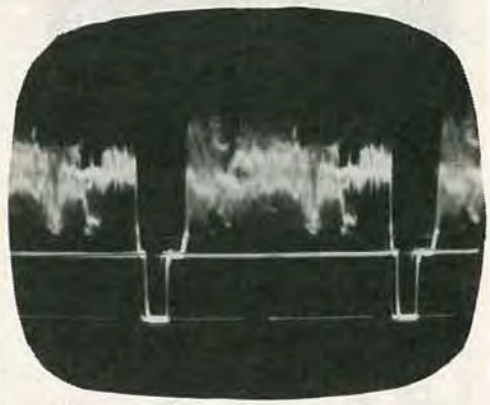
TV SIGNAL DESCRAMBLING



More on PLL's and how they can be used in practical descrambling circuits.

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Part 4 LAST TIME, WE looked at some practical descrambling circuits. At the heart of several of those circuits was the *P*hase-*L*ocked *L*oop (PLL). This month, we'll begin by looking more closely at PLL's, and how they can be used to descramble various types of signals.

Over the next few months, **Radio-Electronics** will be presenting a series of articles describing the techniques used by pay-TV and cable companies to scramble their signals. While specific circuits for specific scrambling systems will be discussed, they are presented for *informational and experimental purposes only*. Therefore, parts lists, parts suppliers, and additional technical support *will not be available* for those circuits.

Phase-locked loops

Thanks, in part, to the widespread popularity of FM stereo radio, a number of single-IC PLL FM-stereo demodulators have been developed. Generally those devices contain an input amplifier, a phase detector, a VCO (*V*oltage *C*ontrolled *O*scillator), some form of lock detector for audio muting or stereo lamp switching, a decoder matrix, and a voltage regulator that allows the unit to operate from a wide variety of supply voltages. Some of those devices require little in the way of external components, including hard-to-find coils, to operate.

PLL's are ideal for regenerating the 15-, 31-, 40-, or 62-kHz subcarriers used in the gated-sync, sinewave, or SSAVI systems that we have discussed previously. Where appropriate, PLL's can also be used to demodulate hidden audio subcarriers, thus doing two jobs for the price of one. Further, because PLL's are mass produced, they are easily obtained and inexpensive.

Figure 1 is a block diagram of a typical PLL. Basically, a PLL operates by comparing the frequency of an input signal with that of a signal generated by an onboard VCO. The VCO is set up to shift frequency such that its output frequency and that of the PLL's input signal are identical. Both signals are applied to a phase detector, which is where the actual comparison takes place. (In some instances the VCO is set up to operate at a multiple of the input frequency range. In PLL's where that is done, a frequency divider is inserted in the loop between the VCO and the phase detector.) If the frequencies of the input and the VCO signals differ, the phase detector produces an AC signal. Otherwise, a DC voltage that is proportional to the *phase* difference between the two signals is produced. Thus, once the PLL is "locked," that is, once the input and VCO frequencies match, only a phase error exists between the two signals. The frequencies of the input and output signals are equal. The output of the phase detector is fed to an amplifier/integrator. That stage produces the control voltage for the VCO.

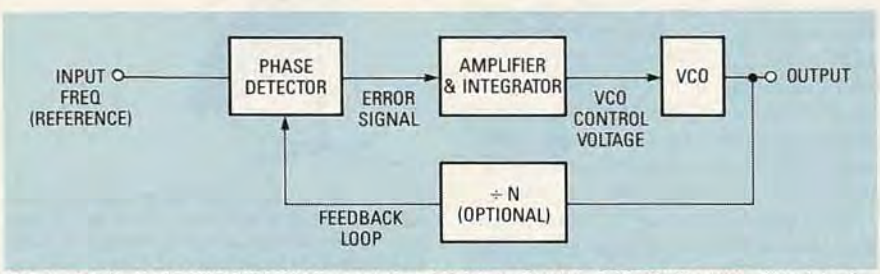

FIG. 1—A PLL IS AT THE HEART of many descrambling circuits. A block diagram of that device, commonly available in IC form, is shown here.

A circuit that can be used for subcarrier regeneration is shown in Fig. 2; the heart of the circuit is an LM1800 PLL stereo-demodulator IC. The circuit is very similar to the one that would be used for FM-stereo detection. With subcarrier-regeneration circuits, we do not have to worry about stereo separation, since we are recovering only one mono channel. Therefore, only one of the audio outputs is used. However, we do need to recover the pilot signal. In FM-stereo systems, the pilot is used only to indicate the presence of a stereo signal. But in some scrambling systems, such as gated pulse, that signal is needed for sync regeneration. For other scrambling systems, the pilot signal could be used to switch in the decoder automatically at the appropriate time.

The PLL used in the circuit of Fig. 2 is designed for 19/38-kHz operation. If needed, we feel that the LM1800 could be made to operate at frequencies up to 100 kHz because it's fabricated using transistors that inherently can operate to several megahertz. However, we have not been able to confirm that.

In any event, the most commonly used subcarrier frequencies are within the range of the LM1800. In the gated-pulse system, where the audio is usually encrypted on a 15-kHz subcarrier, the circuit of Fig. 2 could be used both to recover the subcarrier and to decode the audio.

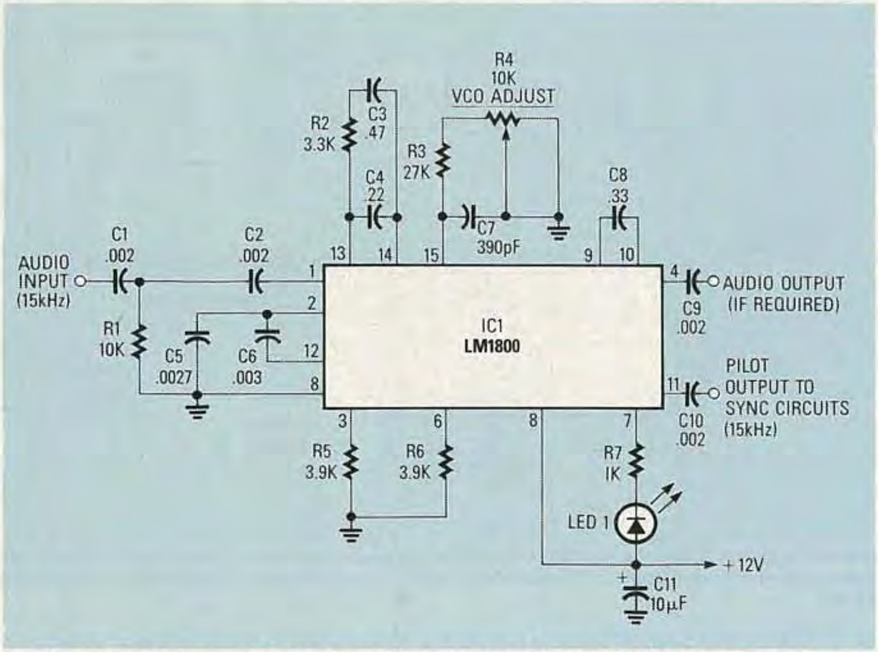

FIG. 2—THOUGH DESIGNED FOR FM-STEREO DEMODULATION, the LM1800 PLL can be used to good advantage in descrambling systems. Here that IC is used to regenerate a hidden subcarrier.

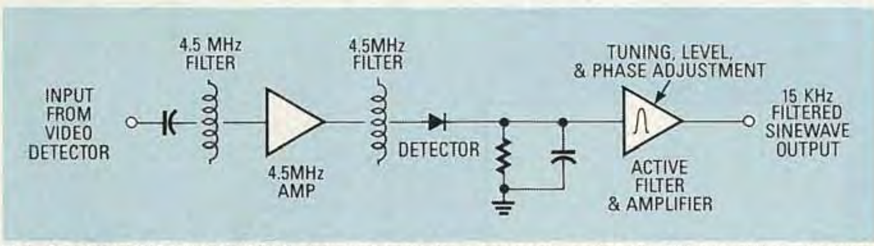

FIG. 3—THIS BLOCK DIAGRAM shows the system used to recover the descrambling sinewave required by a sinewave decoder.

In the sinewave system, the audio is placed on a 62.5-kHz subcarrier. For that scrambling system, the circuit of Fig. 2 would be used only for recovering the audio. Note that some modifications to the highpass filter at pin 1 and the VCO's frequency-control circuit at pin 15 would be necessary to accommodate the different frequency. The circuit as shown is designed for 15-kHz operation. In the highpass filter, C1 and C2 should both be changed to 470-pF units. In the VCO control circuit, C7 should be replaced with a 100-pF unit. Alternately, R3 and R4 could be replaced with 6.8K and 5K units, respectively. You may need to modify the PLL loop filter and the threshold filter.

A worthwhile experiment would be to set up the circuit on a breadboard and to check out its operation using an audio or function generator to supply the needed input signal.

Sinewave decoding

The procedure used to recover the sync in the sinewave scrambling system differs somewhat. In the sinewave system, the synchronized 15-kHz sinewave is encoded on the 4.5-MHz sound subcarrier. In a conventional TV-sound limiter, that AM component is stripped away. Therefore it does not appear at the output of the sound detector and we must obtain that signal at a different point in the signal processing trail.

Figure 3 shows a block diagram of a circuit that could be used to recover the decoding sinewave. The 4.5-MHz sound subcarrier is taken from the video detector. It could also be taken from the TV set's sound/sync detector, if the set has one (not all do), or, if possible, from the sound IF *before* limiting has taken place.

After the 4.5-MHz sound subcarrier has been obtained, it is amplified and then fed to an envelope-detector stage. The output of the detector contains the low-level 15-kHz signal (modulation percentages of 5 to 15 are typical), as well as unwanted components such as induced AM audio from the sound channel.

The unwanted components are removed by a high-Q active filter. In that stage the signal is also amplified and its phase adjusted so that it differs from the encoding signal by 180°. Finally, any distortion due to non-linearity, harmonics, etc. is removed; the recovered signal must match the encoding one exactly, except for the phase difference, or incomplete cancellation will take place. The result would be ripples, shading, etc. in the picture.

It is possible to distort the recovered signal deliberately to compensate for non-

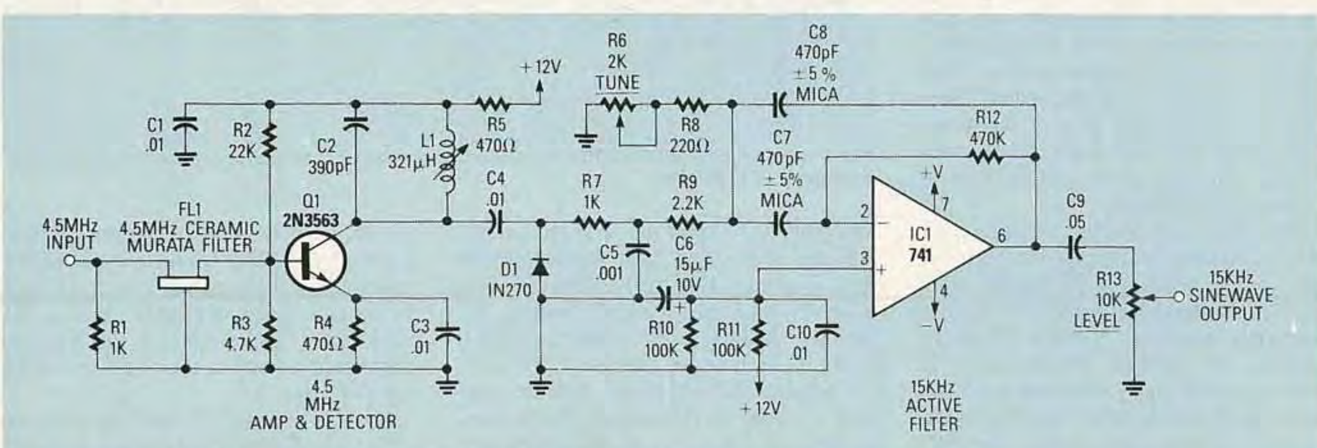

FIG. 4—HERE THE BLOCK DIAGRAM OF Fig. 3 is translated into a practical circuit. Any op-amp designed for audio work may be used for IC1.

linearity elsewhere in the decoder, such as in the modulator. However the best decoders are the ones that are well designed (i.e. linear) in the first place. Generally, if the sinewave-recovery circuit requires tweaking or tailoring to match the balance of the decoder, it is an indication of a poorly designed system. A circuit that is well engineered should work the first time, and not require any critical adjustments or adjustment techniques. For the most part, the circuits that we are presenting in this series meet that criteria. If the circuit is unstable, or requires critical adjustment, it is an indication that something is wrong.

Now let's translate our block diagram into a practical circuit. One representative circuit is shown in Fig. 4. In that relatively simple circuit, the 4.5-MHz signal is taken from the TV sound system *before* limiting. It is passed through a 4.5-MHz ceramic filter to eliminate any "junk" (unwanted components), and then amplified by Q1, an NPN transistor that has a gain of 25 to 30 dB. A 4.5-MHz tuned circuit in the collector circuit of Q1 serves as a load, across which the 4.5-MHz output-signal is developed. The signal is then diode detected and fed to the active-filter stage. The filter has a nominal gain of 40 dB and is tuned to 15 kHz. In that stage the phase shift of the signal is adjusted as previously described. That adjustment is made by varying the setting of R6. The response of the active filter is much like that of a tuned LC circuit. While a 741 is specified for IC1, almost any op-amp designed for AF operation is suitable. Among the other possible choices are an RC4558, an LM1458, or a 747. The output of the circuit is taken from R13, the 10K LEVEL potentiometer.

During operation, the circuit should be checked with a scope for linearity. To be conservative, the 15-kHz signal seen at the output of the op amp should never exceed about one half the supply voltage. For example, in the circuit of Fig. 4, which is designed to use a 12-volt supply, that voltage should not exceed 6-volts p-p. The level of the 4.5-MHz input signal will be between about 30 and 100 millivolts, depending on the modulation level. Note that levels higher than that could cause limiting in either the amp or the active filter stages. That will result in a distorted 15-kHz sinewave at the output and incomplete descrambling.

The circuit shown in Fig. 4 can be combined with the circuit shown in Fig. 7 of Part 3 of this series (see the August, 1986 issue of **Radio-Electronics**) to form a functional sinewave decoder. However, installing the decoder would require at least some familiarity with how a TV set works, as several internal connections are required. Among other things, you must know where to tap off the required inputs, where to feed the descrambled output,

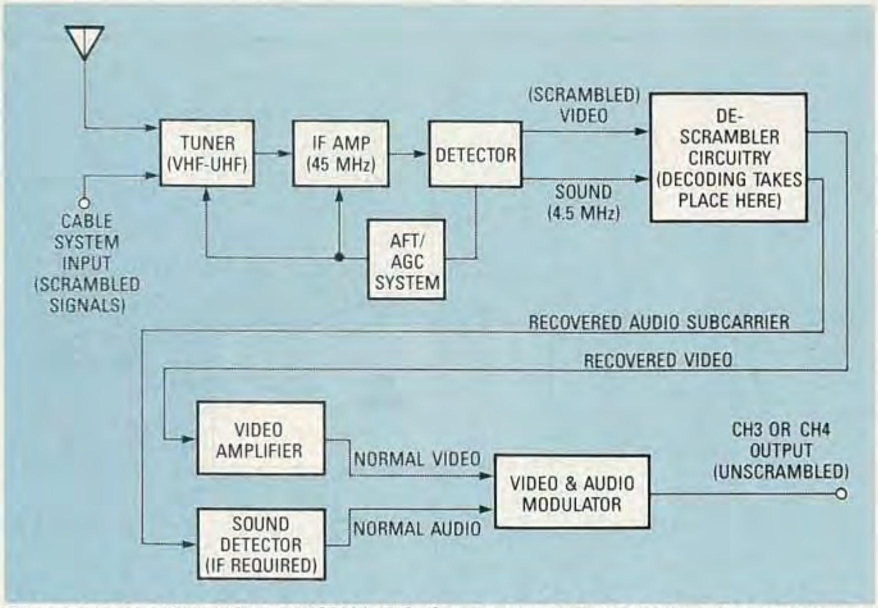

FIG. 5—TO AVOID COMPLICATED INSTALLATIONS, the decoder can be combined with a TV front-end to form a converter-descrambler. The output of that circuit can be fed directly to the antenna input on a TV set.

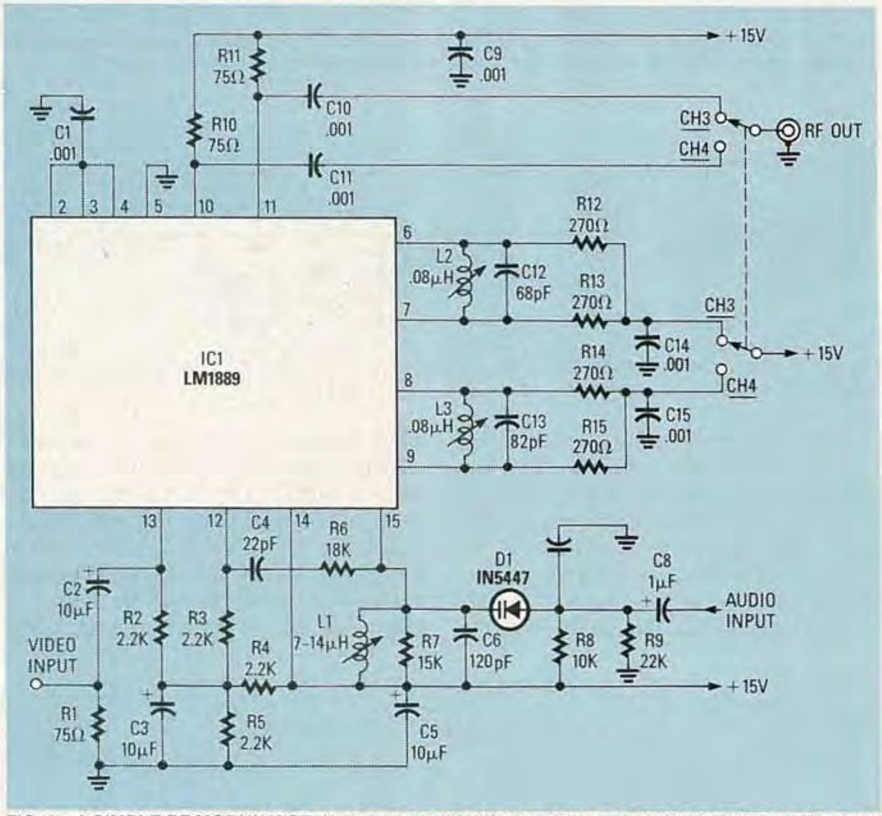

FIG. 6—A SIMPLE RF MODULATOR. If you wish, a modulator could also be obtained from a discarded videogame or computer.

and where to obtain the required supply voltages. For some, that would present little problem. But many others do not have the required expertise. Further, the growing use of IC's in TV sets presents a problem. In many IC-intensive TV sets, the required tap-off points may be contained within an IC, making them inaccessible. In that case, it would be virtually impossible to connect our decoder.

The solution to those problems is to design a decoder that essentially contains a complete TV-set "front-end." The decoder would then contain a tuner, IF amp, video and audio detectors, and an RF modulator. The output of the decoder could then be fed to a user's TV set via the antenna input.

Such a unit would most properly be called a converter-descrambler. Its block diagram is shown in Fig. 5. In it, signals from an antenna or cable system are fed to

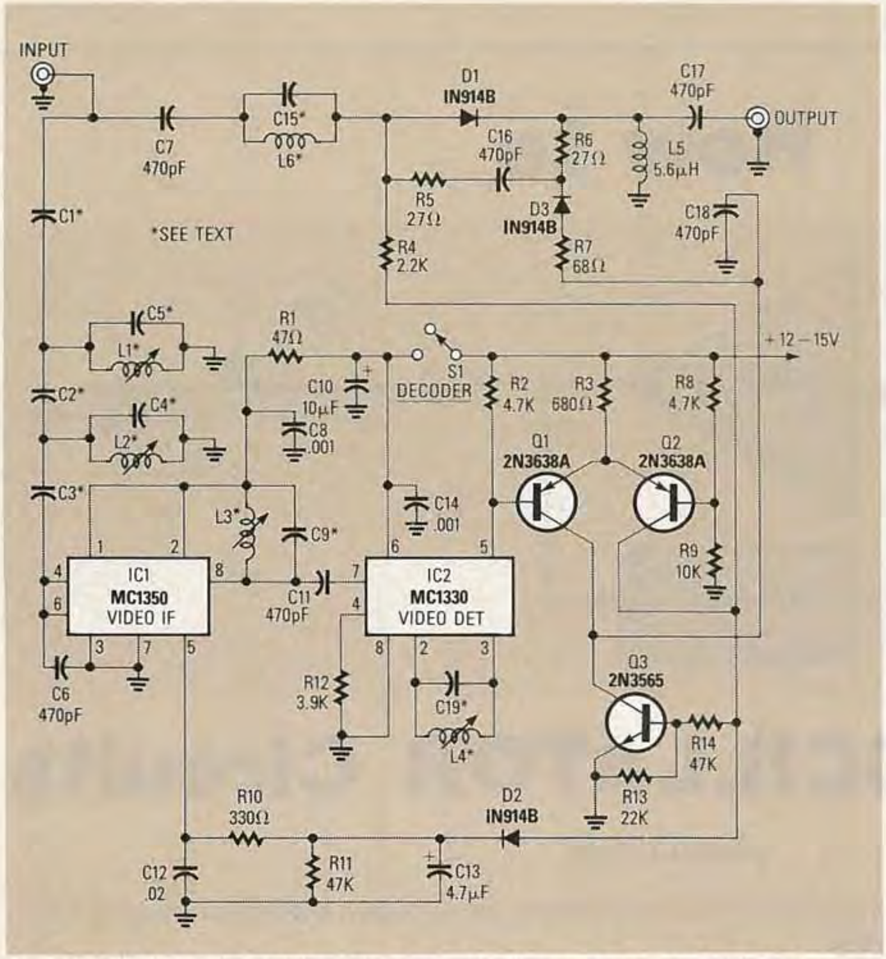

FIG. 7—IN THE OUTBAND SYSTEM, used only on cable-TV systems, the sync is hidden on an unused frequency, outside of the channel itself. Therefore, a decoder, like the one shown here, must have some way to "tune in" that out-of-channel sync signal.

a tuner and on to a 45-MHz IF amp; 45 MHz is a standard TV IF frequency. From the amp, the signal is fed to standard TV sound and video detectors. The outputs from the detectors are scrambled video and the 4.5-MHz audio subcarrier. Those are the signals that the descrambler needs to do its job. The outputs of the descrambler stage are a normal video signal and either a normal audio signal or a recovered audio subcarrier, depending on the scrambling system. In the latter case, the subcarrier is fed to a second sound detector to recover a normal audio signal. The audio and video could be fed directly to a set with audio/video inputs, but a more "universal" approach would be to feed those signals to an RF modulator set up to output on either Channel 3 or 4. A standard RF modulator circuit is shown in Fig. 6. Alternately, RF modulators are available commercially or can be salvaged from a discarded videogame or computer.

The SSAVI system

As previously discussed, SSAVI (*S*uppressed *S*ync *A*nd *V*ideo *I*nversion) is one of the more sophisticated of the scrambling techniques. In that system, four modes of operation are possible. Those are: suppressed sync and inverted video, suppressed sync and normal video, normal sync and inverted video, and normal sync and normal video (unscrambled). The system has the capability to switch between any of the four modes on a frame-to-frame basis. Therefore the scrambling method can change as often as 60 times-per-second, if desired. The sound is stripped from the audio subcarrier and placed on another subcarrier located at 39.335 kHz (2.5 times the horizontal frequency).

Further complicating the task of descrambling is the fact that no reference signal is sent with the scrambled picture. The decoder must provide its own reference. Also, the decoder must be able to detect whether or not the video is inverted. Note that the sync signal is never inverted, so the decoder circuitry must only invert the video portion of the signal, when required. The sync signal may, however, be suppressed.

How does a decoder regenerate the sync and detect when the video is inverted? In the SSAVI system, the first 26 lines of the picture are sent with normal sync pulses. A PLL can lock onto that information and supply the missing information for the rest of the frame. The regenerated sync is used to restore normal sync, which in turn is used as a reference. The leading edge of the vertical sync pulse is used as a reference from which all operations are timed. During the 20th line, which is picked out by the decoder by using a counter circuit, information is sent as to whether the video in the frame is inverted or normal.

As you can see, the SSAVI decoder is called on to perform a number of tasks. Because of that, the circuitry is rather extensive. Fortunately, it is also rather straightforward. We will look at the details in the next installment in this series.

Note that the typical SSAVI descrambler contains much circuitry that is not involved in the descrambling process. That includes anti-theft circuitry, as well as circuitry that allows for two or more tiers of premium programming. As such circuits play no part in the descrambling process, they will not be discussed.

Outband descramblers

Before we wrap up for this month, let's look at a system that is used in many cable systems. Called the outband system, in it the sync signal is placed on a subcarrier, but the subcarrier frequency is not within the channel. Instead, it is within an unused cable channel. The frequencies most often used are somewhere around 50 MHz (below broadcast Channel 2) or between 90 and 120 MHz (those frequencies fall in the FM-broadcast and aviation bands).

As described in a previous installment, to recover the sync the decoder requires a circuit that can "tune in" the out-of-channel carrier. A typical outband decoder is shown in Fig. 7. In that circuit, the composite cable signal is split two ways. The sync frequency is passed by an appropriately tuned input filter and fed to a video IF-amp stage. A trap, set up to be resonant at the sync-carrier frequency, prevents the sync signal from appearing at the output. From the IF amp, the sync signal is fed to a video detector. The output of the video detector (pin 5, IC2), which consists solely of sync pulses, drives a differential amplifier. The differential amp drives a voltage-controlled attenuator. When a sync pulse is not present, the output of the video detector goes negative and the current from the differential amp reverse biases D1 and forward biases D2. That "inserts" the attenuator in the circuit. When a sync pulse is present, the output of the detector goes positive. Then, D1 is forward biased while D2 is reverse biased. That removes the attenuator from the circuit.

Note that values for the components in the traps and filters have not been specified. That's because those values can vary widely, depending on the frequency of the sync channel. In a future installment we will present a more detailed version of the circuit. **R-E**