SYNCHRONOUS DETECTION OF AM SIGNALS

What Is It and How Does It Work?

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Interest in synchronous detectors seems to be on the rise. This phenomenon is no doubt due in part to the commercial availability of synchronous detection in a popular, moderately priced short-wave receiver, the Sony ICF-2010. Simplified implementation utilizing current IC technology now makes synchronous detectors easier than ever for the experimenter to build and use.

Amplitude Modulation

A firm understanding of amplitude modulation is essential before being able to fully appreciate synchronous detection—especially sideband and carrier phase relationships. A brief summary therefore follows:

The typical AM signal is of a complex nonrepetitive nature, such as music or speech. For the sake of clarity and simplicity, however, the following discussion will consider only an AM signal modulated with a single sine-wave tone. The principles are the same.

An ordinary AM signal is generated by the nonlinear mixing of two signals—the RF carrier and the AF modulating audio, shown in Figs 1A and 1B, respectively. This mixing results in a wave form as shown in Fig 1C. For comparison, linear mixing is shown in Fig 1D.

This nonlinear mixing of the audio and radio frequencies of an AM signal produces two new frequency components—the sum and difference frequencies—commonly referred to as sidebands. The upper sideband (USB) frequency, equal to the RF plus the AF, the lower sideband (LSB) frequency, equal to the RF minus the AF, and the carrier frequency are all shown in the spectral display of Fig 2A.

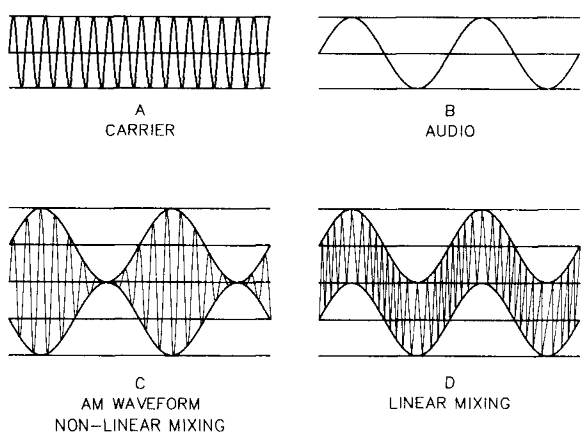


Fig 1

Each of these three components of an AM signal, as with any radio signal, can be represented as a rotating vector commonly referred to as a phasor.[1] The rotational speed of each phasor corresponds to the corresponding signal frequency. For example, the phasor that represents a 7.325-MHz signal (a popular BBC frequency here in North America) rotates 7.325 million times per second. Mathematical convention requires these phasors to rotate in a counterclockwise direction relative to a phasor of lower frequency. The phasor length corresponds to the signal amplitude.

Fig 2B shows three such phasors. They represent the carrier and upper (USB) and lower (LSB) sidebands of the AM signal in the previous figures. The USB, being higher in frequency, rotates more rapidly than the carrier, which rotates more rapidly than the LSB. In Fig 2C, the phase relationship between the three, at any arbitrary instant, is shown with the carrier used as a reference. Phasor rotation for USB and LSB, in this case, is shown as the difference between their actual rotation and the rotation of the carrier phasor. Fig 2D shows these same three phasors rotating about a single common point.

The envelope of the AM signal, or any radio signal for that matter, is at any given point in time determined by the vectorial sum of its phasors at that point in time. As an example, the AM signal depicted in Fig 3A shows one audio cycle of an AM signal broken up into 90 degree intervals. The corresponding resultant phasors for each of these intervals is shown inside the waveform. The

[1]A vector is used to denote magnitude and direction; a phasor, on the other hand, is used to denote magnitude and phase angle. The mathematics of both is the same.

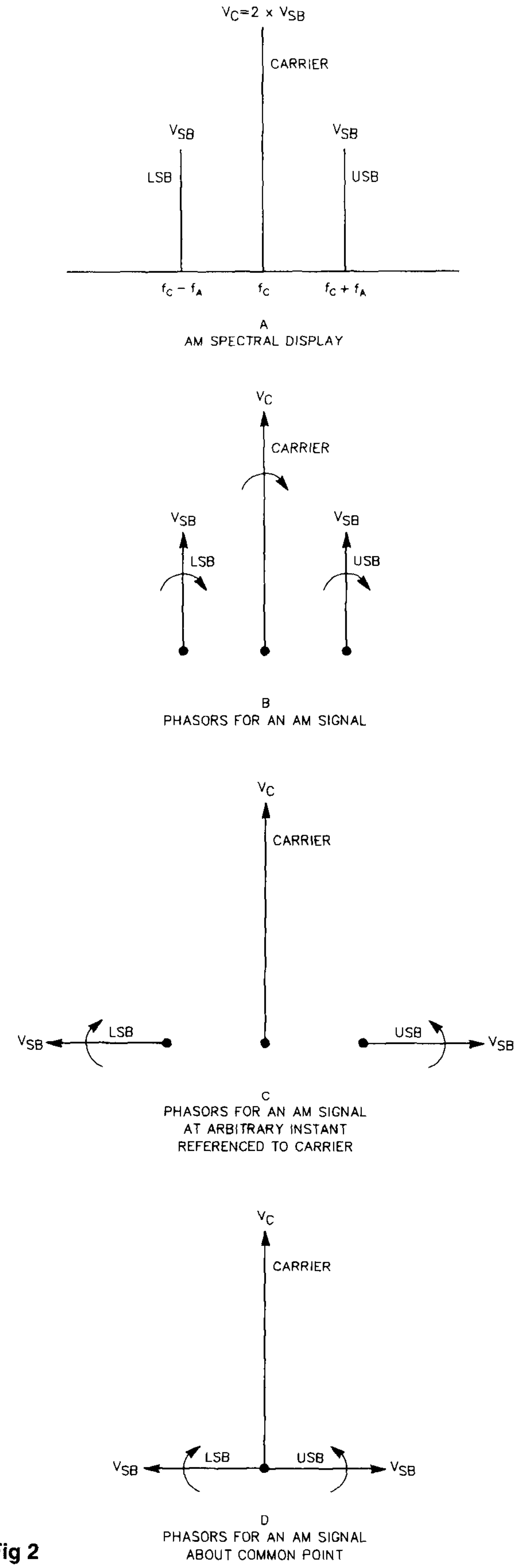


Fig 2

same phasors are also depicted about a common point in Fig 3B. The resultant is determined as follows:

1) 0 Degrees: The LSB and USB are 180 degrees apart from each other and, therefore, cancel each other out. The carrier level at this point is unaffected by the sideband components and is the same as if the carrier were unmodulated.
2) 90 Degrees: The USB, the LSB and the carrier are all in alignment and, therefore, reinforce each other. The RF envelope is the sum of both sidebands and the carrier.
3) 180 Degrees: The sidebands again cancel each other as at the 0 degree point. The carrier level is again unaffected by the sideband components. Note, however, that the sideband phasors have each advanced by 180 degrees.
4) 270 Degrees: Both sidebands are in alignment but are opposite the carrier. The net result is zero—the two sidebands cancel the carrier at this point.
5) 360 Degrees: This point completes one full audio cycle. The phasors have all returned back to the same positions they originally had at the zero degree point.

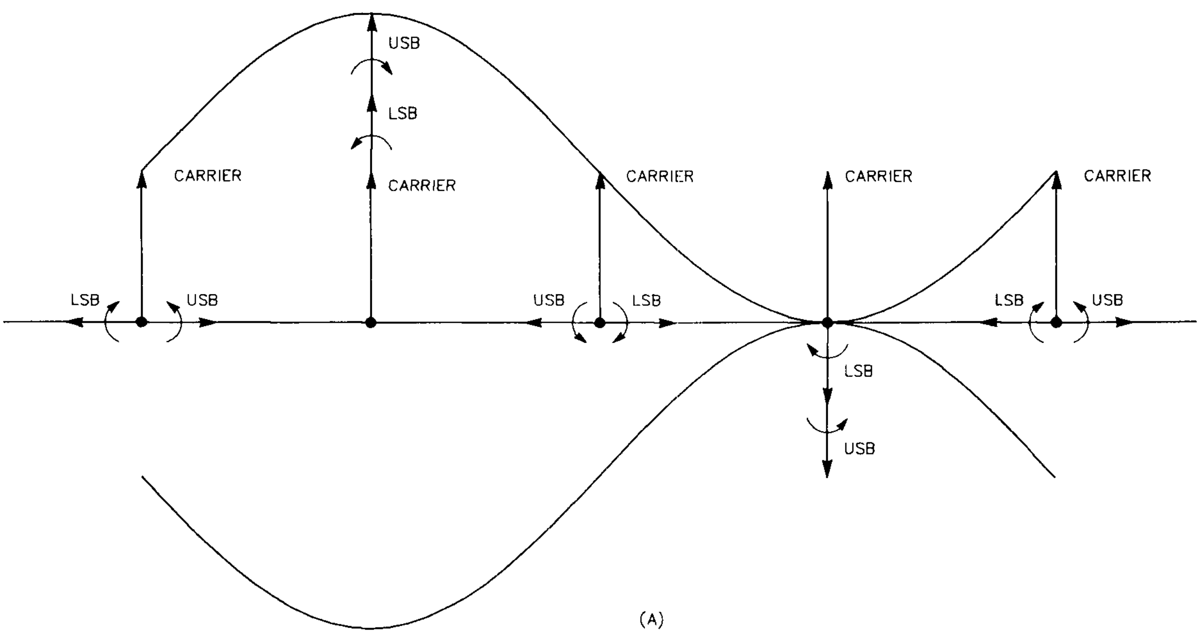
The reader may observe that only the upper half of the AM wave form envelope appears to be defined by the phasors detailed in Fig 3B. One must keep in mind that the carrier phasor is rotating at an RF rate—many times the audio rate of the sidebands relative to the carrier. This rotation of these phasors will cause the lower half of the AM wave form to be swept as time advances. (Picture in your mind's eye a strip of paper passing under a pen on the tip of the rotating resultant phasors. The AM wave form will be produced.)

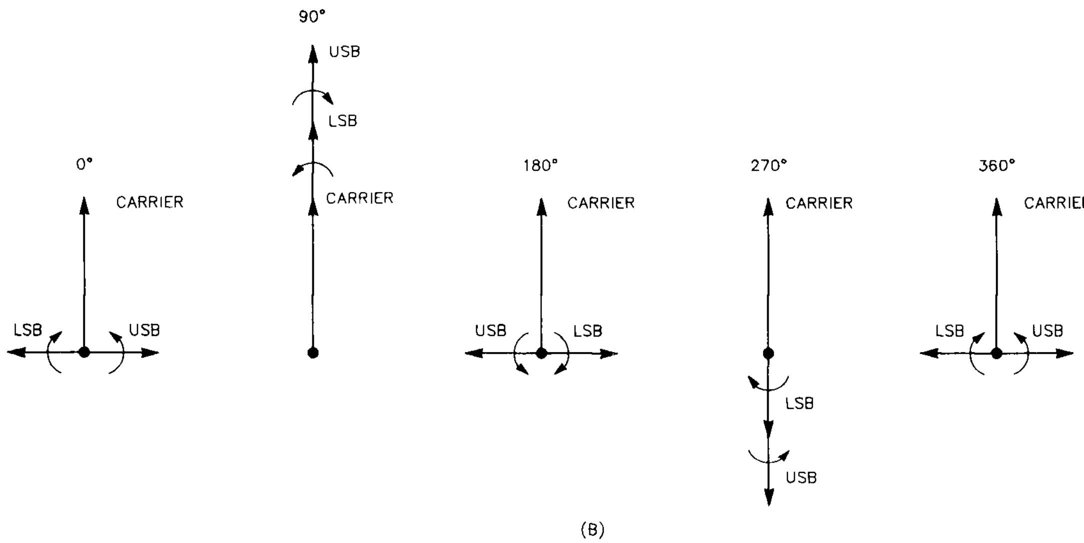
Envelope Detection

As indicated by the previous discussion, an ordinary AM signal consists of three parts, the upper sideband, the lower sideband and the carrier. An envelope detector, such as the common diode detector, is a nonlinear device. This nonlinearity introduces distortion when an AM signal is applied to it, and the desired difference frequency component is produced. In order for this detection process to function correctly, a full carrier is required. Should a selective fade reduce the carrier, severe "overmodulation" type distortion will result as shown in Fig 4; should noise be present on one of the sidebands, noise will also be present at the demodulated output. As we shall see, synchronous detection offers immunity from a selective carrier fade and provides the option to utilize phasing techniques to reject an unwanted sideband.

What is Synchronous Detection

The term "synchronous detection" is somewhat ambiguous. For purposes of this discussion, however, synchronous detection will refer only to a demodulation system having a locally generated carrier that is phase-locked to information derived from the transmitted





Figs 3A & 3B—Vectoral components of an AM signal

signal—usually the carrier. (The incoming AM signal is then mixed, or heterodyned, with the locally generated carrier.) This process essentially recovers the audio from the AM signal by translating to baseband.

The easiest, and probably the most common implementation of a synchronous detector, shown in Fig 5, is simply a phase-locked loop IC that is locked to the carrier of the signal. One notable exception, however, is the Costas loop. First described in 1956 by John P. Costas, K2EN, in a paper entitled "Synchronous Communications," this detection process obtains the necessary phase information for loop lock from the sidebands. This technique can therefore be used to demodulate double sideband AM with a full, reduced, or suppressed carrier. Despite the theoretical advantage of the Costas loop, its added complexity does not buy much when demodulating signals with sufficient carrier to capture and hold phase lock. Since the HF broadcasters will no doubt continue to transmit some form of carrier for some time to come, if for no other reason than phase locking, no fur-

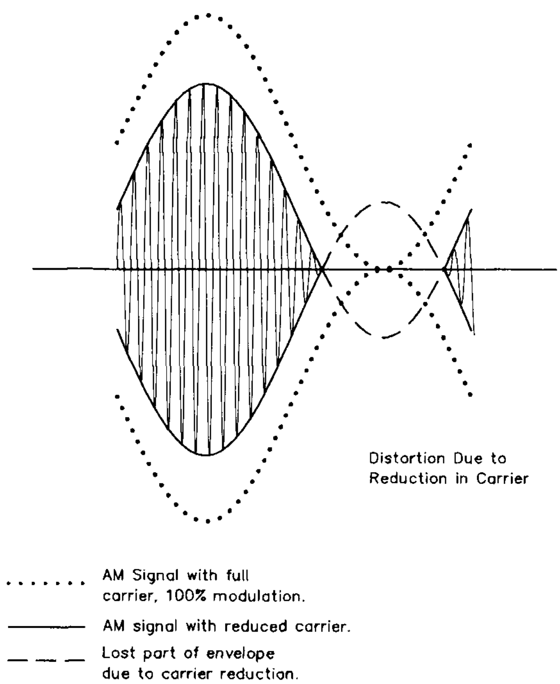


Fig 4

ther consideration will be given to the Costas loop in this discussion. The reader may, however, refer to the bibliography for further information on this topic.

Another similar detection scheme is called the "exalted carrier" method. A carrier sample is first taken from the AM signal and then amplified. It then typically undergoes a hard limiting process before being recombined with the original AM signal. Demodulation can then finally be accomplished by either envelope detection, or, as in true synchronous detection, by a translation process. This technique differs from true synchronous detection in that there is no locally generated carrier. Stability considerations and the simplicity of implementing true synchronous detection with modern IC chips, while offering no significant advantages, have now rendered exalted carrier detection somewhat obsolete.

Two terms often associated with synchronous detection are "synchrodyne" and "homodyne." Both of these terms are extremely ambiguous. Some of the more common meanings for them include: Synchrodyne—a receiver with synchronous detection, and, Homodyne—a receiver with exalted carrier detection. It is most important, however, if encountering these terms to understand their meanings as they apply to the literature at hand.

Why Synchronous Detection?

Synchronous detection offers several significant advantages over the common envelope detector. Unlike envelope detectors that require a minimum of 6.02 dB of carrier above the sidebands for proper demodulation of the signal, synchronous detectors need only sufficient carrier to capture and hold phase lock. Testing was conducted at the ARRL Laboratory with the sync detector of a Sony ICF-2010 to determine the practical level of carrier reduction possible with this circuit. A single-sideband test signal with variable carrier was used. Approximate results with speech and music audio signals are as follows:

	MAXIMUM LSB TO CARRIER	CARRIER BELOW PEP
CAPTURE LOCK:	Not Measured	−11 dB
HOLD LOCK:	9 dB	−16 dB

This characteristic of sync detectors provides increased immunity from selective fading of the carrier relative to the sidebands. This advantage can be significant when the reception of sky-wave signals is considered. In the above case, the carrier could fade by 15 dB before any noticeable degradation in the audio would become apparent. (The potential loss of phase lock dur-

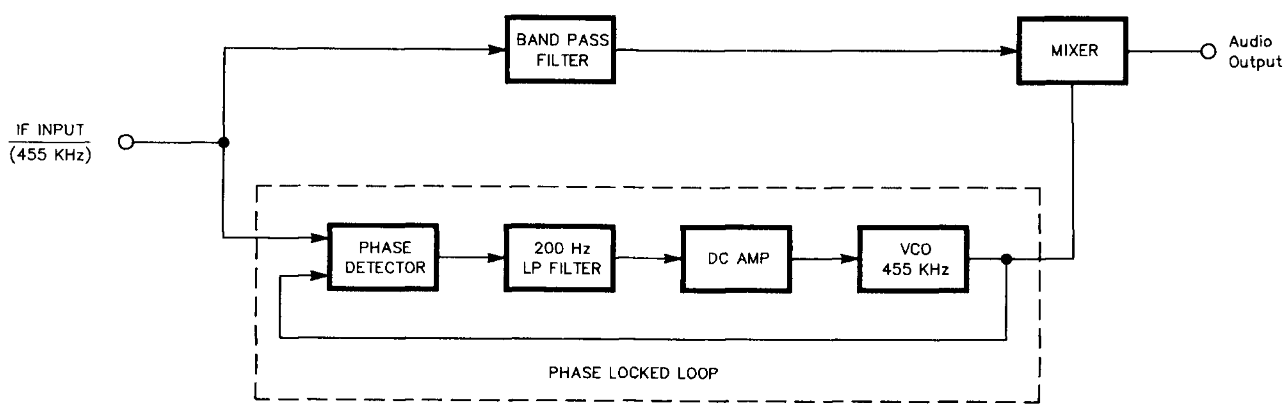


Fig 5—Synchronous detector block diagram

ing a severe fade, however, can result in a burst of noise instead of the less disagreeable reduction in audio typically associated with envelope detectors. The Sony design has provisions to overcome this problem.) Synchronous detectors are also compatible with AM signals having partially reduced carriers and/or one sideband.

Distortion as a result of the receiver being mistuned can in some cases also be eliminated. An envelope detector, being a nonlinear device, works correctly only when both sidebands are mirror images of each other and the carrier is of sufficient amplitude. If the receiver is tuned off to one side of the signal, the sidebands, and possibly the carrier, may be down the skirt of the IF filter. This asymmetry will cause distortion. A synchronous detector, however, if able to achieve proper phase lock on the carrier, is capable of producing an undistorted audio output from the same signal.

Another significant advantage of synchronous detectors is their compatibility with phasing techniques to select between the upper and lower sideband of an AM signal. The advantages include:

1) cancellation and reduction in noise and interference,
2) increased immunity from selective fading and phase shifting between sidebands, and
3) improved signal to noise ratio.

The primary characteristic unique to synchronous detectors that makes this possible is the ability to mix a synchronized carrier that is either in phase (I) or quadrature 90 degrees out of phase (Q) from the original carrier. Audio phasing techniques can then be used to cancel the undesired sideband while reinforcing the desired sideband. See Fig 6 for a block diagram and the associated phasor diagrams. The Sony ICF-2010 design is similar to this concept.

It is clear that synchronous detectors, especially in certain cases, can provide dramatic improvement in the reception of AM signals over the common envelope detector. Selective fading, overmodulation due to carrier fading, heterodyning, phase shift distortion and adjacent channel interference can be reduced or, in certain cases, be eliminated by use of this technology. Although these conditions are most common on the HF bands with crowded conditions and sky-wave propagation, the benefits of synchronous detection are also apparent on the MF AM broadcast band. Amateur AM activity, although enjoying the same benefits of broadcast AM reception, does require retuning if the stations drift or are more than a few hundred hertz apart from each other.

Synchronous Detection Considerations

Synchronous detection can be performed at both radio (RF) and intermediate (IF) frequencies—lending itself to both superheterodyne and direct conversion receivers. Frequency stability of both the transmitter and the receiver, however, becomes far more critical than with envelope detectors. A synthesized or crystal controlled tuning system is optimum and may be required to ensure stability and provide the predictable tuning resolution necessary to capture and hold lock. It is imperative to keep these factors in mind when determining the compatibility of a receiver for an outboard home-brew sync detector.

The frequency range of the phase-locked loop must be limited to reduce the possibility of capture and hold on anything other than the desired carrier. The Sony ICF-2010 often loses lock when tuned away from a station by more than three or four hundred hertz. It is important to note that unless phase lock has been achieved, the signal in most cases is completely unintelligible. An envelope detector, therefore, is best when tuning across the band or attempting to locate a particular station. Once a desired signal has been located, the synchronous detector may then be switched in. (The ICF-2010 incorporates electronic switching to accomplish this function automatically.)

Synchronous Detection Implementation

Probably the first question that comes to mind about synchronous detection is, "Can I build one with a single chip design." The answer to this question is a qualified yes. A simple phase-locked loop, or chip with a phase-locked loop, such as an AM stereo decoder or similar, will do the job. If, however, one desires to incorporate the selectable sideband feature into the project, an audio phase shift and audio summing network must be included in the design.

AM stereo chips for a 450-kHz IF typically operate with a VCO frequency of 3.60 MHz, or 8× the IF frequency. This makes it easy to obtain the quadrature phase necessary for a selectable sideband feature. The ICF-2010 receiver uses a Sony CX-857 AM stereo decoder chip. This IC is compatible with all AM stereo systems (including Kahn and C-Quam). This chip is particularly attractive for synchronous detection applications because it provides easy access to both the I and Q outputs. An additional 90-degree RF phase shift circuit is not required.

The audio phase shifting is no doubt the most difficult part of the circuit to produce. A wideband shift of 90 degrees total is required. The audio phase shift network in the Sony is provided on a separate board by four transistors, six capacitors and twenty-one resistors! This circuit provides all the necessary audio phase shifting and summing to produce the USB and LSB. These outputs are then fed to automatic switching circuitry in the ICF-2010 to provide for the upper or lower sideband depending upon whether the receiver frequency is above or below the carrier frequency.

Over the years, a number of synchronous detector construction projects have appeared in various amateur and electronic publications. They seem to range from vacuum tubes and discrete solid state components to

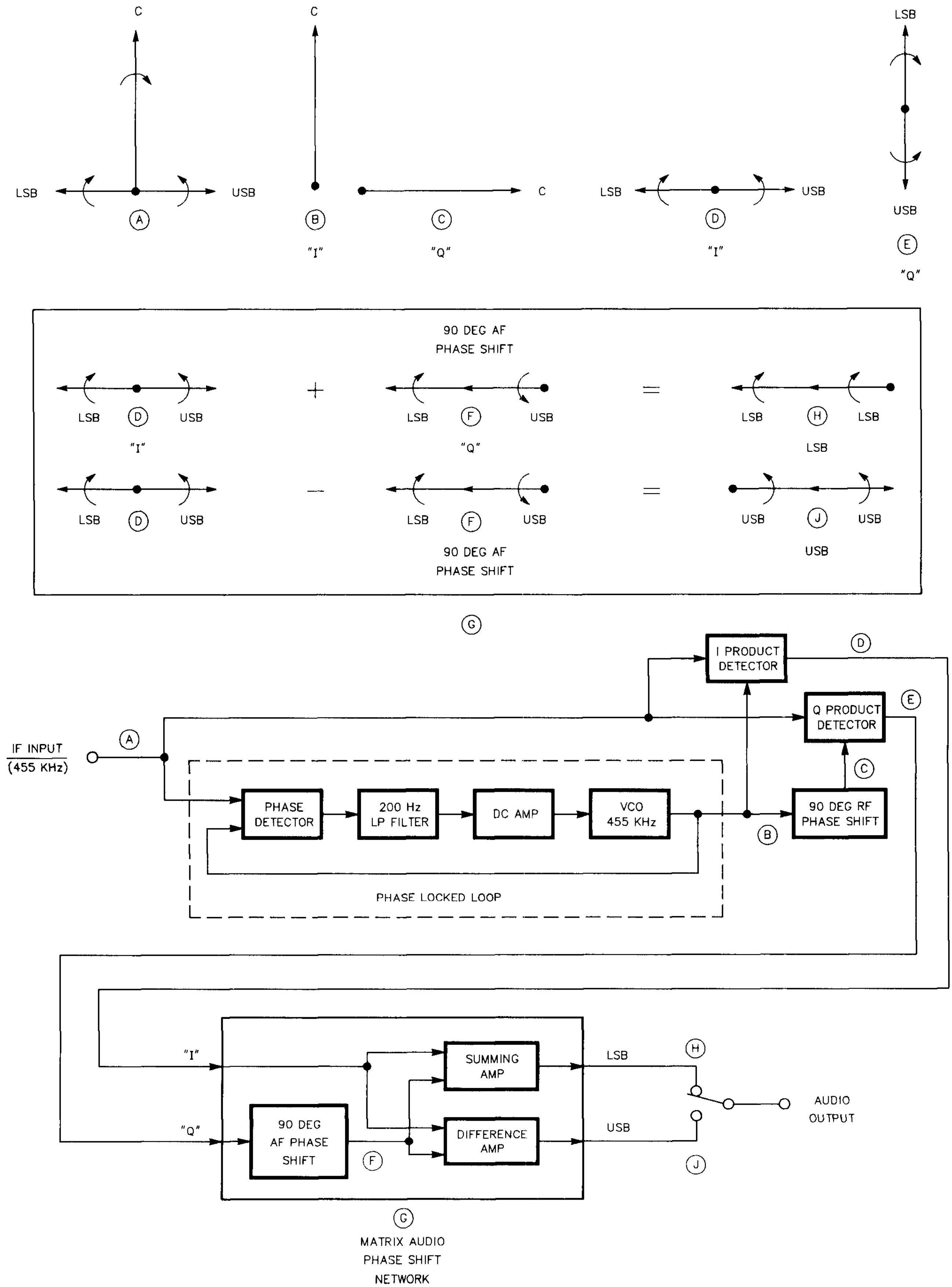


Fig 6—Synchronous detector with selectable sidebands block diagram.

HOW IT WORKS

The input to the sync detector is an AM signal as shown by the phasor diagram in Detail A. The I and Q locally generated carriers are shown by Details B and C, respectively; note the 90-degree phase shift in the Q channel. These carriers are then mixed with the original AM signal to produce the outputs shown by Details D and E. Although these signals are at audio frequencies, the USB and LSB components at this point are not in correct phase for proper audio recovery. A 90-degree audio phase shift is required and its affect is shown in Detail F. As shown by the vector analysis in the box of Details G, the desired sideband can be obtained at this point by either the sum or the difference of the I and Q channels. The desired sideband component from each channel is added in proper phase while the undesired component is simultaneously rejected by cancellation. This is shown in details H and J.

In the example of this figure, the USB is obtained by the difference between of the I and Q channels while the LSB is obtained by the sum of the I and Q channels. Other variations are possible. For example, only the sum is required to obtain either sideband provided an audio phase shift is in the I or Q channel. In this case, the USB is obtained by adding an audio phase-shifted I-channel to the Q channel. The LSB can likewise be obtained by adding an audio phase-shifted Q-channel to the I channel.

It is very important that a 90-degree phase difference exists between the I and Q channels. There is nothing "special" about single 90-degree shifts, however. For example, a plus 45- on one and a minus 45-degree shift on the other would do fine. You can use vector analysis, as shown here, to prove that to yourself.

obsolete ICs. Unfortunately, it appears that an article utilizing current IC technology and a selectable sideband feature, such as in the Sony ICF-2010, has yet to be published. A bibliography of these construction articles appears at the end of this discussion.

A synchronous detector with a selectable sideband feature has been constructed with spare Sony ICF-2010 parts by Steve Johnston, WD8DAS, and Paul Cianciolo, KB1RP. The parts used for their projects were the CX-857 AM stereo chip and the audio Phase Shift Network (PSN) module. Both Steve and Paul report excellent results with their detectors.

The circuit design that they used was essentially a combination of the circuit shown on page 8 of the CX-857 Data Sheet and the sync detector used in the ICF-2010. The schematic is shown in Fig 7. For those wishing to reproduce Paul and Steve's efforts, kit information and a complete source list for Sony parts and literature kit is included as an Appendix.

The construction of the detector is not particularly critical, but can be a bit tricky due to the surface-mount requirements of the IC. Paul used a piece of printed circuit board material mounted inside a Hammond Diecast 1590 B box, but almost anything similar should be satisfactory. Use construction techniques that are suitable for the frequencies involved and keep the coax input lead as short as is practical.

Proper selection of the candidate receiver for the sync detector is essential. The importance of stability cannot be overemphasized. The detector should have a free-running frequency equal to the receiver's IF and, have compatible impedances and signal levels.

The specifications for this project are as follows:

IF Center Frequency:	455-kHz typical, adjustable from 400 to 500 kHz
Input Impedance:	1 MΩ
Input Level:	500-mV typical, 100-mV minimum, 1-V maximum
Output Impedance:	10 kΩ
Output Level:	100-mV typical
Power Requirements:	12 V dc at 20-mA typical, but 4 to 14 V dc acceptable.

Paul and Steve both used a parallel tuned circuit for the VCO. (Paul used a 620-pF silver mica capacitor and a variable inductor centered approximately around 3.15 μH. The inductor could then be tuned to the desired free running frequency.) The ICF-2010, however, uses a

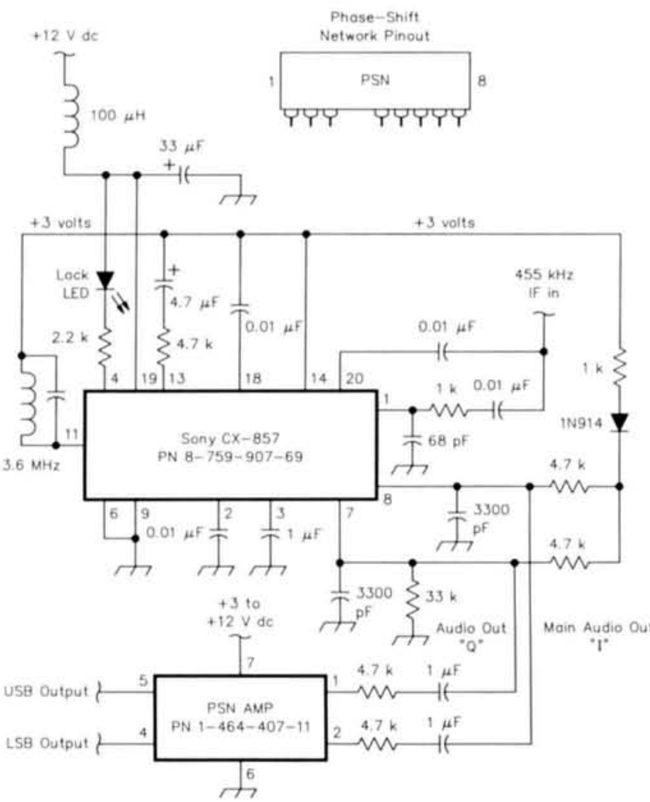


Fig 7—Synchronous detector.

I first became acquainted with selectable sideband synchronous detection when I purchased a new Sony ICF-2010 several years ago. The ability of this feature to reduce or eliminate certain types of distortion and interference was quite remarkable. It quickly became an indispensable asset to my shortwave listening enjoyment.

I soon began to desire an outboard sync detector for my other radios. To this end, albeit several years later, I built the unit described in this article. It has been used with great success in both my R-390A and FRG-7700 receivers. Selective fade distortion is virtually eliminated and the ability to select sidebands has proven to be a real asset. SWLs, AMers and broadcast band listeners are sure to enjoy this form of detection.—*Paul A. Cianciolo, KB1RP*

crystal for this purpose. The crystal version might be preferred in some cases, especially if receiver stability will allow for it due to the reduced locking range. The PLL is less likely to lock onto something other than the carrier of the desired signal.

The Future of Synchronous Detection

The introduction of single-sideband techniques to the HF broadcasting bands was established in the Resolutions and Recommendations of a World Administrative Radio Conference. Recommendation No. 517 (HFBC-87) specifies an initial 6 dB below PEP of carrier reduction. By the end of the year 2015, the final carrier reduction of 12 dB below PEP is to take effect and all DSB transmissions are to cease on these bands.

The initial 6 dB of carrier reduction will be only partially compatible with envelope detectors, and the final 12-dB reduction will require alternative detection methods. Synchronous detectors can be made fully compatible with such reduced carrier signals and will no doubt be the most popular detection technique for these new signals. It is expected, therefore, that the next generation of budget short-wave receivers will help proliferate at least some form of synchronous detection as full carrier DSB is being phased out. The resulting new chips and dedicated circuitry components should make for easy and inexpensive synchronous detection for mass produced radios as well as the home hobbyist.

Bibliography

NOTE: The first nine and last two articles are primarily construction projects featuring complete construction details.

1. Dave Hershberger, W9GR, "Build a Synchronous Detector For AM Radio," *Popular Electronics*, April 1982, pp 61-71. Correction, July 1982, p 6. *(An additional error appeared in this article that was never published. The* envelope *position of switch S1B should be grounded. It is shown being unconnected.)*
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22. J.W. Herbert, "A Homodyne Receiver," *Wireless World*, September 1973, pp 416-419.

Appendix

Parts

Sony CX-857 AM Stereo Chip
P/N 8-759-907-69 Price: $19.87
Sony Phase Shift Network
P/N 1-464-407-11 Price: $19.87

Literature

Sony ICF-2001D/2010 Service Manual
Sony CX-857 AM Stereo Decoder Data Sheets

Sources

Sony Service Company
Part Division
8281 NW 107th Terrace
PO Box 20407
Kansas City, MO 64195-0407
816 891-7550

Steinberg Electronics, Inc
2220 North Broad Street
Philadelphia, PA 19132
800 523-0894

Synchronous Detector Kits

Steve Johnston has indicated that he will be offering this project in kit form. The price is $139.00 for the kit and $199.00 for an assembled and tested unit. The cost for a single board is $15.00.You can contact him for further information at:

Steve Johnston
PO Box 3420
York, PA 17402-0420