SYNCHRONOUS DETECTION

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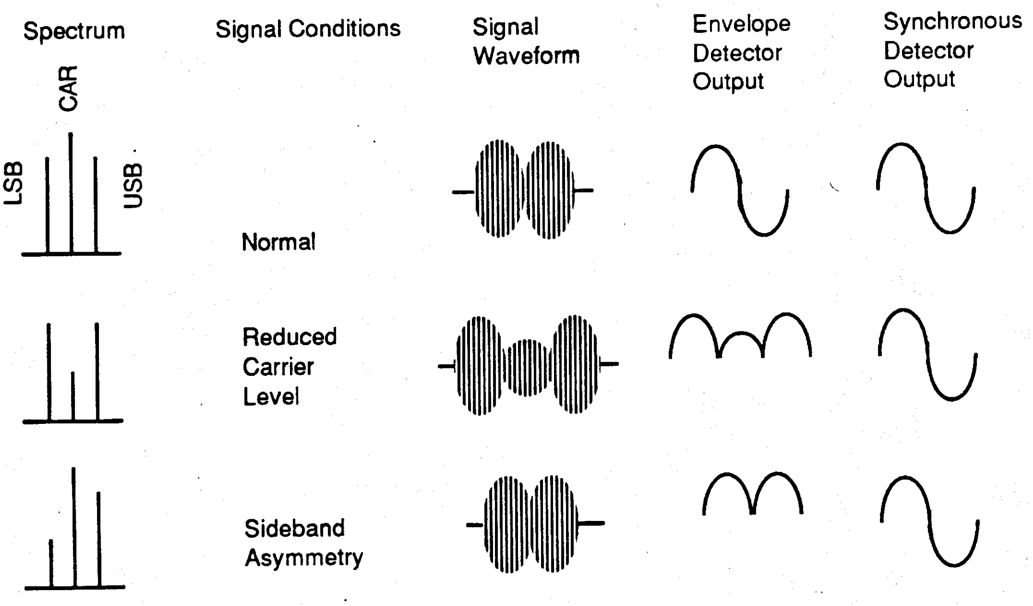
Radio signals are converted to audio at the detector. The detector is one of the most important elements of a receiver because it ultimately determines the sound quality. If the detector performs poorly, the audio will sound rough and edgy. When the detector can recover the audio exactly as received, the sound quality improves without introducing any additional distortion. Synchronous detectors are more nearly "ideal" detectors in performance than conventional detectors found in most receivers.

SYNCHRONOUS DETECTION VS. ENVELOPE DETECTION

The conventional AM detector found in all but a few receivers is called an envelope detector. It receives it's name by the way it strips the envelope or audio information from the carrier. The typical envelope detector is extremely simple, costs pennies to the manufacturer, and is usually nothing more than a germanium diode. The radio pioneers of the early twenties used a "cat's whisker" detector which is identical in performance to the germanium diode, and seventy years later, little has changed!

What's wrong with envelope detection? The most serious problems occur during multipath reception. This is a common occurance with shortwave signals as two different signal wavefronts arrive at the antenna with different phase characteristics. At one moment the signals might add, another moment they might subtract. This is one way that fading is created. The distortion resulting from a deep fade is a familiar sound to any shortwave listener.

During a fade, the balance between the audio (sidebands) and carrier is sometimes upset. The envelope detector creates severe intermodulation distortion when this balance is altered. An imbalance between the carrier and sidebands is a type of selective fading. Selective fading can also occur between the lower and upper sidebands which also creates distortion with the envelope detector. The following diagram shows the difference between envelope detection and synchronous detection with a radio signal modulated with an audio tone.



The benefits of using a synchronous detector are as follows:

1. It does not suffer from distortion when there is an imbalance between the carrier and sidebands.
2. It does not suffer from distortion when there is an imbalance between the upper and lower sidebands.
3. Using a synchronous detector will generally result in lower audio distortion compared to an envelope detector especially at the higher modulation levels.

These characteristics describe the "ideal" synchronous detector. There are numerous ways of creating synchronous detection and no one method is perfect. Each method has advantages and disadvantages but overall, the performance is significantly better than the envelope detector.

BASIC DEFINITION

What is synchronous detection? The Oxford American Dictionary defines synchronous as:1. existing or occurring at the same time. 2. operating at the same rate and simultaneously.

A synchronous detector is simply a detection process that uses a signal that is synchronous with the original carrier (occurring at the same rate or time).

For those interested, a better definition can be explained mathamatically ,where an AM monaural signal can be represented by the following[1].

$$E(t) = (1 + m(t)) \cos wt$$

In this equation the $m(t)$ is the envelope or modulation and the $\cos wt$ is the carrier.

An analog synchronous detector is a multiplier whereby the original AM waveform is multiplied by a signal that has the same frequency and phase characteristics as that of the carrier.

It's that simple. Mathamatically, this is represented by[1]:

Detector Output $D(t) = (1+m(t)) \cos wt \times \cos wt$

Note that the original waveform is multiplied by $\cos wt$. Now if the multiplying $\cos wt$ is identical with the original carrier, (same frequency and phase characteristics) the equation results in[1]:

$$\begin{aligned} D(t) &= (1+m(t)) \cos wt \times \cos wt \\ &= (1+m(t))\ 1/2\ (\cos (wt-wt) + \cos (wt + wt)) \\ &= (1+m(t)\ 1/2(\cos 0 + \cos 2wt) \\ &= (1 +m(t))\ 1/2(1 + \cos 2wt) \\ &= \underline{1/2(1 + m(t))} + \underline{1/2(1 + m(t) \cos 2wt} \end{aligned}$$

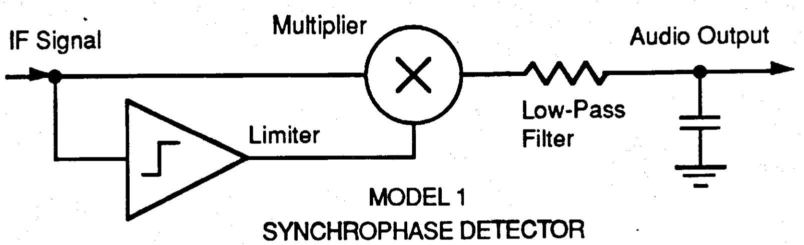
The left half of the final product (1/2 (1 + m(t)) is an exact replica of the original modulation (hence detection), only level shifted with DC offset. The right half (1/2(1 + m(t) cos 2wt) is a high frequency component that can be filtered out after the detection process.

Probably the most important element of the mathamatical definition is the fact that the equation does not specify how the multiplying (cos wt) should be created. Or in simpler terms, it does not specify how the synchronized signal should be created.

How this signal is developed determines the type of synchronous detector. The remainder of this article will explore the various models of synchronous detection and their performance. It should be mentioned that the following models will refer to the original waveform (carrier and sidebands) as it is converted within the receiver to an IF signal. Also, it is important to point out that the term "multiplier" is synonymous to a "product detector".

SYNCHROPHASE DETECTOR

The first example of synchronous detection is the synchrophase detector. The term "synchro-phase" was used by Drake with the introduction of the R-7 receiver. A similar detector is now used in the Japan Radio NRD-525 receiver.



MODEL 1
SYNCHROPHASE DETECTOR

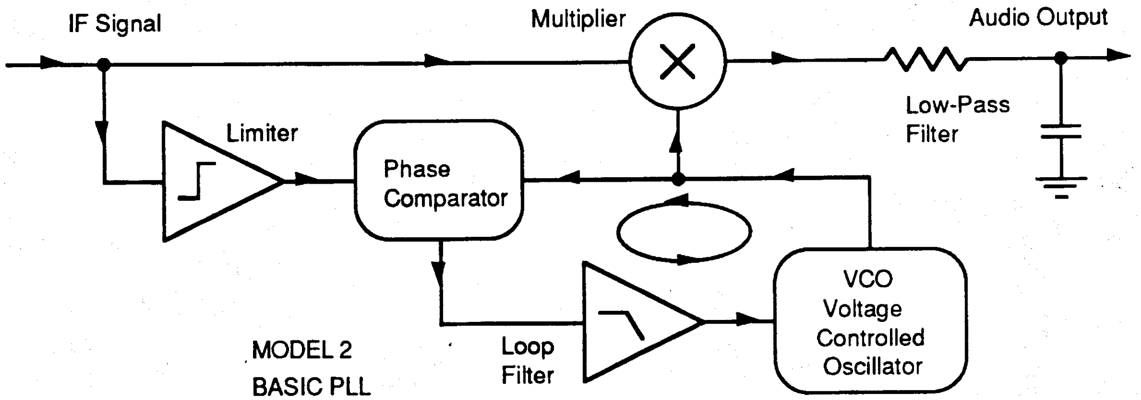
The basic building blocks of a synchrophase detector are the limiter and multiplier. The limiter is a high gain amplifier that removes the audio from the input signal, leaving only the carrier. The multiplier is the actual detector where the original waveform is multiplied (or detected) by the synchronizing signal (output of the limiter). The output of the multiplier is audio mixed with a high frequency component which the lowpass filter removes. It should be made clear that this type of detector is true synchronous detection. It models the mathematical definition perfectly, since the original waveform is multiplied by it's own carrier.

The main problem with this detector occurs during severe selective carrier fading or when the carrier fades into the noise. Under these conditions, there is insufficient carrier level and no amount of limiting will properly extract the carrier signal.

An improved synchrophase detector has been developed by KIWA Electronics. This detector is designed for low level signal detection and is a feature of the **Multiband Am Pickup** or **MAP**. The **MAP** uses a process of regenerative carrier feedback to improve the detector's performance during selective carrier fading or when the carrier is subjected to noise. In field tests with the NRD-525, the **MAP**'s detector was able to extract weak audio from DX signals where the original receiver's detector was only able to extract noise[6].

BASIC PHASE LOCKED LOOP

The next model is a basic phase locked loop design. As with the synchro-phase detector, there is a limiter to extract the original carrier, and a multiplier. The elements of the phase locked loop consist of the VCO-voltage controlled oscillator, the phase comparator, and the loop filter.



MODEL 2
BASIC PLL

How does it work? Notice how a circular path or loop is established between the phase comparator, loop filter and voltage controlled oscillator. The name "phase locked loop" describes the operation of this circular path. Basically, the phase comparator compares the original carrier with the output of the VCO. Any difference in phase (meaning frequency) creates a correction voltage that retunes the VCO accordingly. When the VCO is tuned to the original carrier, the PLL is said to be "locked". This process creates a second carrier signal that is identical to the original in frequency and phase and this new signal becomes the synchronizing signal for detection. It is important to point out that the PLL only generates the second carrier. Detection still takes place in the multiplier, as in the first example.

Why generate a second carrier? The original is often plagued by noise and a simple limiter as in Model 1 will not remove the noise adequately. The second carrier is for the most part noise free, which improves the detection process. In effect , it becomes a more accurate example of what the original carrier should be when reception is difficult.

Unfortunately the PLL has its limitations. The first is that it is dependent on the limiter for the carrier signal. If the carrier signal is plagued with severe noise, the limiter will also have noise which in turn confuses the tuning of the PLL. This can create a condition where the PLL will "unlock" creating a howl or a loud snap. The same situation can occur with co-channel interference. The second limitation is at the loop filter. The loop filter is a lowpass filter which is necessary to slow the tuning of the PLL. Without it, the PLL would try to retune with impulse noise. A properly designed loop filter will provide short term memory, holding the VCO's frequency and phase characteristics when subjected to interference from impulse noise or if the carrier level momentarily drops into the noise. The advantage of using a loop filter with memory becomes a disadvantage when one considers propagation. A shortwave signal seldom arrives at the antenna from the same direction. The changes in propagation means the carrier phase characteristics are changing from one instant to the next. If the PLL is slow to retune to these phase changes, it will create artificial fading. (This condition occurs when the carrier and VCO phase characteristics differ by 90° or 270°.) It is interesting to note that portables using the basic PLL detector with a short whip antenna would exhibit less of this problem than receivers with a similar detector and using a wire antenna that can effectively capture several signal wavefronts[2].

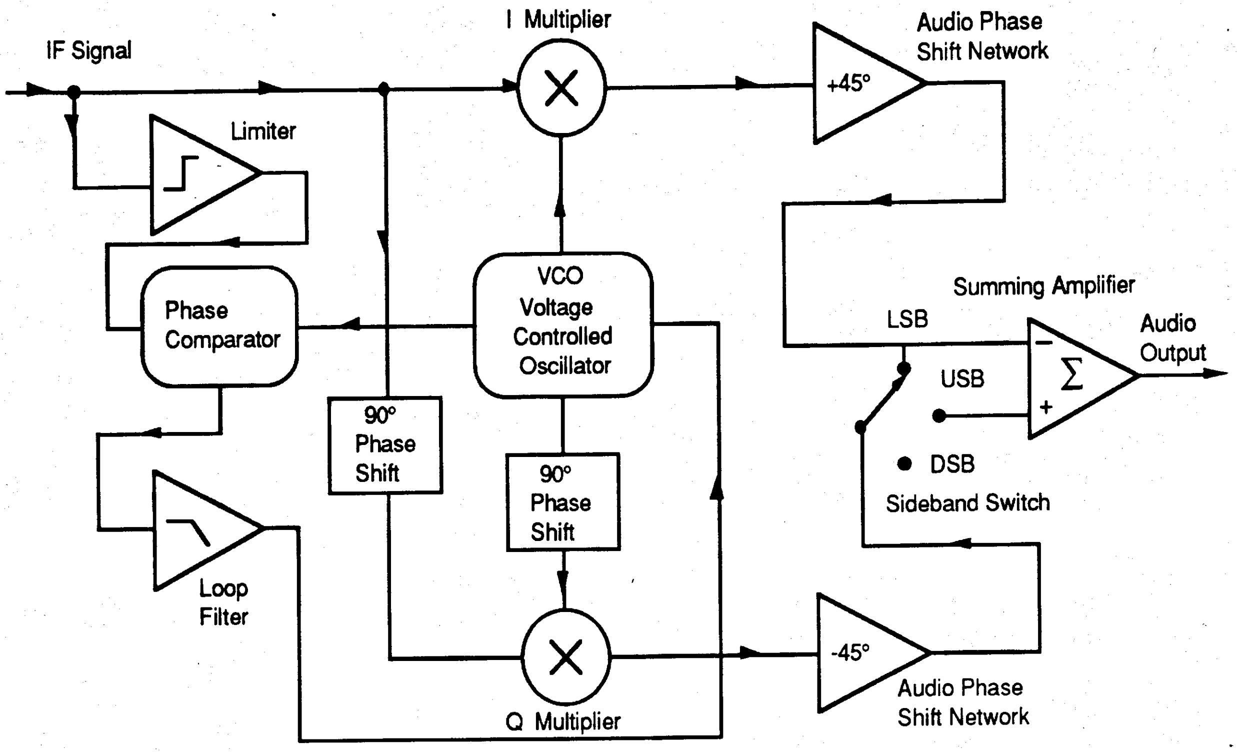
The advantage of using this type of PLL and for that matter the synchrophase detector, is that it is possible to offset tune the receiver. That is, the receiver can be tuned above or below the carrier frequency to favor one sideband. As long as the carrier is within the passband established by the IF filters, synchronous detection is possible. With proper choice of IF bandwidths, these basic detectors will allow synchronous detection of nearly the entire upper or lower sideband or somewhere in between. This has definite advantages to the DX'er, since the receiver can be tuned to the exact spot of least interference. Tuning to one sideband will reduce selective fading from the opposite sideband. The degree of isolation between the sidebands is determined by the IF filter response. Sharper filters (filters with good shape factors) will provide better isolation between the sidebands. The disadvantage of using this tuning scheme is that the audio frequency response suffers when the receiver is tuned off center frequency. This is the result of phase differences between the sidebands, established by the IF filters and combined in the detection process. On the other hand, it can also be an advantage since tuning off carrier will capture more of the higher sideband frequencies which may improve intelligibility - especially if these frequencies are in the 2.5 kHz to 3.2 kHz range. An example of a similar PLL appeared in last year's *Proceedings* [3] and other designs have appeared in magazines[4] and club publications.

SYNCHRONOUS DETECTION WITH AUTOMATIC SIDEBAND SELECTION

The next model is the most difficult to understand, but it is important to include it within this discussion because it is a PLL design that offers the ability to select either sideband. A similar design is used in the SONY ICF-2010 receiver.

Like the basic PLL, there are a few building blocks that are similar. First, there is a limiter to extract the original carrier. Second, there are the basic elements of a PLL (VCO, phase comparator, and loop filter). But notice there are two multipliers (detectors); one labeled I, the other Q. The I multiplier is the "In-phase" multiplier, meaning the synchronizing signal is "in-phase" with the original carrier. The Q multiplier is the "quadrature multiplier", meaning the synchronizing signal is "in-quadrature" or phase shifted 90° from the original carrier. This phase shift is established by the 90° phase shift network. It is important to note that the Q multiplier used in this detector has no relationship to the Q Multiplier used in receivers to enhance the selectivity of an IF circuit.

The output of the I multiplier is detected audio, in-phase with the original signal. The output of the Q multiplier is detected audio that exhibits a 90° phase shift difference. Both multiplier outputs enter all pass audio phase shift networks.



MODEL 3

PLL WITH SELECTABLE SIDEBANDS

In the example shown, the in-phase audio is phase shifted +45°, the Q audio is phase shifted -45°. The total phase shift difference between the I and Q signal paths now totals 180°. The established 180° phase difference between the two audio signals allows sideband selection when combined in a summing amplifier. As shown, the switch in the upper position will select the lower sideband - LSB. The USB - upper sideband is selected with the switch in the middle position. Both sidebands are present (DSB) when only the I audio is selected as shown when the switch is in the lower position.

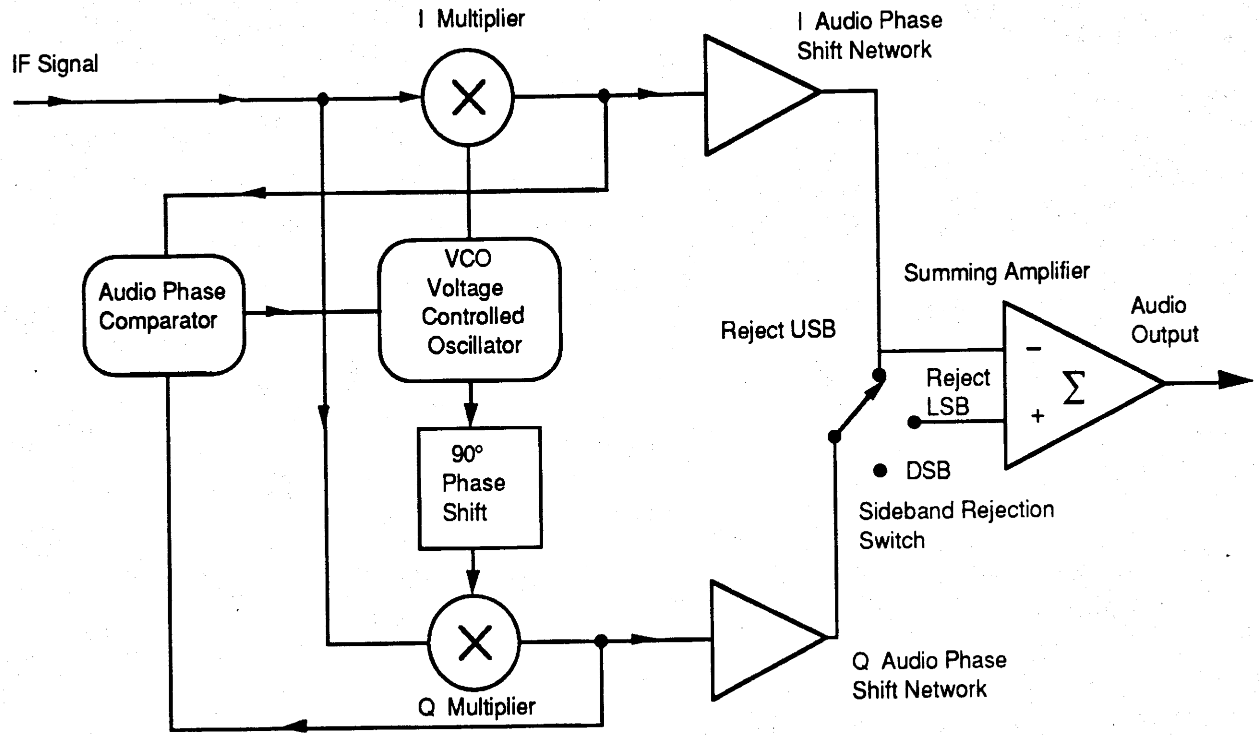
This is probably the easiest detector to use for general listening. It is very easy to flip to the other sideband if one is subjected to interference. However, it does not allow tuning to the spot of least interference if both sidebands are subjected to interference. Listening to one sideband will prevent selective fading from the opposite sideband. But it will not prevent selective fading from the sideband you are listening to.

The degree of isolation between the two sidebands is called "ultimate sideband rejection". The more isolation there is between the two sidebands results in less chance of hearing, for instance, interference from the upper sideband when you are listening to the lower sideband. Ultimate sideband rejection is mostly dependent upon the accuracy of the audio phase shift networks. Any phase shift other than 90° (between the upper and lower networks) degrades the ultimate sideband rejection. A design using high quality precision components can exhibit sideband rejection of more than 30 dB. Most manufacturers settle for less exact components resulting in sideband rejections that are less than optimum.

The other detector models can often exhibit better sideband rejection when they are used with offset tuning. Mediocre IF filters can reject signals outside their passband with more than 30 dB rejection. It should also be mentioned that the selectable sideband PLL detector does not exhibit the problems of "artificial fading" as with the basic PLL.

SYNCHRONOUS DETECTION WITHOUT THE CARRIER

This model has been included because it establishes a PLL synchronous detector without reference to the carrier (contrary to published information)[5]. The design uses a VCO that is tuned by the output of an audio phase comparator. When modulation is present, and the PLL is locked, the output of the Q multiplier will contain no audio. If the VCO is slightly mistuned, audio from the Q multiplier will be in-phase for one direction of VCO phase shift and will be the opposite polarity for the other direction. By combining the detected outputs in an audio phase comparator, it is possible to obtain a correction voltage that will tune the VCO accordingly.



MODEL 4
PLL WITHOUT CARRIER REFERENCE

This type of detector requires audio for the PLL to lock. Once audio is absent (the announcer stops talking), the PLL goes out of lock. Lock-up response time will be determined by how far the VCO is mistuned and by the response time of the audio phase comparator.

This detector offers advantages over other models that are referenced to the carrier. This is especially true during selective carrier fading. In fact, this model will perform with DSB signals that have suppressed or no carrier.

SUMMARY

These are just a few of the ways synchronous detection can be created. All of them are dependent upon extracting some element of information from the original signal for the detection process. This automatically imposes limitations as to how the detector will perform when subjected to different types of propagation, signal strength and interference.

What is the best detector? For general listening, the selectable sideband PLL detector is excellent. But for DXing, the PLL may not be the best choice. Their tendency to un-lock with weak signals makes them difficult if not impossible to use. A synchronous detector that only extracts the original carrier for detection will out perform the PLL under weak signal conditions.

The radio enthusiast should be aware of the various types of synchronous detection available, especially if planning to purchase a new receiver or any other device that offers synchronous detection. Remember, not all synchronous detectors are the same!

REFERENCES

[1] Harrison Klein, "AM Report Debates Reception Methods" Radio World, January 15, 1985.

[2] O.G. Villard Jr.,"Combatting Interference In Shortwave Reception With Compact Indoor Directive Antennas", WRTH 1990

[3] Dallas Lankford,"The AMSD-1 Synchronous Detector", Proceedings 1989

[4] Richard Factor,"Multimode IF System", Ham Radio, September 1971

[5] John P. Costas,"Synchronous Communications", IRE, August 1956

[6] DXpedition, Grayland State Park, Grayland WA. Grayland State Park was the site for a DXpedition and field tests (18 March 1990), because of its location at the Pacific Ocean and because it is relatively free from electrical interference. The receiving equipment included a Japan Radio NRD-525 and a **MAP**. The antenna was a 1200 ft (310°) beverage antenna, terminated at the ocean end. Radio station HLAZ (1566 kHz) Chenju, Korea was monitored up to 2 3/4 hours past local sunrise with the receiver alone and with the **MAP** installed. Audio from the **MAP** was consistently stronger than from the receiver. As the signal faded, audio was seldom heard from the receiver. But with the **MAP**, audio was present and was monitored up until the station faded into the noise. This observation was confirmed by several members of the DXpedition.