A Synchronous Detector for AM Transmissions - Revisited

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I have been interested synchronous detector circuits for many years and have looked at several circuits. This circuit appears to be the simplest one to construct.

This article was originally published in the 1973 issue of the ARRL handbook. I have made some changes due some components becoming "unobtanium". For space considerations I have deleted the Sagen receiver modification references. The schematics have been re-done with photoshop elements into 8BIT TIFF images so they can be electronically enlarged without smearing. The original text layout in QST was quite jumbled with text box inserts. I have tried to simplify this.

I have tried to make any distinction from the original article and my additions or opinions very clear.

This project is not a "weekender"; it will require parts matching, a tedious tuning set-up, and may require additional shielding depending upon layout. Also the amplitude from the IF is very important. This should be considered a somewhat advanced project.

A "sync" detector far outshines diode detection for good amplitude modulation reception. Here's one you can build and all you need to align it is a digital voltmeter.

Do you relax or "keep up on the news," or by listening to shortwave or long distance medium wave broadcasts? Are you frustrated by raucous distortion during fading minimums? This article describes how to build one solution to this problem: a simple, effective. 455-kHz synchronous detector for your transceiver or receiver. As a bonus, it adds basic CW/SSB reception to receivers unequipped to receive these signals.

Much like switching your receiver or transceiver to SSB and receiving AM as SSB its carrier at zero beat. Synchronous detection overcomes fading-related distortion by supplying an unfading carrier at the receiver. The difference between synchronous AM detection and such simple product detection is that synchronous detection *phase locks* its carrier to that of the incoming signal. There's no tuning error if the received signal happens to fall between your radio's tuning steps and you don't have to correct for modest tuning drift. The result is a dramatic fidelity improvement over diode-detected AM. Enjoyable music audio is recoverable even from reduced-carrier SSB broadcasts.

This Synchronous Detector Circuit Affords:

- No signal to-noise threshold. The incoming signal's IF signal to noise ratio is converted to audio as is something not true of envelope and quasi-synchronous detectors.
- Suppression of over-modulation distortion during carrier fades because the strength of the 10caBy generated BFO remains constant.
- Quality music reproduction with reduced-carrier SSB signals,
- Averaging effect against adjacent channel splash. Partly by suppressing it in detection.
- Rejection of phase noise from transmitter and receiver synthesizers.
- Rejection during reception of reduced-carrier SSB, of phase-modulated second-harmonic distortion and intermodulation-distortion products. Therefore giving less distortion in detected audio than simple product detection,

- Rejection of spurious PM sidebands generated in conventional AM transmitters due to improper neutralization or antenna matching.

- Low harmonic distortion (below 1%) in audio recovery, independent of IF level.

- Low AGC-controlled IF input level, therefore needing less pre-IF amplification.

The Synchronous Detector Circuit

See Fig 1. The unit uses popular NE602AN (mixer/oscillator) and NE 604AN (FM, sub-system) ICs to provide both synchronous and quasi-synchronous detection[1]. Operating at a supply voltage of 6, the circuit draws 10 mA, **U1**, a NE602AN, acts as the **BFO** and product detector necessary for synchronous detection.

Feeding **U1's** balanced inputs in push-pull helps keep **BFO** energy from hacking out of the input pins and into **U3's** limiting circuitry. To take advantage of the chip's internal biasing, the input transformer (T1) is isolated with de blocking capacitors. (**U1** also supplies balanced audio output, but usefully reducing this to a single ended output would have required an operational amplifier. Doing so would reduce even-harmonic distortion in recovered audio. But would not, I decided, justify the increased circuit complexity and power consumption.) ***Note***: This single ended circuit was added to this revision,

U1's oscillator amplitude is optimized to 660 m V P- P (as measured across **L1**) by the 220 Ω resistor at the oscillator output at pin 7. The BFO frequency is adjusted by two variable-capacitance diodes (D1 and D2) in addition to the tank coil **L1**.

D2 receives its control voltage via switch S3 (**BFO MODE**), which selects control voltage from either **U3's** phase detector (**SYNC**) or a constant voltage from a resistive divider (**CW/SSB/TUNE**),

The fixed **CW/SSB/TUNE** voltage 2.16 V, (set by the ratio of R5 and R6) corresponds to the phase detector's optimum output voltage at lock[2].

R2, **BFO TUNING**, drives **D1** to provide manual detector tuning without upsetting **D2's** control-voltage optimization.

S2, **BFO OFFSET**, presets R2's tuning range into the optimum regions for **LSB (-2 KHz**), DSB AM (**±0 kHz**) and **USB** (+2 KHz).[3]

The **BFO TUNING** control therefore provides fine adjustment for detector lock around the receiver's tuning steps (coarse - 1 **KHz -** in my receiver).

U3's phase detector requires a 90^{o} phase shift between the incoming and reference phases to give the correct zero-phase output (again, approximately 2.16 V). The all-pass stage **Q1** operates as an isolation stage and adjustable phase shitter to generate the 90^{o} phase shift.

U3 is a NE 604N FM IF subsystem IC that contains limiting-amplifier stages (total gain, 101 dB) and a quadrature detector. Band limiting can be inserted between the limiter stages, but experiments with various RC and LC filters brought no improvement and instead led to increased delay that upset the carrier sideband phase relationships necessary for good quasi-synchronous detection. The Fig 1 circuit uses **U3's** quadrature detector as a phase detector that outputs control voltage for **D2**.

The most difficult aspect of the phase locking chain is the selection of a time constant for the locking loop. Signal fading, and the relative absence or presence of phase-modulation components in the transmitted signal, play important roles in detector lock.

Were fading not a problem, a short time constant-one allowing fast locking would suffice for DSB AM.

For **SSB AM** with carrier (which includes a phase-modulation component at all modulation frequencies), however, and **DSB AM** with fading (during which a fast PLL may unlock on the sudden phase shifts that can accompany fast, deep carrier fades), a long rime constant is necessary, Particularly for SSB with carrier, the loop bandwidth must be reduced to below the lowest expected modulation frequency, **C1** and **R4** set the PLL time constant in the Fig 1 circuit.

The received signal strength indicator (RSSI) output at pin **5** of **U3** follows the input level logarithmically, giving an output of 1.1 V on noise only (**RF INPUT** shorted in Fig 1) and 3.3 V at a **RF INPUT** level of 3 mV.

The **RSSI** output is adaptable as an AGC-detector output, making the NE 604AN attractive for simple **IF AGC** designs. Because of the NE 604AN's high gain circuit layout can be critical, requiring short leads and physically small bypass capacitors.

Coupling must be minimized between pin 9 of **U3** and the **U1** oscillator components. **U2**, a NE602AN, operates as a quasi-synchronous detector. The BFO energy it requires is readily available as a square wave at pin 9 of **U3**. Except for the fact that its BFO input is derived from a limited input signal instead of a VCO, **U2** functions the same way as **U1**.

Construction

Two evaluation models were constructed using ground-plane construction, mounting the ICs upside down and soldering their ground pins directly to ground with minimal lead length. The later version is constructed onto a long narrow piece of circuit board intended to be the bottom plate of an add-on box to be fixed under a Sangean ATS-80S receiver. (Fig 2 shows the general layout of this version,)

To avoid crosstalk, I made the receiver detector IF-AF connections with small diameter coaxial cable. With these precautions and circuitry arranged as shown in Fig 2, **BFO** signal leakage is unmeasurable at U3; that is the voltage at **RSSI** does not change when the BFO is temporarily disabled under no signal conditions.

Connecting the detector cable detunes T9, which though difficult to reach, must be re-tuned by turning its slug outwards a few turns to obtain maximum audio output. *(Ed Note: The coil maybe easier to tune using substitutes currently available.)*

IF pick-off locations will very among receivers but the original circuit a 56pF input capacitor

The detectors audio output was then returned to the author’s receiver.

Operation

After checking the circuit, connect it to a 6V power supply. The total current consumption should be approximately10 mA.

Switch the **DETECTOR** switch to **ENVELOPE**; you should hear band noise. Tune in a strong **AM** signal, switch **S3**, **BFO MODE** to **SSB/CW/TUNE**, and set the **DETECTOR** switch to **SYNC**. The detector may sound very quiet at this point.

Adjust L1's core until you hear the signal you were listening to in **ENVELOPE** mode swoop into audibility. Now you know that the **BFO** is oscillating. If possible, measure the **BFO** level across **L1** with an oscilloscope and 10:1 probe; it should be about 660 mV. (If you can't measure the BFO level, go to the next paragraph.) If it's not experiment with **R3's** value to make it so.

Accurately tune the receiver to a strong, pure carrier such as a beacon. Adjust **R2, BFO TUNING**, for a wiper voltage of 2.00 with **S2** BFO **OFFSET** set to **± 0 kHz**.

Mark as **CENTER** this point in its knob's travel.

With the **BFO MODE** switch in the **SSB/CW/ TUNING** position, use a non-metallic tool to adjust L1, the VCO coil for zero beat with the incoming carrier.

Returning **S3** to the **SYNC** position should allow carrier lock if **R1**, **SHIFT ADJ**, is reasonably near adjustment.

Adjust **SHIFT ADJ** for carrier lock if necessary. This completes coarse adjustment of **SHIFT ADJ**.

Return the **BFO MODE** switch to the **SSB/CW/TUNING** position; the BFO should still be at or very close to zero beat with the incoming signal.

Return the **BFO MODE** switch ta the **SYNC** position. After the detector locks, Fine tune **SHIFT ADJ** to minimize detected low frequency hiss.

(If it sufficiently strong unmodulated local signal is not available off air, transmit into a dummy antenna with a PLL-synthesized transceiver and make this adjustment by listening to its signal. You should find a **SHIFT ADJ** setting at which detected hiss distinctly nulls. As a less desirable alternative tune to an unfading **AM** signal modulated with a 1 kHz tone and adjust **SHIFT ADJ** for maximum tone recovery.)

Once this is done, the detector's carrier phase is exactly 0° or 180° of the BFO signal applied to the amplitude detector (U1), and you have minimized the detector's response to phase noise. Significantly, this alignment procedure also sets the detector to lock in a range centered on the control voltage that corresponds to optimum locking sensitivity and minimum phase noise demodulation. That's, it-you're ready to listen.

To zero-beat and lock on a given station: Set the **BFO TUNING** control to its center (2.00 V) position. **BFO MODE** switch to **CW/ SSB/TUNE** and **BFO OFFSET** to match the sideband(s) LSB, USB or both-you want to receive.

Tune your receiver as close to zero beat as its tuning steps allow, adjust **BFO TUNING** for zero beat.

Switch the **BFO MODE** switch to **SYNC** to lock the detector. Toggling S1, **DETECTOR** between **ENVELOPE** and **SYNC** allows you to easily compare the effects of detection mode under adverse propagation conditions.

You'll find the synchronous mode to be considerably superior much of the time. The semi-synchronous **(ENVELOPE)** mode may give crisper audio under average or poor signal conditions; this effect may be due to increasing distortion as the signal approaches the noise floor, however.

The sound picture compared to the original A TS-808 detector in addition to level difference is slightly different, probably as a result of the "loudness" band limiting in the original circuit prior to the selection switch. The audio may be processed to individual taste.

Properly adjusted, the synchronous detector operates at less than 1 % total harmonic distortion. (The quasi-synchronous detector provides comparable performance-but only on a nonfading test signal.)

Measurements confirm the importance of setting **R1**, **SHIFT ADJ**, properly: improper adjustment can increase low-order harmonic-distortion products detected from possible phase modulation sideband components and allow the detection of phase noise,

Conclusion

The synchronous detector I've presented opens new possibilities for simple receiver design by requiring as little as 3 mV of IF output for proper operation. This means that 30 dB less pre-detector gain is required compared to traditional designs. Outfitted with this detector my Sangean ATS-808 receiver can now receive CW and SSB signals. Although the '808 AGC decay time is too short for enjoyable SSB listening.[4] A simple synchronous detector therefore may be the best solution for a compatible, multimode detector.

I hope that you'll put this circuit to work with *your* receiver, perhaps modifying it for use 1t another intermediate frequency. I look forward to hearing of your results,

Notes:

1. This article refers to U1 and U2 as NE602ANs, but NE602Ns, 5A602Ns and SA602ANs will work equally well in this application. Likewise, an NE604N, NE604AN, SA604N or SA604AN will work well at U3 in this application,

2. The resistances given for R5 and R6 set this value only with a 6 volt supply. If a different supply is used (The NE602s and NE604 can be operated at up to 8 V), change R5's value to return the **SSB/CW/TUNE** voltage to 2.16.

This 2.16 V value should itself be considered only as an average for the NE604; the optimum value can be found by using a DVM to measure the voltage across **C1** when the receiver is tuned to an empty channel. This optimization is important because manually tuning with **BFO MODE** set to **SSB/CW/TUNE** zero beats the incoming signal at this control voltage.

When **BFO MODE** is then switched to **SYNC**, the detector's VCO idling frequency is therefore still almost correct, and easiest locking is guaranteed.

3. Whether this correspondence between LSB and USB and S2's -2 kHz and +-2 kHz positions holds with receivers other than the author's Sangean ATS-80B depends on whether the radio in question inverts SSB signals in moving them to 455 kHz. At the ATS-808's 455 KHz IF, SSB signals are reversed relative to their on-air sense (USB becomes LSB, and vice versa).

For radios in which SSB signals are not inverted at 455 kHz, S2's (-) position will correspond to USB, (+) to LSB. During selectable-sideband synchronous reception with communication-quality radios using tighter SSB filtering than that afforded by ATS-808's narrow filter, BFO offsets on the order of $\pm$1.5 KHz will likely be required for optimum carrier lock and tonal balance in recovered audio.-ARRL Ed.

4. Proper adjustment of the **SHIFT ADJ** trimmer minimizes the detector's sensitivity to phase noise, but only when the detector is phase locked. Thus, this phase-noise rejection doesn't apply when the detector is operated in its fix-tuned, unlocked **(CW/SSB/TUNE)** mode.

With the A TS-808, receiving strong CW signals therefore includes the addition of keyed noise-the '808's synthesizer phase noise transferred to the CW note. This illustrates how non-synchronous product detection reveals the true quality at a communication system's various oscillators -and sets stringent quality requirements for their design and performance.

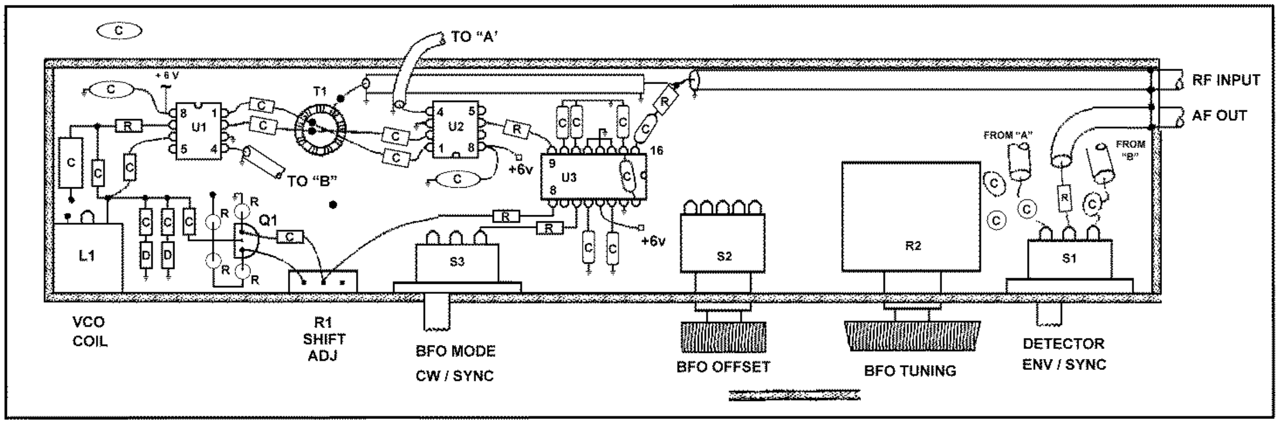


FIG 2 - ONE RECOMMENDED LAYOUT FOR THE SYNCHRONOUS DETEECTOR THAT WAS USED BY THE AUTHOR TO MATCH THE FOOTPRINT OF HIS ATS - 808 MULTI-BAND RECEIVER. U3'S HIGH GAIN REQUIRES CARE IN CONSTRUCTION - SEE TEXT.

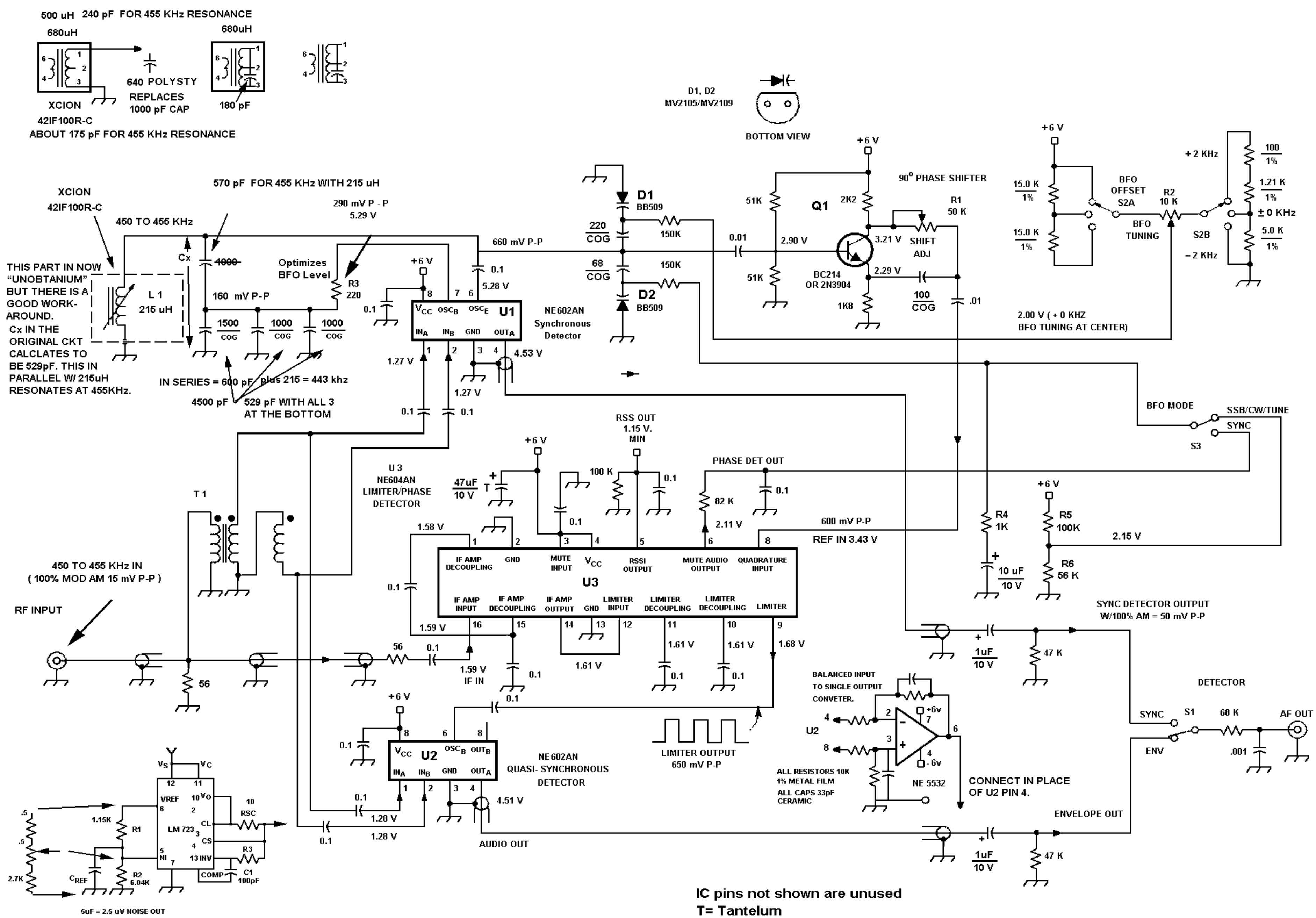
Quasi-Synchronous Detection

Synchronous detection can be mimicked by amplifying and limiting the AM signal sufficiently (at IF) so that only carrier remains, and, substituting this signal for the BFO at the product detector. This *quasi-synchronous detection* acts much like envelope ("diode") detection and works best when the received signal does not fall to zero, as can often occur with SSB and, with AM, during fading,

As the signal fades and the carrier-to-noise (C/N) ratio decreases, noise renders the detector's switching action inconsistent, and detection quality deteriorates rapidly, Thus, under conditions of low C/N ratio, quasi-synchronous detection exhibits a distinct detection threshold, as does a diode detector.

The chief advantage of quasi-synchronous detection over simple diode rectification Is Its much lower input level compared to that required by a diode. The detector circuit I present in this article includes a *quasi-synchronous detector* for flexibility and NB comparison with the synchronous circuit.-OH2GF

Next page. Fig 1- The OH2GF synchronous detector operates In the 450- to 455-kHz region. Except as otherwise specified, its fixed value resistors are 1% .5w metal film units, and its capacitors' working voltages can be 10 or higher.



IC pins not shown are unused
T= Tantelum
● = Phasing

Parts and the editors' parts opinion

1. Use only through hole parts to save your sanity.

2. To increase stability use 1/2 W 1% metal film resistors.

3. In the tuning resistor network you may be able to select resistors for matching rather than absolute values.

4. Consider using small low ohmic value cermet multi-turn trim pots to make the tuning resistors exactly to spec. Dan's Small Parts often has them at very reasonable prices as well as several choices in value.

5. One should use a simple LM 723 regulator trimmed to 6.0 volts as it is a buried-zener type with very low noise. Use 1% metal film resistors to set the voltage value as they have less noise. It needs to be low noise and very stable. The formula for the resistors is given in the LM 723 data sheet. I've added a circuit to the detector circuit schematic. The negative 6 volts for the opamp can be supplied by 79Lxx regulator.

6. Dan's Small Parts has such good deals on tuning diodes it may be economical to buy enough so you can get a close match. Dan's also is a good source for high quality ceramic and bypass capacitors cheap!

7. The IC's are all available in DIP packages although you might have to go to a China supplier to get them. (But they are very reasonable.)

8. Consider using 10 or 20 turn cermet trimmer pots for the adjustment pots.

9. Try to use polystyrene capacitors in all of the tuning circuits as they have the best stability at the lowest cost. Avoid using ceramics caps in the tuning circuits. Mica caps are great but very pricy.

D1, D2-BB809 or BB409 tuning diode. Each of these, a "28-V" diode, exhibits approximately 33 pF at 2 V and an unusually high voltage-versus capacitance slope of 10.

WJ1Z has used two paralleled 30-V Motorola tuning diodes (one MV2109 -45 pF at 2 VI and one MV21051-18 pF at 2 VI, both with a slope of 3) to replace each 88809 or 88409 in this application:MV2105 and MV21 09

Obtaining a L1 substitute.

The original part had approximately 215 uH inductance. (A Toko RWRS T1019Z.)

L1 is now "unobtanium". There are however four viable choices for replacement. Two from XCION, one from Dan's Small Parts and the fourth is using a fixed Bourns/J.W. Miller shielded inductor.

The best choice in my opinion, is to use the Xcion IF transformer P/N 42IF100-RC. It is a bit deceiving at first glance as it is spec'd at 796 KHz. But further reading shows an inductance of 360µH @ 455 KHz between pins 1and 3. Also it has no resonating capacitor inside. The original inductor was 215µH. The four capacitor network across the coil calculates close to 529 pF. This combination resonates at 455 KHz.

Replacing L1 with the 42IF100-RC pins 1 and 3 means we need to change the value of the original 1000pF capacitor. Using some calculating formulas on the internet I came up with the following values. With and inductance of 360 µH's we need 569 pF for 455 KHz resonance.

Now we have to deal with the four capacitor network to achieve the 569 pF equivalency. So back to the calculator on the net. So 4500 pF in series with 640 pF equals 567 pF.

Now that leaves us with two problems. First, is our capacitor network truly 4,500 pF and secondly 640 pF is not a standard value. So what to do?

I think the least expensive method is to buy XCION polystyrene capacitors from Mouser at about 30 cents each and make parallel combinations to get the values needed. They are rated at 5% of value and are extremely stable. Their only problem is they are limited to a 50 volt rating. One should avoid ceramics because of their temperature co-efficients.

The same previous process applies to the next series of IF transformers except they have a 180 pF capacitor in parallel with the high impendence side.

Dan's Small Parts has almost the exact equivalent of L1 at this time. But you have to buy a package of coils.

Parts List – mostly complete

C	**Value**	R	**Value**			
1		1	50K 10 Turn		L1	XCION 42F100R-C
2	Varies	1	10K Lin Pot			
3	1500	1	100R		T1	See Text
4	1000	1	220*			
5	1000					
16	0.1					
3	.01	1	1K		D1, D2	BB509
1	.001	1	1K8			
	220 pF	1	1.21 K			MV2105
	68 pF					MV2109
	100 pF	1	5.0K			
		1	2K2			
	47/10				Q1	2N3904 or BC214
	10/10					
	1/10				U1, U2	NE 602AN
	1/10	2	47K			
					U3	NE604AN
		2	51K			
		1	68K		U4	NE 5532
		1	82K			
		1	56K	1		LM 723
		2	100K			
		2	150K	1	S1	2 POL 3POS
		2	150K*			
				2		2PST
				1	S3	SPDT

R1-50 K trimmer.

R2- 10 K linear control.

T1-13 trifilar turns of #28 enameled wire twisted, on an FT-37-77 toroidal ferrite core.

U1, U2- Slgnetics NE602N, NE602AN, SA602N, SA602AN mixer/oscillator IC.

U3- Signelics NE604N, NE604AN, SA604N or SA604AN FM receiver subsystem IC.

Non- Phasing Synchronous Detection: The Better Way?

Amateur Radio transceivers generally select USB or LSB through intermediate-frequency (IF) filtering. Most consumer multiband radios with synchronous AM detectors use phasing synchronous detection in which audio frequency (AF) and IF phasing are used to select the upper or lower signal sideband.* Such a system requires two synchronous detectors. One that responds to amplitude and another that responds to phase.

The phasing approach has two serious drawbacks. First, even though phasing detection can attenuate opposite-sideband *audio*, it cannot prevent opposite-sideband RF from driving IF-derived automatic gain control (AGC) circuitry and affecting receiver gain.

The second drawback is that a phasing synchronous detector detects the phase noise sidebands of transmitted carriers and its receiver's local oscillator (LO) and converts them to audio. (The system's amplitude detector demodulates AM and no phase noise; the system's phase detector demodulates phase noise and quadrature AM. Demodulated phase noise is therefore present in their summed output)

This problem is not trivial. International shortwave broadcasters are working on moving from full-carrier double sideband (DSB) to reduced-carrier SSB transmission by sometime next century. Receivers with the simple diode detectors long established for AM reception, reduced-carrier SSB may be unacceptably distorted.**

Synchronous detection would seem to solve this, but synchronous detection requires greater receiver stability and tuning accuracy than has ever been necessary with diode detection. PLL synthesis, now used in consumer shortwave receivers even in the US $100 to $200 range, is arguably the best means of achieving these aims economically. But PLL synthesizers economical enough for this service are generally so phase-noisy that they compromise phasing synchronous detection when it is applied. Despite this, most of the radios currently available with consumer multiband radios with synchronous AM detectors use phasing detectors!

Seeking to add a synchronous detector to my Sangean ATS-808 receiver, I therefore decided that a simple basic model-one that uses the receivers IF filtering to reject the unwanted sideband-would give better overall quality.

Whether the marketplace will arrive at the same conclusion remains to be seen!-QH2GF.

* It follows, of course, that when only one sideband is transmitted, there's, no opposite sideband to reject. Even If no other stations are using the frequencies represented by the absent sideband, opposite-sideband rejection is entirely worthwhile because it keeps us from receiving the band noise and static present In that slice of spectrum. When both sidebands are present the ability to receive either of them at will let us choose whichever of the two is least troubled by interference.-*ARRL Ed*.

** For a nonsynchronous, high-dynamic--range system embodying these principles, see R. Campbell, "High-Performance. Single~ Signal Direct-Conversion Receivers,", QST, Jan 1993. pp 32.40.

*** The severity of the distortion depends on how much the carrier is reduced relative to its full-carrier value. Broadcasters intend to use SSB-(but) SSB with carrier enough for synchronous detection, but considerably less than that necessary for useful envelope detection. In practice. envelope-detected SSB sounds like suppressed-carrier SSB received with the BFO turned off.-*ARRL Ed*.