COHERENT CW
(ARRL2115.txt + bmp images)

While spectrum management has received much attention in the recent Amateur Radio literature, the problems and possibilities of "more QSOs per kilohertz" were first recognized more than half a century ago. The late Frederick Emmons Terman, 6FT, presented his vision of narrow-band communications in "Some Possibilities of Intelligence Transmission When Using a Limited Band of frecquencies," published in Proceedings of the Institute of Radio Engineers, January 1930

As early as 1927, the Bell Telephone Company had reported successful experiments with 200-WPM Baudot TTY communications in a 50-Hz bandwidth over undersea cables. The bandwidth reduction resulted from synchronization of the transmitter and receiver.

Technology made giant leaps in the next 45 years. In September 1975 QST, Ramond Petit, W6GHM, described the experiments of some radio amateurs with a mode he called "coherent CW." Petit did not acknowledge Terman's paper, so we must conclude that he rediscovered the wheel. In any case, CCW is an idea whose time has come. Adrian Weiss, WORSP, disclosed some of the technical details of the CCW system, in June and July 1977 CQ. The presentation contains some errors, but the astute reader will be able to recognize the significant principles.

The bandwidth required for transmitting a radiotelegraph signal is directly proportional to the keying rate. For a speed of 12 WPM the unit pulse length is 0.1 second. Since a dot and a space each require 0.1 second a string of dots at 12 WPM is a square wave having a fundamental frequency of 9 Hz. To preserve the square-wave characteristic of the emission, an SSB transmission bandwidth of at least 15 Hz is required. A baseband (or dc wire telegraph) however needs a similar bandwidth for conventional information recovery. Terman reported that with synchronization techniques, the receiver bandwidth could be reduced to 1.5 or 2.0 times the keying rate. In conventional (Morse) radiotelegraphy, the intelligence IS ultimately received as an audio tone. Even a 15-Hz bandwidth filter centered on, say, 500 Hz, would require a Q of 33, causing intolerable ringing. The ringing problem can be overcome with time-domain processing at both ends of the communications path. The transmitter is stabilized to within I Hz of the proper frequency by phase-locking to a reference standard. Precisely timed keying pulses are derived from the same reference standard. A similar reference standard stabilizes the receiver frequency and synchronizes the audio output filter. The receiver output is sampled at twice the keying frequency. A block diagram of a CCW communications link is shown in Fig. 22.

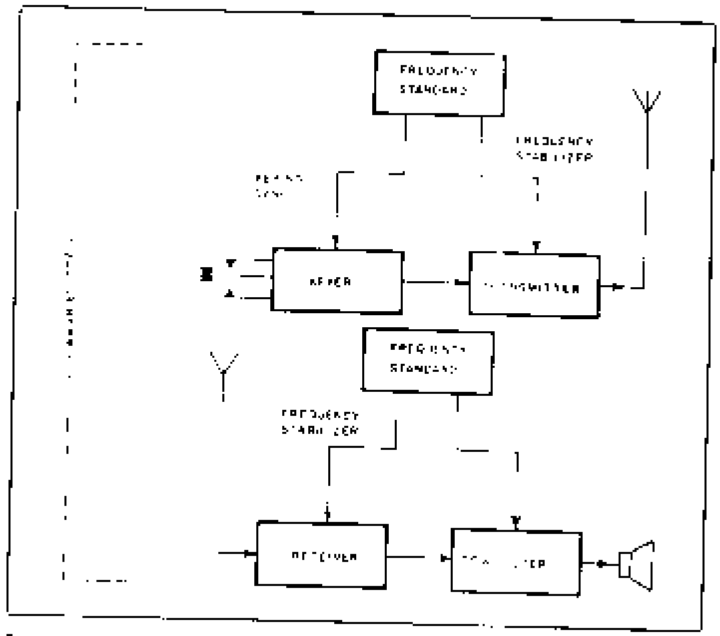

Fig. [illegible] A CCW communications line

Increased frequency stability and accuracy can be achieved through phase-locking both reference generators to a standard frequency broadcast station. A good signal for this purpose is broadcast on 60 kHz from WWVB.

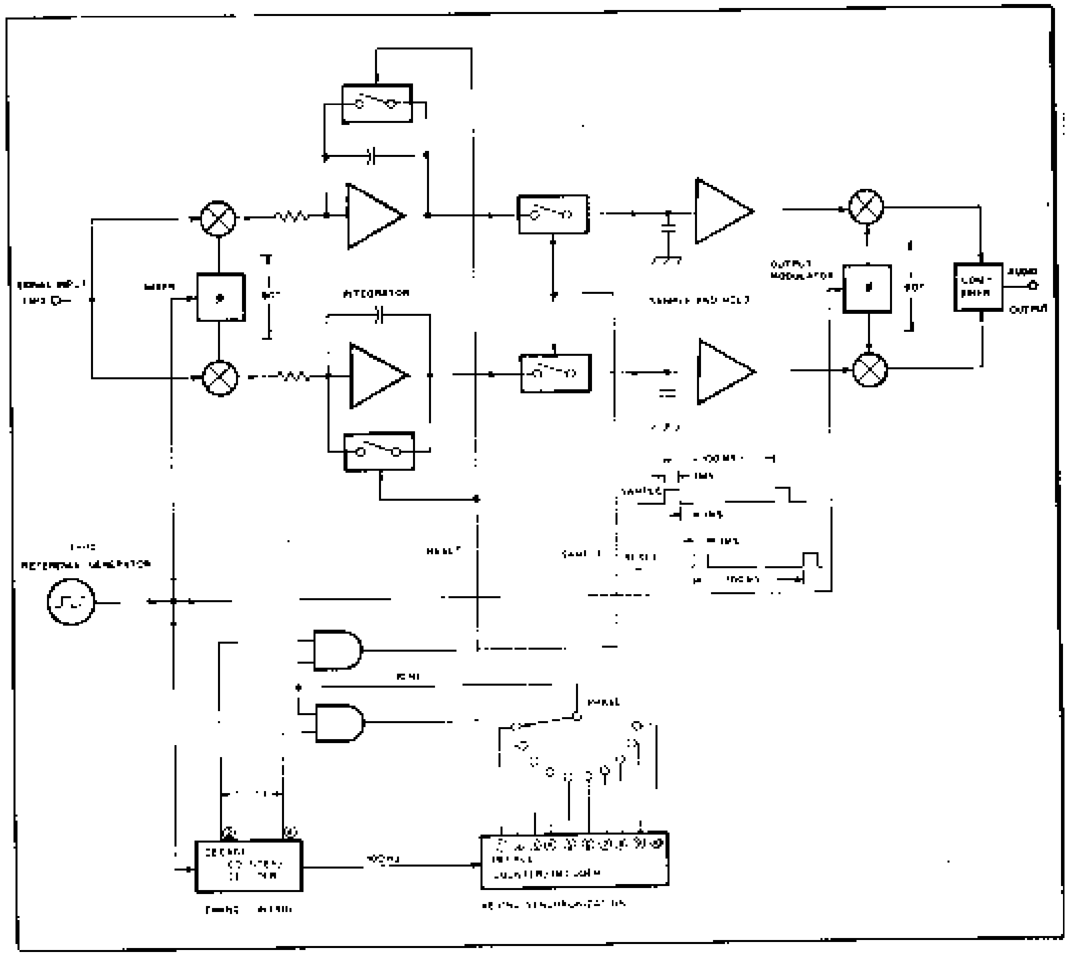

Fig. 23 — Block diagram of a CCW receiving filter. The operation is outlined in the text.

Fig. 23 shows the elements of' the audio output filter in more detail. A combination of digital and analog techniques produces a 3-dB bandwidth of 9 Hz, which is within the range predicted by Terman. When the receiver is properly tuned, the filter input signal frequency is 1 kHz. Since this frequency is "zero beat" with the reference (LO) signal, the mixer output is a dc voltage proportional to the cosine of the phase angle between the input and reference signals. When the signals are phase-coincident the mixer produces a maximum positive voltage.

The mixer output voltage swings negative when the input reference signals are 180 degrees out of phase. A 90 degree relationship results in zero owput voltage. The actual hardware uses square waves for mixer LO injection, so the phase detection transfer characteristic is linear rather than sinusoidal, but the minimum and maximum voltage occur at the same points. The phase of the input signal varies randomly with respect to the reference, even though the reference generators at each end of the communications link may be locked to the same standard frequency transmission. This variation results from changing propagation conditions. Phase variations of the input signal have little effect on the timing of the sampling window because the sampling rate is only one-hundredth of the signal frequency. The sampling window position is adjustable, in any case.

To prevent loss of output voltage when the input/reference phase relationship swings through 90', two signal-channels are driven in phase quadrature by the reference generator. Thus, if the input signal is shifted 90' from the reference signal applied to one mixer, that Mixer 0utput will be zero, butt the other mixer will see a O' or 180'relationship. The two channels are summed at the filter output, so the output amplitude is independent of the input phase, provided the frequency is zero-beat.

The voltage from the mixer is integrated over a 0.1 -second period. Near the end of this interval, the timing logic causes the sample-and-hold circuit to acquire the integrated output voltage. One millisecond later, the logic resets the integrator and the cycle repeats. The sample-and-hold voltage controls the amplitude of the reference signal passed by the output modulator.

Fig. 23 shows a separate phase-shift net-work at the output modulator for clarity, but the input network can serve both circuits. The square-wave outputs are in phase quadrature. The combined output wave-form is a staircase that can be filtered into a sine wave with relative ease.

The timing signals are derived from the 1 -kHz reference, which is synthesized from the master frequency standard used to stabilize the receiver LO. A decade counter with a decimal decoder produces 10 outputs, each having the duration of one input pulse and a frequency of one-tenth of the input clock. Output one goes high during the first clock pulse, output two goes high during the second clock pulse, and so on. Every second pulse of a sequence of 10 commands the sample-and-hold circuit to sample, and every fourth pulse resets the integrator. A second decade counter/decoder is cascaded with the timing control, and its phase-adjustable output gates the timing signals to select a 0.1-second integrating window that is synchronized with the incoming keying pulses. Because the signal is sampled at the end of the integration interval, the filter output is delayed 0.1 second with respect to the input.

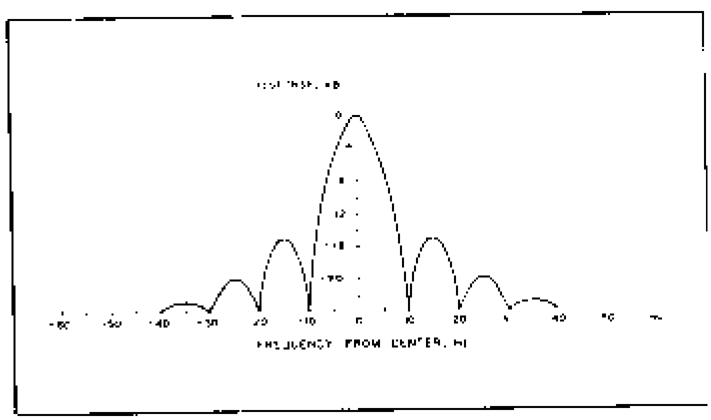

Fig. 24 — Amplitude vs. frequency response of the receiving filter

Fig. 24 shows the approximate amplitude-versus-frequency response of the filter. Note the symmetry of the skirts. Unlike analog filters composed of linear circuit elements, the sampling filter does not exhibit arithmetic selectivity. The spurious responses on either side of the main passband resemble the infinite rejection notches characteristic of an elliptic filter and arc called aliases. The frequency response is quasi-periodic because signals that are not zero-beat with the reference frequency produce a difference frequency signal from the input mixer. If the input signal is 10 Hz away from the reference, the mixer output will be a 10-Hz ac signal. At the end of the 0.1 -second integrating period, the mixer output waveform will have completed one cycle. Assuming the cycle started at zero volts, the sample-and-hold will acquire the integrated mixer voltage at the zero crossing and instruct the output modulator to pass zero reference signal. (This assumption isn't necessarily valid for a single channel, but it holds for the resultant of the quadrature channels.) Any whole number of beat-frequency cycles will cause the sampled voltage to be zero. Since the sampling interval is 0. I second, the response nulls occur every 10 Hz away from the peak. If the input and reference signals differ by a multiple of 5 Hz, the mixer voltage is sampled at the peak of a half cycle, causing an alias. The aliases diminish 6 dB every time the beat frequency doubles because the integrator is a first-order low-pass filter having a 6-dB-per-octave rolloff.

Noise bursts and strong adjacent-channel signals result in an occasional extra dot or an elongated dash, but are otherwise unnoticed. At the 12-WPM keying speed used by CCW experimenters, a signal-to-noise ratio improvement of about 20 dB can be realized over the bandwidths typically used for CW. Faster speeds are possible, but the bandwidth must be increased at the expense of signal-to-noise ratio.

To establish CCW contact, one station sends a preamble of dots to allow the receiving operator to synchronize his filter. Experience thus far indicates that once the filter has been synchronized, it usually won't need adjustment for several hours.

Fig. 25 depicts a typical CCW station. The early experimenters built their stations around simple QRP equipment to dramatize the communications advantages offered by the mode and to emphasize the accessibility of the necessary technology. The simple gear requires some add-on circuitry to allow oscillator stabilization.

The more modern synthesized transceivers can be outfitted for CCW more easily - replacing the internal reference oscillator with an external standard is all that's required. To send CCW, the paddle-actuated clock in the keyer must be replaced by a continuous pulse train from the frequency standard. Coordinating one's paddle movements with the "metronome" requires a different keying technique. A buffered keyboard (controlled by the standard) is the ideal CCW sending instrument. When more stations have CCW capability, the mode may prove highly useful for emergency communications. Another possible use for CCW is in EME work.