BUILD AN SCA ADAPTER FOR FM RECEPTION

Phase-Locked Loop Technique Simplifies Design

One of the inherent advantages of integrated circuits is the manufacturer's ability to design a complex circuit that would otherwise necessitate scores of discrete components on a single chip. This circuit is built around the Signetics NE-565 IC in a phase-locked loop configuration. This is the first hobby use of this IC to appear in a national electronic experimentation magazine.

MANY FM STATIONS broadcast special educational material and music (without commercials) on the SCA subcarrier. This programming material is used (on a subscription basis) by commercial institutions for background music. The normal home receiver cannot pick up the SCA program without a special adapter. It is illegal to use such an adapter in a commercial establishment; but you can do so for your own personal pleasure at home.

The SCA subcarrier frequency is 67 kHz—which is high enough not to interfere with either the main carrier or the stereo subcarrier sidebands. A suitable filter and detector may be used to extract the SCA subcarrier, but because the modulated frequency deviation of the SCA subcarrier is such a large percentage of the subcarrier center frequency, it is difficult to make an FM detector using tuned circuits. In most cases, the very low Q that would be required to get linear demodulation using this method would result in a very low detected output. Also, the exacting alignment of the filter and detector requires special equipment and critical adjustments. All of these problems can be alleviated by using a "phase-locked loop" (PLL) detector to demodulate the SCA subcarrier. Using such a concept and taking advantage of a new integrated circuit to simplify the design and construction, it is possible to construct a modern SCA adapter that has no critical adjustments and is easily coupled to any good FM receiver.

Theory of Circuit Design. A phase-locked loop such as that shown at Fig 1A consists of three elements: a phase comparator or detector, a low-pass filter, and a voltage controlled oscillator. The phase detector compares the phase of the incoming signal with the phase of the signal from the voltage-

BY VINCENT WOOD

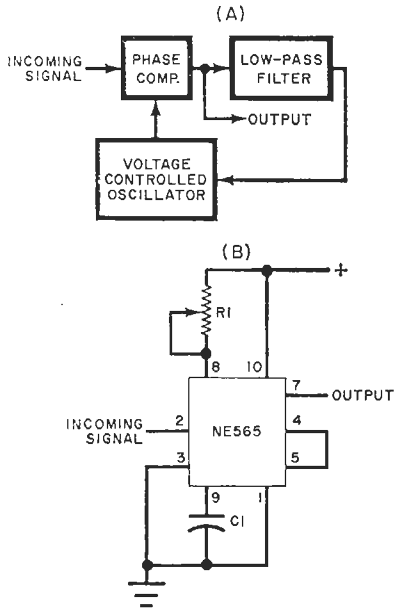


Fig. 1. The VCO tries to lock to the frequency of the incoming signal because of error voltage coming from the phase comparator. The filter removes the audio leaving the dc component. Error voltage varies with the SCA signal and becomes the audio.

controlled oscillator and generates an output voltage that is proportional to the phase difference between the two. This voltage is filtered and applied to the oscillator so that it always tries to reduce the phase difference between the two signals. The loop is "locked" when the control voltage causes the oscillator frequency to equal the average frequency of the input signal.

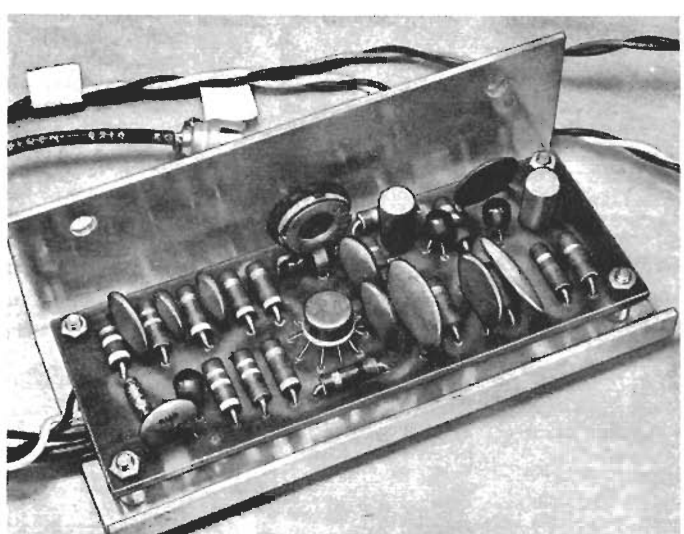
Most television receivers use a similar phase-locked loop in the horizontal sync section. The phase detector in the TV set compares the frequency of the horizontal oscillator with a large number of horizontal synch pulses and adjusts the horizontal oscillator frequency so that the average phase difference is very small. The effect of any noise that may be present is greatly reduced by the phase-locked loop since it is an averaging process.

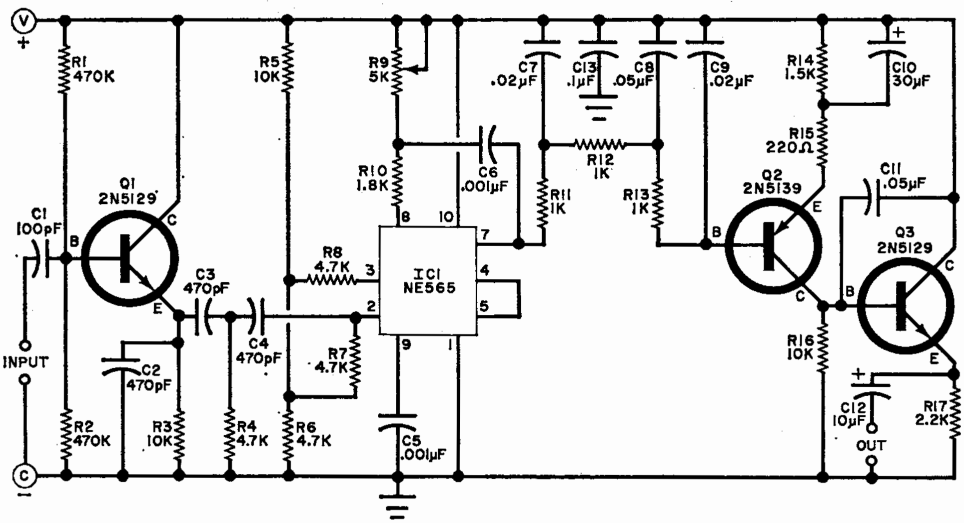
Note that the oscillator frequency tries to track the incoming frequency if the latter should change for any reason. Since the input to the PLL SCA system is a signal with some noise and the output of the VCO is clean, noise coming in is rejected.

The integrated circuit used in this project contains all of the elements necessary for the phase-locked loop and can provide highly linear FM demodulation over a range of 60% of the center frequency. Linearity is typically within 0.5% and the IC can be used to 300 kHz.

The VCO portion is set to oscillate at approximately the frequency we desire to demodulate by changing the values of *R1* and *C1* as shown in the simplified circuit in Fig 1B. When a frequency-modulated input is applied to pin 2, the output at pin 7 consists of the error signal generated by the phase difference between the VCO and the incoming signal. This error signal is exactly the same as the frequency modulation of the incoming signal, less noise; and, after proper de-

The SCA adapter is small enough to be mounted within the FM receiver being used, with a small bracket for support. The low power requirements enable this unit to be directly connected to the 9-to-18 volts usually used in solid-state receivers. The text explains a simple circuit to be installed if you use a vacuum-tube unit.





PARTS LIST

C1—100-pF polystyrene capacitor
C2-C4—470-pF ceramic disc capacitor
C5, C6—0.001-µF ceramic disc capacitor
C7, C9—0.02 µF ceramic disc capacitor
C8, C11—0.05-µF ceramic disc capacitor
C10—30-µF, 6-volt electrolytic capacitor
C12—10-µF, 15-volt electrolytic capacitor
C13—0.1-µF ceramic disc capacitor
IC1—NE565 integrated circuit (Signetics)
Q1, Q3—2N5129 transistor
Q2—2N5139 transistor
R1, R2—470,000-ohm
R3, R5, R16—10,000-ohm
R4, R6-R8—4700-ohm
R10—1800-ohm
R11-R13—1000-ohm
R14—1500-ohm
R15—220-ohm
R17—2200-ohm
R9—5000-ohm trimmer potentiometer (IRC X-201 or similar)
Note—The following are available from Southwest Technical Products Corp., 219 W. Rhapsody, San Antonio, TX 78216: etched and drilled printed circuit board #179 at $2.15, postpaid; complete kit of parts #179C including PC board at $14.55 plus postage and insurance for 8 oz.

Fig. 2. Phase-locked loop IC is connected through an emitter follower (Q1) to remove any loading on the FM detector. Once R9 is properly adjusted, there are no further adjustments to be made.

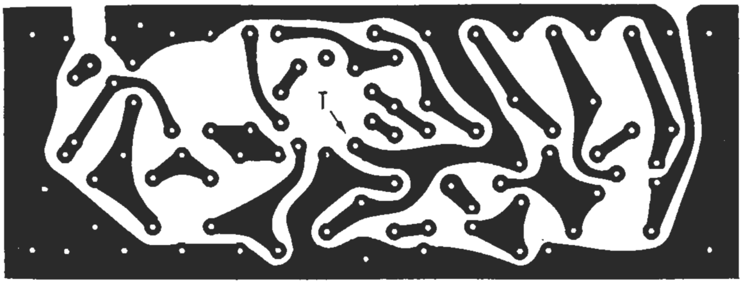
emphasis, it can be used to drive an audio amplifier.

Transistor *Q1* is a high-input-impedance emitter follower which prevents loading on the tuner output. The signal is filtered by *R3*, *R4*, *C3*, and *C4* to remove as much signal below 50 kHz as possible. This makes it much easier for the PLL system to lock on and retain the SCA subcarrier at 67 kHz.

The demodulated output at pin 7 is passed through another filter to remove any high-frequency noise and provide de-emphasis, before voltage amplification (to 1 volt) by *Q2*. Transistor *Q3* is a conventional emitter follower used to drive the outboard audio system. The top of the frequency range of the entire system is approximately 7 kHz, which is sufficient for the type of programming usually carried on the SCA subcarrier.

Construction. The schematic of the adapter is shown in Fig. 2. The entire circuit is assembled on a printed circuit board as shown in Fig. 3. All parts, with the exception of the transistors and the IC, should be pulled down firmly against the board with their leads bent over and soldered to the foil. Leave about ⅛" of lead exposed on each transistor and be sure pin arrangement is correct before soldering them in place. The leads of the IC must be separated and bent to form a "spider" arrangement. Again be sure the leads are properly oriented before soldering it in place. The "T" on the foil pattern indicates where the tab should be. Use a low-power soldering iron and fine solder (resin flux).

The adapter circuit board can be mounted on a support within the existing tuner or receiver or it can be mounted separately on a



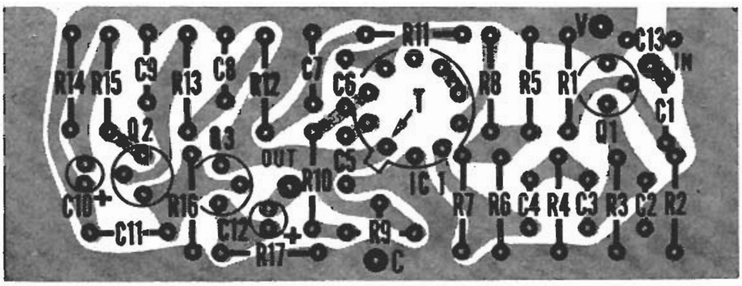


Fig. 3. When installing the components on the board, make sure the IC is oriented properly by noting exactly where the tab is located. Also observe the polarity of the electrolytics and the transistors.

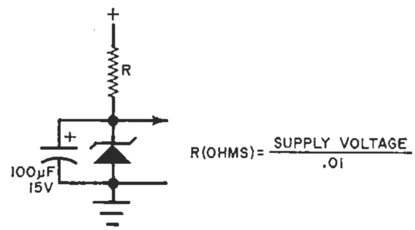
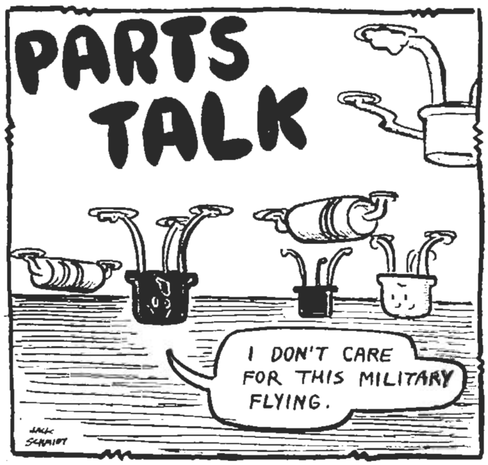


Fig. 4. This circuit is used if you happen to have a vacuum-tube receiver with its high dc voltage. After selecting a 9-to-18-volt zener, and allowing about 10 mA for it, calculate the resistor value.

small metal support. It requires 9 to 18 volts dc at 5 mA, which can be obtained from almost any solid-state tuner or receiver. If you have an older tube-type receiver, a voltage-dropping network such as that shown in Fig. 4 will be necessary. The resistor should be selected to supply approximately 10 mA to the zener diode with the available voltage supply. The zener can be any type within the 9-to-18-volt range.

Operation. The adapter is connected to the FM tuner at the output of the FM detector, before the internal de-emphasis network. It will not work on either stereo output jack. If the tuner or receiver contains a stereo multiplex circuit, the adapter can be connected to the same point where the multiplex circuit is connected.

The output of the adapter is connected to one of the high-level inputs of the audio amplifier. Tune in a station known to have SCA and adjust *R9* until the sound is clear. Once the center of lock range is found, the control may be left alone for all other stations. If you hear some feedthrough during pauses in the SCA transmission, the cause is probably insufficient bandwidth, improper alignment of the tuner i-f strip, or FM detector nonlinearity. In some areas, stations often turn off their SCA subcarrier when not in use. When this happens, the adapter will produce typical interstation noise. —30—



SOLID STATE

One Hundred Seventy-Eighth in a Monthly Series by Lou Garner

MANY READERS who have built the PLL SCA Adapter (December 1970), have requested a squelch circuit to remove the background noise when the SCA carrier is removed during portions of the program. Such a circuit is shown in Fig. 1.

The input is connected to the emitter of *Q1* of the original circuit, while the output is taken from the emitter of *Q3* (of the original circuit) and passed to the squelch circuit via diode *D1*. The output terminal and *C12* of the original circuit are not used, and the audio output is now taken from the same source as the original adapter.

Looking at Fig. 1, the SCA subcarrier is coupled to amplifier *Q1* whose collector load is a tuned circuit at 67 kHz. Emitter follower *Q2* provides the impedance change required to drive the squelch rectifier (*Q3*) without loading the tuned circuit. When the 67-kHz SCA carrier is present, the squelch rectifier collector voltage drops to near zero, thus making diode *D1* conductive, and allowing the audio signal to reach the audio output terminal.

When the 67-kHz subcarrier disappears, *Q3* does not turn on, thus its collector voltage goes up, reverse biasing diode *D1*. This does not permit the audio signal to reach the output terminal. The control potentiometer at the input to the squelch circuit should be set at the point where the SCA audio passes through the circuit. If this potentiometer is set too high, the background noise will turn on the squelch rectifier, nullifying the circuit.

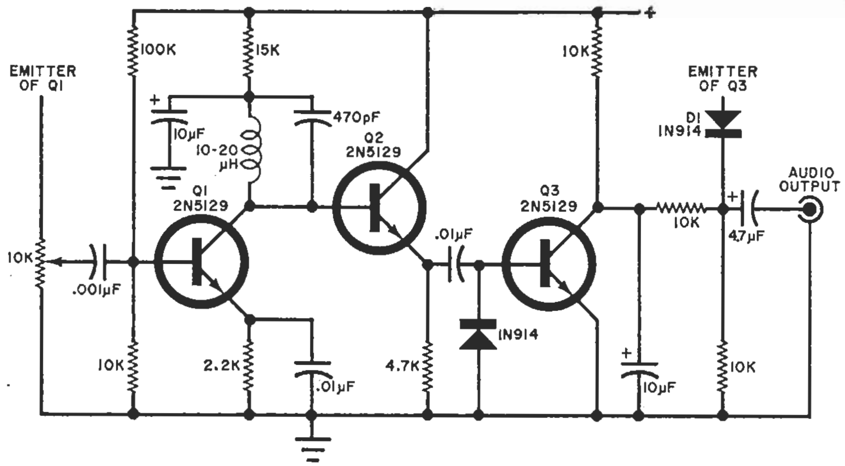
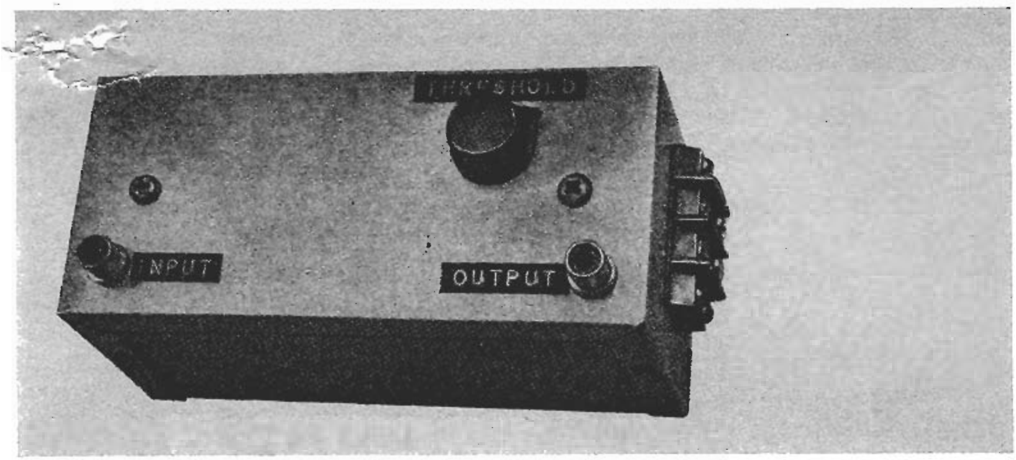


Fig. 1. This squelch circuit can be used with the PLL SCA Adapter to remove the background noise when the SCA carrier is removed during portions of the regular program.



Simple SCA Adapter

FM MUSIC SANS COMMERCIALS

BY WILLIAM F. SPLICHAL, JR.

MANY FM BROADCAST stations transmit a secondary frequency-modulated subcarrier that is offset from the regular carrier frequency by 67.5 kHz. This sub-carrier channel (called SCA for Subsidiary Communications Authorization) provides the listener with continuous music programming that is uninterrupted by commercials, news, weather, or other reports. The SCA should not be confused with the 38-kHz subcarrier normally used to carry the complementary channel in normal stereo FM broadcasts; it is a separate system which no home entertainment receiver is designed to receive.

Perhaps you are already familiar with the SCA broadcasts. You hear them in such places as restaurants, supermarkets, and other commercial establishments as "background" music. If you would like to receive the SCA subcarrier with your present receiver, all you need is a simple multiplex adapter that can extract the program material without interference from the "normal" program channel transmissions from the FM station.

Adding the SCA Adapter (described in this article) to your FM receiver will in no way interfere with the receiver's normal operation. If anything, it will add to the receiver's versatility by providing an extra source of entertaining music.

How It Works. Referring to Fig. 1, the frequency-modulated SCA subcarrier is introduced into the adapter through input jack *J1* where it encounters a 67.5-kHz parallel-tuned circuit consisting of radio frequency choke *RFC1* and capacitor *C3*. Then it is passed through a high-pass filter made up of *C2*, *C4*, and *RFC2*. From here, the frequency-modulated subcarrier is amplified and limited by *Q1* and *Q2*, respectively. At this point, the frequency modulation will have been converted to a series of pulses whose frequency is the same as that of the original frequency modulation.

Once amplified and limited, the signal is coupled to monostable multivibrator stage *Q3*-*Q4*. Here, *Q3* is normally conducting, while *Q4* is held in cutoff. Potentiometer *R12* acts as a "threshold" control, allowing only the higher amplitude 67.5-kHz subcarrier signals to trigger the multivibrator. Each time the multivibrator fires, a negative pulse is generated at the collector of *Q4*.

Since the width of the generated pulse is essentially independent of the triggering rate, the average voltage level appearing at the collector of *Q4* will be directly proportional to the triggering frequency (the 67.5-kHz modulation) up

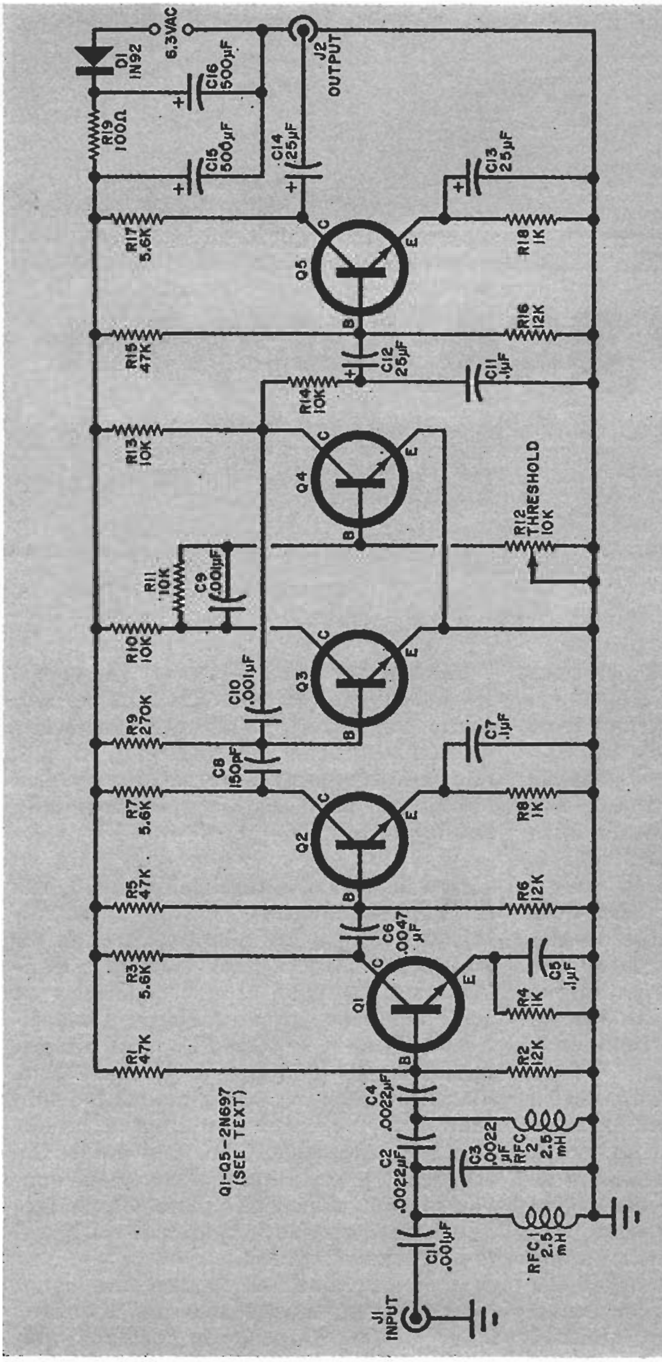


Fig. 1. Adapter circuit is almost a complete unit. All that is needed to make it totally independent is to connect a 6.3-volt, 1-ampere filament transformer, power switch, and a.c. line cord at upper right.

PARTS LIST

C1,C9,C10—0.001-µF disc capacitor
C2-C4—0.0022-µF (2200-pF) disc capacitor
C5,C7,C11—0.1-µF disc capacitor
C6—0.0047-µF (4700-pF) disc capacitor
C8—150-pF disc capacitor
C12-C14—25-µF, 15-volt electrolytic capacitor
C15,C16—500-µF, 15-volt electrolytic capacitor
D1—1N92 diode
J1,J2—Phono jack
Q1-Q5—2N697 transistor (see text)
R1,R5,R15—47,000-ohm
R2,R6,R16—12,000-ohm
R3,R7,R17—5600-ohm
R4,R8,R18—1000-ohm
R9—270,000-ohm
R10,R11,R13,R14—10,000-ohm
R19—100-ohm
(All resistors ½-watt)
R12—10,000-ohm linear-taper potentiometer
RFC1,RFC2—2.5-mH r.f. choke
Misc.—5" x 2¼" x 2¼" aluminum utility box; control knob; two-contact screw-type barrier block; tag strip (or printed circuit board); hookup wire; solder; hardware; etc.

to the point where $Q4$ is cut off completely all the time. This point is slightly above the audio spectrum; therefore, the multivibrator will deliver an output for the full subcarrier modulation range.

Power for the SCA adapter is derived from any 6.3-volt, 60-Hz, source. A built-in half-wave rectifier/filtering circuit, consisting of *D1* and *C15*, *C16* and *R19*, provide the d.c. voltage required for proper operation of the adapter.

Although the SCA Adapter so far described makes use of five commonly available *npn* silicon transistors, germanium or *pnp* transistors can be substituted. Merely change the polarities or values of a few components. The changes that must be made for transistor substitutions are given in the table on the next page.

Construction. The circuit of the SCA Adapter is really very simple, lending itself to just about any type of chassis

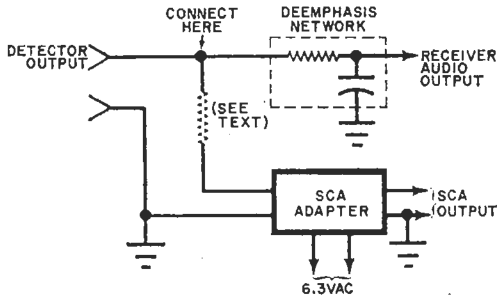


Fig. 2. For proper operation, SCA adapter must be connected between detector and deemphasis net.

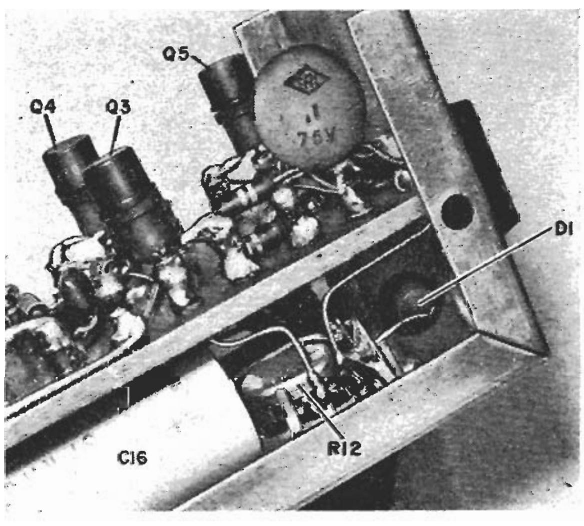
construction you prefer. While the photos show the original prototype assembled on a double-row solder-terminal tag strip, which is essentially point-to-point wiring, a printed circuit board layout would have been just as appropriate for assembly.

The circuit can be assembled in any enclosure you choose. A 5″ × 2¼″ × 2¼″ aluminum utility box was used for the prototype, with *J1* and *J2* mounted at opposite ends of the top surface. Threshold control *R12* was also mounted to the top, while to one side is located a screw-type barrier block for bringing in the 6.3 volts a.c. for the power supply circuit.

Installation and Use. To operate properly, the SCA adapter must be electrically connected to your receiver. This is a simple process that can be performed in a couple of minutes.

A NOTE ABOUT THE LAW

There is no FCC Regulation that prohibits the reception of Subsidiary Communications Authorization broadcasts for private home entertainment purposes. However, there are regulations that do prohibit the use of SCA programs to promote business (or any other reason) by commercial establishments unless such businesses are authorized subscribers and use only the SCA channel to which they subscribe.



Transistors can be installed in sockets or soldered directly to lugs. Locate a.c. filter capacitors on underside of terminal board and the barrier block at end of box.

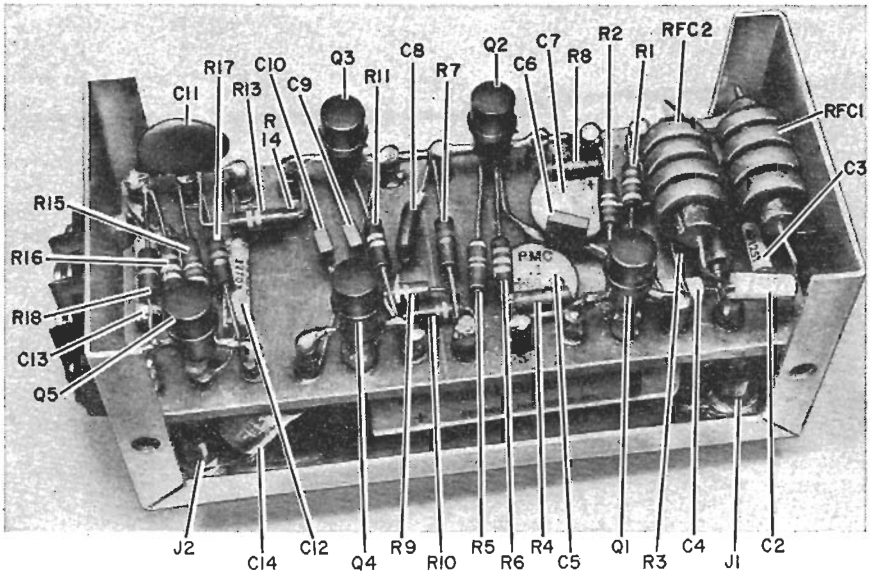
Before digging into your receiver (or tuner), carefully study its schematic diagram to locate the detector stage and resistor/capacitor de-emphasis network. Then, study the receiver layout to locate the point indicated in Fig. 2. You will notice that the SCA Adapter's input must be connected to a point *between* the detector output and the de-emphasis network. If the connection is made *after* the de-emphasis network, no SCA signal will pass through!

The filter (SCA Adapter) was designed to operate most efficiently with a 3000-ohm load. So, it may be necessary to couple the adapter to the receiver circuit via an isolation resistor with a value of a few thousand ohms, depending on your particular receiver.

Now, connect a twisted-pair cable between the 6.3-volt a.c. winding on your receiver's power transformer and the screw-type barrier block on the adapter. If 6.3 volts a.c. is not available from your receiver, use a separate 6.3-volt filament transformer. Then connect a shielded audio cable from the adapter's output jack to the auxiliary (AUX) input jack on the rear apron of your receiver.

Turn on and tune the receiver to a local FM station known to be broadcasting SCA program material. Set the receiver's source switch to AUX and function switch to MONO, and adjust threshold for the clearest audio. (Note: in some receivers, when the source switch is moved out of the TUNER or FM position, the power is disconnected from the tuner. In this case, connecting the output of the adapter to the receiver's AUX input will not work—a separate amplifier will be required unless you can figure a way of restoring power to the tuner when the source switch is in the AUX position.

Although a printed circuit board or multi-lug terminal strips could be used, wiring is just as simple with a parallel-row terminal board having 13 solder lugs per row as shown here.



Tuning across the dial, you may find that several SCA programs are available. This is true especially in the large cities where different types of background music are required by the subscribers. So much the better for your choice of programs. -30-

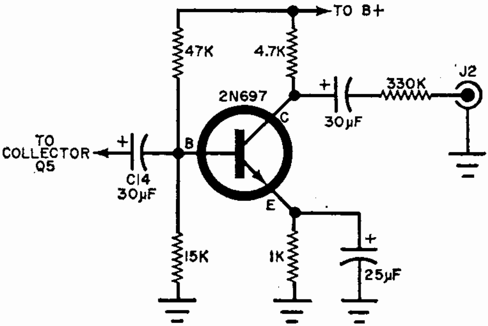
TRANSISTOR SUBSTITUTION TABLE

Transistor Type	Changes
PNP silicon	Invert polarities of D1, C12-C16
NPN germanium	Change R2,R6,R16 to 6800 ohms
PNP germanium	Combine both of the above changes

letters FROM OUR READERS

SCA ADAPTER MODIFICATION

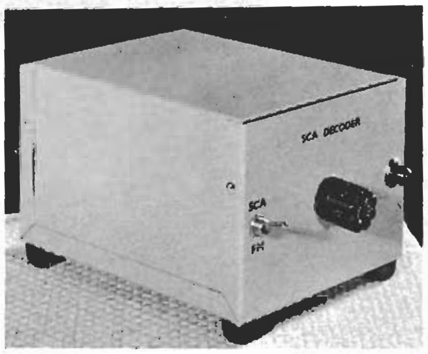
I was quite pleased with the "Simple SCA Adapter" (June 1970). However, after testing it in the lab, I found that several changes would sufficiently improve rejection of the regular stereo signals at my home.



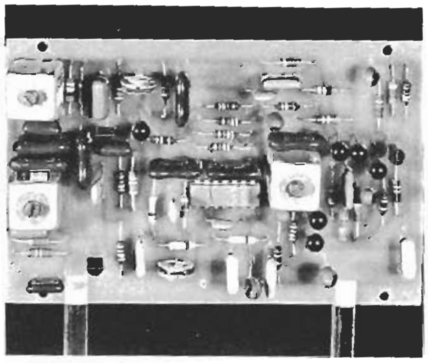
First, in areas where transmission towers are located nearby, a higher degree of rejection can be achieved by changing capacitor C2 from 0.0022 µF to 0.05 µF. Then, to obtain a lower output between selections, another stage can be added to the adapter as shown in the schematic diagram.

P. J. Sussman
Electro Communications
Dayton, Ohio

Build a Practical SCA Decoder



Completed decoder built by authors.



Layout of decoder PC board (see also Figure 6).

by G. Neal* and R. A. Wright*

Many FM stations in Canada and the US transmit a 67 kHz FM subcarrier along with their regular mono or stereo programme material (Figure 2). Most stations use this channel to carry commercial-free background music to bowling alleys, shopping plazas, and supermarkets, while a small number employ it for control purposes from studio to transmitter, and so forth.

All commercial FM receivers reject this SCA (Subsidiary Communications Authorization) signal so that a special decoder connected ahead of the filter must be used to receive it. A block diagram of such a unit is shown in Figure 1 which, when used with any FM set, is capable of reproducing the background music mentioned above. Before going further, it must be pointed out that the use of this adapter is restricted to non-profit use in the home and *must not* be used for any commercial purposes whatsoever!

The word "practical" has been used in the title of this article for

continued on p. 54

*Division of Radio and Electrical Engineering: National Research Council, Ottawa.

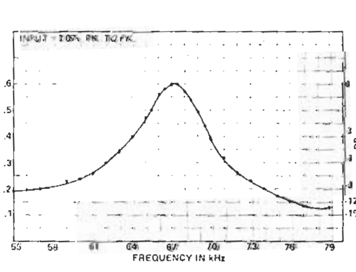
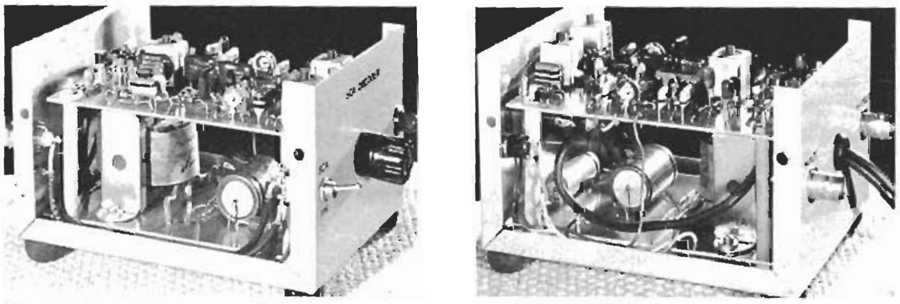


Figure 4 — Input to Pin 2 of IC_1 vs. input signal frequency for decoder.



Two views of unit with cover removed showing mounting of decoder and power supply PC boards.

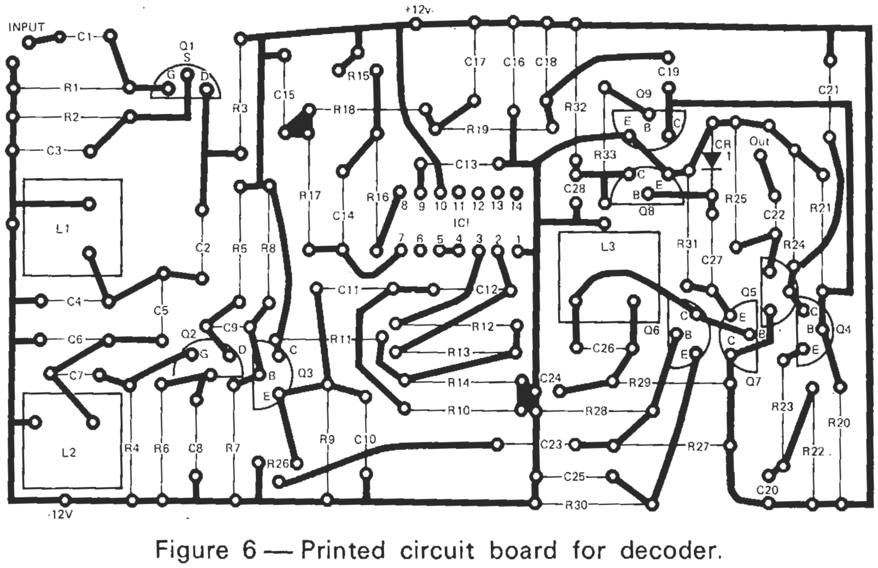


Figure 6 — Printed circuit board for decoder.

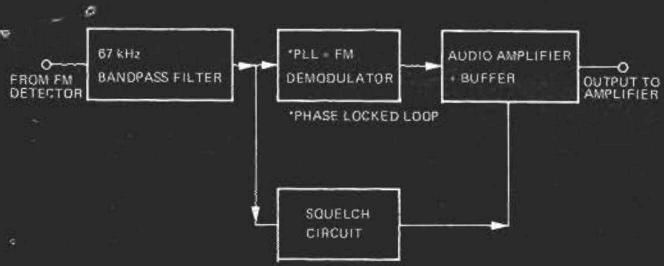


Figure 1 — Block diagram of SCA decoder.

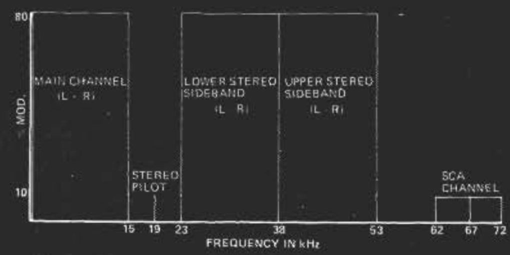


Figure 2 — Frequency allocations within an FM channel.

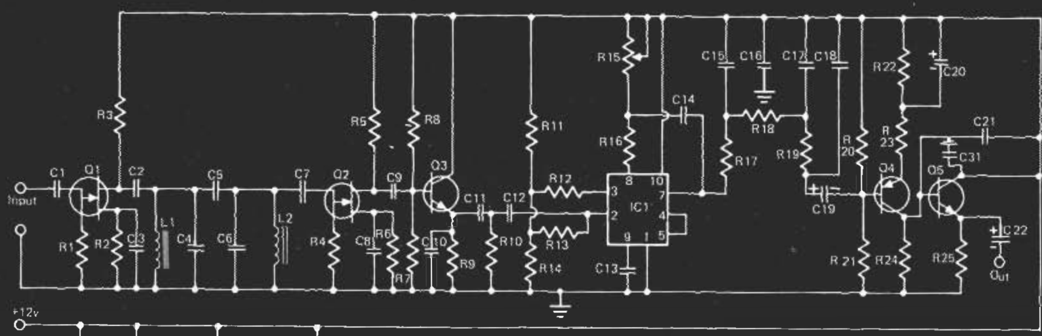
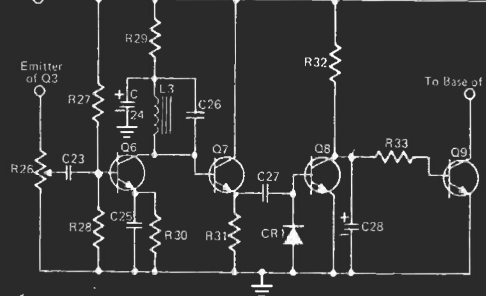



Figure 3 — Schematic diagram of SCA decoder.

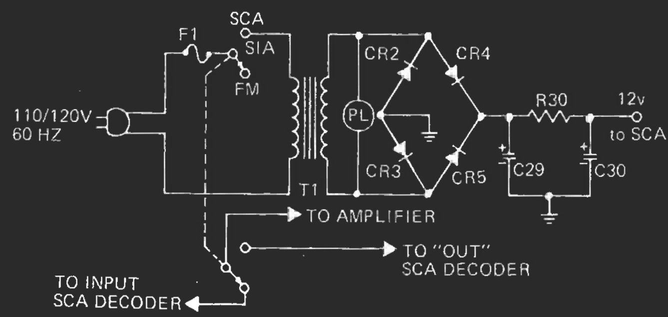


Figure 8 — Optional power supply for SCA decoder.

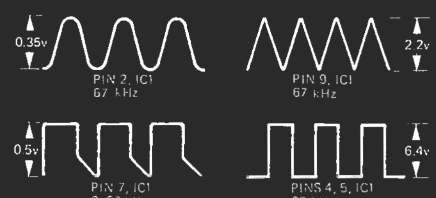


Figure 9 — Waveforms at various pins of IC_1 with SCA signal applied to decoder.

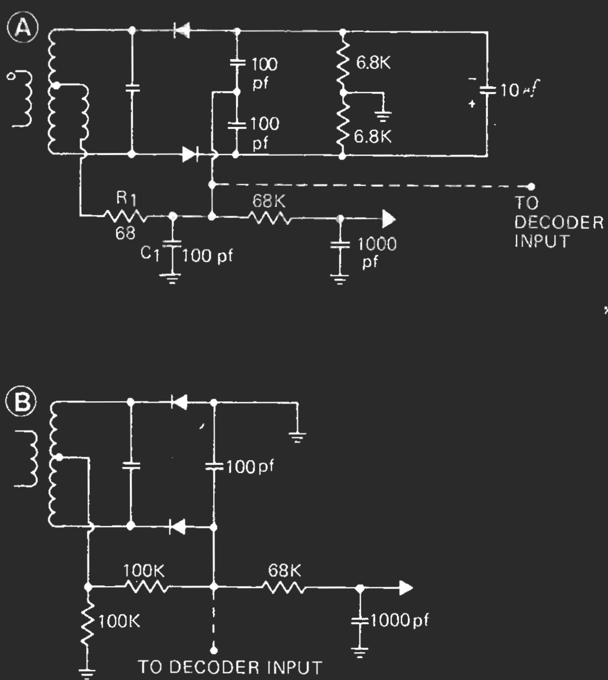


Figure 5 — Typical ratio-detector (a) and discriminator (b) circuits, showing take-off points for connection to decoder.

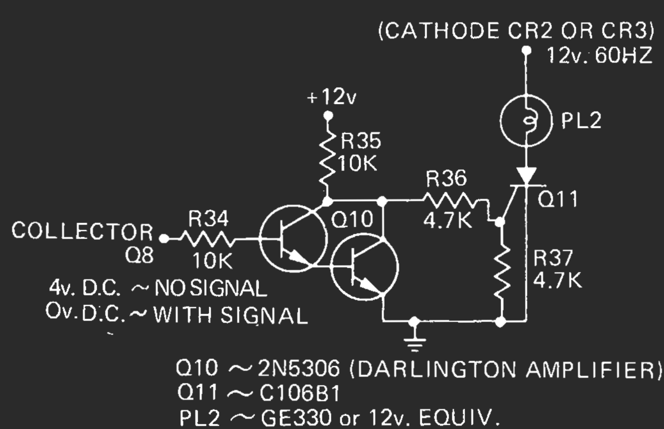


Figure 11 — SCA signal indicator schematic diagram.

SCA Decoder *(Cont'd from p. 24)*

a very good reason. Many different decoders, including commercial kits, have been built by the authors; but they have all suffered from one or both of the following faults:

1) Interference and distortion from the main channel programme.
2) Faulty or non-existent "muting" during quiet periods between sets of musical selections.

The unit to be described below has overcome both of these problems, and would make a worthwhile addition to any home music system within range of an SCA station.

Circuit Description

The bandpass filter between Q_1 and Q_2 (Figure 3) removes the regular channel material below 53 kHz (Figure 4). Sharper filters than those shown were tried but rejected because they produced poorer audio quality at the decoder output.

Q_3 is an emitter follower that isolates the PLL (IC_1) from the filter amplifiers. This integrated circuit demodulates the FM signal and ap-

Canadian and US. FM Stations with SCA that can be received in Canada.

Canada

British Columbia	
Vancouver	CHQM - FM
Manitoba	
Winnipeg	CBW - FM
	CFRW - FM
	CJOB - FM
	CKY - FM
New Brunswick	
Saint John	CFBC - FM
Nova Scotia	
Kentville	CKWM - FM
Ontario	
Kitchener	CFCA - FM
Oshawa	CKQS - FM
Ottawa	CFMO - FM
	CKBY - FM
Toronto	CHFI - FM
	CJRT - FM
	CKFM - FM
Windsor	CKLW - FM
Quebec	
Drummondville	CFDM - FM
Montreal	CFQR - FM
	CJFM - FM
Verdun	CKVL - FM
Saskatchewan	
Regina	CFMQ - FM
Saskatoon	CFMC - FM

U.S.A.

Maine	
Bangor	WABI - FM
Brunswick	WCME - FM
Portland	WGAN - FM
	WPOR - FM
Michigan	
Alpena	WHSB
Coldwater	WANG
Dearborn	WKNR - FM
Detroit	WABX
	WBFG
	WGPR
	WLDM
	WQRS - FM
	WXYZ - FM
East Lansing	WFMK
Lansing	WJIM - FM
	WITL - FM
Midland	WSVC
Petoskey	WJML - FM
Port Huron	WHLS - FM
Saginaw	WSAM - FM
Minnesota	
Duluth	WGGR
Montana	
Great Falls	KOPR - FM
New Hampshire	
Mt. Washington	WMTW - FM
New York	
Auburn	WRLX
Buffalo	WADV
	WBUF
Depew	WBLK - FM
De Ruyter	WOIV
Fulton	WOSC - FM
Jamestown	WJTN - FM
Niagara Falls	WHLD - FM
Plattsburgh	WEAV - FM
Rochester	WBFB
	WVOR
Syracuse	WONO
Watertown	WOTT - FM
North Dakota	
Fargo	WDAY - FM
Minot	KCJB - FM
Ohio	
Ashtabula	WREO - FM
Barberton	WDBN
Bucyrus	WBCO - FM
Canton	WHBC
	WHLQ
Cleveland	WCLV
	WELW - FM
	WNCR
	WXEN
Manfield	WCLW - FM
	WVNO - FM
Salem	WSOM - FM
Toledo	WMHE
Pennsylvania	
Erie	WWGO - FM
Ridgway	WKBI - FM
Warren	WRRN
Vermont	
Burlington	WJOY - FM
	WVNY
Washington	
Aberdeen	KDUX - FM
Bellingham	KERI
Edmunds	KBIQ
Opportunity	KZUN - FM
Seattle	KBBX
	KBLE - FM
	KIRO - FM
	KZAM
Spokane	KCFA - FM
	KDNC - FM

plies the resultant to amplifier stage Q_4. A filter made up of $R_{17\text{-}19}$ and $C_{15\text{-}18}$ removes the high frequency noise which is present at pin 7 of IC_1. Emitter follower Q_5 is used to provide a low impedence output to drive an amplifier.

The "squelch" circuit, composed of $Q_{6\text{-}9}$, is necessary to "mute" the decoder output when tuning between SCA stations or when the 67 kHz subcarrier is turned off between musical selections. If the 67 kHz signal is present, it is amplified by Q_6. Q_7 isolates the tuned circuit composed of L_3, C_{26} from CR_1 which clips the negative signal swings, so that the positive half may drive Q_8 into conduction. Q_9 is thereby kept off, allowing the demodulated signal from IC_1 to pass through $Q_{4\text{-}5}$ in the normal way.

If the subcarrier is not present, however, Q_8 does not conduct, Q_9 is turned on, shorting to ground the output of IC_1 and muting the decoder output.

Connection may be made to the FM tuner at the multiplex output jack, if one is provided, or ahead of the de-emphasis network as shown in Figures 5A and 5B.

Some solid-state radio detector circuits omit R_1 and have C_1 = 0.01 μf. In this case, R_1 must be added, and C_1 changed to 100-270 pf of (Figure 5A) before connecting the decoder as shown.

The switch on the front panel of the adapter controls the AC to the power supply as well as switching the output from the regular stereo channel to the SCA programme.

Construction of the unit, using either the printed circuit boards shown in Figures 6 and 7, or Vector-board, should present no problem since the layout is not critical.

Current drain of ≈25 mA at +12 V may be supplied from the receiver, if available, or the power supply given in Figure 8.

Fixed inductors of 2×10^{-3} H may be substituted for L_1 and L_2 if the variables specified are not available, or in the interest of economy.

C_{16} prevents high frequency oscillations from feeding back through the power supply to the audio output. C_{31} also suppresses oscillations in the Q_5 stage, and should be connected with the shortest possible leads between collector and ground.

	Drain	Source
Q1	+ 6.4v.	+ 2.6v.
Q2	+ 6.1v.	+ 2.7v.

IC1	
Pin 2	+ 3.8v
3	+ 3.8v
4,5	+ 8.0v.
7	+ 10.7v.
8	+ 10.8v.
9	+ 5.5v.
10	+ 11.9v.

	Emitter	Base	Collector
Q3	+ 4.7v.	+ 5.3v.	+ 11.9v.
Q4	+ 10.4v.	+ 9.9v.	+ 8.1v.
Q5	+ 7.5v.	+ 8.1v.	+ 11.9v.
Q6	+ 0.49v.	+ 1.08v.	+ 8.5v.
Q7	+ 8.2v.	+ 8.5v.	+ 11.9v.
Q8	0v.	− 0.12v.	+ 0.07v.
Q9	0v.	+ 0.07v.	+10.0v.

Figure 10—DC voltages found in SCA decoder. Measured with VTVM, supply of 11.9 V. Input signal from FM receiver was 1.0 V (peak-to-peak); and decoder output was 1.5 V (peak-to-peak).

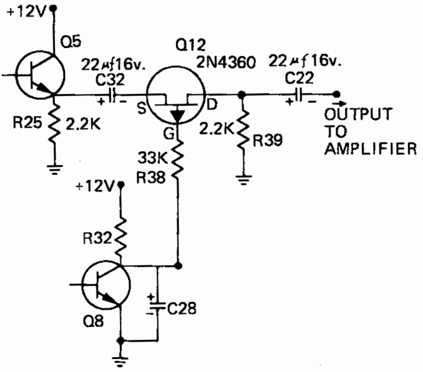


Figure 12 — Schematic for improved muting circuit.

Alignment

For best results, a signal generator capable of producing 67 kHz and an oscilloscope should be used. Connect the scope to pin 2 of IC_1, feed the 67 kHz into the decoder input, and adjust L_1 and L_2 for maximum level. Be sure to keep the generator level low enough to prevent saturation in any of the input stages. Next, transfer the scope lead to the emitter of Q_7 (R_{26} set for maximum input to Q_6) and tune L_3 for maximum deflection. Then connect the decoder input to the FM detector as described above, and the decoder output to the audio amplifier. Set pots R_{15} and R_{26} to mid-range, and tune to a station known to be transmitting the SCA service (see list on page 54). When the background music is heard, adjust R_{15} for best audio quality and minimum main channel interference.

The last adjustment to be made is that to pot R_{26} for proper squelch action. If it is set too low, the decoder output will be permanently cut off. The best way to proceed is first to reduce R_{26} to minimum, and then increase it slowly until the background music just "pops" on. The audio output should then be fully "muted" during any breaks between musical selections.

If neither signal generator nor scope is available, a VTVM may be used for alignment purposes. The slugs in inductors $L_{1\text{-}3}$ should be set at the middle of their travel, the receiver tuned to an SCA station and $L_{1\text{-}2}$ adjusted for maximum AC signal at the base of Q_7 ($\approx$1.3 V RMS.).

Waveforms (Figure 9) and a chart of DC voltage measurements (Figure 10) are given to assist in

continued on p. 62

SCA *(Cont'd from p. 59)*
troubleshooting, should any problem arise in putting the unit in service.

One addition which may be made to the decoder is a lamp, somewhat analogous to the stereo indicator light on most FM stereo receivers. In this case, while tuning, across the band in the stereo mode, the SCA lamp would come on whenever a station was received transmitting a 67 kHz subcarrier. This modification would be most useful in large metropolitan areas within range of several stations transmitting the SCA service. The wiring would have to be changed to apply the +12 V to $Q_{1-3,6-9}$ continuously, as well as the added transistor Q_{10} (Figure 11) and 110 V, 60 Hz to T_1.

An improved muting circuit is shown in Figure 12 which eliminates the fairly loud "thump" that is heard with the original circuit whenever the 67 kHz subcarrier is turned off. This change makes use of Q_{12} as an audio switch (Reference 5), controlled by Q_8 acting as before on the presence or absence of the subcarrier. R_{33} and Q_9 are eliminated, while C_{31}, Q_{12}, and R_{35-36} are added. No reduction in output level or increase in distortion is produced by substituting this muting circuit for that in the original design. ■

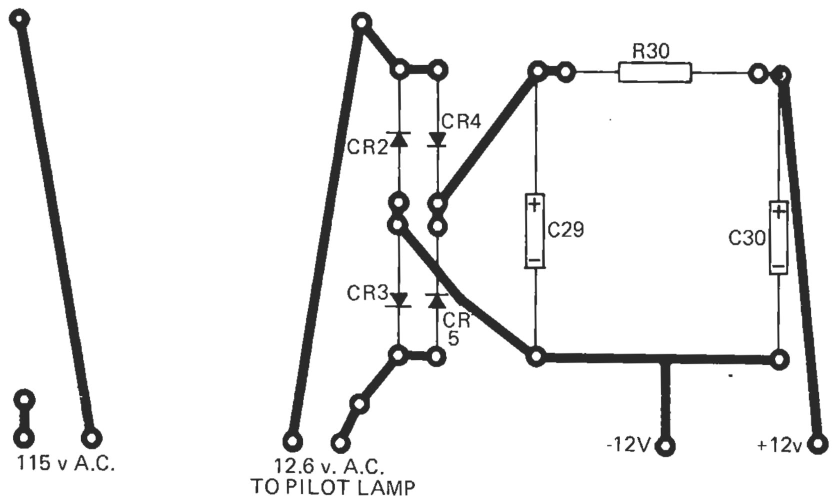


Figure 7 — Printed circuit board for decoder power supply.

References

1. "SCA Background-Music Multiplexer", Robert W. Winfree, *Electronics World,* Dec/63.
2. "SCA Background-Music Demultiplexer", Garland P. Kuntz, *Electronics World,* Sept/64.
3. "SCA-Private Music Channels on FM stereo", Leonard Feldman, *Audio,* Sept/68.
4. "How to Build an SCA Background Music Adapter", Leonard Feldman, *Audio,* Oct/68.
5. "FETS as Audio Switches", G. Neal, *Electronics World,* Aug/70.
6. "Build an SCA Adapter for FM Reception", Vincent Wood, *Popular Electronics,* Dec/70.

Parts List

C1, 7, 9	100 pf
C2, 13, 14, 23, 31	.001
C3, 8,	.1
C4, 6, 26	.0022
C5, 10, 11, 12	470 pf
C15, 18, 21	.02
C17	.047
C16, 19, 20, 22, 24	22μf, lbv.
C25, 27	.01
C29	640μf, 25v
C30	250μf, 25v.
C28	4.7μf, 35v.
R1	220k
R2, 6, 25, 30	2.2k
R3, 5, 10, 12, 13, 14, 20, 31, 33	4.7k
R4, 27	100k
R7, 8	470k
R9, 11, 24, 28, 32	10k
R15	4.7k, ¼w carbon trim pot
R16	1.8k
R17, 18, 19	1k
R21	22k
R22	1.5k
R23	220Ω
R26,	10k, ¼ w carbon trim pot
R29	15k
R30	220Ω 1 w
All resistors ¼ w. 10% tolerance unless otherwise stated.	
CR1, 2, 3, 4, 5	1N457A
F1	¼ amp slo-blo
S1A, B,	D.P.D.T. Toggle Switch
T1 Hammond Type 166F12 11sv/12.6v .3 amps	
PL1 12v pilot lamp	
Q1, Q2	MPF105 (2N5459)
Q3, 5, 6, 7, 8, 9.	2N3904
Q4	2N 3906
L1, 2, 3	1.3—3.0 m.h. (Miller #9059)
IC1	N.E. 565A (Signetics) — Phase Locked Loop.

Fm decoder improves SCA subcarrier detection

by Robert F. Woody
Christiansburg, Va.

The 67.5-kilohertz subcarrier required for subsidiary communications authorization (SCA) service in the fm band can be recovered by a decoder that needs only two chips and one discrete amplifier. And it can be built for less than $10. Besides using fewer parts than existing designs, this circuit provides higher output and offers greater versatility.

As an illustration of its advantages, the 4046 phase-locked loop in the decoder provides an output level approximately equal to the fm level at its input, thereby generating adequate drive to succeeding stages. In addition, the PLL's filter also serves as the deemphasis filter, thus eliminating the need for a separate network. Finally, upon loss of the subcarrier, the circuit generates a signal that can cue a recorded message to the audience receiving SCA service.

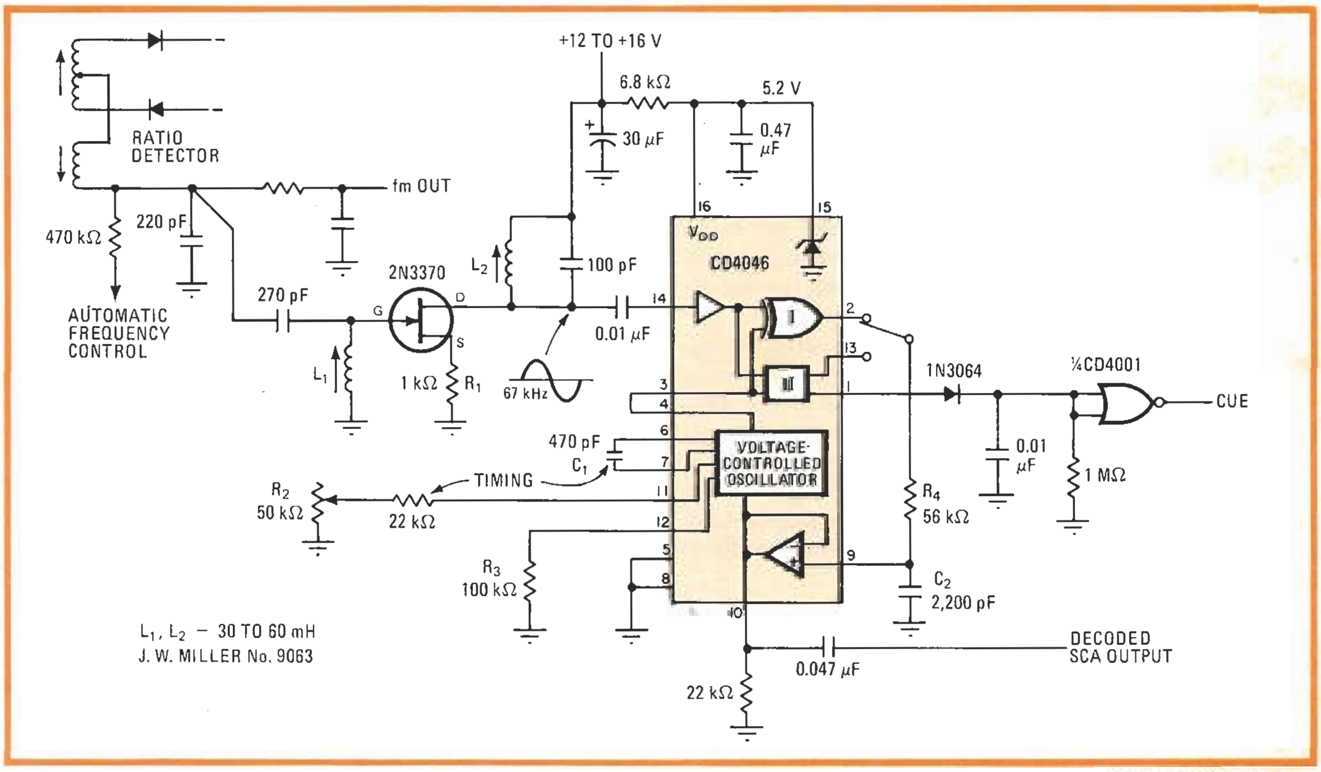
The decoder is attached to an fm receiver at its ratio-detector output, ahead of the deemphasis filter. For best performance, it is recommended that the signal be taken from a stereo receiver because its bandwidth, which is designed to be broad for the stereo carrier, provides good reception of the 67.5-kHz SCA signal.

The 2N3370 tuned field-effect-transistor amplifier separates the low-level subcarrier from the other program material, including the very strong stereo carrier. Resistor R_1 yields maximum amplifier gain at 1 kilohm. This resistance can be increased to reduce the amplifier's gain for fm receivers that deliver high-level output signals. Values to 5 kΩ are within the amp's range.

The CD4046 PLL performs the decoding. C_1 and R_2 set the loop's center frequency. R_3 sets the conversion gain (volts/radian) of the PLL's voltage-controlled oscillator. Increasing R_3 makes the VCO less sensitive to input-voltage changes. Decreasing R_3 reduces the SCA output level.

C_2 and R_4 comprise the low-pass filter. As placed in the circuit, these elements also deemphasize the SCA signal at high frequencies, the amount of deemphasis being about 3 decibels at 1.3 kHz.

A string of pulses is emitted from pin 1 of the 4046 when the PLL is in lock. The pulses are rectified by the 1N3064 diode and filtered by the 0.01-microfarad capacitor. Thus a dc level is derived. Should the subcarrier disappear, however, the level will fall and the CD4001 NOR gate will go high. This signal can be used to cue the playing of recorded messages, such as typical commercial advertisements. □



Simple service. Improved fm decoder for detecting SCA subcarrier yields higher output, uses fewer parts, provides good selectivity and cue option. Requiring only two chips, and one tuned amplifier for separating the stereo from the SCA subcarrier, it costs less than $10.

SCA DECODER

I am modernizing my old tube-type FM receiver and would like to add a solid-state SCA decoder so I can receive the programs that some FM stations transmit on a 67-kHz subcarrier. Can you provide an appropriate circuit?—J.C.M., Baldwin, NY.

I have found that replacing a high-performance vacuum-tube circuit with a solid-state version does not always ensure equal or superior operation. It should be done only when no alternatives are available. However, putting together a tube-type SCA circuit is impractical because of its high component count. Instead, use a solid-state circuit like the one shown in Fig. 1. That circuit uses a Signetics NE565 PLL (*P*hase-*L*ocked *L*oop) as a detector to recover the SCA signal; the circuit is taken from that company's data sheet for the device. The input to the SCA decoder circuit is connected to an FM receiver at a point between the FM discriminator and the de-emphasis filter network.

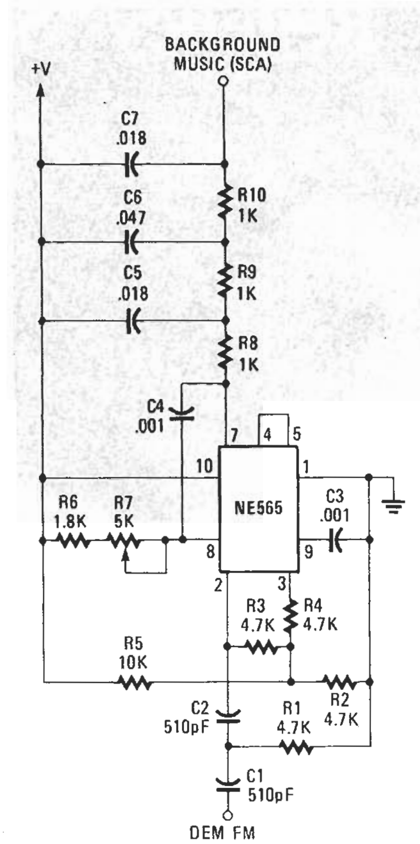


FIG. 1

The early tube-type SCA decoders that I'm familiar with have several resonant circuits that must be tuned and aligned. Since resonant circuits are not used in the circuit shown in Fig. 1 there will be some slight spill from a stereo station's main channel. The PLL, IC1, is tuned to 67 kHz by R7, a 5K potentiometer. Tuning need not be exact since the circuit will seek and lock onto the subcarrier.

The demodulated signal from the FM receiver is fed to the input of the 565 through a high-pass filter consisting of two 510-pF capacitors (C1 and C2) and a 4.7K resistor (R1). Its purpose is to serve as a coupling network and to attenuate some of the main-channel spill. The demodulated SCA signal at pin 7 passes through a three-stage de-emphasis network as shown. The resulting signal is around 50 mV, with the response extending to around 7 kHz. **R-E**

SCA/FM-STEREO RECEIVER

Tune into the "hidden" signals on your FM dial with this SCA receiver.

RUDOLF GRAF and WILLIAM SHEETS

DID YOU KNOW THAT WITH A STANDARD FM-broadcast receiver you can only hear part of the signals available on that band? The rest, called SCA (*S*ubsidiary *C*ommunications *A*uthorization) transmissions, are hidden away on subcarriers and are intended to be received only by certain segments of the public.

SCA originated with the founding of the 88–108-MHz band in the 1940's. It was intended as an income producer to help FM stations financially until the band became economically viable. It has been used for various purposes, such as background music without commercials for restaurants and offices, for medical news, for second-language programming, and for radio reading and news services for the visually handicapped.

In this article we are going to explore the world of SCA. We'll discuss, what it is, what makes it possible, and what types of programs and services make use of it. We'll also show you how to build an FM stereo/SCA receiver that will let you tune in to all of the signals on the FM band.

But before we get too far along, it would be helpful to have an understanding of FM-radio basics. Let's take care of that step first.

FM-radio basics

An FM (*F*requency *M*odulation) signal is simply any RF (*R*adio *F*requency) signal whose instantaneous frequency is determined by the modulation. The deviation of an FM signal is the component of change in carrier frequency that is determined by the amplitude (primarily) and frequency of the modulating signal. In the U.S., FM broadcast stations are permitted ±75-kHz deviation, which is defined as 100% modulation. Both a 20-Hz audio signal and a 15-kHz audio signal can produce 75-kHz deviation because it's the combination of the frequency and the amplitude of the modulating signal (program audio) that determines the deviation. If one volt of fixed-frequency audio produced ±75-kHz deviation, then one tenth of a volt would produce ±7.5-kHz deviation. Although deviation and modulation frequency are independent variables, the ratio of deviation to modulation frequency is called the *modulation index*, or β, where

$$\beta = \text{deviation/modulation frequency}$$

In a typical FM-broadcast situation, with a 1-kHz audio signal at 50% modulation (37.5-kHz deviation), β = 37.5 (37.5 kHz/1 kHz).

It's noisy

Because the ear is most sensitive to high-frequency noise, and because the FCC wanted FM to have the best possible signal-to-noise ratio, FM broadcasting incorporates a system of preemphasis/deemphasis equalization, whose parameters are based on the fact that the high-frequency energy of the sounds that are commonly part of programming decreases at an almost fixed rate per octave above 1000 Hz. (That was before the era of electronic instruments.) That allows the high frequencies to be preemphasized before transmission, and mirror-image deemphasized at the receiver. The end product is a "flat audio response"; however, noise generated anywhere between the preemphasis and the deemphasis (such as atmospheric noise) is attenuated. Because the equalization reflects nature's own frequency characteristics, it is therefore possible to preemphasize say, a concert orchestra that is reading 100% modulation on a VU

WARNING!

SCA is not a broadcast service, and SCA transmissions are not intended for reception by the general public. As a result, SCA transmissions may be governed by Section 605 of the FCC Rules, which forbid unauthorized individuals from receiving such communications and using them for their own or other's profit, or divulging their contents, intent, or meaning to any other unauthorized individual.

Many for-profit services make use of SCA, and reception of those in most cases is permitted by paying subscribers, and under certain circumstances, only. Some not-for-profit services do make use of SCA also, however, such as those providing assistance to the blind. It may be possible to receive those without obtaining prior permission or paying a subscription fee, as long as the terms of Section 605 are observed. We advise you to contact the approriate programmers in your area for more information and to obtain any necessary authorizations.

meter (which indicates average rather than peak power) without worrying that the preemphasized highs will cause overmodulation of the transmitter.

Electronic instruments and "signal processors" that came along many years after the founding of the modern FM band were to interfere with the established pre-emphasis/deemphasis concept; however, the equalization is still required to ensure optimum signal-to-noise ratio, (although it can be modified to accommodate FM-Dolby transmissions). By the way, if FM preemphasis/deemphasis noise reduction sounds similar to *Dolby-B* tape noise reduction it's because they are similar in overall concept. Dolby simply "floats" the high-frequency reference level.

Pre-emphasis/de-emphasis of some kind is used in all forms of FM communications, including SCA. That is, the FM signal has it, and so does the SCA signal.

Because the earliest FM detector was also an AM detector it was sensitive to AM atmospheric noise (static), and so receivers used IF limiter amplifiers to clip the amplitude level of the IF signal so that most AM variations—including those caused by multipath reception—were eliminated before the signal was detected. Even though modern FM detectors barely respond—if at all—to AM signal variations, receivers still use IF limiting to ensure minimum AM noise, and in particular, to eliminate many troublesome effects caused by multipath reception.

FM bandwidth

The occupied bandwidth of an FM signal, at first glance, appears to be simply the peak-to-peak deviation. However, that is not always true. A 75-kHz deviation FM broadcast signal, for instance, requires somewhat more bandwidth than simply the peak-to-peak deviation. Obviously, it is important to know the required bandwidth for various reasons, among them channel spacing, necessary receiver bandwidth, and signal-to-noise ratio considerations.

For signals with a very high modulation index, the necessary bandwidth is very close to the peak-to-peak deviation. As an example, that would be true for a 100%-modulated FM signal (75-kHz deviation in commercial broadcasting) with low audio-frequency modulation (on the order of 20 Hz, for example). However, the situation changes for signals with a low modulation index. At a modulation index of 10 the bandwidth required would be about 2.8 times the peak-to-peak deviation (75 kHz), or 210 kHz. At a modulation index of 5 (as would result from a 75-kHz signal with 15-kHz audio modulation) about 3.3 times the peak-to-peak deviation, or 247 kHz, would be required.

That increased bandwidth is due to the sidebands generated in FM. The sidebands, as in the AM case, are separated by the modulation frequency from the carrier. However, depending on the modulation index, the sidebands vary in amplitude. They appear, reach a maximum, then, at higher modulation indices, some sidebands disappear. In fact, the carrier disappears at a modulation index of 2.4. That means, if we apply a tone of about 31 kHz to an FM transmitter and adjust the level of the tone to produce a deviation of 75 kHz, the carrier will actually null out. Of course, the FM signal has not disappeared—all of its energy is now contained in sidebands spaced 31 kHz from the carrier—at ±31 kHz, ±62 kHz, ±93 kHz, etc.

While the mathematics required to describe sideband amplitude and hence required bandwidth are very complex, a rule of thumb that works out relatively well in practice for low distortion is that the required receiver bandwidth is *approximately* twice the deviation plus the highest modulating frequency. That figures out to about 240 kHz for an FM-stereo/SCA receiver. Note that FCC channel bandwidths are 150 kHz, with 50 kHz guardbands between assigned channels.

As another example, commercial 2-way FM radio used for police, fire, taxicab, etc. as well as 2 meter FM radio use ±5-kHz deviation with audio restricted to 3 kHz (3000 Hz). Receivers for those services use 13-kHz bandwidth IF filters. That, of course, is twice the deviation plus the highest modulation frequency.

The FM signal

The various components of a stereo FM broadcast signal are as follows:

- Audio baseband (0–15 kHz). That is a monophonic signal comprised of the *sum* of the left and the right (L+R) audio channels; it is the program audio received by a a monophonic FM radio.
- Stereo baseband (19 kHz and 23–53 kHz). That consists of the pilot carrier at 19 kHz, and a DSB (*D*ouble *S*ide*B*and) suppressed carrier AM signal centered at 38 kHz. The 38-kHz carrier is suppressed, and the low-level pilot carrier at 19 kHz is used by the receiver to regenerate the 38 kHz suppressed carrier. In that way the 38 kHz DSB signal is recovered and detected. That signal is comprised of the *difference* between the left and right

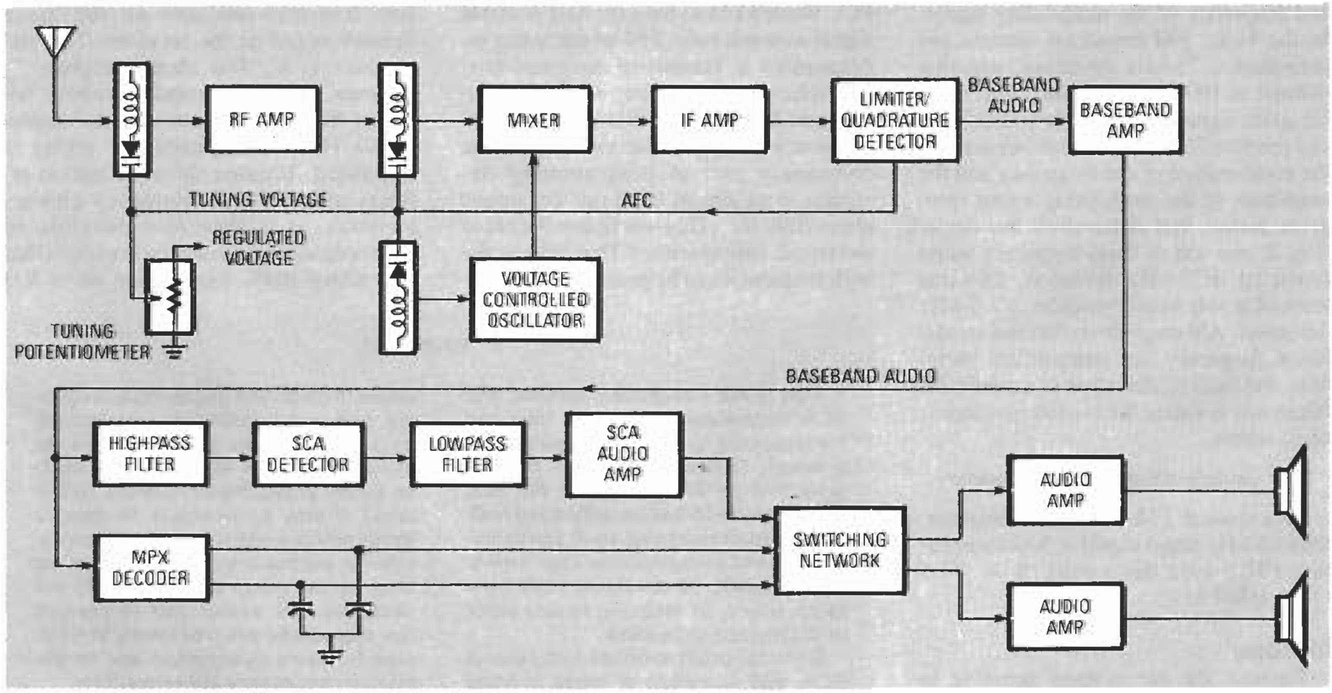


FIG. 1—OUR SCA RECEIVER is shown here in block diagram form.

PARTS LIST

Resistors ¼ watt, 10% unless otherwise noted
R1, R3, R7, R8, R10, R46, R60—100,000 ohms
R2—47,000 ohms
R4, R25, R28, R68, R70—100 ohms
R5, R31, R32, R35—470 ohms
R6, R21, R39—150 ohms
R9, R11—220 ohms
R12, R14, R18—2200 ohms
R13—3500 ohms
R15, R30, R56, R57, R62, R66, R76—1000 ohms
R16, R23, R27, R36–R38, R40, R43, R45, R49, R54, R58, R59, R61—10,000 ohms
R17—1 megohm
R19, R67, R69—10 ohms
R20, R24, R29, R33—330 ohms
R22, R26—33,000 ohms
R34, R42, R44—22,000 ohms
R41, R47, R51–R53, R64, R65—4700 ohms
R48, R50—18,000 ohms
R55, R63—15,000 ohms
R71–R75–10,000 ohms, potentiometer
Capacitors
C1, C7, C17—2–18 pF trimmer
C2, C5, C6, C8, C9, C11, C13–C15, C18, C20–C26, C28, C30–C34—0.01 µF, ceramic disc
C3, C4, C66—470 pF, ceramic disc
C10, C16, C37—100 pF, silver mica
C12, C29, C35, C36, C39, C47, C49, C59, C62—10 µF, 16 volts, electrolytic
C19—8 pF, silver mica
C27–not used
C38—3–40 pF, trimmer
C40–C43—220 pF, silver mica
C44—0.001 µF, Mylar
C45, C60, C63—0.1 µF, Mylar
C46, C51—0.047 µF, Mylar
C48, C52—0.0022 µF, Mylar
C50, C53—0.22 µF, Mylar or tantalum
C54—0.47 µF, Mylar or tantalum
C55, C65—470 pF, silver mica
C56, C57—0.022 µF, Mylar
C58, C61, C64—470 µF, 16 volts, electrolytic
Semiconductors
IC1—LM3189N FM receiver IF system (National)
IC2—LM565 phase-locked loop (National)
IC3—LM1310N FM stereo demodulator (National)
IC4, IC5—LM386 audio amplifier (National)
Q1, Q2—40673 dual gate MOSFET transistor
Q3–Q5—2N3563 NPN transistor
Q6, Q7—2N3565 NPN transistor
D1, D2, D4—MV2107 varactor diode
D3—1N757 diode
D5—1N4001 diode
LED1—jumbo red LED
LED2—jumbo green LED
Other components
L1, L3, L5—see text
L2, L4—1.8 µH
L6, L7—18 µH
CF1–CF3—10.7 MHz ceramic filter
J1—stereo headphone jack
J2–J8—phono jacks, RCA type
S1—SPST toggle switch
S2—3P4T rotary switch
Miscellaneous—PC board, No. 20 solid uninsulated wire for winding L1, L3, and L5 (18 inches total required), wire, solder, hardware, knobs, cabinet, etc.
The following are available from North Country Radio, P.O. Box 53, Wykagyl Station, NY 11804: Kit consisting of PC board and all PC-board mounted parts (jacks, switches, D5, LED's, power-supply components, etc. *not* included), $75.00 plus $2.50 postage and handling; Etched and drilled PC board, $12.50 plus $2.50 postage and handling. NY residents please add appropriate sales tax.

PARTS LIST—POWER SUPPLY

C67—2200 µF, 25 volts, electrolytic
C68—0.01 µF, ceramic disc
C69—0.1 µF, ceramic disc
C70—470 µF, 16 volts, electrolytic
T1—117-volt primary, 16–18 volt 500-mA secondary
IC6—LM7812 three-terminal regulator
D6–D9—1N4001 diode

audio channels (L − R). In a stereo receiver, the L − R and L + R signals are combined in such a way as to recreate the left and right audio channels.

- ARI (*A*utomobile *R*adio *I*nformation) subcarrier (57 kHz). That is a narrow-band channel used for traffic bulletins. Originated in Europe, that service has been recently implemented here and may become popular in the future. It is currently used on a trail basis in some major metropolitan areas.
- SCA subcarrier (most often 67 kHz and/or 92 kHz). The SCA subcarrier is used for "hidden" radio programs, background music, and digital data transmission. The signals are FM with ±7.5-kHz deviation *maximum*. SCA is not a high fidelity service; its audio-response bandwidth is limited to about 5000 Hz.

Our immediate interest, of course, is in the SCA signal. It is normally used as an auxiliary, income-producing service by the operators of an FM broadcast station. However, we do not get something for nothing. Modulating any of an FM channel's subcarriers reduces the maximum modulation available for the main audio channel. In the case of SCA, modulating one subcarrier of a stereo signal uses up about 10% maximum of the total 75 kHz deviation (100% modulation). In practice, that reduces the main channel's signal strength by about 1 dB. Normally, such a drop in signal level would not be noticeable. However in areas with crowded FM bands, every dB counts in the race for ratings, and revenue. Stations in those locations are likely to think twice about using both available SCA subcarriers, which would cost about 2 dB in signal level, let alone ARI, etc. On the other hand, leasing those subcarriers can be a significant source of income for the license owner.

SCA is noisy

At best, the SCA of a stereo-FM signal can represent only 10% of the total FM transmission; hence, the received SCA signal is unusually weak, and therefore prone to be noisy. Also, depending on the design of the receiver and the care taken with the SCA signal at the transmitter, the received SCA can suffer from "splatter" or "spillover sputter" from an FM station's main audio channel. The splatter and sputter is usually 30–40 dB below the SCA audio, but that's a level that can be heard as intermittent "noise." With proper filtering in the receiver, however, main-channel interference to the SCA caused by the receiver's circuits—not by the transmitter—can be attenuated low enough so it can't be heard.

In fact, the SCA channel—particularly when received on an SCA-dedicated receiver—is good enough so that in addition to background music it has been used for digitized stock-market quotes, digital-data transmission, telemetry, radio paging, and slow-scan color TV. And at present, out in California (where else?) the SCA is being used to distribute information and advertising to computer users in the Los Angeles area.

Receiving SCA

A block diagram of our SCA/FM-stereo receiver is shown in Fig. 1. The complete schematic is shown in Fig. 2. The circuit uses a MOSFET RF amplifier whose input and output (mixer) circuits are tuned by varactor diodes. Those varactors can be thought of as voltage-variable tuning capacitors. The DC tuning voltage is variable from about 1.5- to 8-volts DC. The local oscillator operates at the tuned signal frequency plus 10.7 MHz. The oscillator is also tuned by means of a varactor diode. The three varactors are biased by a common DC bias line, so as to simultaneously tune the RF amp, mixer, and oscillator circuits.

The mixer output circuit is tuned to 10.7 MHz and feeds an IF preamplifier that has a gain of about 30 dB. This preamplifier uses two transistors and three fixed-tuned ceramic IF filters centered at 10.7 MHz. Since the filters are fixed-tuned, no alignment is necessary. That eliminates the need for complex sweep alignment and allows a novice builder to automatically get the good IF-bandpass response necessary for SCA/FM-stereo reception.

A National LM3189N FM receiver IF system (an RCA CA3189E can be sub-

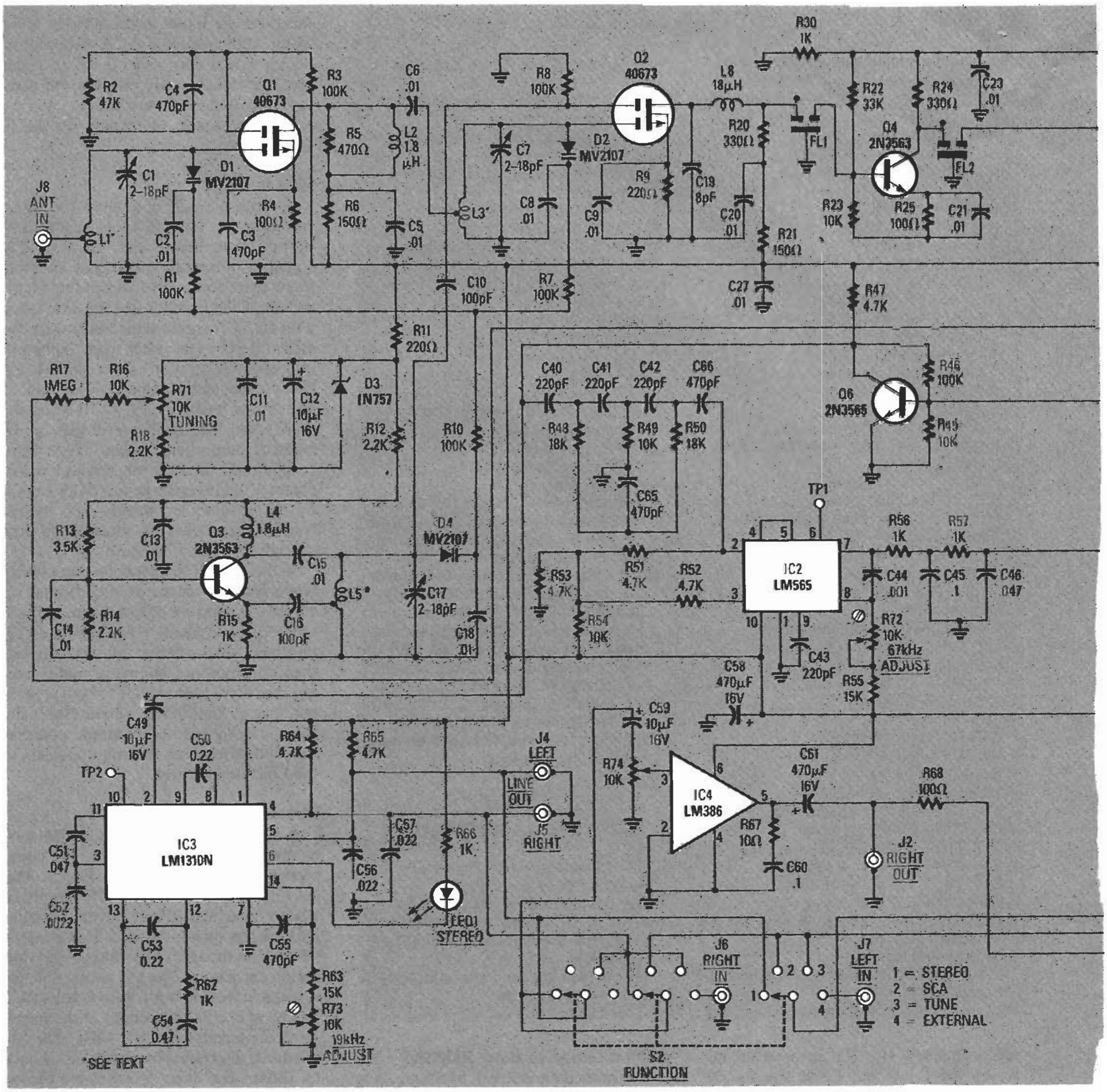


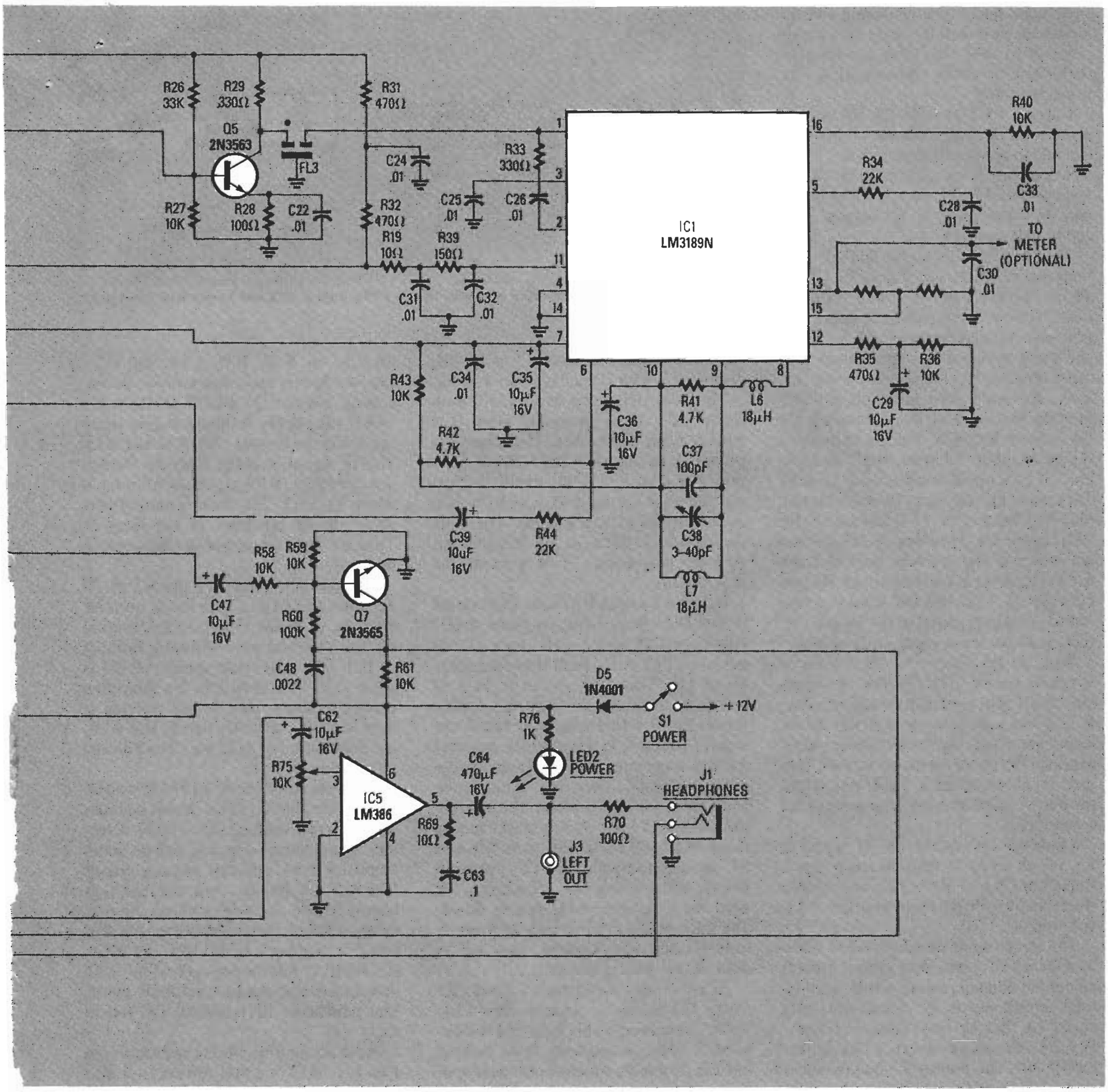
FIG. 2—THREE OF THE INDUCTORS shown in this schematic diagram must be wound by hand. Even so, they are simple to make; complete details will be given in the next installment of the article.

stituted) IC, IC1, performs limiting and quadrature detection of the FM signal, and recovers the original audio baseband. That IC offers high gain, good limiting, and low-distortion detection. It also provides an AFC voltage to correct drift in the local oscillator and to aid in tuning a selected station. Due to the very high gain, layout is *very* critical and we strongly recommend using the PC layout that will be presented next time. Otherwise you may leave yourself open to RF-instability problems.

The audio output of the LM3189N is fed to an 2N3565 audio amplifier, which delivers an output level of about 3-volts p-p. That baseband audio is used to feed the phase-locked-loop SCA detector (an LM565) and the FM-stereo detector (an LM1310N).

A high pass and twin-T R-C filter designed to reject frequencies below 50 kHz passes the SCA carrier to the LM565. The output of the IC is the VCO control voltage, which follows instantaneous frequency variations of the 67- or 92-kHz subcarrier. That output (about 50 to 100 millivolts p-p) is the SCA audio. It is passed through a low-pass de-emphasis R-C network to remove high-frequency noise. An SCA audio amp (a 2N3565) amplifies the signal to about 500-mV p-p, which is sufficient to fully drive the audio power amplifiers.

The LM1310N is designed to accept the baseband audio and reproduce the original L and R audio channels. Baseband audio of about 2–3-volts p-p is fed to the LM1310N and L and R audio signals ap-



pear at the outputs. Shunt connected capacitors provide de-emphasis. An LED can be connected to the decoder to indicate stereo reception.

A 3P4T (three pole, 4 throw) switch selects among FM (stereo in the case of stereo broadcasts), SCA, tune, and auxiliary positions for input to the dual power amps. In the tune position, FM main channel audio is input to one of the amps while SCA audio is input to the other. That makes tuning in an SCA subcarrier easier; more details will be provided when we talk about using the receiver. In the auxiliary position the unit becomes a power amp and will accept an external input via its LINE IN jacks.

The dual power amps are identical and are built around a pair of LM386N's. Power output is ½ watt (500 mW) per channel. That is sufficient to drive a pair of small speakers, but we recommend using stereo headphones for best results. If desired, the LM386N amps can be omitted and the outputs fed to the line inputs or tuner inputs of an audio system. About 500 mV into a 10k load is available at the LINE OUT jacks.

More detail

Looking at the circuit in more detail, FM signals from the antenna are applied between the tap on L1, which is the antenna coil, and ground. The antenna coil is tuned by C1 and varactor D1 to the signal frequency. The varactor has a variable back bias of 1.5 to 8 volts across it. That will sweep its capacitance from 15 to 30 pF. When that capacitance is added to the stray capacitance on the board and the input capacitance of Q1, it yields a tuning range of 87–109 MHz; that is more than sufficient to cover the complete FM broadcast band.

Capacitor C2 provides an RF ground and allows DC bias from the tuning-voltage line to be supplied through R1. It also cleans up any noise present on the tuning voltage line. No DC current flows in R1, and therefore there is no voltage drop across that component.

The tap on L1 is placed so that Q1 sees a high input impedance. Transistor Q1 is a 40673 MOSFET device with a noise figure of 4 dB or less (typically 2–3 dB at FM frequencies); that ensures high sensitivity and there is no base-emitter junction to cause unwanted rectification of strong signals. Resistor R4 and capacitor C3 provide biasing and RF grounding for Q1's source terminal. The G2 terminal is biased at about +4 volts by R2 and R3, and C4 bypasses that terminal to ground. The gain of the stage may be controlled by reducing that bias to −2 volts (cut-off) for AGC purposes. However, AGC was not necessary in the receiver, and was not used. The drain is biased through R6 and L2 to about +11-volts DC. Drain current (which is exactly equal to the source current) is about six to eight milliamperes.

Resistor R5 limits the stage gain to about 6 times. That is the optimum amount of gain to ensure circuit stability; it is quite adequate to override mixer noise, yet not so high as to unnecessarily overload the mixer on strong signals. Further, it allows about a 3-dB margin for mistracking and errors in alignment of the tuned circuits.

Capacitor C6 couples the RF signal to L3, which serves to tune the mixer input. Capacitor C5 is an RF bypass and resistor R6 decouples the RF stage from the +12-volt line.

The mixer-input tuned circuit is tuned by C7 and D2, with stray circuit capacitances once again playing a role. Ideally, total capacitance in the circuit is exactly equal to that in the antenna circuit. However, the operating Q is a little higher (about 30). The overall RF bandwidth is about 2 to 3 MHz, which provides quite adequate image rejection—about −30 dB or better.

The mixer is driven by a signal of about 3-4 volts p-p on G2 of Q2. Since the transconductance of the 40673 is a function of the G2 voltage with respect to the source, the local oscillator (more on that in a moment) signal in effect modulates the transconductance of Q2. That results in the 40673 acting as a mixer. Resistor R8 returns G2 to DC ground. Resistor R9 and capacitor C9 provide about a 0.6-volt bias, which places both gates at about −0.6 volt, with respect to the source terminal. The power gain of the mixer (the ratio of the IF signal at 10.7 MHz to the

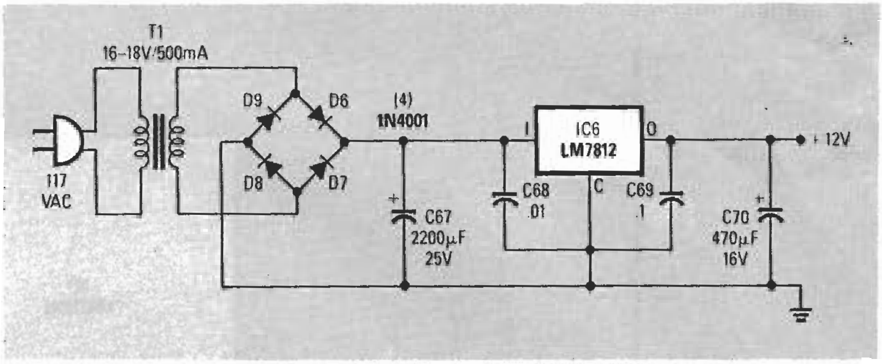


FIG. 3—THE CIRCUIT REQUIRES a regulated 12-volt power supply. The one shown here fills the bill nicely.

RF input signal) is about 12 to 15 dB, depending on local oscillator drive level.

The local oscillator uses a 2N3563 transistor, Q3, whose operating point is 4 volts at 1.5 milliamperes. That operating point is established by the network comprised of R12, R13, R14, and R15. Note that the local oscillator is actually a voltage controlled oscillator set up to be in the common-base mode at RF frequencies. At such frequencies, C14 grounds the base of Q3.

Inductor L4 is an RF choke that is used to feed DC voltage to the collector of Q3. Capacitor C15 couples the tank circuit made up of L5, C17, and D4 to the collector of Q3. That tank circuit is used to determine the oscillator frequency, which should be 10.7 MHz above or below the signal frequency. In this receiver, the local oscillator operates 10.7 MHz above the incoming signal. Therefore, it must tune from about 98 to 120 MHz. The spacing should be 10.7 MHz over the entire tuning range of 87-109 MHz. Resistors R16 and R17 are used to couple the AFC correction voltage to the tuning line, eliminating the need for a separate AFC tuning diode. The value of R16 can be anything from 1K to 100K, depending on how much AFC is desired. We used a 10K unit.

As previously mentioned, L5 and C19 match the mixer to ceramic filter FL1. Those components also help prevent unwanted VHF components from leaking into the IF stages, which could cause spurious responses. A ceramic filter is a piezoelectric device that is the equivalent of an IF transformer. It acts as a double-tuned transformer with a 1-dB bandwidth of 250 kHz, centered at 10.7 MHz. The device's insertion loss is about 6 dB, and its termination impedance is specified as 330 ohms.

The first IF amplifier is built around Q4. That transistor is biased by R22, R23, and R25 to about 2 milliamperes when the collector voltage is 4. Ceramic filter FL2 couples Q4 to Q5, which is biased identically to Q4, using R26, R27, and R28. Capacitors C21 and C22 bypass the emitters of Q4 and Q5 respectively. The IF stages are decoupled from the power-supply line by R32, R31, C24, and C23. Resistor R30 is used to determine the operating points of Q4 and Q5. It results in a +4.5-volt supply to those stages, forming a voltage divider with R31 and R32. The IF signal is coupled to the limiter/detector stage (IC1 and peripheral components) by FL3. The three ceramic filters shape the IF bandpass of the receiver. They are fixed tuned and no alignment is required.

The gain of Q4 and Q5 is about 26 to 30 dB. That gives a total gain so far, from the antenna, of about 55 to 60 dB, ensuring that the front-end noise will cause limiting in IC1. The maximum output of Q5 is about 0.25 volt, which is the saturation point, no matter how strong a signal is received; IC1 can easily handle that without distortion. No AGC was found necessary in this receiver.

Most the functions of an FM IF system are provided by IC1. That device includes a three-stage limiter, signal-level detectors, a quadrature detector, and an audio amplifier with optional muting circuit (squelch). It has its own internal regulators for DC voltages, and can drive an external tuning meter. While we specified using a National LM3819N, an RCA CA3189E is pin-for-pin compatible with that device and can be used in its place. Use whichever IC is easiest for you to find.

Input signal from FL3 is applied to pin 1 of IC1. R33 is a bias resistor and also terminates FL1. Capacitors C25 and C26 are RF bypass capacitors. The 12-volt supply line is connected to pin 11 of IC1 by R19, C31, R39, and C32; those components provide RF decoupling as well. While they are not used in the receiver, the IC's squelch (mute) circuits must be terminated; R34, C28, C29, R35, and R36 serve that function.

An optional tuning meter can be installed in the receiver. We chose not to do so, but if you do, install it at the junction of C30 and R37 as indicated in Fig. 1. Otherwise, the junction makes a good test point for aligning of the front-end's tuned circuits.

continued on page 81

STEREO RECEIVER

continued from page 44

The IC's AGC function was not used in the design. Instead, pin 16 was terminated by R40 and C33.

A 10.7-MHz tuned circuit is formed by L7, C38, and C37. Resistor R41 acts as a swamping resistor to obtain the wide bandwidth of the quadrature circuit, C37, C38, and L7. Drive voltage from pin 8, IF out, to pin 9, quadrature detector input, is delivered via L6. The value of that inductor is somewhat critical for proper squelch-circuit operation. It should be between 18–22 μH. We had an 18-μH unit on hand so it was used.

A load for the AFC circuit is provided by R43, and R42 biases the audio circuit in the IC. Capacitor C38 is used to tune the quadrature circuit to 10.7 MHz. It is adjusted for best received audio and zero DC voltage across R43.

Recovered total modulation is present at pin 6. It contains the FM baseband and the SCA signal. The baseband audio is taken off through R44 and C39.

The baseband-audio amplifier is built around Q6, a 2N3565. It is set up for a nominal gain of about 5 (the ratio of R44 to R46 is the approximate gain of this stage). Resistors R45 and R46 bias Q6 to about 6 volts at 1 milliampere. R47 is a load resistor. About 2 volts of baseband audio is present at the collector of Q6.

Audio from Q6 is fed to two separate circuits. One circuit is an SCA demodulator; the other is an FM stereo decoder.

SCA demodulation

Audio from Q6 is fed to an SCA take-off R-C high-pass filter made up of C40, R48, R49, C41, C42, and R65. That filter substantially attenuates audio components below 50 kHz.

The SCA demodulator, IC2, is an LM565 phase-locked loop. It contains a VCO (*V*oltage *C*ontrolled *O*scillator) and phase detector comparator. If a signal of sufficient amplitude (about 100 millivolts) is fed into pin 2 or 3 of that device, and its frequency is sufficiently close (say within ±30%) to the VCO frequency, the VCO will lock to the input frequency and track it; that is, the voltage that controls the VCO will follow any changes in the frequency of the input signal. The control voltage for the VCO is present at pin 7 and is a linear function of the input-signal frequency. Therefore, the LM565 can function as an FM detector with no external inductive components required. (At the SCA-subcarrier frequencies of 67 or 92 kHz, inductors can become rather large and somewhat costly. It is therefore to our advantage to eliminate those coils, and their alignment.)

The LM565 is biased by external resistors R51, R52, R53, and R54. The VCO frequency is determined by C43 and the resistance of R72 and R55. The setting of R72 is adjusted so that the VCO frequency, which can be measured at pin 4, is near 67 kHz.

Adjustment of R72 is not critical, and simply adjusting it for clearest SCA reception is adequate. (If 92 kHz operation is desired, R55 should be changed to about 6.8K.) Capacitor C44 is used as a loop filter for the phase-locked loop. Audio appears at pin 7 of the LM565. A de-emphasis network made up of R56, C45, R57, and C46 will suppress any 67-kHz components and attenuate high-frequency noise.

An audio-amplifier stage, Q7, brings up the detected audio level to about 500 mV. From the amplifier, the signal is sent to the selector switch, S2, for routing.

FM decoding

Audio from Q6 is also sent, via blocking capacitor C49, to IC3, an LM1310N FM-stereo multiplex decoder. The LM1310N contains a VCO, a phase-locked loop for regenerating the 38-kHz stereo subcarrier, a lock detector used as a stereo-indicator circuit, and a decoder circuit for deriving the left and right audio channels. The internal VCO operates at 76 kHz and the 19-kHz and 38-kHz signals are derived from an internal frequency divider. No indicators are required and alignment consists simply of adjusting R73 for a 19-kHz signal at pin 10.

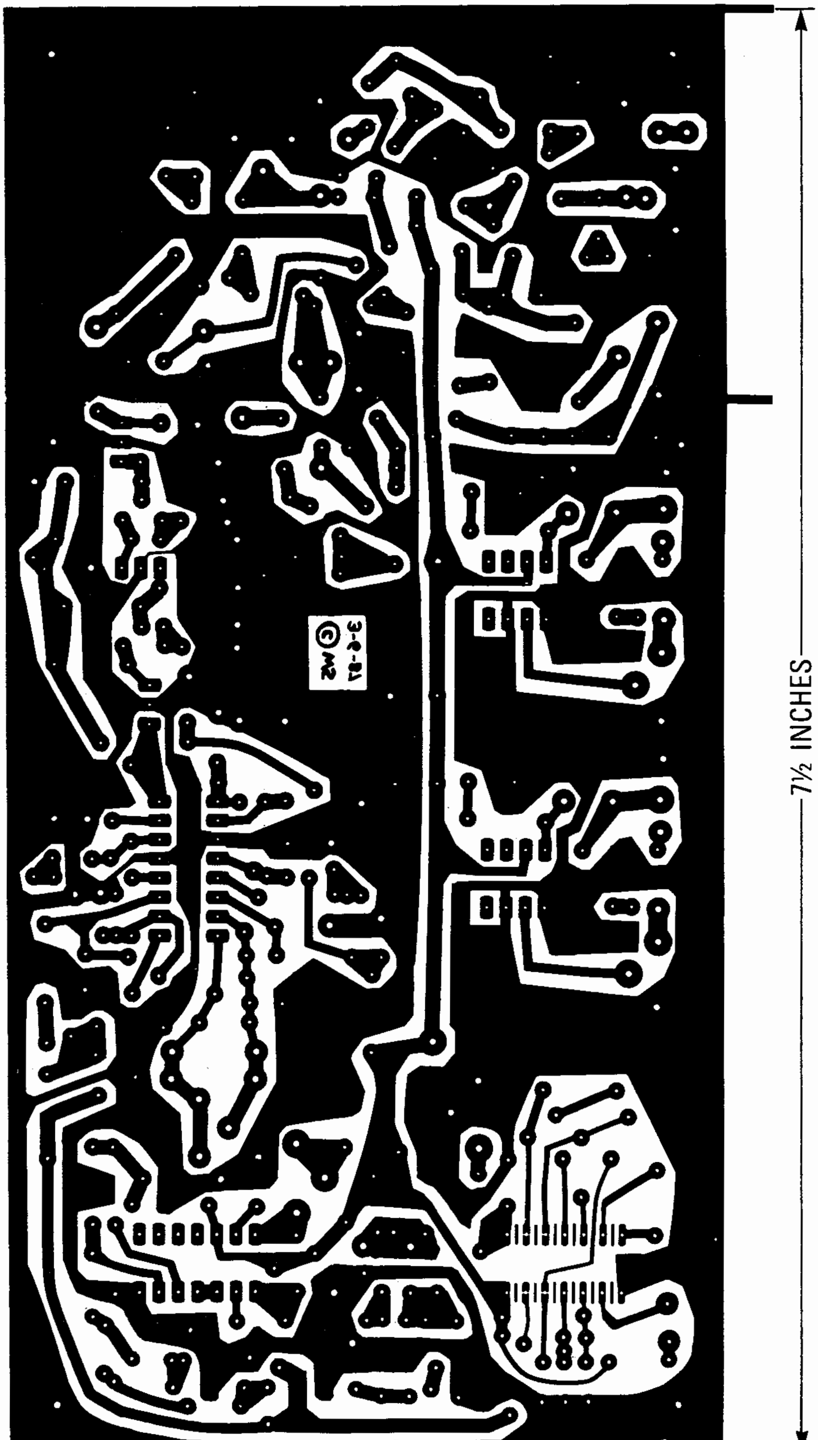
Getting back to the circuit, C53, R62, and C54 form a compensating network for IC3's internal phase-locked loop. Capacitor C50 is the loop filter for the phase-locked loop. The network made up of C55, R63, and R73 control the center frequency of the internal VCO, which should be 76 kHz. The 19-kHz pilot signal (derived from an internal divider) is available at pin 10 for test purposes. Audio output appears at pins 4 (left) and 5 (right). Resistors R64 and R65 serve as loads for the internal audio amplifiers. FM-audio de-emphasis is provided by C56 and C57. The right and left audio from pins 4 and 5 is fed to S2.

The audio amplifiers in this circuit, IC4 and IC5, are LM386N's. They each provide about a 0.5-watt output, adequate for driving an eight-ohm speaker. Do not use speakers that present less than an eight-ohm load.

The entire receiver draws about 125 milliamps at 12-volts (the recommended supply voltage). The supply should be regulated and have good filtering. A suitable power supply is shown in Fig. 3.

Next time

That's all the room we have for now. Next time we'll show you how to build, align, and use the receiver. The PC pattern will be presented at that time. **R-E**



TUNE IN THE HIDDEN WORLD of FM radio with the SCA receiver. Most of the components mount on this single-sided PC board.

SCA/FM-STEREO RECEIVER

Tune into the "hidden" signals on your FM dial with this SCA receiver.

RUDOLF GRAF and WILLIAM SHEETS

Part 2 LAST TIME, WE looked at the circuit for an FM-stereo/SCA receiver. This month we'll show you how to build that circuit.

Construction

The parts-placement diagram for the receiver is shown in Fig. 4. The pattern for the single-sided board is shown in PC Service. Upon examination, you may notice that the board uses a rather unusual parts layout. The layout shown was used to solve stability and crosstalk problems that are commonly encountered in high-gain, high-frequency designs of this type. It is based on the authors' experience with similar receivers, and with the particular IC's and transistors used.

The decision to use a single-sided board was made for several reasons. One, it makes it easier for a hobbyist with limited resources to reproduce the PC board at home. It also minimizes stray board capacitances, which can be a real problem at the frequencies involved. However, the use of a single-sided board does present some problems of its own. Such boards are much more difficult to lay out, and present RF grounding and stability problems. Those problems have been solved in the layout shown. Therefore, we *strongly* urge that you use our layout if you are contemplating building the receiver or any portion of it.

When stuffing the board, use a low-wattage iron (25 watts) and keep soldering time to a minimum to avoid overheating the components. All capacitors should be mounted as flush with the board as possible to minimize lead length. Be sure to adhere to the types and values specified in the Parts List. In particular, C16, C19, C37, C43, and C55 should be dipped silver-mica or NPO-ceramic types only.

With the obvious exception of the potentiometers (R71–R75), all resistors are ¼-watt, 5% types. Again, make sure that all components are mounted flush with the PC board.

Be sure to observe the polarity on all appropriate components, such as the electrolytic capacitors. Varactor diodes D1, D2, and D4, and Zener diode D3 must be oriented correctly or the circuit will not work. Be sure to orient all IC's as shown in Fig. 4; otherwise they will be instantly and permanently damaged when power is applied. Care must be taken with ceramic filters FL1–FL3; they are somewhat delicate and easily broken. When you mount the AFC jumper (between C34 and R17), use a direct run to keep the lead as short as possible.

The tuning potentiometer, R71, should be mounted off the board, on the front panel. Further, it should be a good-quality multiturn unit for greatest tuning ease. (Note that the R71 included in the kit available from the supplier is a PC-mounted unit; if the supplied R71 is used, it is mounted directly on the board and R18 is deleted. While that configuration is satisfactory for testing and experimentation, we recommend using a good-quality multiturn unit as described for best results.) If desired, R74 and R75 can also be mounted on the front panel.

Use a cabinet that is ample for the board. In particular, you should be able to mount the board at least ½-inch away from the sides, top, or bottom. The unit shown in the photographs has a wood base and a plexiglass front panel. We mounted the board on ½-inch metal spacers.

You can arrange the front-panel controls to suit your needs or preferences.

WARNING!

SCA is not a broadcast service, and SCA transmissions are not intended for reception by the general public. As a result, SCA transmissions may be governed by Section 605 of the FCC Rules, which forbid unauthorized individuals from receiving such communications and using them for their own or other's profit, or divulging their contents, intent, or meaning to any other unauthorized individual.

Many for-profit services make use of SCA, and reception of those in most cases is permitted by paying subscribers, and under certain circumstances, only. Some not-for-profit services do make use of SCA also, however, such as those providing assistance to the blind. It may be possible to receive those without obtaining prior permission or paying a subscription fee, as long as the terms of Section 605 are observed. We advise you to contact the approriate programmers in your area for more information and to obtain any necessary authorizations.

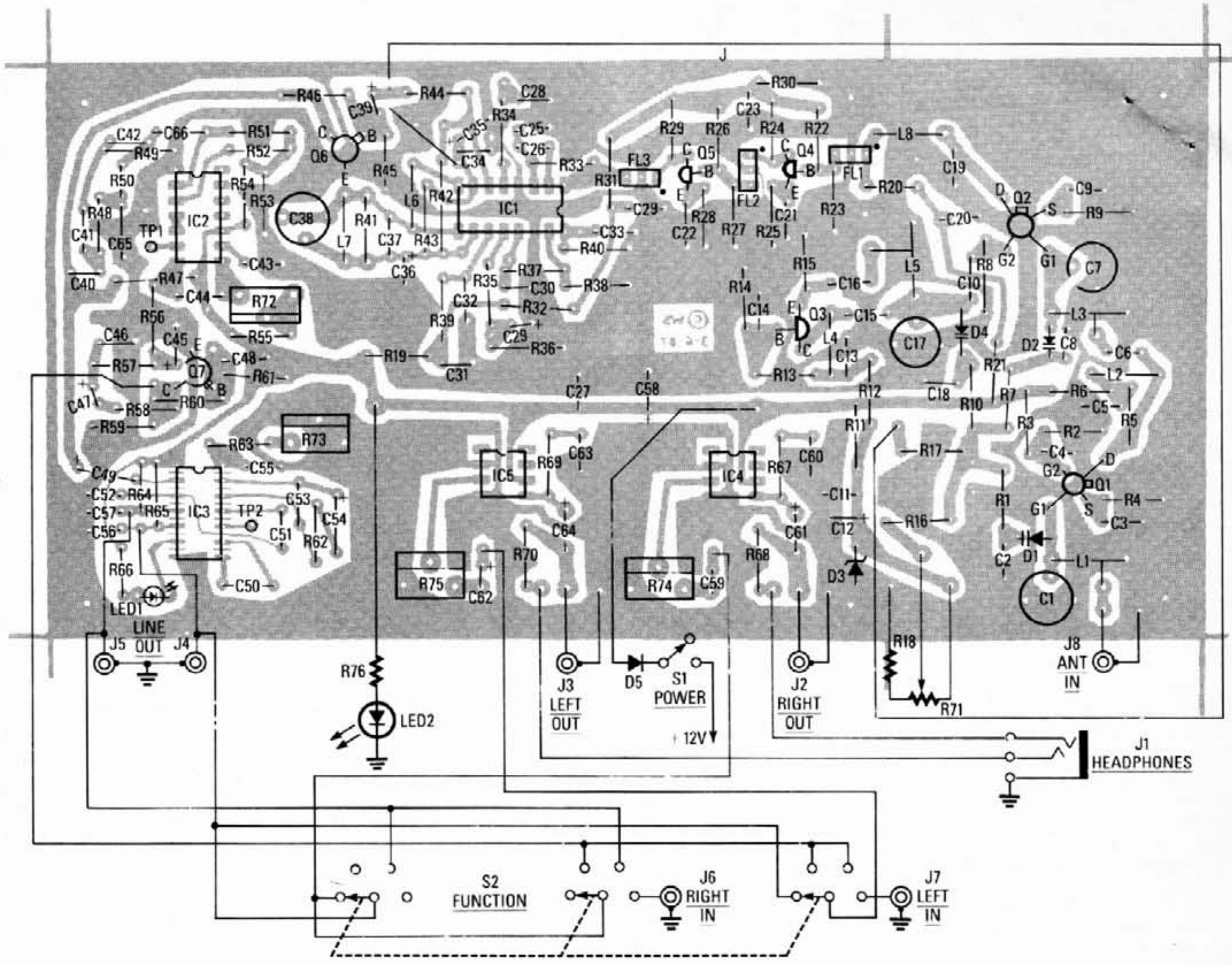


FIG. 4—**MOST OF THE COMPONENTS mount on a single-sided PC board. However, for best results, we recommend removing R71, replacing it with a multiturn potentiometer, and mounting that unit on the front panel.**

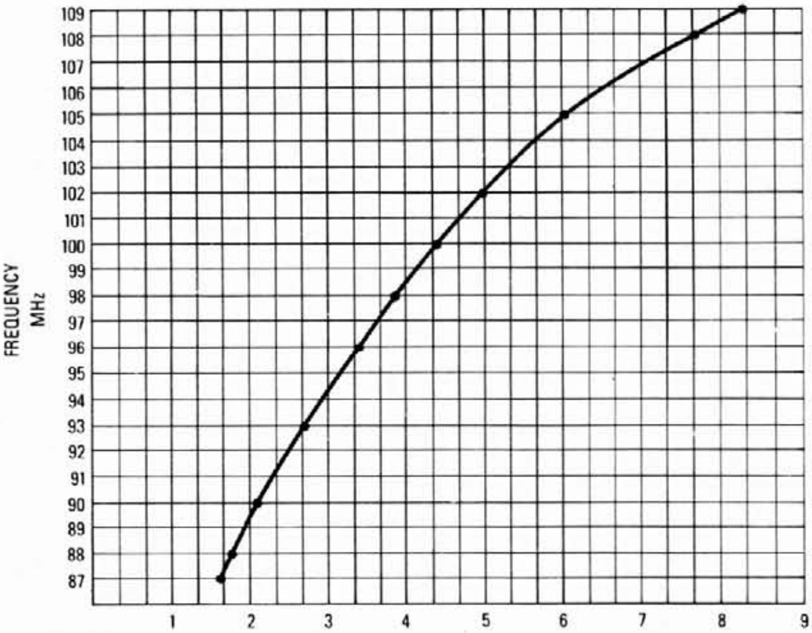


FIG. 5—**USE THIS CHART to find the tuning voltage for the frequency of interest. Then adjust the setting of R71 so that voltage appears at the junction of R16 and R17 and tweak C17 until the station is received.**

Connect front-panel mounted potentiometers to their appropriate pads using shielded cable for best results, especially if any of the runs are long. If the power supply is located physically close to the receiver, the AC power cord should be routed as far away from the front panel as possible. Otherwise, the leads from the potentiometers (particularly if shielded cable is not used) may be susceptible to AC-hum pickup.

The handwound coils for the front end are made using No. 20 tinned copper wire. They should be wound on a 3⁄16-inch form; the shank of a 3⁄16-inch drill bit is ideal for that purpose. Coils L1 and L3 are 5 turns each, and are tapped at 1.5 turns from the grounded end; L5 is four turns, tapped at 1.5 turns from the grounded end. The easiest way to build the coils is to wind each one, install it so that it sits 1⁄8- to 3⁄16-inch from the PC board, and then, using a length of No. 22 or 24 wire (a clipped-off lead from a resistor or capacitor is useful for that purpose) install the tap on the coil—simply tack-solder it on. You also can can use short lengths of clip-

PARTS LIST

Resistors ¼ watt, 10% unless otherwise noted
R1, R3, R7, R8, R10, R46, R60—100,000 ohms
R2—47,000 ohms
R4, R25, R28, R68, R70—100 ohms
R5, R31, R32, R35—470 ohms
R6, R21, R39—150 ohms
R9, R11—220 ohms
R12, R14, R18—2200 ohms
R13—3500 ohms
R15, R30, R56, R57, R62, R66, R76—1000 ohms
R16, R23, R27, R36–R38, R40, R43, R45, R49, R54, R58, R59, R61—10,000 ohms
R17—1 megohm
R19, R67, R69—10 ohms
R20, R24, R29, R33—330 ohms
R22, R26—33,000 ohms
R34, R42, R44—22,000 ohms
R41, R47, R51–R53, R64, R65—4700 ohms
R48, R50—18,000 ohms
R55, R63—15,000 ohms
R71–R75–10,000 ohms, potentiometer

Capacitors
C1, C7, C17—2–18 pF trimmer
C2, C5, C6, C8, C9, C11, C13–C15, C18, C20–C26, C28, C30–C34—0.01 µF, ceramic disc
C3, C4, C66—470 pF, ceramic disc
C10, C16, C37—100 pF, silver mica
C12, C29, C35, C36, C39, C47, C49, C59, C62—10 µF, 16 volts, electrolytic
C19—8 pF, silver mica
C27–not used
C38—3–40 pF, trimmer
C40–C43—220 pF, silver mica
C44—0.001 µF, Mylar
C45, C60, C63—0.1 µF, Mylar
C46, C51—0.047 µF, Mylar
C48, C52—0.0022 µF, Mylar
C50, C53—0.22 µF, Mylar or tantalum
C54—0.47 µF, Mylar or tantalum
C55, C65—470 pF, silver mica
C56, C57—0.022 µF, Mylar
C58, C61, C64—470 µF, 16 volts, electrolytic

Semiconductors
IC1—LM3189N FM receiver IF system (National)
IC2—LM565 phase-locked loop (National)
IC3—LM1310N FM stereo demodulator (National)
IC4, IC5—LM386 audio amplifier (National)
Q1, Q2—40673 dual gate MOSFET transistor
Q3–Q5—2N3563 NPN transistor
Q6, Q7—2N3565 NPN transistor
D1, D2, D4—MV2107 varactor diode
D3—1N757 diode
D5—1N4001 diode
LED1—jumbo red LED
LED2—jumbo green LED

Other components
L1, L3, L5—see text
L2, L4—1.8 µH
L6, L7—18 µH
CF1–CF3—10.7 MHz ceramic filter
J1—stereo headphone jack
J2–J8—phono jacks, RCA type
S1—SPST toggle switch
S2—3P4T rotary switch
Miscellaneous—PC board, No. 20 solid uninsulated wire for winding L1, L3, and L5 (18 inches total required), wire, solder, hardware, knobs, cabinet, etc.

The following are available from North Country Radio, P.O. Box 53, Wykagyl Station, NY 10804: Kit consisting of PC board and all PC-board mounted parts (jacks, switches, D5, LED's, power-supply components, etc. *not* included), $75.00 plus $2.50 postage and handling; Etched and drilled PC board, $12.50 plus $2.50 postage and handling. NY residents please add appropriate sales tax.

PARTS LIST—POWER SUPPLY

C67—2200 µF, 25 volts, electrolytic
C68—0.01 µF, ceramic disc
C69—0.1 µF, ceramic disc
C70—470 µF, 16 volts, electrolytic
T1—117-volt primary, 16–18 volt 500-mA secondary
IC6—LM7812 three-terminal regulator
D6–D9—1N4001 diode

ped resistor or capacitor lead for the pc-board test points.

Once construction is complete, check your work carefully. Make sure that all components are oriented correctly. Examine your work for poor solder joints and for solder bridges. Once you are certain that everything is OK, you can proceed.

Checkout and alignment.

Begin by setting all potentiometers to the middle of their ranges. Set C38 so it is ½ meshed. Set C1, C7, and C17 so they are about ¼ meshed. Connect two 8-ohm speakers to the audio outputs, or a pair of 32-ohm headphones to the headphone jack. Connect about 6 feet of hookup wire to the antenna input, J8, to serve as a temporary antenna.

Once that is done, measure the DC resistance between the power and ground traces on the board. It should be above 100 ohms. If it is significantly less, you likely have a short somewhere on the board. Find it and fix it before proceeding.

If everything is OK, apply +12-volts DC to the +12-volt input. Check the current drawn from the supply; it should be about 125–150 mA at 12 volts.

When power is applied, you should hear a rushing noise in both speakers (or headphones). If not, find the source of the problem and correct it before going on. If only one channel is dead, the best place to look is around the appropriate audio amp (IC4 or IC5).

Set the FUNCTION switch (S2) for FM-stereo and rotate R71. In most areas of the U.S. you should hear a few FM signals. Note that at this point the audio may seem distorted. Using a non-conductive tuning tool, adjust C38 for clearest audio (lowest distortion). Adjust R74 and R75 for a comfortable volume level.

Next, we'll calibrate the tuning potentiometer. Locate and identify a weak station at the high end (between 106 and 108 MHz) of the FM broadcast band using a commercial FM receiver. Try to tune that station using our receiver. If your tuning range does not extend high enough, adjust C17 to correct the tuning range. Once the station is tuned in, use Fig. 5 to find its corresponding tuning voltage. Set R71 so that that voltage appears at the junction of R16 and R17. Then tweak the setting of C17 so that the station is tuned at that setting of R71.

To calibrate at the low end of the broadcast band, locate and identify a weak station between 88 and 91 MHz. Adjust R71 to get the appropriate tuning voltage at the junction of R16 and R17 as before. Then, compress or expand the turns of L5 until that station is received at that setting of R71. Double check your calibration to be sure that the entire band is covered.

Once you are satisfied with the band coverage, adjust C1 and C7 for best reception and note their settings. To tweak reception, tune in a weak signal between 88 and 91 MHz. Adjust C1 to see if a different setting will provide better reception. If it does, note whether the adjustment results in increasing (greater meshing) or decreasing (less meshing) the capacitance of C1. Return C1 to its original setting. If increasing the capacitance resulted in better performance, compress L1 for optimum reception; if decreasing capaci-

SCA RADIO MANUFACTURERS

Commercial Elects./Multiplex Music 38-40 Washington Avenue, St. Louis, MO 63108
Dynamic Sound, PO Box 840, Exeter, NH 03833
Fox Marketing, Inc., 4518 Taylorsville Rd., Dayton, OH 45424
Johnson Electronics, Inc., PO Box 4728, Winter Park, FL 32707.
McMartin International, Inc., 111 Camino Del Rio, Gunnison, CO 81230
Norver Co., Inc., 7300 North Crescent Blvd., Pennsauken, NJ 08110
Panasonic/Matsushita Technology Center, 1 Panasonic Way, Secaucus, NJ 07094
Radio Systems, Inc., PO Box 356, Edgemont, PA 19028
Repco, Inc., 1940 Lockwood Way, Orlando, FL 32854
SCA Data Systems, Inc., 3000 Ocean Park Blvd., Suite 1040, Santa Monica, CA 90405
SMC International, 14745 Madison Cir., Omaha, NE 68137
Toa Electronics, Inc., 480 Carlton Ct., South San Francisco, CA 94080

ADDING A FILTER

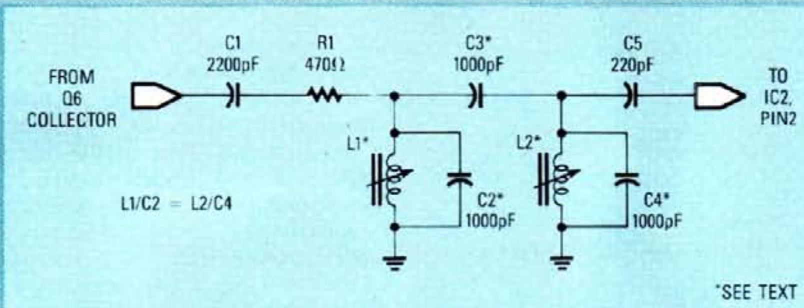
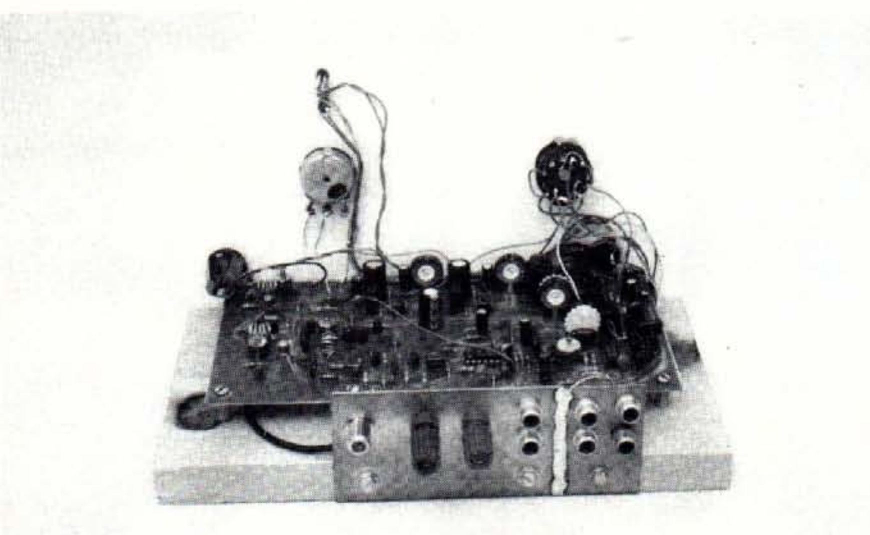


FIG. 1—THIS TUNABLE BANDPASS FILTER effectively suppresses main-channel sputter to provide superior performance for your SCA receiver.

Whether or not the main-channel audio interferes with an SCA signal depends on several factors, both at the receiver and transmitter. In particular, however, the precision of the components used in the Twin-T filter that feeds the SCA demodulator strongly affects how much main-channel sputter and splatter will be heard in the SCA signal's background. If the filter is made from high-tolerance components—1% resistors and capacitors—the main channel suppression will be adequate in most instances.

If you need an SCA signal that is virtually immune to interference by the main channel, then we suggest adding the tunable bandpass filter shown in Fig. 1 to your receiver. The value of L1 and L2 is found from the formula $L = (1/6.28 \times f)^2/C$, where *f* is the SCA subcarrier frequency and C is the value of the capacitor in the resonant circuit. The values of C2–C4 depend on a number of factors, including the characteristics of the coils used, the impedance at the filter's input and output, etc. Start with a value of 1000 pF for each as shown, but be prepared to experiment with the values of the components marked with an asterisk to obtain optimum performance. Of course, bear in mind that L1/C2 and L2/C4 must be resonant at the subcarrier frequency.

The filter can be assembled on a small PC or wire-wrap board and piggy-backed onto the main board with double-sided tape, or small metal brackets. **R-E**



THE AUTHOR'S PROTOTYPE was mounted in a simple homemade cabinet. Whatever cabinet you use, be sure that it is ample to house the board.

tance yielded better reception, expand the coil. Repeat the procedure for C7 and L3. Then tune to a weak station at the high end of the band and repeat. Continue the process until you are satisfied that no further improvement is noted.

Adjust C38 so that the voltage across R43 is zero when a station is tuned in properly. Detuning the station should cause that voltage to rise or fall slightly (±1 to 2 volts is typical). Adjusting C38 in that manner should produce the clearest audio.

Next, tune in a weak station that you are certain is transmitting its signal in stereo. Adjust R73 for best stereo reception. When R73 is adjusted properly, LED1 should light. For more precise adjustment, connect an oscilloscope or frequency counter to TP1 and adjust R73 to produce a 19-kHz signal.

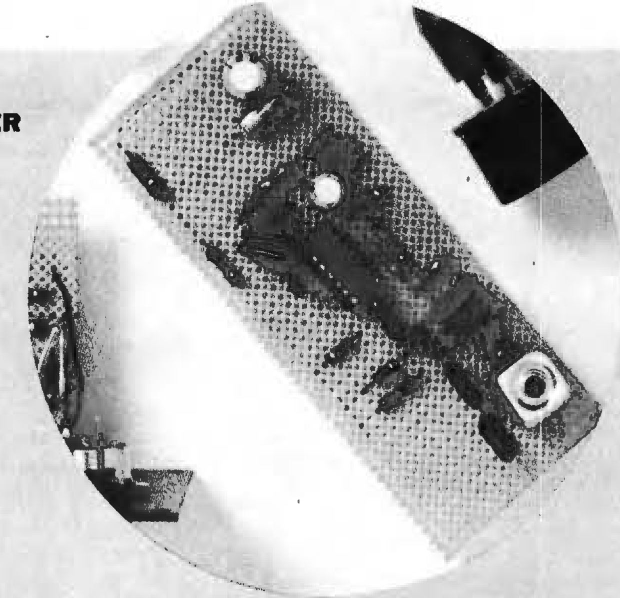
Now, set S2 for SCA reception and R72 to its midrange position. *Slowly* tune across the FM broadcast band. You may hear several SCA signals. Tune one in and adjust R72 for best reception. If you cannot hear any SCA signals, change the setting of R72 *slightly* and try again. Note that if you do not have good fortune, aligning the receiver in this manner can be tedious and time-consuming, but with patience it can be done. There is, however, a short cut available to you if you have access to a frequency counter or an oscilloscope: Simply connect the instrument to TP2 (pin-6 of IC2) and set R72 to produce a 67-kHz signal there. To tune in other subcarrier frequencies, set potentiometer R72 to produce a pin 6 signal of the appropriate frequency.

If you know that a certain FM station has SCA activity, the receiver's TUNE function offers yet another method of alignment. When S2 is set to TUNE, the main channel audio is fed to one output, while the SCA audio is fed to the other. That allows you to hear both the main channel and the SCA subcarrier simultaneously. Using a pair of headphones for best results, tune the receiver so that the desired station's main-channel audio can be heard in one ear. Then, adjust R72 until the desired subcarrier can be heard in the other ear.

That completes the alignment procedure. Though there are a lot of steps to follow, most of the adjustments are broad and the radio should work in the FM-stereo position even with just the initial adjustments outlined. An exception to that is the setting of C38, and, to a lesser degree, the setting of C17; correctly adjusting those components requires some precision. Still, if the setting of any component is so critical that even breathing on it causes problems, something is not working properly.

Searching the bands

One of the authors lives on the New York/Vermont boarder, about 50 miles north of Albany, NY. From that relatively rural location he has received FM-stereo signals from as far as 170 miles away using only a two-foot clip-lead antenna. In addition, six SCA subcarriers could be received. Obviously, in major metropolitan areas many more SCA signals should be heard. In the New York City area alone, for instance, upwards of 20 FM-radio stations have some type of SCA activity. If you want to find out what stations in your area have SCA activity, and what type of programming is available, an excellent reference is the *FM Atlas and Station Directory*, written by Bruce Elving (FM Atlas Publishing, Adolph, MN 55701-0024). **R-E**



SCA Decoder. Our final PLL project is an SCA decoder built around the 565 phase-locked-loop IC. This is essentially a 67-kHz FM detector. However, a PLL is a better detector for FM than any of the traditional detector designs because it has the ability to dive 6 dB below the noise level and still lock onto a signal.

In the case of an SCA subchannel where the information is only 10% of the total program power (most of that lost in the audio filtering), the 565 IC's ability to reject noise is an important factor in building a simple and effective SCA decoder.

Capacitors *C1*, *C2*, and *C3* and coil *L1* (Fig. 4) form a bandpass filter that peaks at 67 kHz and rejects all low-frequency components of the audio signal in an FM tuner. Transistor *Q1* amplifies this signal and passes it to *IC1*. The PLL IC is tuned by *C7*, *R6*, and *R10*. Since the tuning frequency is also a function of the supply voltage, the IC should be zener-diode regulated.

The demodulated audio signal comes out of the decoder at a 50-mV level. It has a 7,000-Hz audio bandwidth that can hardly be considered hi-fi. This bandwidth, however, is more than sufficient for background music.

The tuning procedure is simple. Connect the output of your FM tuner to the input of the SCA decoder and the output of the decoder to your audio amplifier. Set *R10* to the center of rotation. Scan the FM dial; all you should be able to hear at this point is noise and no stations. An SCA subchannel will appear as a sharp drop in the noise level, accompanied by a distorted music program. Now, adjust *R10* for the best signal-to-noise (S/N) ratio and highest fidelity.

Tune to the weakest SCA subchannel you can find. Adjust *L1* for the lowest possible noise level. The SCA decoder is now ready to use.

Closing Comment. The preceding four projects illustrate only a small portion of the possible applications to which the versatile phase-locked-loop IC can be put. A couple of the projects should be able to suggest other projects of your own. ◈

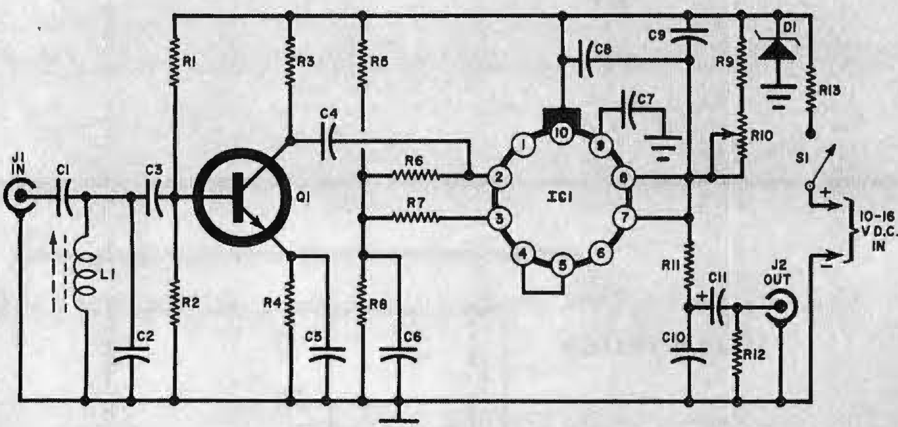


Fig. 4. SCA decoder.

PARTS LIST

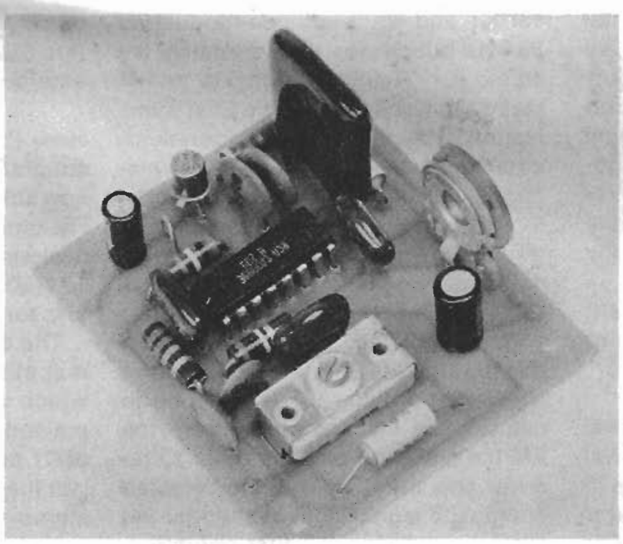
C1—220-pF disc capacitor
C2—0.002-µF disc capacitor
C3—330-pF disc capacitor
C4—560-pF disc capacitor
C5,C9,C10—0.04-µF disc capacitor
C6—0.1-µF disc capacitor
C7—0.001-µF disc capacitor
C8—0.001-µF disc capacitor
C11—30-µF, 15-volt electrolytic capacitor
D1—12-volt zener diode
IC1—565 PLL IC
J1,J2—Phono jack
L1—10-mH slug-tuned inductor (Miller No. 9060)
Q1—2N2926 npn transistor

The following are ¼-watt, 10% resistors:
R1—100,000 ohms
R2—22,000 ohms
R3—8200 ohms
R4—1500 ohms
R5—15,000 ohms
R6,R7,R11—4700 ohms
R8—6800 ohms
R9—1000 ohms
R12—47,000 ohms
R10—10,000-ohm, linear-taper potentiometer
R13—47,000-ohm, ½-watt, 10% resistor
S1—Spst switch
Misc.—Battery clip; hookup wire; solder; etc.

SCA DECODER

I'm having some difficulty getting the SCA Decoder from "Experimenting with Phase-Locked Loops" (October, 1975) to work. I've doublechecked my wiring and it looks OK. Any ideas?—*Edward Fagan, Portsmouth, NH*

First modify the circuit as follows: R13 should be 100 ohms. Ground pin 1, and remove the connection between pins 7 and 8. If you have connected the input of the SCA decoder to the standard output jacks of your tuner, there might not be enough drive signal, due to the effects of de-emphasis and SCA traps. If your tuner has a "Composite Output" or FM Detector Output" jack, connect the decoder input to that point. If you have an older tuner without such a jack (multiplex output jacks usually won't provide enough SCA signal), tap some of the signal directly from the discriminator output. If this loads down the circuit, use resistive coupling.



BY FRANK P. KARKOTA, JR.

SCA ADAPTER REVEALS HIDDEN MUSIC AND NEWS ON YOUR FM RECEIVERS

IN AN EFFORT to utilize more fully the radio spectrum, the Federal Communications Commission some time ago authorized FM radio stations to use special subcarriers to broadcast additional program material. This was covered in the FCC's Subsidiary Communications Authorization — hence the letters SCA, applied to the process in general. The most common use of SCA is in the transmission of background music; but other broadcasts include detailed weather forecasting, special time signals, and other material designed and intended for special-interest groups, doctor's offices, stores, factories, and other public places.

Broadcasters who use SCA generally make their profits by leasing the special receivers required to detect the subcarriers. However, the SCA adapter described here will enable the owner of almost any conventional FM

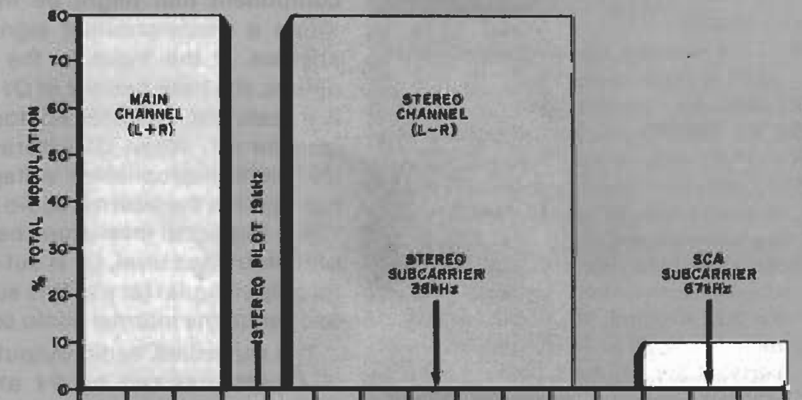


Fig. 1. Makeup of the frequency spectrum of an FM transmitter carrying both stereo and SCA signals. Main channel is at left, stereo at center, and SCA subcarrier at right.

receiver to listen to these broadcasts. (*A word of caution*: it is illegal to use SCA broadcasts for commercial purposes without written permission from the broadcaster.) Using a single IC, this low-cost SCA adapter can derive its operating power from the receiver with which it is used. In many cases, the adapter can be built directly into the cabinet with the receiver. A small pc board and simple alignment procedures make the project easy to construct and use.

How SCA Is Handled. In mono FM broadcasting, the main channel transmits only audio frequencies up to 15 kHz, and the transmitter/modulator is designed for this range only. For all stereo FM broadcasting, the transmitter/modulator is designed to pass not only the 15-kHz main (L + R) channel, but also a 19-kHz stereo pilot carrier and an amplitude-modulated 38-kHz subcarrier that contains the stereo (L − R) information. For an FM station to transmit also the SCA information, it must be able to accommodate the SCA channel as a narrow-band (7-kHz deviation) subcarrier centered at 67 kHz. The audio-modulation frequency spectrum for an FM transmitter carrying both stereo and SCA is shown in Fig. 1.

To extract the SCA material from this composite signal requires the equivalent of two receivers — one to demodulate the composite from the FM transmission and the other to recover only the SCA from the detected composite signal. A conventional FM receiver performs the first operation, and the output of its detector forms the input signal for the second "receiver." Essentially, the latter is in the form of a narrow-band FM receiver tuned to 67 kHz. The audio output of this SCA adapter is used to drive an external amplifier and speaker.

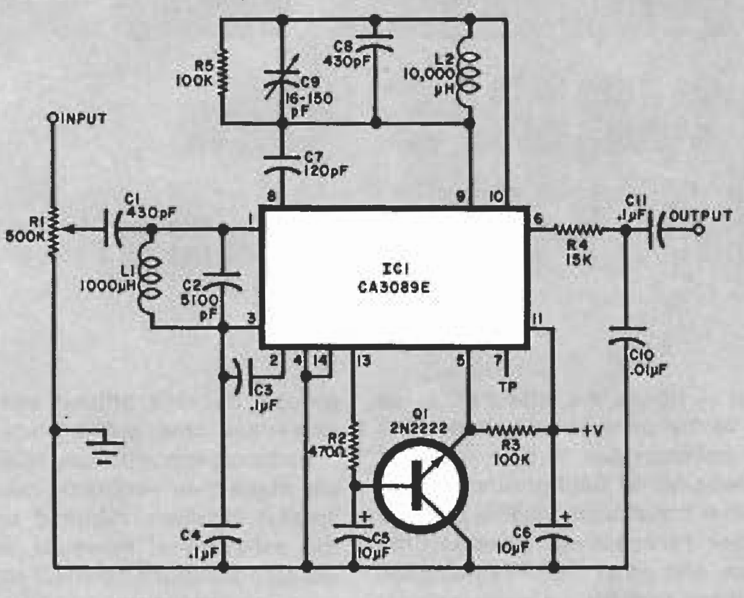


Fig. 2. Single IC contains a complete i-f system, a quadrature FM detector and an audio amplifier.

PARTS LIST

C1, C8—430-pF, 5%, silver-mica capacitor
C2—5100-pF, 5% silver-mica capacitor
C3, C4, C11—0.1-μF, 10-volt disc capacitor
C4, C6—10μF electrolytic capacitor
C7—120-pF, 5% silver-mica capacitor
C9—16-150-pF trimmer capacitor (Arco 424 or similar)
C10—0.01μF disc capacitor
IC1—CA3089E
L1—1000-μH, 5% inductor (Nytronic WEE-1000 or similar)
L2—10,000-μH, 10% inductor (Nytronic WEE-10,000 or similar)
Q1—2N2222
R1—500,000-ohm trimmer potentiometer (CTS X-201 or similar)
R2—470-ohm, ½-watt resistor
R3, R5—100,000-ohm, ½-watt resistor
R4—15,000-ohm, ½-watt resistor
Misc.—Power supply, interconnecting shielded cables, pc board, optional mounting hardware, etc.
Note—The following are available from Communications Poly Services, 46 Groton Rd., Westford, MA 01886: etched and drilled pc board at $2.10; complete kit of parts at $11.95, both postpaid. Massachusetts residents, please add 3% state sales tax.

How It Works. The schematic of the adapter is shown in Fig. 2. The IC is a new unit which contains a complete FM strip on a single chip. Although designed to work at the conventional 10.7-MHz i-f, this IC works well at 67 kHz for SCA.

The demodulated composite signal is applied to control potentiometer *R1* which acts as a squelch (to be explained later). The relatively low value of *C1* provides a high-pass filter to reject the main channel and most of the stereo subcarrier. Capacitor *C2* and inductor *L1* form a tuned circuit that helps to reject noise above and below 67 kHz. Capacitors *C3* and *C4* are used as bypasses to allow one side of the tuned circuit (*C2*−*L1*) to remain at signal ground while current from pin 3 biases the i-f amplifiers connected to pin 1.

The internal i-f amplifiers also provide the limiting that eliminates any amplitude variations that might be present on the input signal. This also improves the rejection of the stereo subcarrier since the stereo information appears as amplitude noise.

The limited and amplified signal then enters the internal quadrature detector where capacitor *C7* and the tuned circuit formed by *L2*, *C8*, and *C9* form the required phase-shift network for tuning the detector. Resistor *R5* connected across the tuned circuit determines the bandwidth of the detector. The detected signal then drives a squelch-controlled audio preamplifier (also on the chip) and a set of level detectors in each i-f amplifier that provides a dc output proportional to the log of the input signal. This dc voltage is applied through *R2* to the base of *Q1*, while *C5* removes any 67-kHz component that might be included. When a predetermined signal level appears at the input to the i-f amplifiers, the base current of *Q1* causes it to saturate. Resistor *R3* forms the load for *Q1*. When *Q1* saturates, the low emitter-to-collector voltage cannot squelch the internal audio system. When the signal level drops below the predetermined level, *Q1* is cut off; and its output signal (at pin 5) is sufficient to operate the internal audio squelch.

The recovered audio output (pin 6) is de-emphasized by *R4* and *C10* while *C11* blocks the dc component from the audio output.

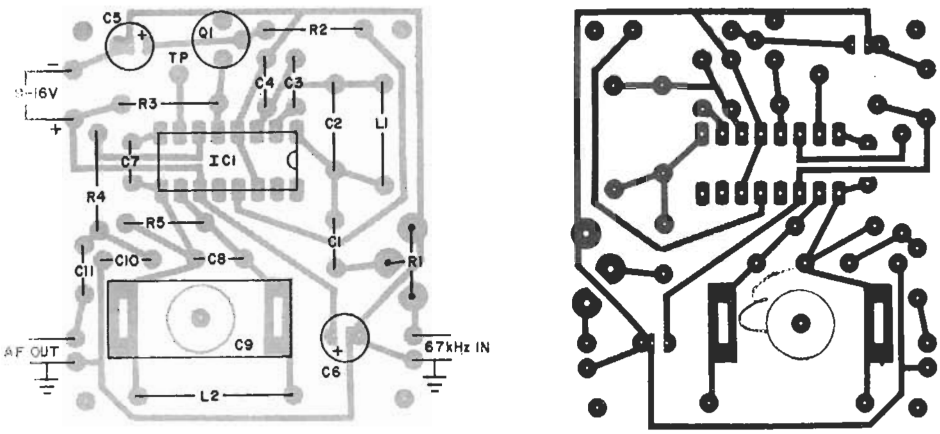


Fig. 3. Actual-size foil pattern and (far left) component installation. Observe polarities on electrolytics.

Construction. Although there are no r-f signals present, the high gain of the IC makes parts placement in the circuit somewhat critical. A pc board is therefore recommended (Fig. 3). When the tuning capacitor, *C9*, is installed, the side of the capacitor having the top plate should be closest to capacitor *C6*. Observe the notch code on *IC1* and the polarities of the two electrolytic capacitors.

The test point is simply a small loop of bare wire, soldered into the board at the point (TP) shown in Fig. 3.

The demultiplexer requires between 9 and 16 volts dc at 20 to 30 mA. If it is not available from the conventional receiver, a small supply can be built using the circuit shown in Fig. 4.

Alignment. Use shielded cable to connect the adapter input to the FM receiver. If you are lucky, the FM stereo receiver will have a phono jack marked "detector out," "composite out," "output to MPX adapter," "output to stereo adapter," or some variation of these. If the receiver does not have this jack, or if it is a mono receiver, a connection must be made to the FM detector *before* the de-emphasis network. Make the connection as shown in Fig. 5. Connect the output of the SCA adapter to the external audio amplifier and speaker.

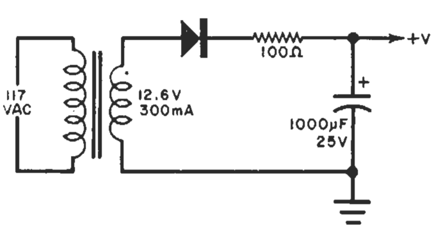


Fig. 4. This power supply can be built if not available elsewhere.

Before applying power, temporarily connect a short circuit between the emitter and collector of *Q1*. Adjust variable capacitor *C9* for half mesh, and set potentiometer *R1* fully clockwise (rotor at input end).

Connect a dc voltmeter from the test point to the side of *C9* closest to *C6*. Turn on the FM receiver and apply power to the SCA adapter. When the FM receiver is tuned across the band, noise and distorted main-channel programming will be heard on those stations not carrying SCA. When a station carrying SCA is tuned, this material will be heard. Adjust *C9* for zero volts on the dc voltmeter. If a dc voltmeter is not available, adjust *C9* for best results.

Remove the temporary short across *Q1*. If the audio output drops away when this is done, the SCA adapter is receiving too little signal. Check the connection to the FM receiver to make sure it is properly made.

The internal squelch circuit is used to quiet the SCA adapter between music selections in the event that the station making the SCA broadcasts turns off the subcarrier between selections. In this case, adjust potentiometer *R1* to silence the noise between selections.

The ultimate quality of the demultiplexed SCA signal is largely a function of the FM receiver. It is important to have a strong signal, as free of multipath as possible. It should be noted that the signal level required for noise quieting increases as the bandwidth of the received signal increases. It is for this reason that a stronger signal (compared to a mono transmission) is required for adequate reception of stereo broadcasts; and an even stronger signal is required when an SCA subcarrier is added. Note, also, that any distortion (such as phase) present in the FM receiver will appear in the demultiplexed signal as crosstalk.

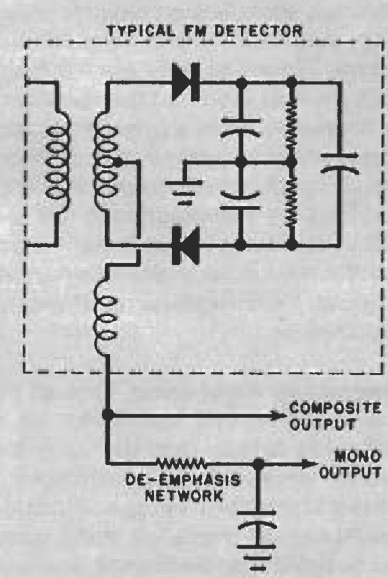


Fig. 5. Typical FM detector showing where the composite output can be taken out.

Modifications. There have been rumors of a proposal to reallocate the FM subcarriers to accommodate four-channel sound. If this comes about, or if you hear of any frequency other than 67 kHz being used for the SCA subcarrier, the SCA adapter described here can easily be modified for the new frequency by changing the value of two capacitors. For *C2*, the value is $10^9/(4\pi^2f^2)$; and for *C8*, use $10^8/(4\pi^2f^2)-70$; where C is in picofarads and f is in kilohertz. ◈