Coherent CW — The Practical Aspects

Part 2: In Part 1, the concept of ccw was described. You'll now see how you can put the concept into practice.

By Charles Woodson,* W6NEY

Coherent cw operation imposes two basic requirements at the transmitting end. First, the keying must be done within the time frames established by a stable frame reference. These frames must be sufficiently regular to enable the receiving station to determine accurately when they occur. Second, the carrier frequency must be stable within a hertz or so during the contact, including all keying periods. The time frames can be established by a frequency standard with the reference signal being divided by CMOS or TTL to produce pulses which define the frame. Many ccw stations use standards such as those described by Kelley,[1] although any comparable standard would do.

*2301 Oak St., Berkeley, CA 94708
[1]Notes appear on page 23.

To keep the frames accurate within 1/20 of a period for 10 "windows" per second requires a stability factor of 1/720,000 Hz per hour of contact. Since the standard mentioned is accurate and stable to less than 1 part in 10^7 over the required period, it exceeds the required accuracy easily. A station standard suitable for supplying the 10-Hz keying reference and the ccw filter frame reference is shown in Fig. 7.

Keying

Fig. 8 shows a simple system that may be used for ccw keying. I have adapted both the Heath HD-10[2] and the Accu-Keyer[3] for ccw operation. The Accu-Keyer is superior because of its 1-bit memory. At present, I use an AKB-1 keyboard, which is available with a ccw option. I've also used a KIM-1 computer for generation of ccw and ASCII. The computer uses its internal timing clock to generate an interrupt at the beginning of each frame period. The clock frequency must be adjusted precisely for such use.

Hand sending of ccw is different from ordinary random-frame cw and takes a while to learn. This is because dots, dashes and spaces can only occur in pre-established frames and we are accustomed to initiating dots, dashes and spaces whenever we wish. With a bit of practice, the initial sending errors decrease to near that of the error rate of ordinary cw keying. You learn to hold the key down until you hear a dot or dash start and then

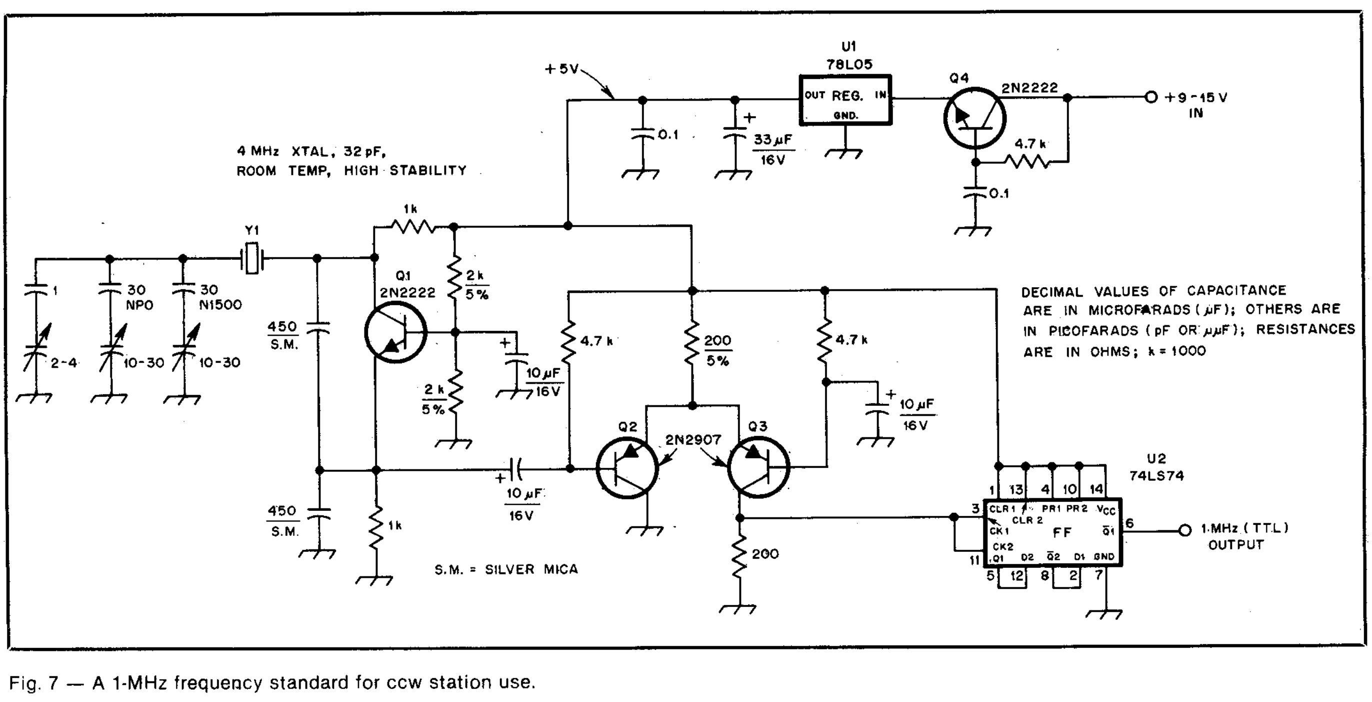

Fig. 7 — A 1-MHz frequency standard for ccw station use.

you're able to send in rhythm with the frames for a word or phrase. A keying monitor is a must!

Transmitter Stability

The receiving filter passband requires that the transmitted frequency be stable during the contact period. This is perhaps the most difficult parameter to be met for ccw operation. For a cw signal time frame of 0.1 second, a 14-MHz signal must be stable to within 1 or 2 Hz. High-quality crystal oscillators have such stability except when a varying load is placed upon them, as when a transmitter is keyed. During keying, the frequency of a typical transmitter crystal oscillator will shift approximately 50 Hz. Under ordinary circumstances this wouldn't be noticed, but for a ccw signal, this would mean loss of reception because the shift is more than five times the receiving filter passband and would equate to a 20-kHz shift of a regular cw signal. Such shifting produces an amusing situation. When copying with the ccw filter in the presence of strong interference, the interfering signals sometimes appear to swish up and down the band during keying. Even if they cross the ccw frequency, the time they are in the filter passband is small. The result is that they have relatively little effect on the ccw signal itself. However, these interfering signals — through cross-modulation, overloading early receiver stages, and their effect on agc — can (and often do) cause problems.

Transmitter stability has been achieved by using high-quality crystal oscillators which are not keyed and which are followed by several stages of amplifiers and buffers to nullify the loading effects of keying. A schematic diagram of such a transmitter-exciter is shown in Fig. 9. The power output of this exciter is about 0.1 watt and it has been used by itself (with an antenna matching network and keyer in

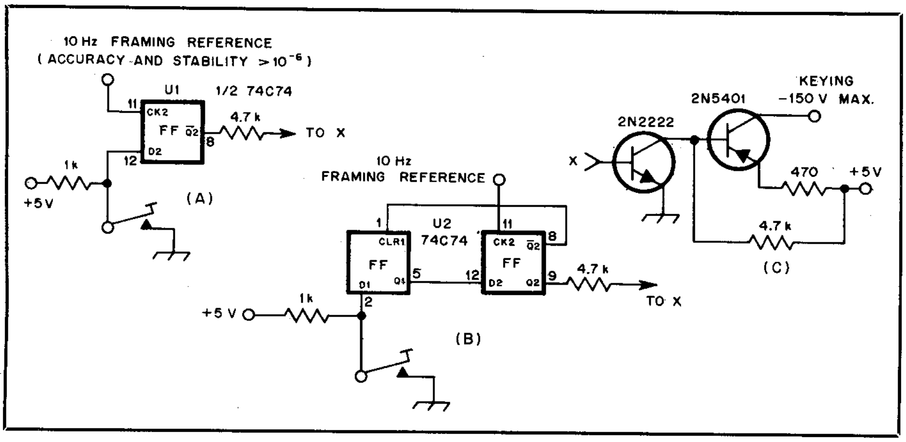

Fig. 8 — Two simple ccw hand keyers. The key must be kept closed until the beginning of a frame, determined by the framing reference signal. Once transmission is initiated, although the key may be opened, the transmitter will remain keyed until the end of the frame period is signaled by the framing reference. The keyer at B includes a one-bit memory which makes coherent keying by hand much more convenient. When the key is closed, the first flip-flop is set and remains set even if the key is opened. When the clock pulse arrives, the second flip-flop is set, which causes the first to be cleared unless the key is still closed. If your rig uses inverted TTL keying, use the $\bar{Q}$ output.

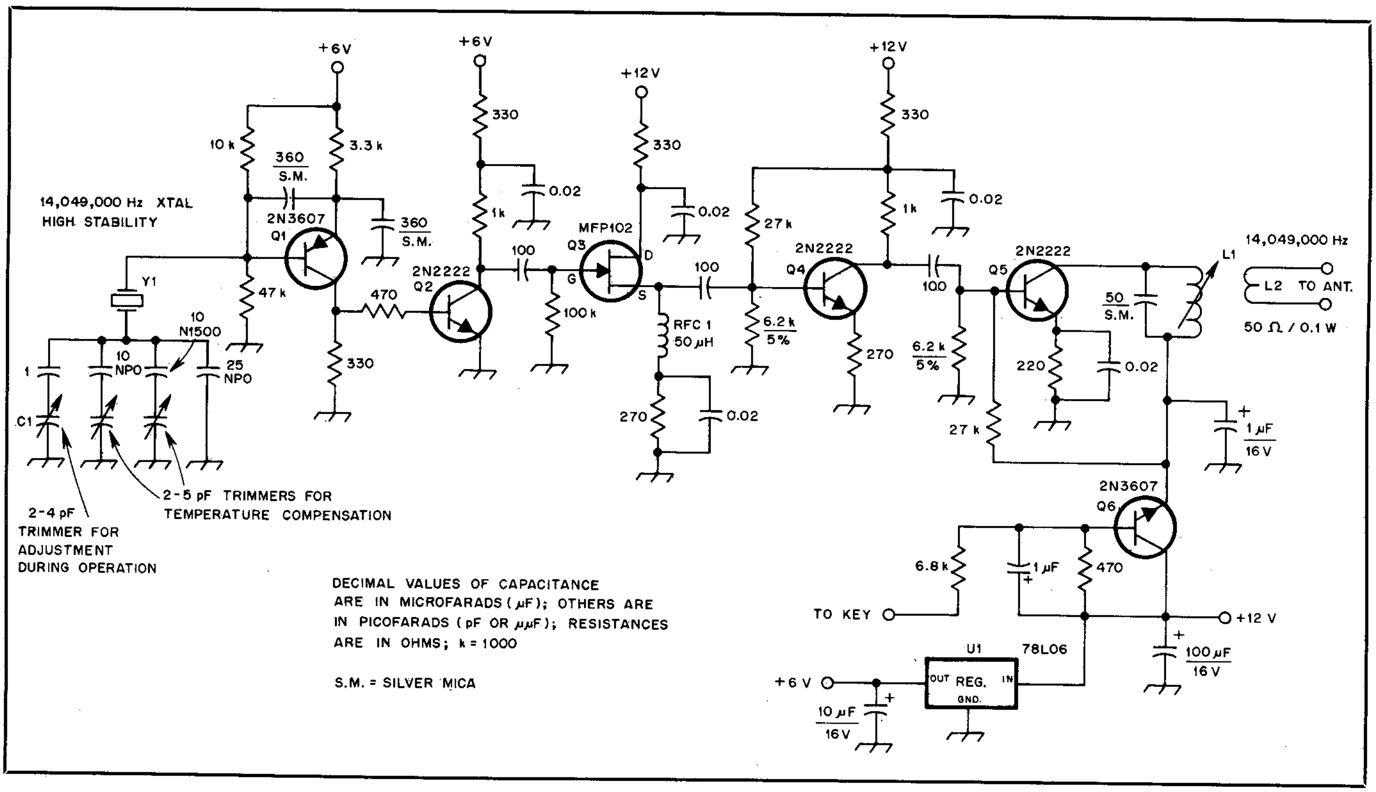

Fig. 9 — Schematic diagram of a low-power ccw exciter/transmitter. The capacitance from the crystal to ground should total about 32 pF. Fixed capacitors should be high quality ceramic or silver mica types. C1 is used to adjust the frequency of operation and affects the total capacitance by less than a picofarad once temperature compensation has been achieved with the other trimmers (see text).

L1 — Miller 4404, approximately 2.5 µH.
L2 — Two turns no. 18 enam. over "cold" end of L1.
Y1 — Fundamental mode crystal, 32 pF load capacitance, room temperature, high accuracy crystal. Available from ICM, 10 North Lee, Oklahoma City, OK 73102.

the final stage) and as a VFO replacement. Tests have shown that after a 30-minute warm-up period the oscillator is stable within a hertz during keying and remains so for over an hour. The crystal tuning allows VFO-type operation over a 20-Hz range. To facilitate stability, very little power is drawn from the oscillator and two stages of isolation are used to minimize the load on the oscillator by later stages. In most situations, particularly when the rig is left on all the time, the N1500 compensation capacitor and corresponding trimmer may be omitted and a fixed capacitance value added in parallel with the rest of the units. When the temperature compensation trimmers are used, they are adjusted while measuring the operating frequency at two different temperatures, say, 68 and 86° F (20 and 30° C). One trimmer is adjusted to decrease capacitance and the other to increase capacitance by a like amount. The frequency is measured at the two temperature extremes again and this process continued until the oscillator frequency is the same at both temperatures.

Another method of transmitter frequency stabilization is to use PLLs to control the frequency of oscillators and use a highly stable oscillator as a reference for the PLL. A direct-conversion receiver employing this technique was described by McCaskey.[4] Maynard used a 5.0- to 5.5-MHz synthesizer output and a 9-MHz frequency standard to control an HW-8.[5] I have used a method which mixes the HFO, BFO and VFO frequencies of a double-conversion transceiver (SB-303/SB-401 combination), locking the result by controlling the VFO frequency.[6] A simple scheme (shown in Fig. 10) is used for locking the VFO (LMO) of an SB-303 receiver by using the built-in variable capacitive diode circuit employed for fsk operation. A high-impedance voltmeter connected to point C can be used to monitor the lock condition. During operation, the VFO is tuned slowly across the frequency of the standard; frequency lock occurs about 250 Hz above and below the reference frequency. Once locked, the crystal oscillator controls the receiver frequency and it can be set more accurately than the VFO. The crystal oscillator can be replaced by a 5.0- to 5.5-MHz synthesizer which is controlled by a suitable reference frequency; Petit has designed such a synthesizer which operates in 100-Hz steps.[7]

A block diagram of the transmitter currently in use at my station is shown in Fig. 11. The 12.9-MHz crystal oscillator is designed for high stability. Similar oscillators are used for operation on 21 and 28 MHz. The synthesizer is controlled by a 1-MHz oscillator similar to that described in Fig. 7. The two oscillators run continuously and are connected to the doubly balanced mixer, but the 14-MHz stage following the mixer is keyed. This allows break-in operation on the same frequency.

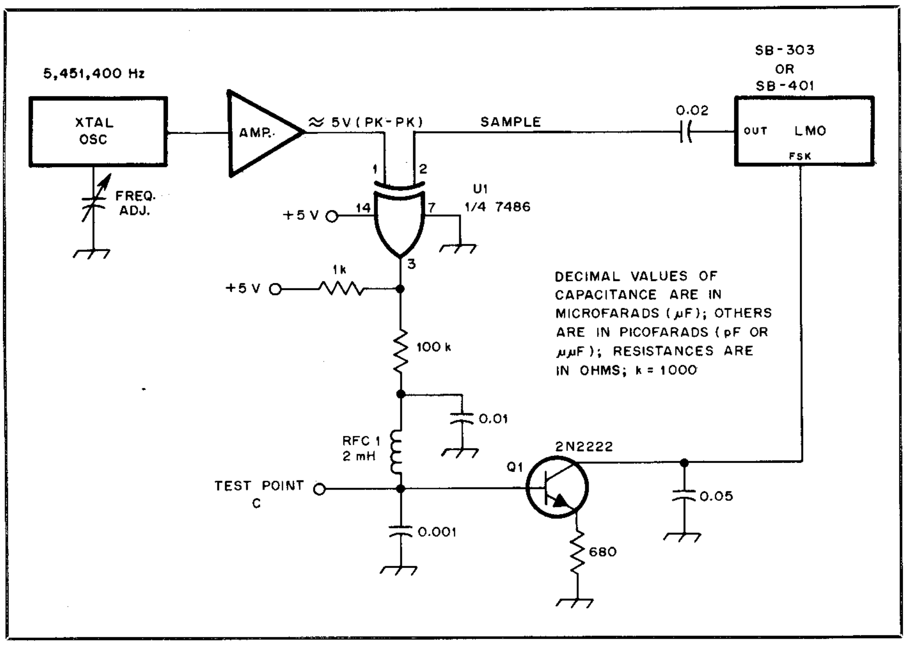

Fig. 10 — This method may be used to lock the LMO of the popular Heath SB series of equipment. Point C is a test point which is used to monitor the lock condition (see text.)

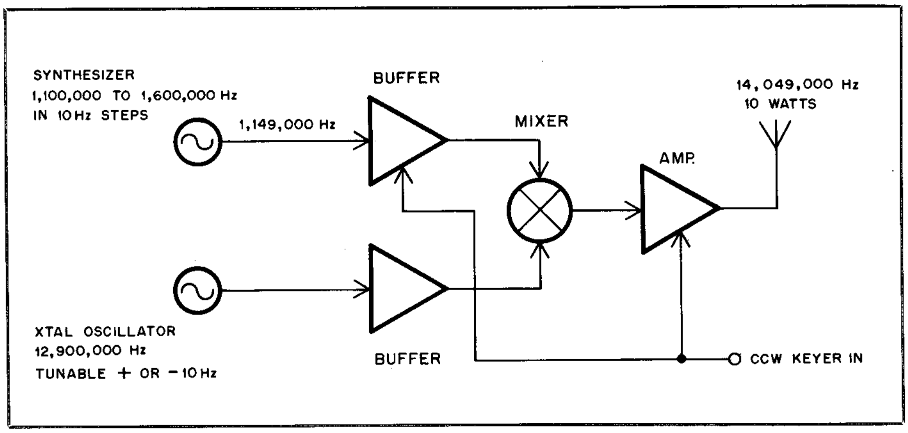

Fig. 11 — Block diagram of the transmitter used by the author. The two oscillators run continuously for improved stability.

Receiver Requirements

In addition to the ccw filter, the receiver must exhibit stability on the order of 1 Hz over the length of a contact and have a tuning resetability which is less than the bandwidth of the filter. Searching for a signal while using a filter bandwidth of only 10 Hz requires almost 200 times as long as it takes to tune a band using a filter with a bandwidth of 2.1 kHz. If the phase and frame size were also unknown, it would take over 1000 times as long to tune a band searching for a ccw signal as it takes to look for an ordinary cw signal. That is why current practice involves agreeing on a precise frequency and frame length in advance. Adequate stability is easy to obtain with good crystal oscillators in receivers when temperature has been stabilized by a long warm-up period and a stable environment exists.

Fig. 12 is a block diagram of the receiver currently in use at my station. Rough tuning is done by adjusting the hf crystal oscillator and the BFO, which have ranges of about 800 Hz, to the desired frequency. The VFO of the ccw filter center frequency reference (four times the center frequency) is used for fine tuning over a range of about 25 Hz. An i-f strip similar to one designed by Hayward[8] provides performance superior to others I have used. Best results are obtained when the agc is controlled by the agc output of the ccw filter.

Keitaro Sekine, JA1BLV, uses a crystal-controlled FT-901 and also has built a 2980- to 3080-Hz RC VFO for use as the reference for the center frequency of the ccw filter. Oscillators in the transceiver have been stabilized by using temperature compensation methods and high-stability crystals.

The Filter

A practical coherent digital filter may be seen in Figs. 13, 14 and 15. The first CD4060A6 is used as a switching mixer while the second controls the sample and dump functions. An audio signal output may be derived from a digital mixer (such as shown in Fig. 14) driven by the output from the two channels. The signal is the difference between the two and can be made single-ended by using an op amp, or both channels may be fed to A/D converters for computer input. A frame reference for the ccw filter is shown in Fig. 15.

A Microprocessor-Controlled Filter

The logic diagram of Fig. 16 is that of the computerized system which has been used at my station. The switching mixers are essentially the same as those used in the filter described previously. A computer program controls the A/D conversion and dump functions. Computer con-

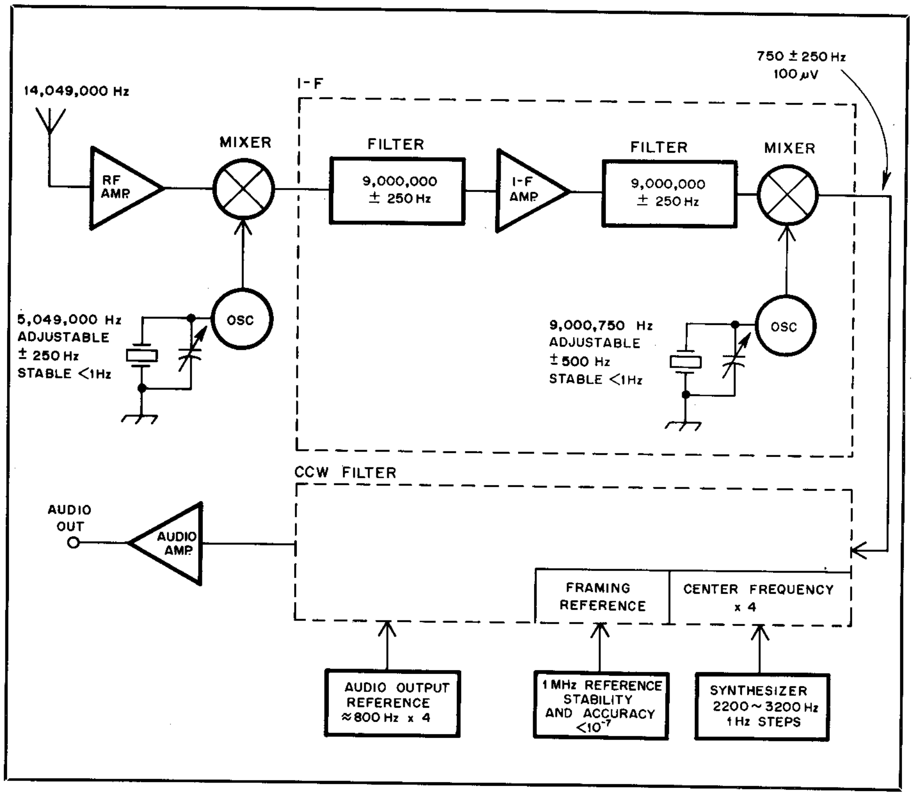

Fig. 12 — A block diagram of the receiver used by the author.

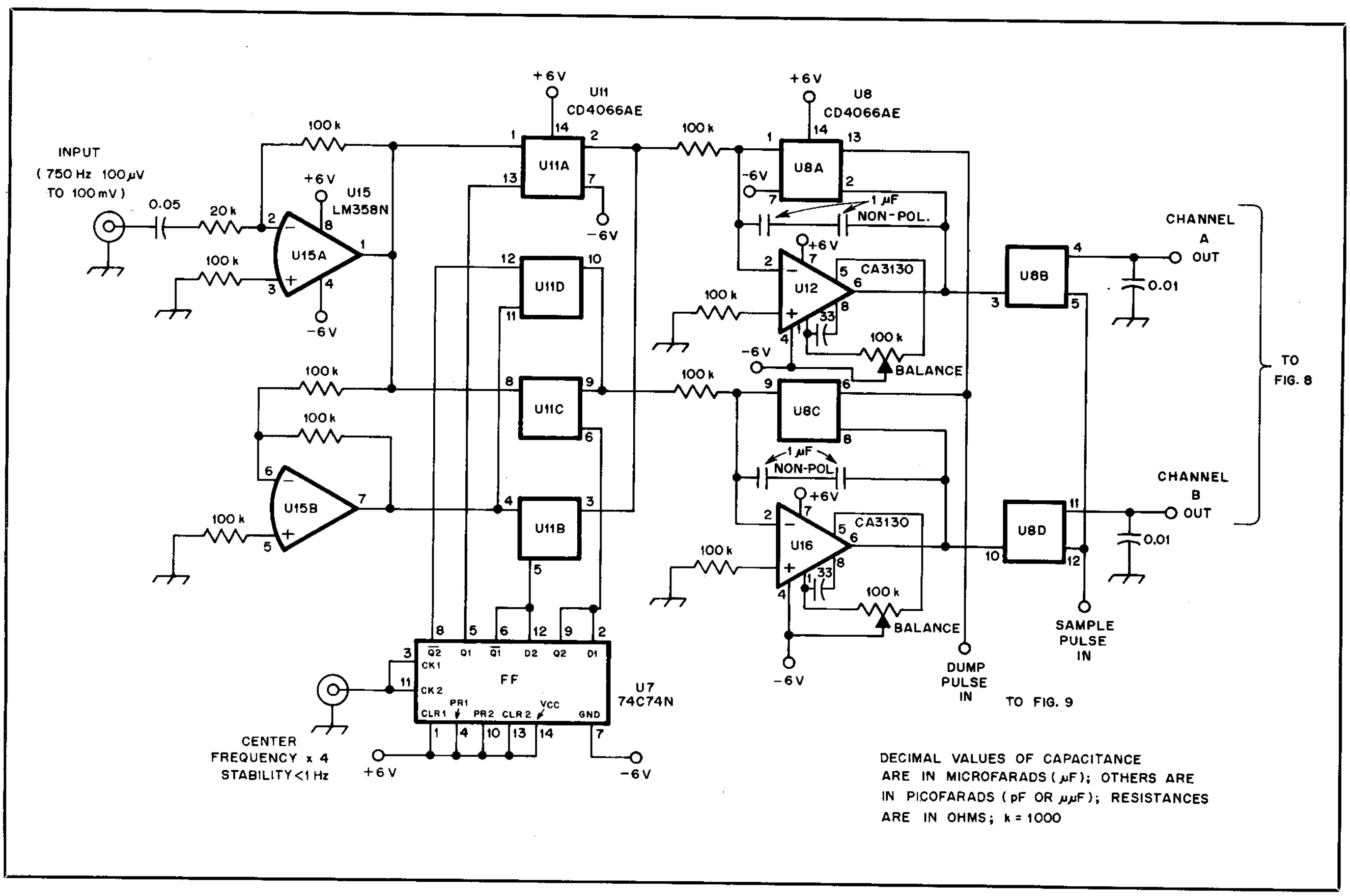

Fig. 13 — The front end of the coherent cw filter described in the text.

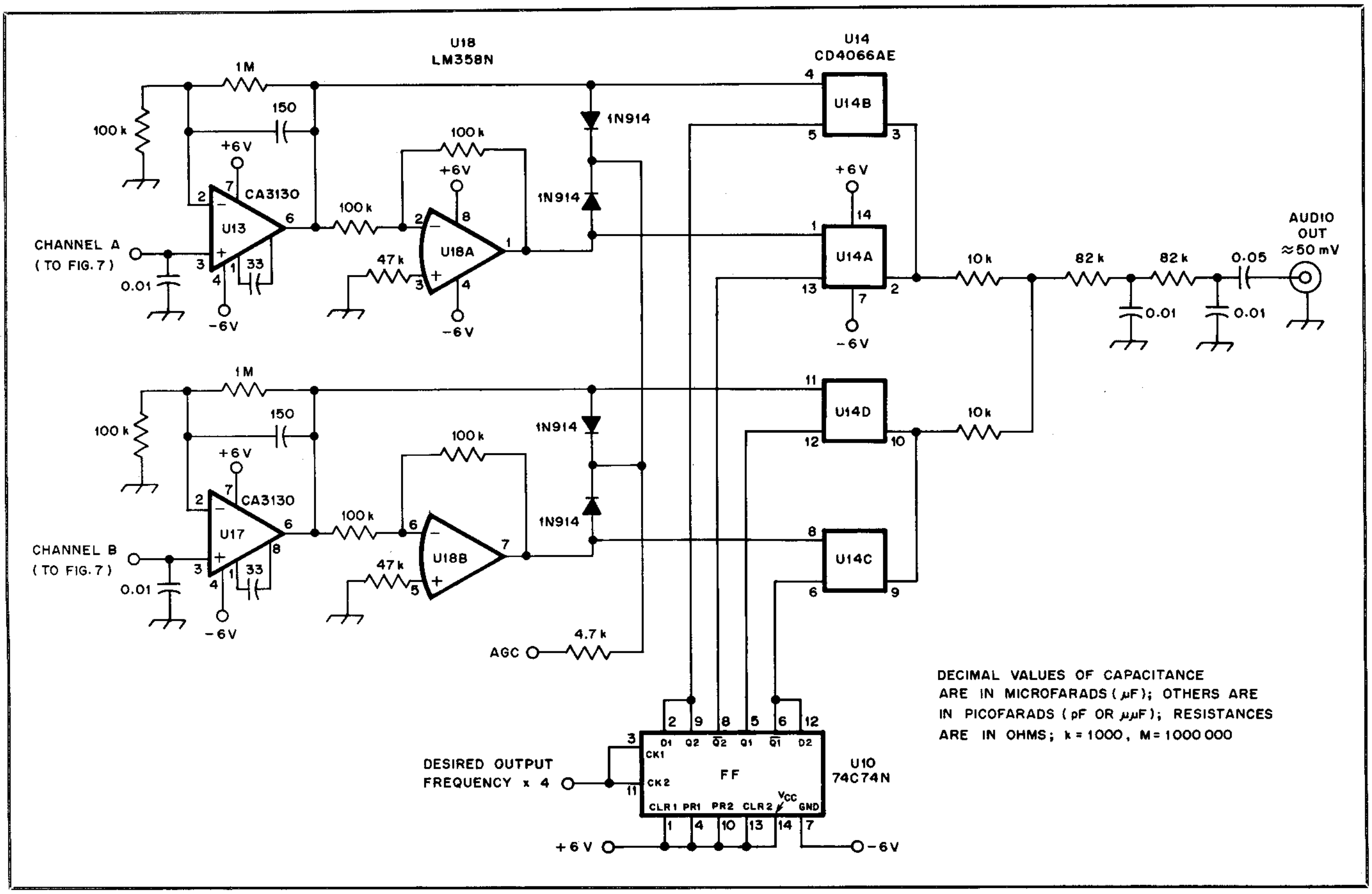

Fig. 14 — This portion of the ccw filter employs digital mixing to generate an audio output.

trol of the mixer has been employed, but use of an operator-controlled VFO is a convenience. The 1-MHz internal clock is stabilized and used to define the ccw frames. Phase is adjusted by the computer program. This is done by operator command. The operator indicates an advancement or retardation of the framing phase in 10 ms increments by pressing a computer key. I have experimented with a computer program to adjust framing phase automatically, but have not yet found a satisfactory way to maintain framing phase lock during breaks in the QSO caused by QRM or pauses. Between control of the sample and dump functions, the computer also converts the received Morse signals to ASCII code and transfers the ASCII code to a CRT character display terminal or printer.

Weak Signals and Noise

The reception of weak ccw signals is quite different from that of ordinary weak cw signals. Under standard conditions, as the cw signal gets weaker, QRN or QRM remain as "no signal" output and we eventually end up with a noise level dependent upon the bandwidth of the filter. With ccw, noise is a series of "dots" in frames and varies randomly in intensity. With the ccw filter, output is limited by design to one frequency and a weak signal is characterized by missing and extra dots randomly mixed with the desired signal.

Frame phase adjustment is important because if it is not accurate, a blurring of the dots and dashes into adjacent frames occurs. This makes the signal unreadable and it might go unnoticed if it is weak. When receiving a series of dots (a standard part of a ccw CQ), you can tune for maximum contrast between dots and spaces. With a strong signal, even a 10% phase error can be noticed. A slight lead error causes a weak mark just *before* each dot or dash while a lag error results in a weak mark just *after* the dot or dash.

Operating Practices

Under favorable conditions, it is often convenient to operate the ccw filter at shorter than optimal frame periods. With 0.01-second frames, the bandwidth is around 100 Hz and phase adjustment makes little difference. Although selectivity is reduced and signal level decreased by 10 dB, this method is used during initial signal detection. Once a signal is located, phase adjustment and longer frame periods may be used to optimize reception.

Phase tuning may be used instead of tuning a band of frequencies. This is accomplished by using an agreed-on frame length and frequency of operation and tuning for proper phase by adjusting the filter phase. Once phase adjustment is close, the frequency may be fine tuned as well. Present practice calls for sending a 15-second stream of dots to help in frame acquisition. A steady carrier of 10 seconds duration is an aid when fine tuning to frequency.

Time-reference signals from stations such as WWV may also be used to adjust the keying and reference frames of ccw receiving filters. Such adjustment must take into account the electromagnetic distance of the standards station to the receiving station as well as the electromagnetic distance between communicating stations. This procedure allows phase to be fixed and the operating to be the primary parameter which must be considered. Communication between stations located in Japan and California has been successfully accomplished using this technique. It is, however, a more difficult procedure to follow than phase tuning.

Conclusions

Ccw offers the possibility of employing some interesting operating techniques. Suppose Amateur Radio stations of the world agreed to operate at frequency multiples of 10 Hz. This would provide 20,000 channels at the bottom 200 kHz of

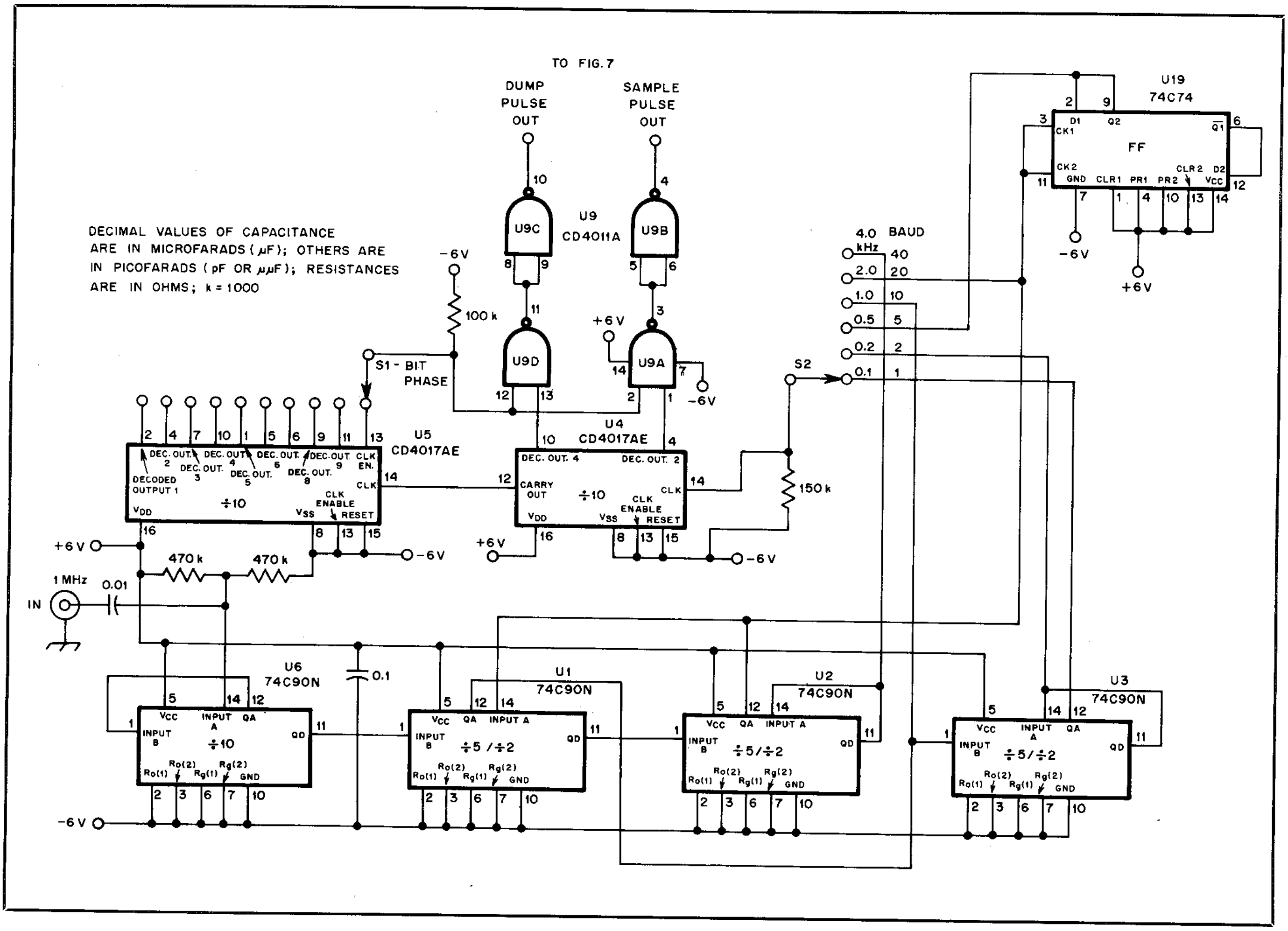

Fig. 15 — Frame reference circuitry of the ccw filter.

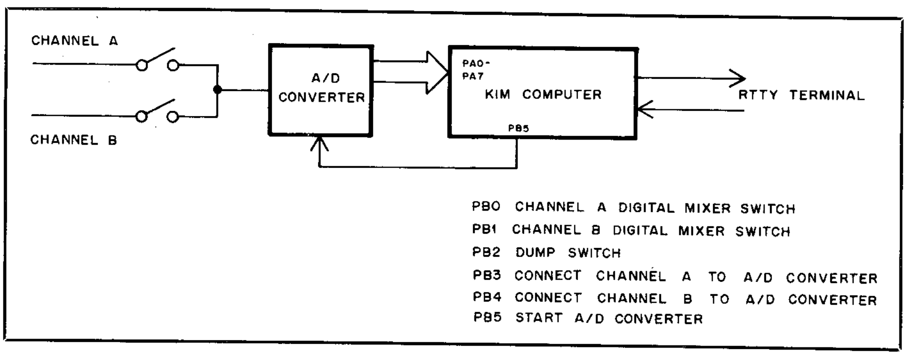

Fig. 16 — An experimental computerized ccw filter system used by the author. The filter used is similar to that of Figs. 13, 14 and 15, except that all switches are computer operated.

a band. If operators further agreed on sending in frames synchronized to 0.1-second UTC time pulses, you could set the framing (about a 0.03 second delay) to correspond to the distance of the stations you wish to contact, say 6200 mi (10,000 km). Once this is set, a check of the channels may be made for a station at the desired distance. Generally, you could detect signals at distances of 5000 to 7500 mi (8000 to 12,000 km) without further adjustment. Imagine microprocessor control over the entire procedure and the automatic detection of stations a particular distance away!

Coherent cw is a useful technique which improves communications effectiveness in excess of 20 dB. This factor can be used to offset poor propagation conditions, small or poorly located antennas, or low-power operation. It has the potential to be as revolutionary to cw as ssb has been to phone communication.

Acknowledgment

Many of the ideas presented here are based on ideas of Ray Petit, W7GHM. It is impossible to discuss ccw without mentioning him. This article has benefited considerably from critical comments and suggestions from Jim Maynard, K7KK, and Ray.

QST

Notes

[1] Kelley, "Universal Frequency Standard," *Ham Radio,* February 1974.
[2] Woodson, "Conversion of the HD-10 Keyer to CCW," *CCWN* 1975:43.
[3] Tyrrell, "Modifying the Accu-Keyer for CCW," *CCWN* 1976:68.
[4] McCasky, "The Coherent Ten-Tec: A Practical CCW Station Assembly," *CCWN* 1975:24.
[5] Maynard, "HW-8 for CCW," *CCWN* 1978:153-155.
[6] Woodson, "Stabilization of the SB-303 Receiver for CCW," *CCWN* 1975:60.
[7] Petit, "Synthesizer for 5 to 5.5 MHz," *CCWN* 1976:65.
[8] Hayward and DeMaw, *Solid State Design for the Radio Amateur,* ARRL, 1977, pp. 225-235.
[9] Double sided, drilled, glass epoxy printed circuit boards for the filter are available from the author at a cost of $40. The ARRL and *QST* in no way warrant this offer. Most component parts may be obtained from Jameco Electronics, 1021 Howard Ave., San Carlos, CA 94070.