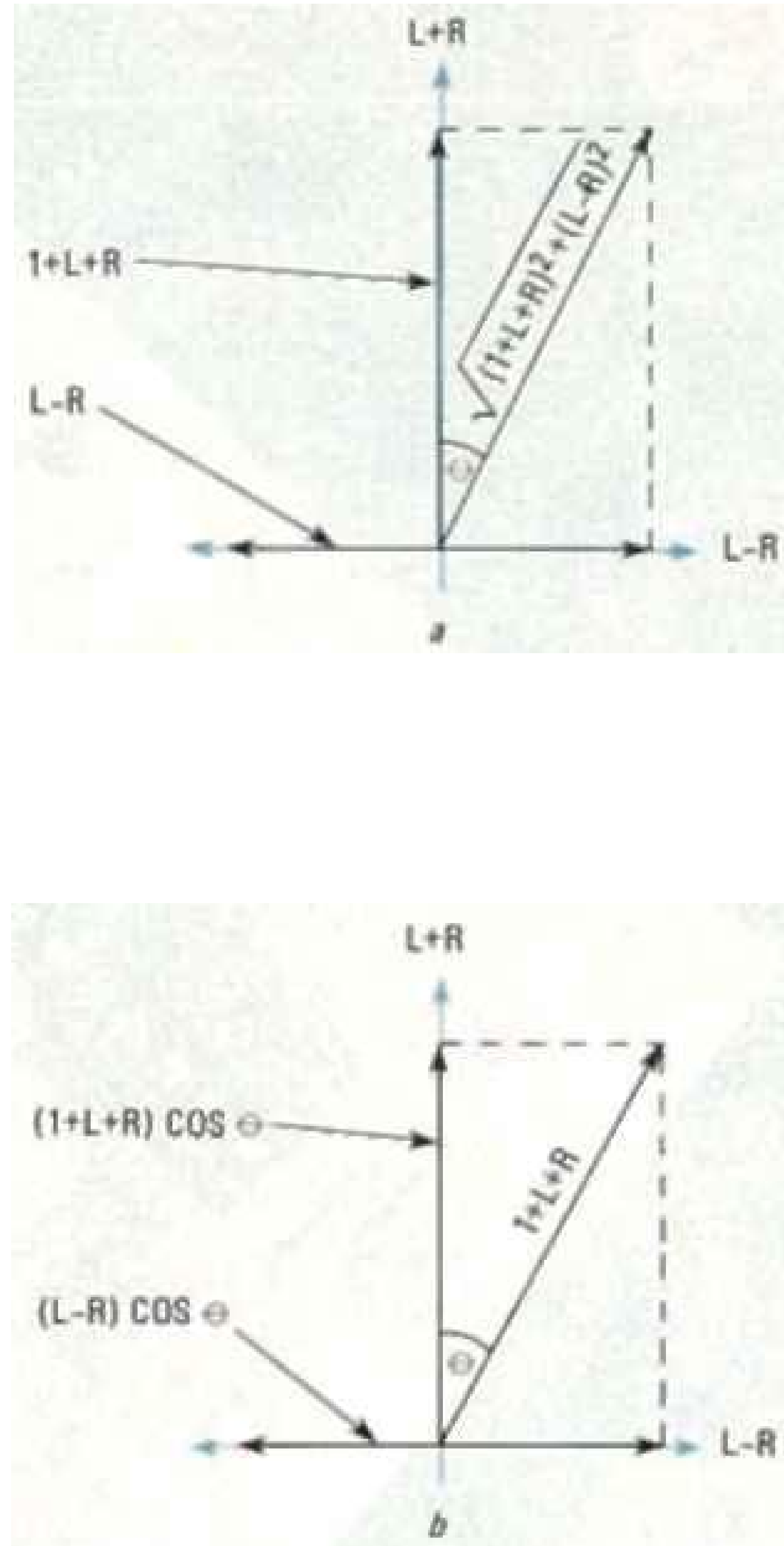

FIG. 2-QUADRATURE SIGNALS are not directly compatible with the detectors used in AM radios. Therefore, they must be converted into signals that will not produce distortion.

the carrier and the left- and right-channel audio, or 1 + L + R. That difference or error is the cause of the distortion or incompatibility problem.

Motorola found, however, that they could eliminate that error by multiplying each carrier axis by the cosine of the angle that resulted from the addition of the L + R and L - R signals. Figure 2-b shows that when that is done, the result is the 1 + L + R that we want—the standard AM radio sees this signal as the same signal received from a monaural AM broadcast. Thus we have complete compatibility.

The C-QUAM system adds a 25-Hz pilot tone to the L - R information at 4% modulation that serves several purposes. It signifies that a stereo transmission is present; it permits decoding of the L - R signal, and it aids in control of mono-stereo switching.

The MC13020P

The MC13020P decoder IC is housed in a 20-pin, standard dual in-line package, or DIP. A block diagram of the IC is shown in Fig. 3. The associated circuitry needed to build a complete decoder is made up of inexpensive components, and, in most cases, no coils or adjustments are necessary. A schematic of the decoder circuit is shown in Fig. 4. The schematic does not show the exact connection of the C-QUAM decoder circuit to the radio to be converted, or an exact external-oscillator circuit. But we'll give details later.

Taking an overall look at the block diagram of the decoder IC (Fig. 3), we see that the decoder takes the output of the AM IF amplifier, decodes the C-QUAM signal, and provides left- and right-channel audio outputs. In the absence of a good stereo signal, it will produce an undegraded monaural output from both channels.

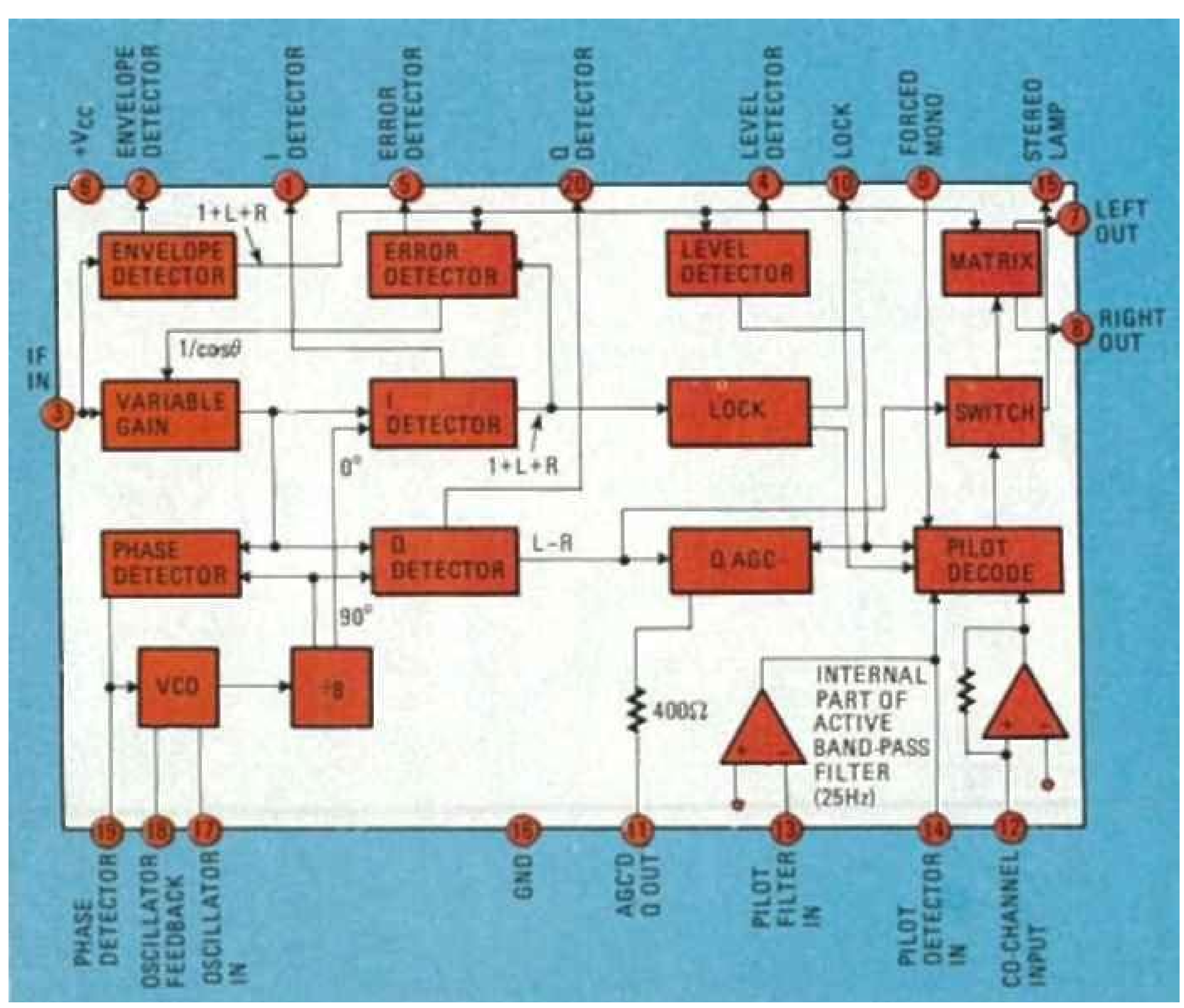

FIG. 3—A BLOCK DIAGRAM of the MC13020 AM-stereo decoder IC.

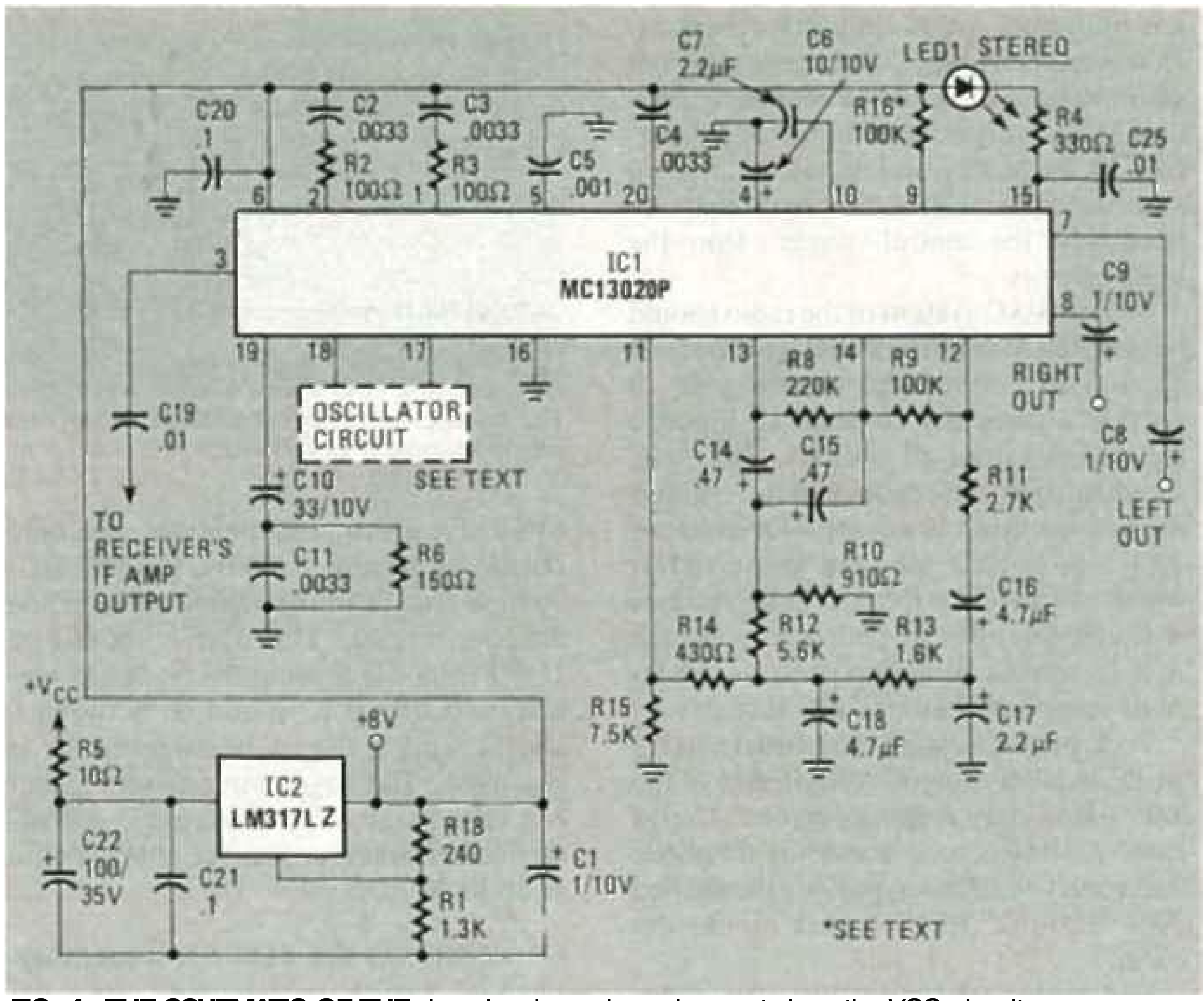

FIG. 4—THE SCHEMATIC OF THE decoder shown here does not show the VCO circuit.

The first step in decoding the stereo information is to convert C-QUAM to QUAM. That conversion is accomplished by comparing the outputs of the envelope detector and the I (L + R) detector in the error detector. Let's say, for example, that the incoming signal is monaural. Then it consists only of L + R information, and the envelope detector and I detector see the same signal. Therefore the error detector does not produce an error signal. However, when the incoming signal is stereo, there will be an error signal produced. That's because the envelope detector sees the same signal as it did before—the sum of the 1 + L + R and L - R signals—because it is not sensitive to the phase modulation. But the I detector—because it is sensitive to phase modulation—sees only the 1 + L + R information. When both signals are sent to the error detector, a $1/\cos\theta$ correction factor is produced.

In the variable-gain block, the incoming C-QUAM signal is multiplied by that $1/\cos\theta$ factor. The resulting product is a conventional quadrature or QUAM signal—not the C-QUAM that is compatible with standard AM-radio envelope detectors. It can be detected (synchronously) by conventional means.

The process to detect or demodulate the conventional quadrature signal involves first deriving a reference phase from the transmitted signal. That's the purpose of the phase-locked-loop (PLL) that we'll now describe. The phase detector is a product detector—its output is equal to the product of the two input signal voltages (in this case, a reference carrier from the VCO and the QUAM signal from the variable-gain block). If the two signals are of the same frequency and 90° out of phase, the DC output of the detector will be zero. That DC output of the phase detector is fed back to the VCO as an error signal. Thus, the frequency of the VCO "zeros in" and locks on the input carrier frequency and we have our phase reference to the I and Q demodulators.

The internal VCO operates at eight times the IF input frequency. That ensures that the VCO's frequency is outside the AM band, even if the receiver's IF is 262 kHz. (Typically, a 450-kHz IF is used with synthesized front ends. But the IF of many auto radios—even if synthesized—is 262.5 kHz.) A 450-kHz IF places the VCO at 3.6 MHz, so you can use an economic ceramic resonator instead of a crystal. (See the Parts List.) But, as we mentioned before, the oscillator configuration will be discussed later in the text.

In the PLL filter at pin 19, C10 is the primary factor setting a loop corner frequency of 8-10 Hz. An internally controlled fast pull-in is provided. (Pull-in time is the time required for achieving synchronization in a phase-locked loop.) Resistor R6 slightly overdamps the control loop, and C11 prevents high-frequency instability. The value of C10 can be increased to 68 µF to lower the filter corner frequency—that may be necessary to accommodate synthesized receivers. It may also be necessary if the filter affects the 25-Hz pilot signal (which must be 0.5 to 0.7 volts P-P at pin 14.). Resistor R6 may also affect the pilot amplitude, and can be decreased slightly if it's necessary to increase the pilot voltage to the required level.

The level detector senses carrier level and operates on the Q AGC block to provide a constant amplitude of the 25-Hz pilot signal at pin 11. It also sends information on signal strength to the pilot decoder.

The Q AGC output drives a low-pass filter, made up of a 400-ohm internal resistor, C18, and R15. From that point, an active filter (made up of both internal and external components) is coupled to the pilot decoder, pin 14, and another low-pass filter is connected to the co-channel input, pin 12.

Stereo/mono switching

A 50% reduction in the level of the 25-Hz pilot signal sent to the pilot-decode circuit will cause the system to go to monaural . A signal at a selected level to the co-channel input will also cause the system to go into its monaural mode.

That co-channel input signal contains any low-frequency beat notes caused by interference from a source very close in frequency to the desired signal. The level of the input that will cause the pilot-decode circuit to go into monaural can be adjusted by changing R11. The values that are shown in the schematic set the "trip" level at about 7% modulation.

The pilot decoder has two modes of operation. On a strong signal, the decoder will switch to stereo after it sees seven consecutive cycles of the 25-Hz pilot waveform. When conditions are bad, pilot decoder detects the interference and waits until it sees thirty-seven consecutive cycles of the 25-Hz pilot (that takes about 1.5 seconds) before it goes into the stereo mode. (In a frequency-synthesized radio, the logic that mutes the audio during tuning can be connected to pin 9 of the decoder to hold that pin low until the synthesizer and decoder have locked onto a new signal.) When pin 9 is held low, the decoder is held in its monaural mode and switches to the short count.

If no pilot is detected for seven consecutive counts, it is assumed the incoming signal is a monaural station and the decoder is switched to the long count (37 consecutive cycles of pilot). That reduces the possibility that noise or signal-level fluctuations will cause stereo triggering. The decoder will also switch to the long count if the PLL is out of lock, or if interference is detected by the co-channel detector before seven cycles are counted. (Each disturbance will reset the counter to zero.) The level detector will keep the decoder from going into stereo if the IF input level drops 10 dB, but will not affect the pilot counter.

Once the decoder has entered the stereo mode, it will switch instantly back to monaural if either the lock detector at pin 10 goes low, or if the carrier level drops below the preset threshold. Seven consecutive counts of no pilot also will cause the switch to monaural.

In stereo mode, the co-channel input is disabled. Then, co-channel or other noise is detected by negative excursions of the I detector. When those excursions reach a level caused by about 20% negative modulation of the L - R signals, the lock detector switches the system to monaural, even though the PLL may still be locked. Here, the higher tolerance to co-channel and other interference prevents chattering in and out of stereo because of a marginal signal or high noise-levels (such as during a thunderstorm). If you wish to decrease the effectiveness of the interference sensing (to keep the decoder in its stereo mode in the presence of some narrow spike type of interference) the 2.2 µF capacitor, C17, may be increased to as much as 47 µF.

When all inputs to the pilot-decode block are correct, and the appropriate (long or short) count is complete, the switch block is enabled. That block turns on the stereo-indicating LED and passes the L - R information to the matrix block, which outputs stereo audio signals.

Selecting a radio

Not every AM radio can be converted to receive broadcasts in stereo. But if you are careful when you examine the radio's capabilities, the conversion should go smoothly. Since there are literally hundreds of different radio designs on the market, we can't discuss the details of converting a particular radio. But we can give you some general pointers:

1. Old vacuum-tube radios are unacceptable. You'll undoubtedly have problems because of the high voltages and temperatures involved.

2. Cheap pocket radios, clock radios, small table radios, and the like should not be used in most cases. They typically have narrow bandwidths, poor sensitivity, and self-generated phase and frequency modulations that can seriously degrade channel separation and increase distortion and noise. (The C-QUAM system uses phase-related information, so the decoder is sensitive to phase variations or modulation.)

3. Manually tuned radios, whether variable-capacitor or variable-inductor types, may cause audible microphonics when in stereo mode. (Microphonics are electrical noise signals caused by mechanical disturbances of circuit elements.) Radios with self-contained speakers may be subject to microphonic problems because of the speaker vibrations. Those vibrations may generate phase modulation and the associated problems of poor separation, distortion, and noise.

4. The local oscillator must be stable and produce a reasonably clean sinewave. An unstable oscillator or a severely distorted waveform may cause a fluttering or warbling in the audio in the stereo mode. Disturbances of the front end and local oscillator introduce phase noise or ringing.

5. Radios with synthesizer front ends or logic-controlled varactor tuning are best adapted to AM stereo because of the more precise, automatic tuning, and better immunity to tuning disturbances. However, those types of receivers are not guaranteed to be trouble free. Phase modulation can originate from the PLL comparison frequency and may appear as an audible tone. Extra filtering may be needed on the control voltages from the logic circuits.

6. The AGC system of the radio should be checked to determine that it is effective enough to control the system gain to provide a generally constant IF input to the decoder from all stations. The AGC should also be slow enough in its response so that distortion is not introduced in the 25-Hz pilot-tone area. In some radios which use an IC for the AM tuner section, it is not possible to gain access to the AGC'd signals. It is important to test for AGC response after all AGC'd stages.

7. A problem with AM tuners using an IC is an IF output voltage that is too low—often only a few millivolts. In this case, a simple, one-transistor amplifier stage must be added to provide the needed 200—350-mV RMS signal to the decoder.

8. A major advantage is a radio with a tuned RF amplifier at the front end. The increased sensitivity and selectivity aid in stereo reception and stability.

9. The IF bandwidth should be at least 5 kHz and reasonably flat. The bandwidth of AM radios can vary from 2 kHz to more than 10 kHz. The wider the bandwidth, the better the performance and audio quality. (The fact that so many radios have narrow bandwidth has prompted radio stations to pre-emphasize the upper audio frequencies—anywhere from 2 kHz on up—to improve sound quality. Such pre-emphasis will be reduced in the future as AM stereo encourages better receiver designs.

FIG. 5—HERE IS A FULL-SIZE foil diagram of the single-sided decoder board.

You can see that determining whether a particular radio is suitable for conversion to AM stereo is really the more difficult part of the conversion process. Once the radio has satisfied (or has been modified to satisfy) all the requirements, the only remaining need is to find a suitable DC-voltage source in the radio to power the decoder circuit. The source should be 11-30 volts when using the on-board regulator (IC2). Or it should be between 6 and 12 volts if the on-board regulator is not used. The regulator provides about 8.2 volts to the IC. and its use is recommended. The source must be able to deliver up to 40 mA continuously.

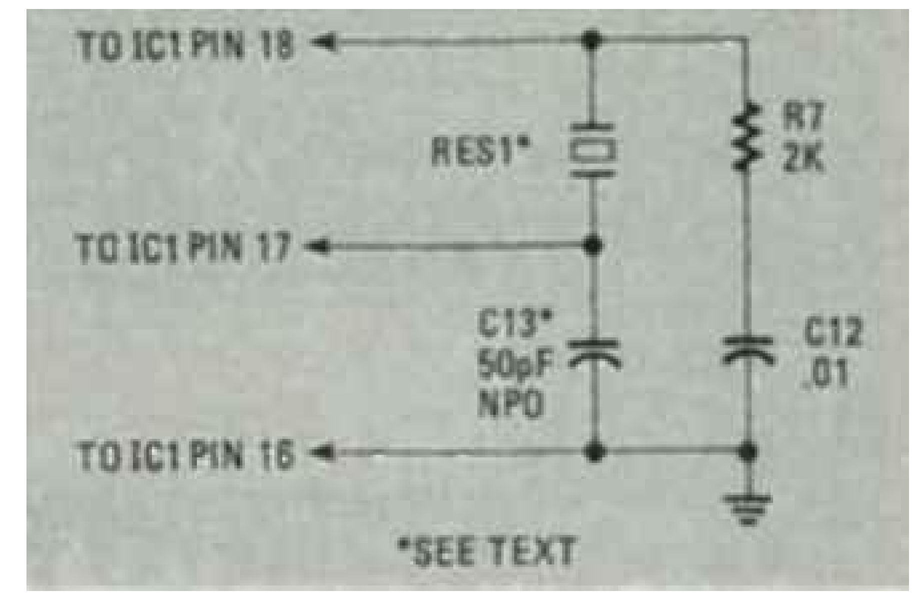

FIG. 6—THE OSCILLATOR CIRCUIT shown here needs an input IF of 450 kHz.

Constructing the decoder assembly

Figure 4 shows the complete schematic of the AM stereo decoder circuit and Fig. 5 shows a full-size foil pattern for a single-sided printed-circuit board. Before we talk about parts-placement, though, we have to select an oscillator circuit. We will discuss three.

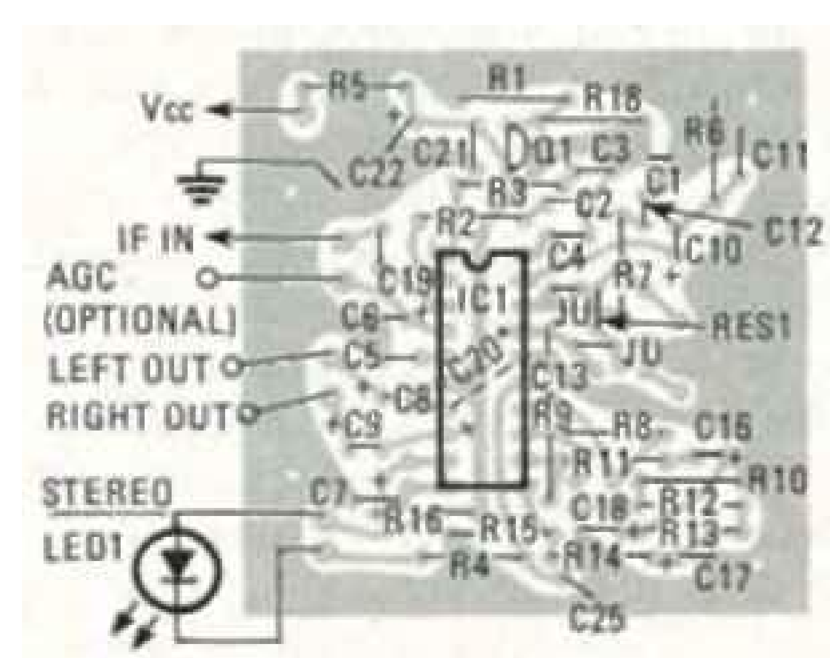

FIG. 7—THE PARTS-PLACEMENT diagram shown here corresponds to the VCO circuit of Fig. 6. Note that C20 is mounted on the foil side of the board.

The requirements of the VCO circuit design are not terribly critical—it must provide a one-volt P-P clean sinewave at 8 times the IF frequency to pin 14 of the MC13020P. One circuit that we can use is shown in Fig. 6. The corresponding parts-placement diagram for the decoder is shown in Fig. 7.

Of the three designs we'll discuss, the ceramic oscillator with its matched NPO (temperature-compensated) capacitor is preferred for its stability and simplicity. Both the ceramic resonator (RES1) and its matched (nominally 50 pF) capacitor are available from the source indicated in the parts list.

A quartz crystal can be used instead of RES1, but that will result in an extremely narrow pull-in range—only suitable for stable, accurate digital front ends. The

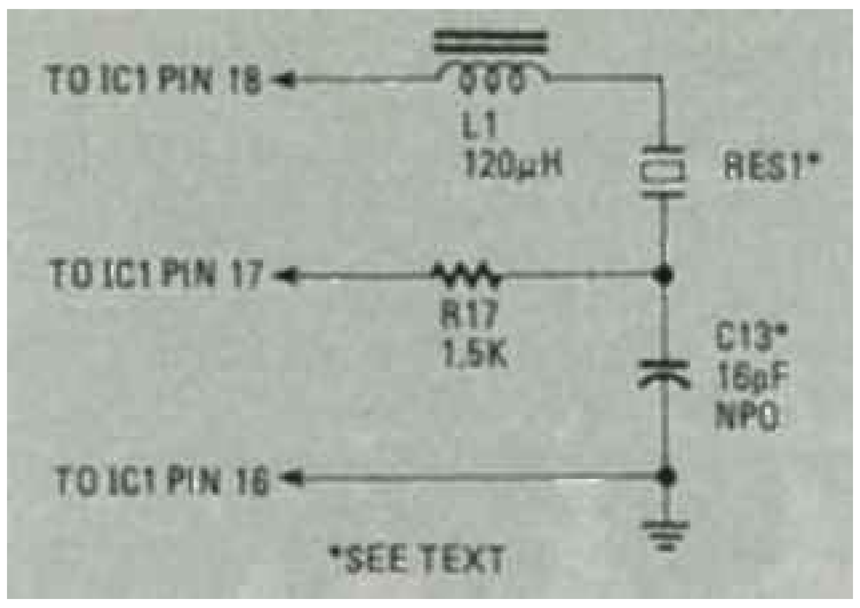

FIG. 8—THIS VCO CIRCUIT can be used if you need to broaden the tuning area to pull the resonator into lock at the required frequency. (Manually tuned radios may require that.)

ceramic resonator permits a much broader pull-in range, but it does have two drawbacks. The available resonator oscillates at 3.6 MHz—that requires a 450-kHz IF input to the decoder. Radios with a 455-kHz IF will have to be re-aligned. The second drawback concerns manually tuned radios. Tuning to the station's center frequency is quite critical. (That's not likely to be a problem with synthesized tuners.) To broaden the tuning area, R7 is added to lower the Q of the VCO. Capacitor C12 provides a DC block.

If greater broadening is needed, L1 and R17 may be added, and C13 changed, as shown in Fig. 8. (The corresponding parts-placement diagram is shown in Fig. 9.) That aids the circuit in pulling the resonator into lock at the required frequency. If L1 and R17 are not used, each must be replaced with a jumper wire as shown.

If your radio does not readily tolerate re-alignment, or if it has an IF of 260 or 262.5-kHz, or if you prefer not to attempt re-alignment, an alternative VCO, using a tunable L-C oscillator circuit, is shown in Fig. 10. It replaces the ceramic-resonator circuit and is very stable. The coil must be tuned so that the oscillator frequency is 8 times the radio's IF frequency. The circuit shown accommodates the 260-262.5-kHz IF range. Coil L2 is an adjustable RF coil made up of 60 turns of No. 36 enamelled wire tightly wound on a 1/8-inch-diameter form with a No. 2 ferrite core, a pot core (ferrite shield) and a shield can.

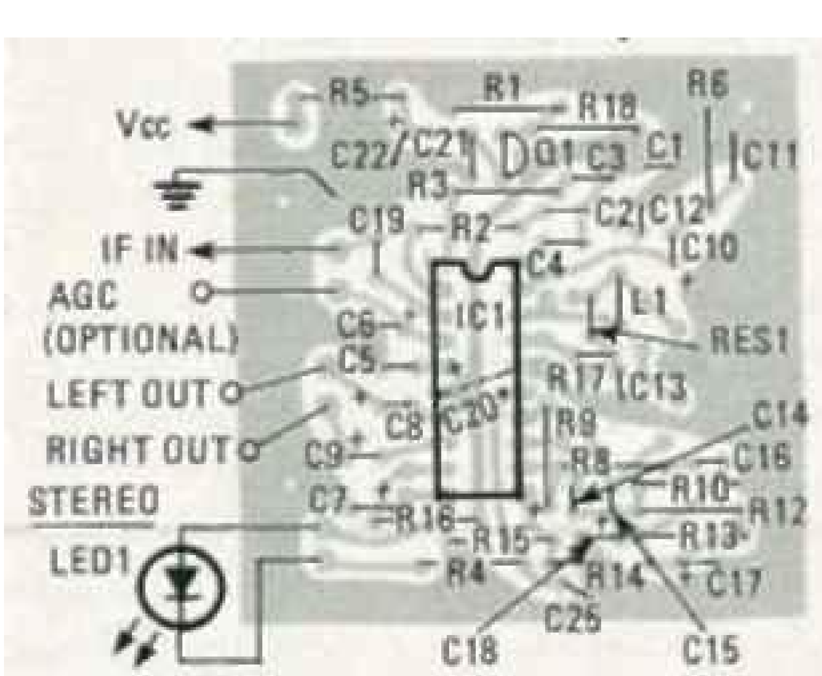

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FIG. 9—THIS PARTS-PLACEMENT diagram corresponds to the VCO circuit shown in Fig. 8. Capacitor C20 is the only component mounted on the board's foil side.

PARTS LIST

All resistors 1/4 W, 5%, carbon film
R1—1300 ohms
R2, R3—100 ohms
R4—330 ohms
R5—10 ohms
R6—150 ohms
R7—2000 ohms
R8—220,000 ohms
R9, R16—100,000 ohms
R10—910 ohms
R11—2700 ohms
R12—5600 ohms
R13—1600 ohms
R14—430 ohms
R15—7500 ohms
R17—1500 ohms
R18—240 ohms

Capacitors
C1,C8,C9—1 µF, 10 Volts, electrolytic
C2,C3,C4,C11—O.0033 µF, ceramic disc, 25-50 volts
C5—0.001 µF ceramic disc, 25-50 volts
C6—10 µF, 10 volts, electrolytic
C7, C17—2.2 µF, 10 volts, tantalum
C10—33 µF, 10 volts, electrolytic
C12,C19,C25—0.01 µF ceramic disc, 25-50 volts
C13—NPO. See Text and Figs. 6, 8, and 10
C14,C15—0.47 µF, 10 volts, tantalum
C16,C18—4.7 µF, 10 volts, tantalum
C20,C21,C24—0.1 µF ceramic disc or monolythic
C22—100 µF, 35 volts, electrolytic
C23—see text and Fig. 10

Semiconductors and other components
IC1—MC13020P C-QUAM decoder (Motorola)
IC2—LM317LZ adjustable regulator
LED1—standard red LED, 20 mA
L1—120 µH choke
L2—55 µH coil: 60 turns of #36 enamelled wire tightly wound on 1/8-inch diameter form with No. 2 ferrite core and shield can.
RES1—Ceramic resonator, Murata CSA2.60MT7 with matching capacitor (C13), Murata CSC500K7

The following are available from Circuit Specialists, Box 3047, Scottsdale, AZ 85257: Complete kit, including PC board and all parts (including parts for the VCO circuit as in Fig. 6 only), S24.95; Circuit board only, $4.95; Ceramic resonator RES1 with matching NPO capacitor (as in Fig. 6) only, S3; MC1320P decoder IC, $3.50. All prices include postage inside the US.

You can use the circuit in Fig. 10 (it's parts-placement is shown in Fig. 11) with an IF of 450 or 455 kHz by making C13 39 pF NPO and C23 10 pF NPO. and adjusting L2 so that the oscillator's center frequency is eight times the input IF.

Except, perhaps, for some of the oscillator parts, the components required for the decoder circuit are common parts. We recommend that you use tantalum capacitors for the polarized capacitors in the filter circuits at IC pins 10-14. They have

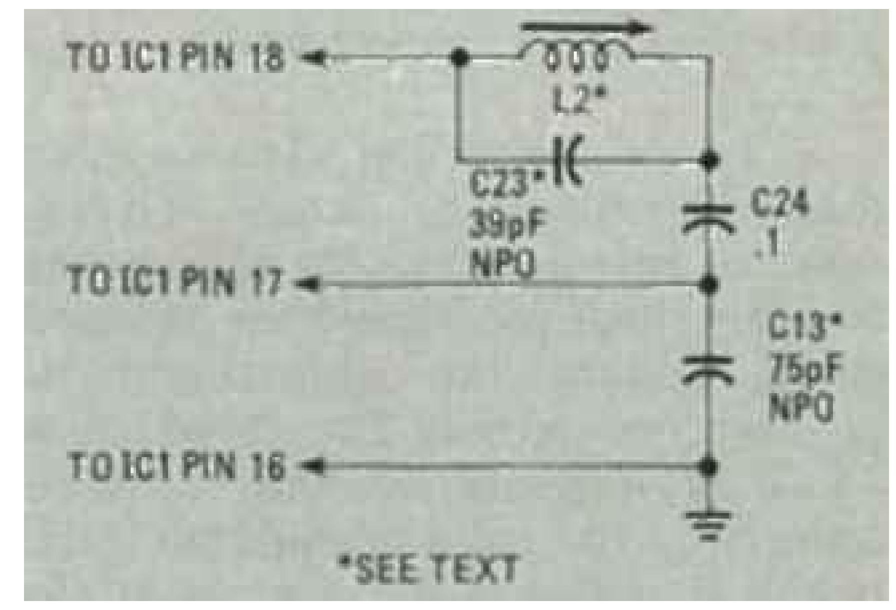

FIG. 10—THIS VCO CIRCUIT can be used to replace the ceramic-resonator circuit if your radio has an IF of 260 or 262.5 kHz. You can also use it with an IF of 450 or 455 kHz if you change the value of C13.

better tolerance and small size. But regular electrolytics, if accurate, can be used with no sacrifice of performance. Non-polarized capacitors may be ceramic-disc types unless otherwise specified in the parts list. The 0.1-µF capacitor, C20—shown in Fig. 4 connected from IC1 pin 6 to ground—should be soldered on the circuit side of the PC board under the IC from pin 6 (V_{cc}) to pin 16 (ground); use short leads when installing that unit. Note that there is intentionally no provision for this capacitor in the board layout.

Converting the radio

The input signal to the decoder must be at least 160 mV RMS for stereo. But for quiet, clean reception, it should be 200-350 mV. That is a typical range for most AM radios. In the radio, the stereo decoder goes where the detector would normally go—after the last IF stage before the detector diode. The radio's detector circuit may be disconnected by removing the diode or disconnecting one lead. In some radios, AGC voltages are obtained from the detector circuit and, in that case, the detector should be left connected. In most instances it won't interfere with the operation of the decoder. In any case, the audio output from the radio's detector must be disconnected, to avoid conflict with the two audio channels coming from the MC13020P.

The decoder assembly may be mounted in any convenient place, but try to keep it

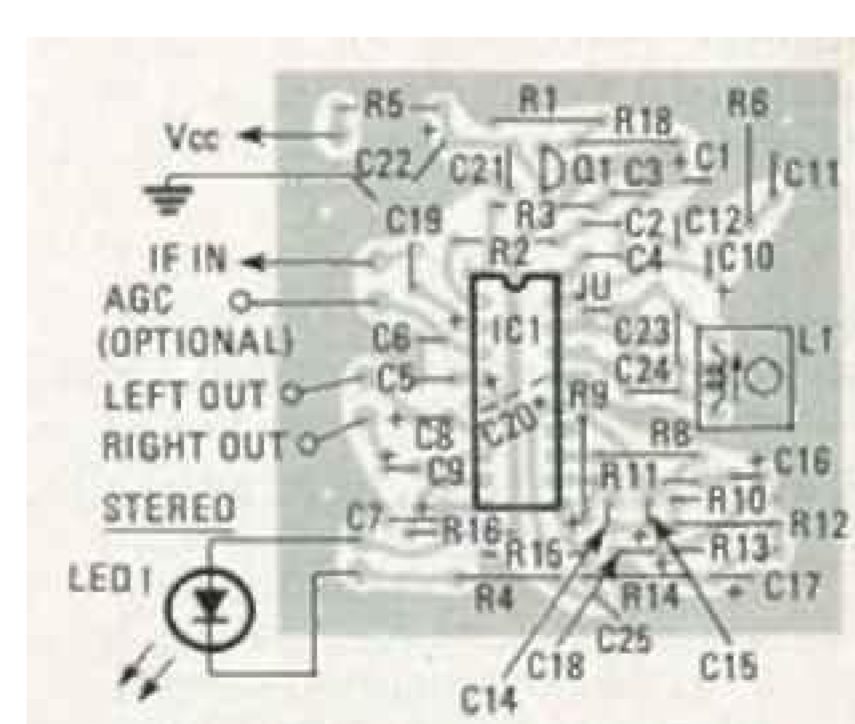

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FIG. 11—THE PARTS-PLACEMENT diagram shown here corresponds to the VCO circuit of Fig. 10.

away from major heat sources such as a power transformer, output transistors, and heat sinks.

If the interconnecting wires are more than a couple of inches in length, or if they will pass near power-supply components or wires, then you should use shielded cable. Connect the cable shields to ground at one end only. The ground return wire from the decoder assembly should be connected to the radio's ground bus at the radio's IF output or detector circuit. To avoid ground loops, this should be the only common ground connection.

If the receiver has a high IF output (over 350 mV RMS) a series resistor can be added to drop the voltage to the desired level of 200-350 mV RMS at pin 3, the decoder input. The input impedance of the decoder is about 27 kilohms.

Pin 9 of the IC is the forced mono control pin. Grounding that pin locks the decoder in its monaural mode. For automatic mono/stereo switching, pin 9 can be pulled up with a 100-kilohm resistor to the 8-volt supply (as shown in the schematic), or it can be connected to pin 10. (That permits the most rapid re-acquisition of stereo after retiming.) If you look closely at the parts-placement diagrams, you'll notice that, although the jumper is not shown, pads are provided on the board so that you can easily tie pin 9 to pin 10. You could also bring pin 9 out to a switch and manually force the decoder to its monaural mode by switching pin 9 to ground. If that is the case, the 100K resistor must be added. But be sure to remember: Do not add the resistor if you jumper pins 9 and 10.

The left and right audio outputs are "tuner-level" signals (100-200 mV RMS) and can be connected directly to the tuner or auxiliary inputs of a stereo amplifier. If the conversion is in an AM/FM receiver, one that has its own stereo amplifier, the decoder outputs should be connected through the band switch. Capacitors C8 and C9 will provide the necessary AC coupling to the audio circuits.

Troubleshooting

If the decoder will not go into the stereo mode even with a strong signal, then you should troubleshoot the circuit as we'll describe. Of course, before you start troubleshooting, you have to know that the local radio station is transmitting Motorola C-QUAM stereo—feel free to call the station to be sure.

When you're certain that a C-QUAM signal is being received, (we'll assume that you've checked that the power supply is working correctly and that 8 volts DC is supplied to pin 6) then, using an oscilloscope, look at the following signals:

1. Pin 3—The input signal. The signal envelope (and that at the IF output of the receiver) should show modulation at the top and bottom edges symmetrically. The average amplitude must be 1 volt peak-to-peak, ± 0.4 volt.
2. Pin 17—The VCO input. The oscillator input should be a sinewave of about 1-volt P-P at 8 times the input IF.
3. Pins 7 and 8—The left and right audio outputs. These signals should typically be about 200 mV P-P, centered on a DC level of about 1 volt.
4. Pin 14—Pilot tone. You should see a 25-Hz sinewave that is steady and 0.5-0.8 volts P-P. The amplitude can be increased, if necessary, by decreasing the value of R12 (but to no less than 1.8K). The pilot signal will be present, of course, only if the radio is properly tuned to a station transmitting C-CUAM stereo.
5. Pin 1—L + R signal. This signal looks like the audio signals on pin 7 and 8 but it is centered on a DC level of about 6 volts.
6. Pin 20—L - R signal. This should appear about the same as L+R signal. (If you observe closely, you should also see the 25-Hz pilot tone as a low-amplitude component of the complex waveform.)
7. Pin 10—DC lock voltage. The voltage should be 4 volts in lock, 0 volt out of lock. If it's out of lock, the VCO is not at 8 times the input IF Adjust the VCO or re-align the radio's IF.
8. Pin 9—forced mono. If wired to pin 10, it must have the same voltage condition as pin 10. If not wired to pin 10, pin 9 must have + 4VDC or higher via a 100k pull-up resistor (R16) to the 8 V supply. If the voltage at pin 9 is at or near 0 V DC, the decoder is held in monaural mode.

If all the above conditions are satisfied, the decoder will switch into the stereo mode. Failure at this point indicates a workmanship problem, defective component, a fault in the receiver system, or an incoming signal that is not correct for C-QUAM stereo detection.

WHERE TO LISTEN

As we went to press, these stations (listed alphabetically by city) were broadcasting C-QUAM stereo, with almost 50 orders on backlog. (Those stations wished to remain confidential.)

KRZY	1450	Albuquerque, NM
WSAN	1470	Allentown, PA
WCHL	1360	Chapel Hill. NC
WAIT	820	Chicago, IL
WFAA	570	Dallas, TX
WJR	760	Detroit. MI
KQWB	1550	Fargo, ND
WKOT	1010	Garyville, LA
WGSW	1350	Greenwood, SC
CKOC	1150	Hamilton, ONT
WIRE	1430	Indianapolis, IN
WNDE	1260	Indianapolis, IN
CKOV	630	Kelowna, BC
WITL	1010	Lansing, MI
CFPL	980	London, ONT
KFI	640	Los Angeles, CA
KZLA	1540	Los Angeles, CA
WISM	1480	Madison, WI
WSM	650	Nashville, TN
CKNW	980	New Westminster, BC
KXXY	1340	Oklahoma City, OK
CJSB	540	Ottawa, ONT
KGW	620	Portland, OR
CJCI	620	Prince George, BC
WHWH	1350	Princeton, NJ
KIPN	1350	Pueblo, CO
KKLS	920	Rapid City, SD
KKYX	680	San Antonio, TX
KFMB	760	San Diego, CA
KYA	1260	San Fransisco, CA
KRDZ	1230	Steam Boat Springs. CO
KJOY	1280	Stockton. CA
CFRB	1010	Toronto, ONT
KRMG	740	Tulsa. OK
CJVB	1470	Vancouver, BC
CKWX	1130	Vancouver, BC
CKLW	800	Windsor, ONT

Proven conversions

In preparation of this article, three radios were converted in our lab. The first was an AM (only) portable radio, a Realistic (Radio Shack) model 12-656A. (It is not listed in Radio Shack's latest catalog.) That radio was chosen because it has an FET-tuned RF amplifier in front, no ceramic filters, (they usually narrow the bandwidth), three tuned IF stages, and a substantial AGC system. Our testing showed that its 3-dB bandwidth was 12 kHz with a very fiat response. One AGC voltage is developed from the detector circuit, so the detector was left connected as is. The IF was re-aligned to 450 kHz. The speaker and battery holder were removed to make room for the decoder circuit and a complete 4-watt-per-channel stereo amplifier with volume, balance, bass, and treble controls. The radio's original audio section was disconnected. The radio lent itself readily to the conversion with only one problem. As previously discussed, manually tuned radios often prove to be microphonic. The 12-656A was no exception. The main culprit was the oscillator coil. Filling the coil assembly with beeswax to stop vibration greatly improved it. The tuning capacitor also was sensitive, but no attempt was made to suppress it because of the possibility of damage. Even so, at this point it took a substantial rap on the cabinet to get a little "ping" sound. The radio was connected to a pair of Radio Shack's Minimus-3.5 speakers that presented a full, clean stereo sound with both laboratory equipment as the C-QUAM signal source and a commercial radio station in Chicago.

The second radio converted was a Sears model *564.50800*, a car radio with digitally controlled varactor tuning, FM stereo, and an 8-track tape player. The unit presented a different challenge because of its compact assembly and complexity. The selected frequency is digitally dis-

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played along with the band, mono-stereo mode and tape track. The IF is 262.5 kHz, and the bandswitching is all-electronic. The section of the tuner that is not in use has its DC supply turned off. Therefore a single-transistor switch was added to appropriately operate the AM-stereo decoder-circuit. The entire AM-receiver section is a single IC but. fortunately, its IF output voltage is high enough. In fact, we had to decrease it by using a 4.7K resistor in series with the decoder input. The decoder VCO circuit shown in Fig. 10 was used to match the 262.5-kHz IF. The audio outputs were connected in parallel with the outputs of the FM multiplex decoder. Since power is switched for band selection, the connected audio outputs did not interfere with each other. Series resistors had to be inserted in the decoder's audio outputs because their level was higher than that of the FM section of the radio. Doing that kept the sound level about the same when switching between bands. Also, we made up a special PC board for the decoder so that we could fit it inside the tightly packed radio.

The stereo system worked well, but the digital control-system caused phase-generated tones at about 600 Hz and also at about 10 Hz (fluttering). The tuner PLL loop compensation frequency was sneaking through the DC control lines to the varactor in the tuner section, causing phase modulation and some frequency modulation that appeared loud and clear in the audio. Rolling off the audio response below 50 Hz with smaller coupling capacitors at the AM decoder outputs took care of that low-frequency problem. An RC filter on the DC line to the varactors eliminated the 600 Hz tone.

That Sears radio worked out very well. Although it is not microphonic, it is sensitive to phase changes. Faint modulation from other stations can sometimes be heard when the selected station is quiet or has very low modulation. That would probably not be a problem in an automobile. Its bandwidth is much narrower than the Realistic portable which is noticeable in the audio-frequency response. But it's still acceptable, especially for automotive use.

The third conversion was installed in a home stereo receiver, a Technics model SA-222. This receiver has a fully synthesized control and tuning system that's operated by a microprocessor. The synthesizer presented noise problems in the very-low-frequency area and required a minor modification to a filter in the preset tuning circuit.

A small resistor was added to the loop-antenna circuit to lower the Q of the loop. That helped maintain a satisfactory bandpass over the entire AM band. The original detector circuit was also modified to smooth AGC response and control. (The detector circuit, although not used for stereo reception, generates AGC voltages and had to be kept intact.) That modification could have been skipped, but a noticeable improvement resulted in output from stations across the band with widely varied signal strengths.

Audio outputs were connected in parallel with the outputs from the FM multiplex system. The stereo indicator already in the receiver could be driven directly from the AM decoder lamp drive through a 470-ohm resistor. The result with this receiver was excellent AM stereo, although the lack of a front end RF amplifier made reception of some stations difficult.

Final suggestions

In radios that are AC powered, it may be necessary to suppress noise caused by rectifier circuit diodes. If a sharp buzz is heard, it may be the result of these power-switching diodes. The problem can usually be corrected by installing a .05 µF, 250-volt (minimum) ceramic disc capacitor across each diode in the power supply circuit.

Household devices such as lamp dimmers or remote-control units that operate lights and appliances can generate tremendous noise, which is distributed by the building's electrical wiring like a huge antenna. AM radios will pick up this noise and make listening very unpleasant if not altogether impossible. The manufacturers of these devices may be able to offer methods or reducing the problem. Otherwise, they will have to be turned off or disconnected when using the AM receiver.

Installation of an outdoor, long-wire antenna for the broadcast band may alleviate most of those interference problems. Another, perhaps more important benefit is that an outdoor antenna will provide a greater source of stereo signals to choose from.

In the near future, when many major, music-program AM stations have introduced C-QUAM stereo broadcast, you'll no longer be limited to hearing good stereo from local FM station whose range is limited roughly to line-of-sight. You'll be able to hear the AM stations from hundreds of miles away (as you can now, especially at night), but in full stereo! R-E