# THE AMSD-1 SYNCHRONOUS DETECTOR

## Dallas Lankford

The AMSD–1 is an AM synchronous product detector which was developed specifically for use with R–390A communications receivers by Richard V. Burnes (KE5GZ), head of Burnes Electronics, and me. At present the AMSD–1 exists only in several prototype forms, but a production model may be marketed later this year.

Before we consider circuit and performance details of the AMSD–1, it seems appropriate to give a simplified description of AM synchronous detectors. Almost all AM synchronous detectors use a collection of circuits called a phase locked loop (PLL). A PLL consists of a phase detector and a voltage controlled oscillator (VCO). A phase detector has two inputs, two signals of frequencies $f_c$ and $f_{osc}$, and one output, an error voltage $V_{err}$, which is proportional to the difference between $f_c$ and $f_{osc}$. For our purposes the phase detector input of frequency $f_c$ may be regarded as an AM signal carrier, say from the IF of a communications receiver. The other detector input of frequency $f_{osc}$ is obtained from the VCO output. A VCO has one input, a voltage which changes the VCO oscillator frequency $f_{osc}$, and one output, the oscillator signal. For PLL operation, a phase detector and VCO are connected together as follows. The VCO output is connected to one of the phase detector inputs. The phase detector output is connected to the VCO input. In other words, $V_{err}$ is both the phase detector output error voltage and the VCO input voltage. Thus, a feedback loop is formed between the phase detector and VCO which permits $f_c$ to control $f_{osc}$.

To illustrate how a PLL works with a communications receiver, let us suppose that the receiver IF center frequency is 455 KHz, the receiver bandwidth is 6 KHz, and the free running VCO frequency (with no error voltage applied) is $f_{osc} = 455$ KHz. As an AM signal is tuned by the receiver, the carrier enters the passband, say at $f_c = 452$ KHz, and an error voltage is produced by the phase detector. The error voltage causes the the VCO frequency $f_{osc}$ to vary around 455 KHz. For the sake of discussion, let us say that $f_{osc}$ varies from 453 to 457 KHz. Now suppose that the receiver is tuned again so that $f_c$ moves towards 455 KHz. At some frequency, the VCO will *lock* onto the AM carrier signal, say at 453.5 KHz. The difference between the free running VCO frequency and the frequency at which the VCO first locks onto the AM carrier is called the capture range, in this case 1.5 KHz. As the receiver is tuned so that $f_c$ increases in frequency, the AM carrier and VCO signal remain locked until they reach a frequency at which circuit parameters can no longer keep them locked, say at 457.25 KHz. If the receiver is tuned beyond that frequency, then $f_c$ and $f_{osc}$ *unlock*; the AM carrier frequency $f_c$ continues to increase and the VCO oscillator frequency $f_{osc}$ returns to varying between 453 and 457 KHz. The difference between the free running VCO frequency and the frequency at which the AM carrier signal and VCO signal unlock is called the lock range, in this case 2.25 KHz. If the AM signal is tuned in the opposite direction, entering the bandpass at 458 KHz and exiting the bandpass at 453 KHz, then we would observe similar, but not necessarily identical, values for capture and lock ranges. For example, when tuning from high to low we might find that the capture range is 2 KHz and the lock range is 1.75 KHz. These observations can be summarized by saying that the capture range is $-1.5$ or $+2$ KHz and the lock range is $-1.75$ or $+2.25$ KHz. To simplify terminology, we will define *the lock range* to be the minimum of the magnitudes of the positive and negative lock range values, and *the capture range* to be the minimum of the magnitudes of the positive and negative capture range values. Thus, for this example the capture range is 1.5 KHz and the lock range is 2 KHz.

Most AM synchronous detectors contain another circuit component, a product detector. The VCO output is also connected to the product detector where it functions as a BFO. The signal from the IF of the communications receiver is split into two paths. One path goes to the phase detector as discussed above. The second path goes to the product detector. If the receiver is tuned so that the VCO is locked onto the AM carrier, then the BFO (which is the VCO) is also locked onto the AM carrier. While the BFO (VCO) is locked onto the AM carrier, the BFO is identical in frequency and phase to the AM carrier, and nearly perfect AM detection takes place.

It is not possible to obtain AM synchronous detection for an extended period of time with a conventional receiver due to instabilities in the receiver high frequency oscillator(s), the BFO, and the received signal. Brief periods of AM synchronous detection can be obtained with a stable tube receiver, such as an R–390A, by turning on the BFO and carefully tuning to zero beat. At one and only one setting of the BFO or KCS tuning, you should hear an improvement in clarity and fidelity which usually lasts for at most a few seconds. What you heard was AM synchronous detection.

Many recent top of the line solid state receivers are not capable of AM synchronous detection because in SSB mode the BFO is fixed tuned, and the BFO frequency normally corresponds to about 20 dB down on the filter skirt. The term ECSS, an abbreviation for exalted carrier selectable (or single) sideband, is often used to describe tuning an AM signal using the SSB mode. However, this is quite different from AM synchronous detection because the BFO is not phase locked to the AM carrier when ECSS is used. Furthermore, in receivers with fixed tuned BFO's the AM carrier is usually attenuated about 20 dB by the receiver bandpass filter when ECSS is used. In that case ECSS does not describe the reception mode correctly because the AM carrier is not exalted, but rather attenuated.

An AM synchronous detector does not require a product detector. The essential ingredient in AM synchronous detection is a BFO which is phase locked to an AM carrier. An AM synchronous detector does not even require a phase detector and VCO. A wonderfully simple AM synchronous detector for most R–390A's was described by

Graham Maynard in *The Hollow State Newsletter*, No. 17, Fall 1987, with additional comments by me, and additional information in *HSN*'s **18** and **19**. Graham's AM synchronous detector is an injection locked oscillator (ILO). In breadboard form his ILO circuit uses two resistors and a trimmer capacitor. A little 455 KHz IF signal is stolen from the R–390A AGC IF amplifier, phase shifted by a low pass filter, and injected at the BFO oscillator tube grid. When the BFO frequency is within about 100 Hz of an AM carrier, it is phase locked to the AM carrier. Graham's first ILO circuit does not work with all R–390A's, in particular those with Collins BFO PTO's. If you have an R–390A with an IF strip which is not manufactured by Collins, then Graham's ILO is the least expensive way to experience AM synchronous detection.

There are several other ways to experience AM synchronous detection, including Sony's 2010 receiver, Sherwood Engineering's SE-3 PLL AM synchronous product detector, Kiwa's MAP unit, and ESKAB's PLAM board. It is beyond the scope of this article to compare these and other approaches to AM synchronous detection.

The AMSD–1 has a wide input dynamic range, from 300 microvolts to 3 volts. A graph in Figure 1 of the input signal level at the unbalanced antenna terminal of an R–390A versus the IF output level at the BNC connector on an R–390A rear panel shows that the R–390A IF output voltage ranges from about 10 to 110 millivolts, well within the AMSD–1 input dynamic range.

One feature of the AMSD–1 sets it apart from all the others. It has an extremely wide lock range as shown in Figure 2. The AMSD–1 capture range is virtually identical to the lock range, and so is not given. As can be seen from Figures 1 and 2, under normal operating conditions, the AMSD–1 lock range is about 120 KHz for all signal levels, even as the signal vanishes into the R–390A noise floor.

Most other AM synchronous detectors have narrow lock ranges, varying from about 100 Hz to as little as about 30 Hz, except for the Kiwa MAP unit which has a lock range of about 3 KHz. This means that in contrast to the others, you never hear the AMSD–1 lock and unlock during normal use. We have found only two ways to unlock the AMSD–1. One way is to use a signal generator to vary the input frequency and signal level widely, as was done to produce Figure 2. The other way is to reduce the RF gain control of the R–390A to near 0 which reduces the R–390A IF output signal level enough so that the AMSD–1 can unlock inside the R–390A bandpass. Because of the extremely wide capture and lock ranges, AMSD–1 operation is completely automatic . There is no BFO (VCO) tuning control or offset switch. The wide capture and lock ranges have one potential disadvantage. You cannot use the AMSD–1 to hunt for weak hets in the noise, a favorite trick which many of us use to locate potential DX, because it produces no hets during normal use.

The AMSD–1 can be adjusted for a wide range of input frequencies. In one AMSD–1 prototype, $C_0$ was a fixed 380 pF capacitor in parallel with a variable 100 pF capacitor (see the schematic in Figure 3), which permitted it to be set up for any IF frequency between about 445 KHz and 560 KHz. With different values for $C_0$, the AMSD–1 input frequency can be adjusted to any value from audio frequencies to about 5 MHz, and by changing a few other circuit values, the AMSD–1 input frequency can be extended to beyond 20 MHz. The audio output level of the AMSD–1 is about 60 millivolts maximum, which is suitable for the AUX or TUNER input of a hi-fi amplifier.

The audio quality produced by any AM synchronous detector depends on the audio amplifier and speaker with which it is used. During AMSD–1 development we tried several simple and inexpensive IC audio amplifiers, but we did not find any which approached the performance of even an inexpensive hi-fi amp, such as the $59.95 Radio Shack SA-150. One obviously does not include an inferior audio amplifier and speaker with a low distortion, hi-fi, AM synchronous detector. So we did not include an audio amp and speaker with the AMSD–1.

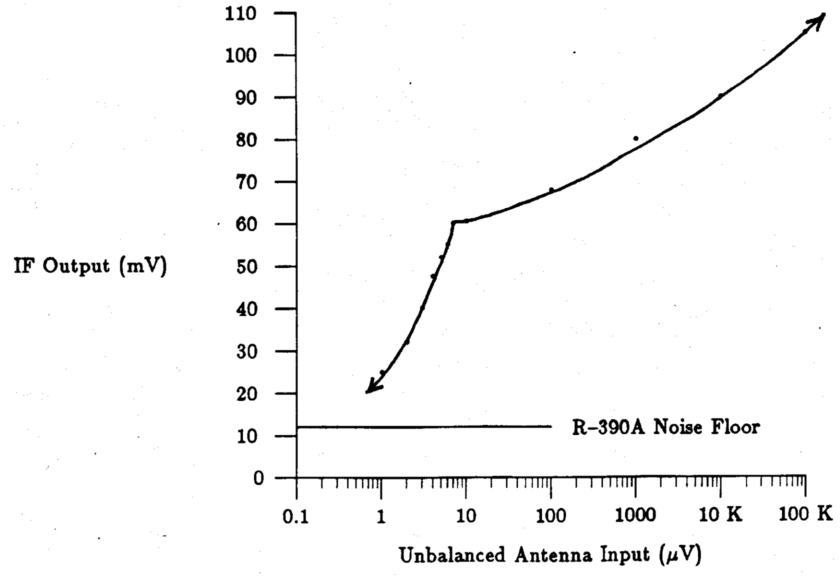


FIG. 1 R-390A UNBALANCED ANTENNA INPUT VERSUS IF OUTPUT

If time, complexity, development costs, and production costs were not considerations, we could have designed and developed a low distortion, hi-fi, audio amplifier as an integral part of the AMSD–1. But it is clearly more cost effective to use a separate hi-fi amp. This also permits the user to customize the audio amplifier and speaker parts of his AM synchronous detector system. In addition, it is easy to add an audio equalizer between the AMSD–1 audio output and the AUX or TUNER input of a hi-fi amp and preprocess the audio in whatever way one desires.

What are the theoretical advantages of an AM synchronous detector over a conventional diode detector? There is really only one. An AM synchronous detector virtually eliminates distortion which results from selective fading of an AM carrier. To understand how an AM synchronous detector sometimes improves the audio quality of fading AM signals, let us consider the three fundamental ways an AM signal fades: (1) the carrier and both sidebands fade by about the same amount, (2) one or both sidebands fade while the carrier remains relatively constant, and (3) the carrier fades while one or both sidebands remain relatively constant. In case (1) the audio level decreases, and the signal to noise ratio decreases. Audio quality cannot be improved in this case. In case (2) the audio level decreases. The signal to noise ratio also decreases, but the decrease is slight and may hardly be noticed. Audio quality cannot be improved in this case. In case (3) the audio is distorted, where the amount of distortion depends on the depth of the fade. Audio quality can be improved in this case. The faded carrier can be augmented or replaced by the VCO output of a PLL which is locked to the original carrier. It is tempting to say that an AM synchronous detector completely eliminates distortion which results from selective fading of an AM carrier. But it is possible that the carrier could fade completely in which case the VCO would not be phase locked to the carrier and some distortion could occur.

How much improvement in audio quality does an AM synchronous detector provide? The answer is subjective. Some will hear no improvement and conclude that the claims made for AM synchronous detectors are a lot of hype. Others will hear much improvement and praise AM synchronous detectors. However, most people will hear modest improvement and conclude that an AM synchronous detector is a luxury rather than a necessity. I am in this last category. The various opinions regarding the improvement provided by AM synchronous detection probably are not a consequence of performance differences among AM synchronous detectors, but rather individual responses to the amount of improvement in audio quality.

However, let me add the following. I am not a SWL, so I don't normally listen to strongly fading signals in the SW broadcast bands. An avid SW DXer may find that the modest amount of audio quality improvement results in significantly reduced listener fatigue after long hours of DXing. And I must say that the AMSD–1 connected to the IF output of my R–390A and driving a bottom of the line Radio Shack hi-fi amp with inexpensive speakers produced such good audio that for the first time I found myself DXing BCB splits without headphones. However, my wife complained about the loud QRM and QRN coming from the speakers in my radio room, so freedom from headphones is an AMSD–1 advantage that I can seldom enjoy. While testing the AMSD–1 with my inexpensive stereo amp, I was amazed at the fidelity of our local MW top 40 station, KRUS 1490 KHz. During the day with the R–390A tuned to 1497 KHz and using the 16 KHz mechanical filter, KRUS 1490 sounded like an FM station. At night adjacent channel QRM is stronger and audio quality is not nearly as good. The 16 KHz bandwidth is almost never useable for SW signals, but the 8 KHz bandwidth frequently provides near hi-fi SW reception.

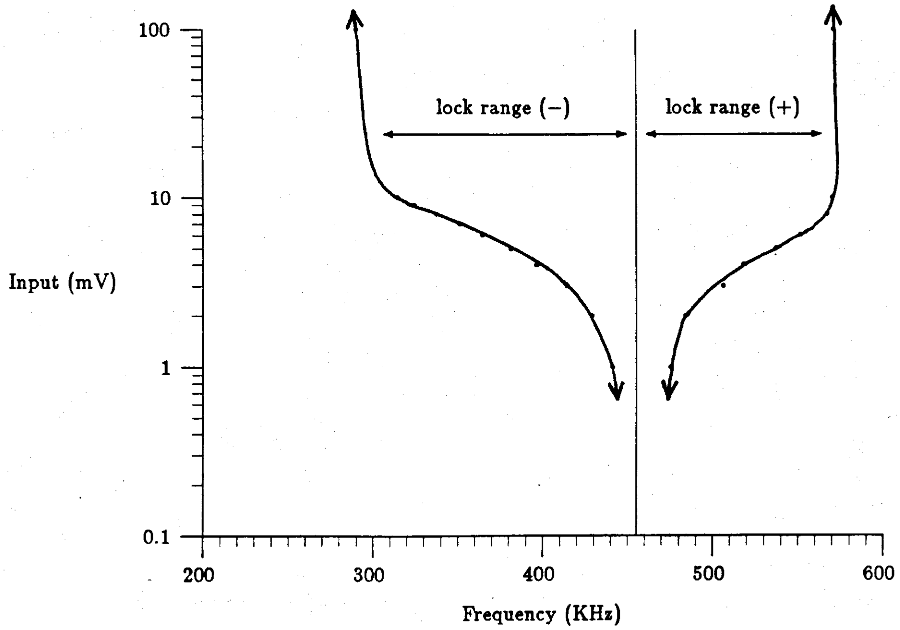
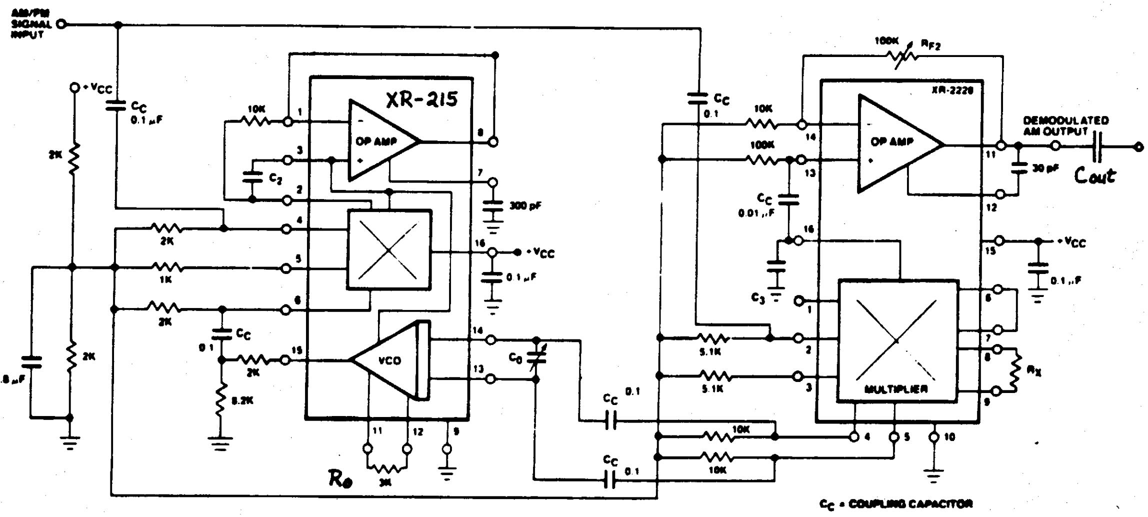


FIG. 2 AMSD-1 LOCK RANGE

After using both an ILO and an AMSD-1 for many hours, I have concluded that both improve the audio quality of most strongly fading AM signals by about the same amount (ignoring the superior audio produced by the hi-fi amp connected to the AMSD-1). But the amount of improvement is not as large as I had expected based on some articles about AM synchronous detection that I have read. With an R-390A the amount of improvement depends on AGC release time, with greatest improvement for fast AGC release and least improvement for slow AGC release. This suggests that some receivers, especially some recent solid state receivers which do not have suitable AGC release times, would have greater audio quality improvement than other receivers when used with an AM synchronous detector. Perhaps this explains much of the variability of opinions regarding AM synchronous detectors.

A schematic of the AMSD-1 is given in Figure 3. The AMSD-1 uses two EXAR integrated circuits, a XR-215 and XR-2228. The input signal is split into two paths. One path goes to pin 4 of the XR-215 chip which is the input of the phase detector. The other path goes to pin 2 of the XR-2228 chip which is the input of the product detector (designated as the multiplier on the schematic). The VCO output is applied both to the phase detector in the XR-215 chip and to the product detector in the XR-2228 chip at pins 4 and 5. The XR-215 chip contains an op amp which is not used. The output of the product detector in the XR-2228 chip goes through a low pass filter consisting of $C_3$ and a 5 K ohm resistor (the resistor is an internal part of the XR-215 chip, and is not shown). This low pass filter determines the audio bandwidth of the AMSD-1. The audio bandwidth can be made wider (up to 100 KHz) or narrower by changing the value of $C_3$ according to the formula in footnote 4 of the schematic notes. From the low pass filter, the audio goes to the op amp in the XR-2228 chip for audio amplification. $R_{F2}$ sets the gain of the op amp. Capacitor $C_{\text{out}}$ blocks DC from the audio output.

For information about the price and availability of the AMSD-1 you should write to Burnes Electronics, P. O. Box 906, Ruston, LA 71273, and include a SASE. Back issues of *The Hollow State Newsletter* are available for $1.25 each; send Chris Hansen a SASE for current prices and availability at P.O. Box 1226, New York, NY 10159.



$+V_{CC}$ — 10 to 20 VDC
$R_0$ — 4.7 K ohms[1]
$R_1$ — 4.7 K ohms
$R_x$ — 4.7 K ohms
$C_0$ — 470 pF at 455 KHz[2]
$C_1$ — 0.002 $\mu$F
$C_2$ — 100 pF[3]
$C_3$ — 0.002 $\mu$F[4]
$C_{\text{out}}$ — 4.7 $\mu$F non-polarized

**Notes:** The 5.1 K resistors at XR-2228 pins 2 and 3 were changed to 4.7 K. The 8.2 K resistor in the impedance matching network at XR-215 pin 15 was changed to 10 K.

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[1] $R_0$ and $C_0$ determine the lock range $\Delta f_l \approx 700{,}000/(\pi R_0 C_0)$ KHz, where $R_0$ is in K ohms and $C_0$ is in pF. $R_0 = 3$ K is shown on the schematic, but 4.7 K seems to give the widest lock range at 455 KHz based on experience with a prototype. $\Delta f_l = 100$ KHz for $R_0 = 4.7$ K and $C_0 = 470$ pF.

[2] $C_0 \approx 213{,}850/f_0$, where $C_0$ is in pF, $f_0$ is in KHz, and $f_0 < 5$ MHz.

[3] $C_2$ determines the capture range $\Delta f_c \approx \sqrt{\Delta f_L/(24\pi C_2)}$ MHz, where $C_2$ is in pF and $\Delta f_l$ is in KHz. The formula predicts $\Delta f_c = 115$ KHz for $\Delta f_l = 100$ KHz and $C_2 = 100$ pF.

[4] $C_3$ is part of an RC low pass filter which determines AM audio bandwidth. The internal resistance at pin 16 of the XR-2228 is 5 K ohms. For $C_3 = 0.002\mu$F the cutoff frequency is about 16 KHz. The low pass filter bandwidth was determined from the cutoff frequency formula $f = 1/(2\pi RC)$ Hz, where $R$ is in ohms and $C$ is in farads.

FIG. 3 AMSD-1 SCHEMATIC