Extracting Stable Clock Signals From AM Broadcast Carriers for Amateur Spread-Spectrum Applications

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This circuit provides jitter-free clock pulses by locking onto a readily available external reference signal source. Although it was designed primarily to provide clock pulses for Amateur Radio spread-spectrum transmissions, this circuit can also be used as a stable reference for frequency-calibration purposes.

Introduction

To recover data from spread-spectrum transmissions, it is necessary to reintroduce, at the receiver end, locally generated signals locked in frequency and phase to the clock used in the original transmissions. At carrier frequencies of up to 50 MHz, the extraction of clock pulses from direct-sequence (DS) spread-spectrum transmissions can be achieved fairly easily, using readily available ICs.[1] The 1986 FCC decision to relegate Amateur Radio spread-spectrum transmissions to frequencies above 400 MHz, however, singularly complicated the design and realization of this type of equipment.[2] Although it will be eventually possible to find a way to extract the clock signal at those frequencies, it is a major stumbling block to the development of uncomplicated amateur spread-spectrum equipment.

Another way to obtain a clock is to use an external reference signal readily available at both the transmitting and the receiving sites.[3] Since our amateur transmissions must take place at UHF, communications will usually occur when the two parties are within a fairly short distance of each other. Locally available reference signals are generated by TV, FM and AM radio stations. I have already explored the recovery of such signals, and have demonstrated the possibility of using vertical synchronization signals from local TV stations to generate reliable clock pulses for slow frequency-hopping spread-spectrum experiments.[4]

DS spread-spectrum on the other hand, requires that clock signals be in the megahertz region.[5,6] In DS, the clock drives a pseudorandom generator, which is modulo-2 added to the carrier, to vary the phase of the UHF carrier by 180 degrees. The carrier is cancelled and replaced by the familiar $[\sin x/x]^2$ spectrum (Fig 1). The ratio of F_c/F_k, where F_c is the RF carrier frequency (in our case $F_c > 400$ MHz), and F_k is the clock, is important. If F_k is low, the ratio is too high, and spreading of the signal does not take place. If F_k is too high, the RF signal is spread over too wide a bandwidth, and the spectrum used exceeds the limits of our amateur bands. In practice, for F_c = 440 MHz, an F_k between 500 kHz and 2 MHz appears reasonable. (In Fig 1, F_c = 146 MHz and F_k = 1 MHz. Nulls are clearly visible at $F_c \pm F_k$, $2F_k$, and so on, ie, 144, 145, 147, and 148 MHz. This experiment was conducted in a test load, and at power levels lower than 0 dBm.)

[1]Notes appear on page 9.

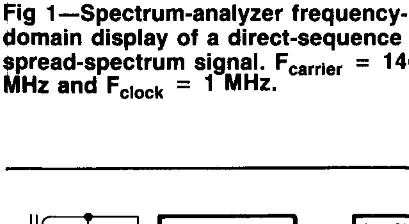


Fig 1—Spectrum-analyzer frequency-domain display of a direct-sequence spread-spectrum signal. $F_{carrier}$ = 146 MHz and F_{clock} = 1 MHz.

Problems

There are many ways to generate clock signals. You could lock onto a TV station's video AM carrier, and divide down to obtain the required clock. The division process, however, introduces an ambiguity that has to be resolved at the receiving end, thus further complicating receiver design.

You can also extract horizontal TV sync pulses (at 15,750 Hz) and multiply that signal by 100 for a clock at 1.575 MHz. The problem here is that the multiplication process (using, for example, a 4046 phase-locked loop oscillating at 1.575 MHz and two cascaded 4017 divide-by-ten stages between the oscillator and the phase comparator) also multiplies the original jitter by 100! Some jitter is always present on the H sync pulse, and a jitter of 10 ns (10 ns = 0.01 μs), perfectly negligible at 15 kHz, becomes 1 μs at 1.5 MHz. This is clearly an unacceptable solution since the period of a 1.5-MHz signal is only 0.66 μs!

I followed a similar approach using the 19-kHz stereo subcarrier available from all FM stereo stations. Here again, jitter (principally because of incidental amplitude modulation and lack of operating-point stability in simple zero-crossing detectors) does not allow for a reasonably stable signal once the 19-kHz signal is multiplied by 100 to yield a 1.9-MHz clock.

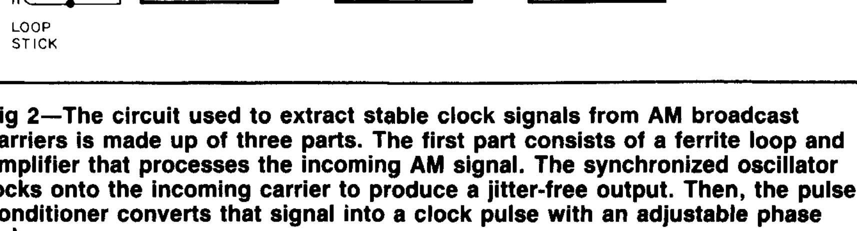


Fig 2—The circuit used to extract stable clock signals from AM broadcast carriers is made up of three parts. The first part consists of a ferrite loop and amplifier that processes the incoming AM signal. The synchronized oscillator locks onto the incoming carrier to produce a jitter-free output. Then, the pulse conditioner converts that signal into a clock pulse with an adjustable phase delay.

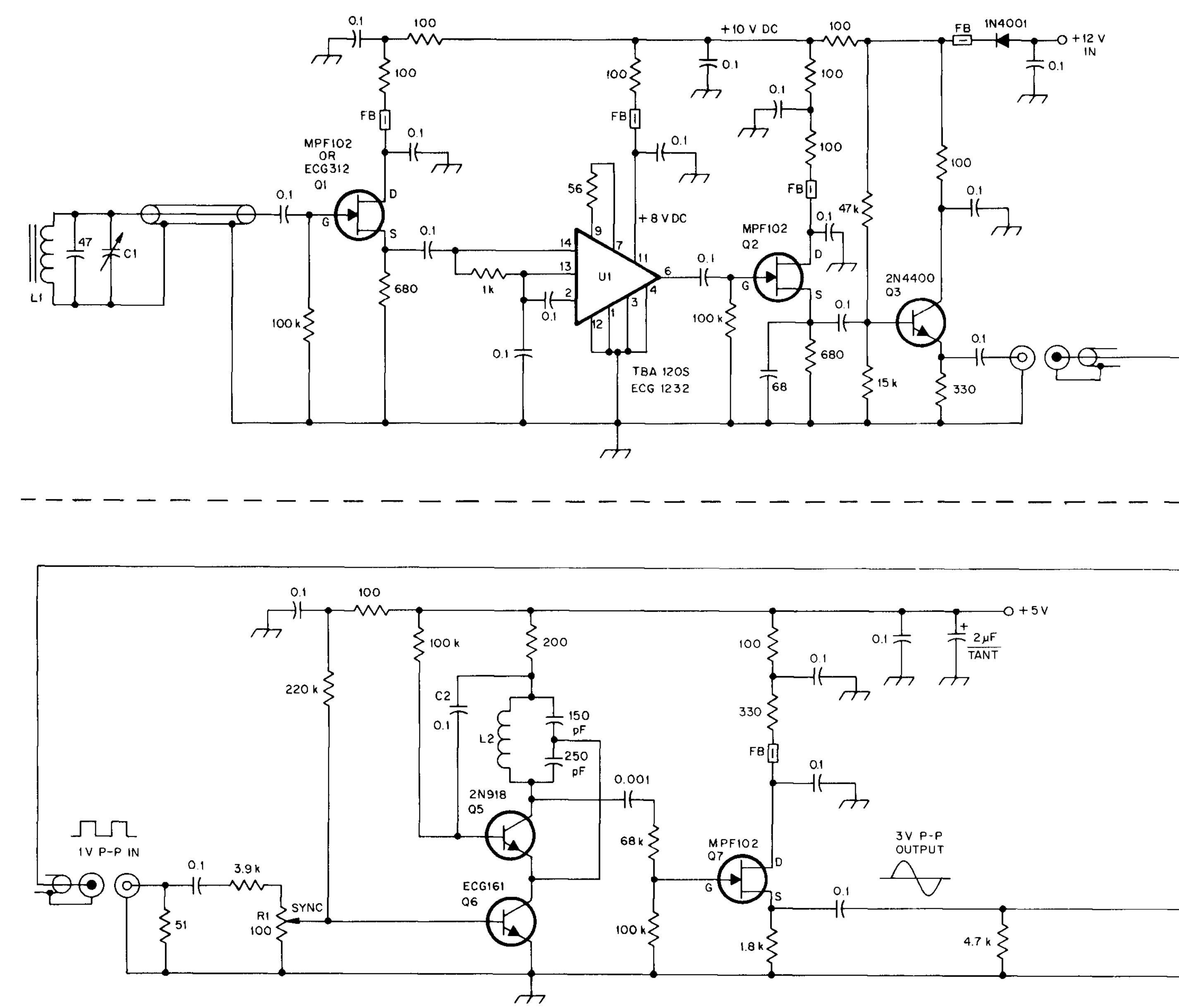


Fig 3—This circuit extracts stable clock signals from AM broadcast carriers for amateur spread-spectrum applications. All 0.1-μF capacitors in coupling and decoupling circuits are miniature 50-V polyester types. All capacitors smaller than 0.1-μF are silver mica.

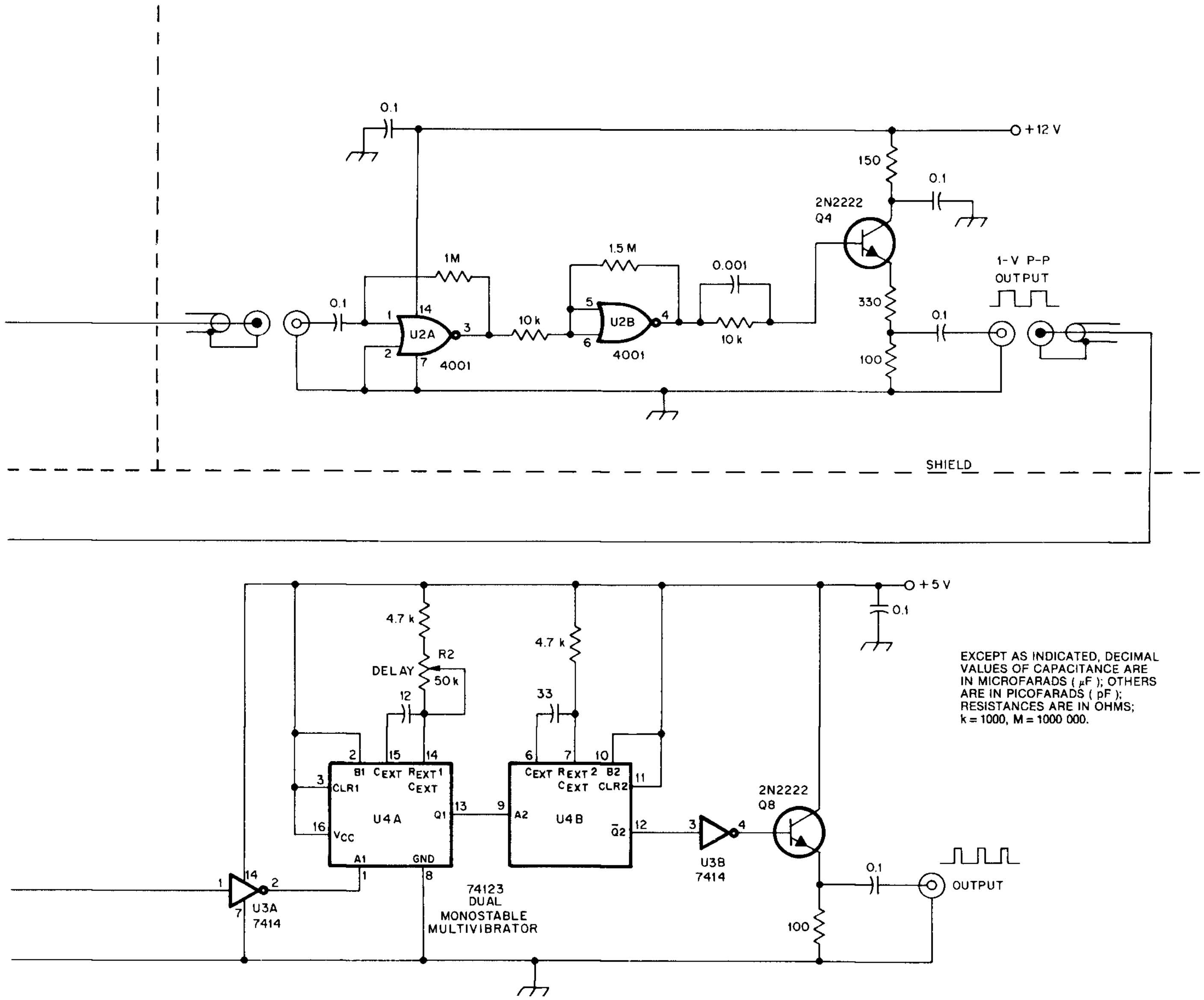
C1—Trimmer capacitor, 4-64 pF.
FB—Ferrite beads, Amidon FB-73-101.
L1—30 turns of 30-gauge wire, wound on an Amidon ferrite rod R-61-050-750.
L2—JW Miller shielded subminiature adjustable RF coil, catalog no. 9055, 60-120 μH.
Q1, Q2, Q7—MPF102 or ECG312 FET.
Q3—2N4400 (or 2N2222) NPN transistor.
Q4, Q8—2N2222 NPN transistor.
Q5—2N918 NPN transistor.
Q6—ECG161 NPN transistor.
R1—Adjustable potentiometer, 100 Ω.
R2—Adjustable potentiometer, 50 kΩ.
U1—TBA120S (Motorola) or ECG1292 (Sylvania) IF amplifier.
U2—CD4001 Quad NOR gate.
U3—7414 Hex Schmitt trigger.
U4—74123 Dual monostable.

I eventually decided to lock onto the carrier of an AM broadcast station, and after experimenting with different phase-locked loops, I settled for this design which uses readily available components. The circuit features a stable clock pulse, adjustable in phase to compensate for propagation delays, and it produces *no* measurable jitter.

The Circuit

Fig 2 shows the three parts of the circuit. The first part includes a ferrite loop and a clipping amplifier. The second part consists of a synchronized oscillator that locks onto the incoming carrier to produce a jitter-free output. Finally, the third part converts that signal into a clock pulse with adjustable phase delay.

Fig 3 shows the complete circuit diagram. The ferrite loop receives the



signal and U1, a TBA120S, amplifies it. U1 is an FM/IF 6-stage differential amplifier with good limiting and AM rejection properties.[7] Its output is amplified by U2A, a section of a CD4001 operated in its linear mode. The output is subsequently fed to U2B, connected as a Schmitt trigger. A 1-V P-P output is available at the emitter of Q4 (shown in the upper trace of Fig 7). This part of the circuit is the RF head (Fig 4). It can be positioned and oriented for best reception.

Fig 5 is the remote unit. It uses the 1-V P-P square wave from the RF head to lock the "synchronized oscillator."[8] The remote unit can be placed several hundred feet away from the RF head. This circuit, used for clock recovery in satellite installations, is yet generally unknown in Amateur Radio circles. Q5, Q6, and Q7 comprise the synchronized oscillator. Q5 functions as a modified Colpitts oscillator. It has two positive feedback paths, one from the common point between the two capacitors in the collector tank to its own emitter, and the other path from the junction of the 220-Ω resistor and the collector tank to the base of Q5, via C2. C2 is large and represents a very low impedance at the operating frequency. Q6 can be thought of as a dynamic emitter resistor for Q5. Since Q5 operates in class C, the conduction angle is very small. Each time conduction occurs in Q5, a voltage develops across Q6, and amplification of whatever signal is present at that time at the base of Q6 takes place. Conduction in Q6 is similar to the opening of a very brief "time window" during which synchronization to the input signal occurs. Because there is a tuned circuit in the collector of Q5, in the event of a temporary absence of sync pulses, the tank (functioning as a flywheel) continues to produce sine waves at a frequency close to the frequency of interest.

An AM input signal consists of a carrier (F_c = 1,390 kHz in our case), plus two sidebands ($F_c + F_{mod}$) and ($F_c - F_{mod}$). Assuming a single modulating frequency of 2 kHz, the input signal consists of three discrete RF frequencies—the carrier at

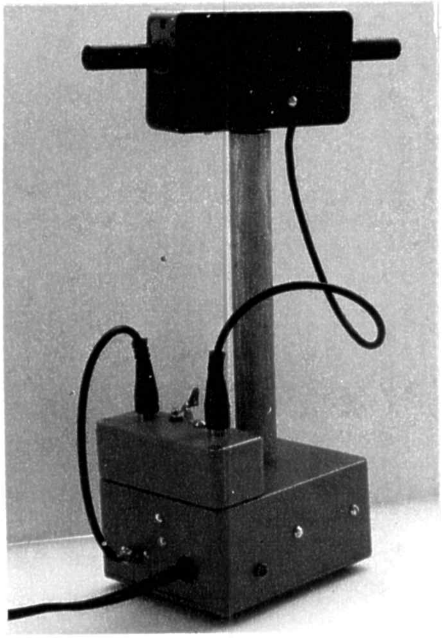


Fig 4—The upper part of the RF head swivels so it can be positioned for best reception. The smaller aluminum box houses U1 and associated components. U2 and the 12-V dc power supply reside in the larger box at the base.

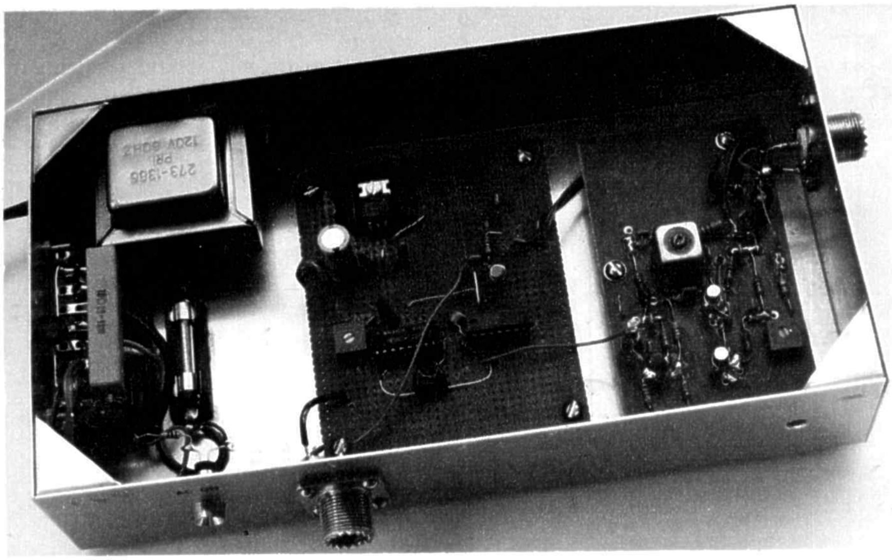


Fig 5—The remote unit. The board on the right supports the synchronized oscillator. The voltage regulator and the pulse-shaping circuitry are mounted on the center board.

1,390 kHz and the two sidebands at 1,388 and 1,392 kHz (Fig 6). In practice, the instantaneous frequencies and amplitudes of the two sidebands depend on the audio input and depth of modulation, respectively. These discrete frequencies in the RF spectrum are visible as jitter on the upper trace of Fig 7.

Although the frequency and amplitude of the sidebands vary continuously, the mentioned attributes of the carrier are constant. Because of the flywheel effect, the synchronized oscillator, operating as a sort of coherent amplifier, tends to accept the carrier as the sync information. Jitter on the input signal tends to be perceived as an aberration, and is essentially ignored. Hence, the output sine wave at the collector of Q5 does not exhibit input jitter.

Finally, Q5's output is buffered by Q7, an FET stage. With the output of a synchronized oscillator being constant in amplitude throughout the synchronized range, it is acceptable to feed that output to U3A, a 7414 Schmitt trigger to obtain a stable trigger pulse. That pulse is then fed to the first of two monostable oscillators connected in series. The first portion of U4, a 74123, introduces a variable delay, adjustable by means of R2, over a range of approximately 270 degrees. U4B, the second monostable, outputs a short positive-going clock pulse, with Q8 connected as a 50-Ω line driver.

Fig 7's upper trace is the leading edge of the input signal to the synchronized oscillator, available at the top of R1. Peak jitter covers about one division, or approximately 0.02 μs. (In practice, average jitter is about 0.01 μs. This is consistent with an upper audio modulation frequency of 10 kHz. The peak jitter displayed in Fig 7 is probably the resultant of several causes, including some incident phase modulation.) The lower trace shows the signal at the emitter of Q8. There is *no* visible jitter at the output, so we know that the synchronized oscillator is operating properly. (Jitter on the upper trace is essentially caused by residual amplitude modulation.)

Construction

Observe good RF construction practices when building the synchronized oscillator, particularly with respect to ground returns and shielding. The prototype of my oscillator is built on fiberglass circuit board, using self-adhesive silvered circuit decals for connection points.

Because of U1's sensitivity, I recommend that it be housed in a separate enclosure from that of the synchronized oscillator. The synchronized oscillator produces several volts of RF at the same frequency as that of the input of U1.

The portion of the circuit comprising Q1, Q2, Q3 and U1 is housed in a small (¼ × ½ × 3½ inches) aluminum die-cast box. U2 and Q4 are mounted in a larger (2¼ × 3½ × 4½ inches) box used for the base of the receiving head. The loopstick is mounted in a plastic box that swivels on a wooden dowel and is positioned for best reception. In my present installation, the receiving head is located near a window so I can orient the ferrite loop for maximum signal reception. The receiving head connects to the synchronized oscillator with 25 feet of RG58 coax cable, with no visible degradation. You could easily use 100 feet of cable, if required. The larger aluminum box also

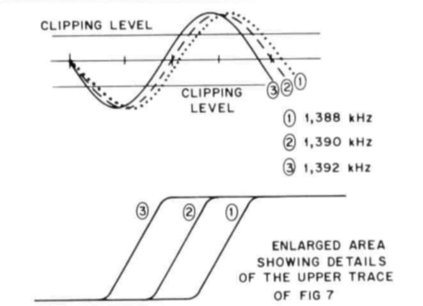


Fig 6—A simplified time-domain representation of amplitude modulation (see text).

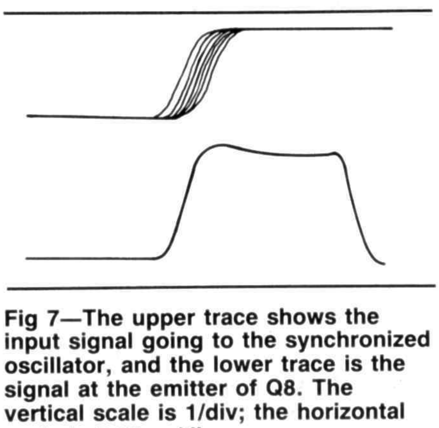


Fig 7—The upper trace shows the input signal going to the synchronized oscillator, and the lower trace is the signal at the emitter of Q8. The vertical scale is 1/div; the horizontal scale is 0.02 μs/div.

contains a 12 V dc power supply (not shown on the schematic) for the receiving head. A separate aluminum box (2 × 5 × 9½ inches) houses the synchronized oscillator, the pulse conditioner elements, and a 5 V dc power supply (see Fig 5).

Adjustments

An oscilloscope and a frequency counter are required to adjust this unit. (I locked onto WMZQ, a Northern Virginia radio station that uses a solid-state transmitter to broadcast on 1,390 kHz.) Connect the oscilloscope probe at pin 14 of U1, and the frequency counter probe at the emitter of Q4. The counter will indicate the carrier frequency of the AM broadcast transmitter you are receiving. The counter will probably jump ±100 Hz around the carrier frequency, representing modulation peaks (this reading depends on the integration time of your counter). On the scope screen, adjust C1, the trimmer across the loopstick coil, for maximum signal amplitude of the carrier you are trying to lock onto. By moving the scope probe to the emitter of Q3, you should see a fairly clean looking 150 mV P-P square wave. Look for a similar signal, 4 V P-P in amplitude, at the emitter of Q4.

In the remote unit, connect the oscilloscope probe to the source of Q7 (*not* to the tank of Q5). Adjust the slug in the collector tank of Q5 to produce a free-running frequency close to that of the AM broadcast station you are locking onto. This adjustment must be made with R1's wiper turned to ground potential. If you have a dual-trace triggered sweep oscilloscope, connect the synchronized channel to the source of Q7 (oscillator output), and the other channel to the input pulse. As the input signal applied to Q6 is slowly increased by adjusting R1, you should see the input pulse lock onto the sine wave (it is actually the sine wave that locks onto the input pulse). Jitter should be visible on the input signal only. (If the oscilloscope were synchronized on the jittery input signal, both the input *and* the output signal would appear to jitter.) Increasing the input level setting can "oversynchronize" the oscillator and possibly drive it into an "injection-oscillator" mode.[9] This results in distortion at the output, and possibly jitter, as the tracking range of the circuit increases.[10] Keep the input signal as low as possible.

Your frequency counter, now connected to the emitter of Q8, should indicate the carrier frequency you are locking onto, with a maximum deviation of ±1 Hz. This deviation represents the least significant digit resolution of your counter, and not a loss of synchronization.

Conclusion

In my synchronized oscillator, a 2N918 transistor was chosen for Q5 because of its good RF properties. An ECG161 was selected for Q6 because of its low noise. If you are only interested in breadboarding a synchronized oscillator for experimental purposes, you may use 2N2222s or 2N4400s in both positions. The result is some degradation of performance. Depending on the type of transistor used, the value of the 220-kΩ bias resistor is adjusted so that Q5's emitter is at about $V_{cc}/2$.

This circuit provides extremely accurate clock signals and uses readily available parts. Whether you are interested in spread-spectrum applications or another phase of Amateur Radio, build a synchronized oscillator, and experiment with this very versatile building block. It can also be used as a divider or multiplier.

Acknowledgements

I thank Mr V. Uzunoglu for devoting his time to discuss with me some of the properties of the synchronized oscillator.

Notes

[1]R. Dixon, *Spread Spectrum Systems*, New York, Wiley, 2nd ed, 1984, pp 215-255.
[2]D. Newkirk, "Our New Spread Spectrum Rules," *QST*, Apr 1986, p 45.
[3]W. Sabin, "Spread Spectrum Applications in Amateur Radio," *QST*, Jul 1983, p 16.
[4]A. Kesteloot, "Practical Spread Spectrum: A Simple Clock Synchronization Scheme," *QEX*, Oct 1986, pp 4-7.
[5]A. Kesteloot, "Experimenting With Direct Sequence Spread Spectrum," *QEX*, Dec 1986, pp 5-9.
[6]A. Kesteloot, "First Steps in Direct Sequence Spread Spectrum," *AMRAD Newsletter*, Vol XIV, No. 1, Jan 1987, pp 5-9.
[7]*Linear and Interface Integrated Circuits*, Motorola, Inc, Phoenix, AZ 1985, p 6-142.
[8]V. Uzunoglu and M. White, "The Synchronous Oscillator: A Synchronization and Tracking Network," *IEEE Journal of Solid State Circuits*, Vol SC-30, No. 6, Dec 1985, pp 1214-1224.
[9]V. Uzunoglu, private communication, May 15, 1987.
[10]V. Uzunoglu and M. White, "Some Important Properties of Synchronous Oscillators," *Proceedings of the IEEE*, Vol 74, No. 3, Mar 1986, pp 516-518.

Midlatitude Es at 220.1 MHz

(continued from page 4)

It is apparent that neither geomagnetic disturbances nor intense thunderstorm activity played a major role in this occurrence of Es.

Appendix

Station Parameters

Station:	W5HUG	K5UGM
Operator:	John Moore	William Duval
Location:	548 Clermont Ave	2316 Spanish Trail
City:	Orange Park, FL	Irving, TX 75060
Latitude:	30°, 06', 15" N	32°, 46', 15" N
Longitude:	81°, 27', 30" W	96°, 57', 30" W

Path distance: 1497 km (931 miles)
Frequency: 220.100 MHz

Equipment

Transmitter Power:	20 W	600 W
Antenna Gain:	14 dBd	14 dBd
Antenna Height:	21 m	10 m
Feed Line Loss:	1.8 dB	0.5 dB
Receiver Noise Figure:	0.5 dB	0.3 dB

Bits

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