A Practical Direct-Sequence Spread-Spectrum UHF Link

In this *QST* exclusive, amateur spread-spectrum communication moves off the drawing board and into practical reality. Read all about it—and warm up your soldering iron!

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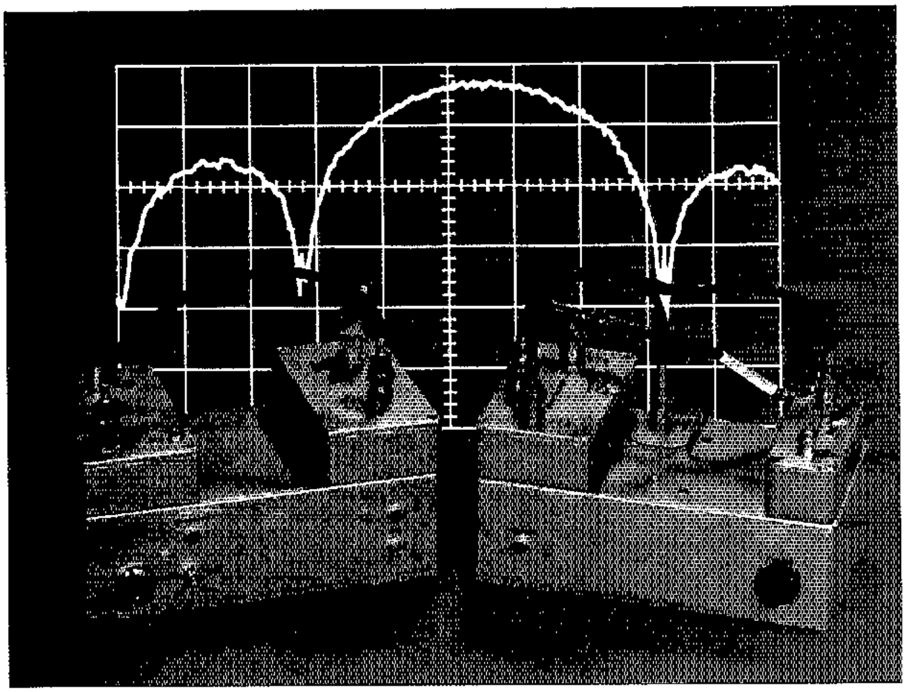

Radio amateurs under FCC jurisdiction have been authorized to use spread-spectrum emission since June 1, 1986,[1] but practical information on how to get an amateur spread-spectrum system up and running has been scarce. This is so for good reason: Military applications of spread spectrum are routinely classified, while space and other civilian applications are usually proprietary. Because of this, the literature abounds with spread-spectrum articles replete with mathematical treatments and block diagrams, but very few articles that give *practical details* of spread-spectrum systems have been published.

This situation has, in effect, forced Amateur Radio experimenters to reinvent parts of the wheel! Notwithstanding the fact that spread spectrum has been around for about 50 years, this article is, to my knowledge, the first to give complete details of the concept, design and realization of a direct-sequence spread-spectrum UHF radio link. Although this article does not present construction information at the component level, experimenters with a good grounding in UHF construction techniques should have no trouble building a functional spread-spectrum system based on the information given here.

Introduction to Direct-Sequence Spread Spectrum

A direct-sequence (DS) spread-spectrum signal can be obtained by mixing a carrier with the output of a clock-driven pseudo-noise (PN) generator (see Fig 1). This is readily achieved in a doubly balanced mixer (DBM), and results in the suppression of the original carrier and the creation of a new signal that is spread over a wide bandwidth (typically several megahertz). This biphase modulation, described in more detail in the references cited at notes 2 and 3, creates sidebands, or "spectral lines," the envelope of which has a $(\sin x/x)^2$ shape as shown at Fig 2A.

A simplified understanding of this phenomenon can be arrived at by considering the PN sequence as a succession of identi-

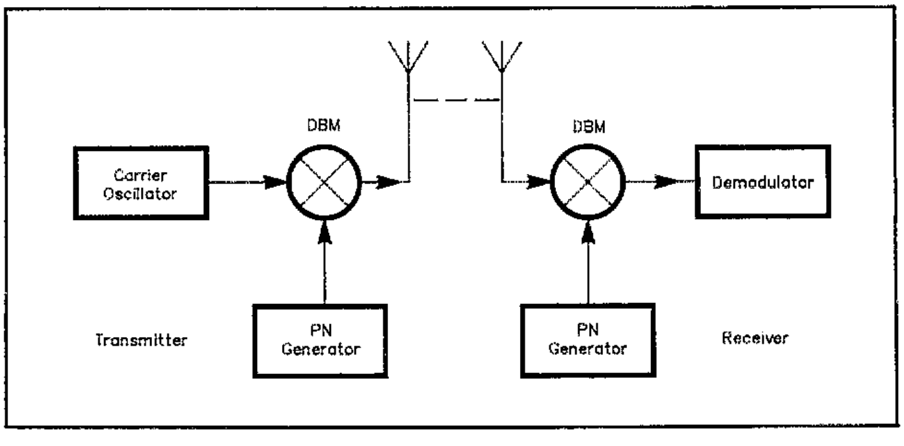

Fig 1—Simplified block diagram of a direct-sequence spread-spectrum communication system. In the transmitter, left, a spread-spectrum signal is generated by mixing carrier oscillator and pseudo-noise (PN) signals in a doubly balanced mixer (DBM). The energy of the resultant *biphase-modulated* suppressed-carrier signal is spread over a wide bandwidth. In the link receiver, right, the spread-spectrum signal is *despread* by mixing it with a PN signal identical to that used in the transmitter. In practice, the most difficult aspect of making this system work is that of synchronizing the PN-generator clocks at the transmitter and receiver sites.

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[1] Notes appear on page 21.

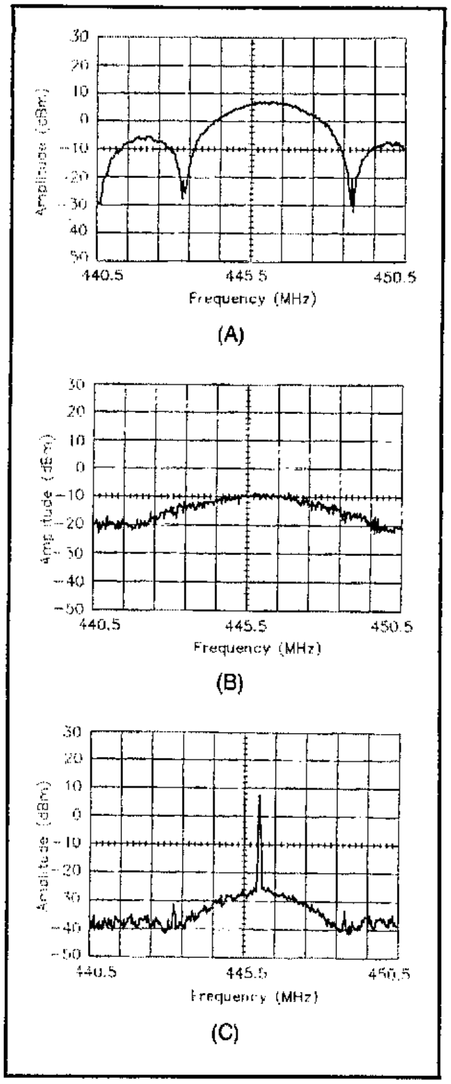


Fig 2—(A) Envelope of the unfiltered biphase-modulated spread-spectrum signal as viewed on a spectrum analyzer. In the practical system described, band-pass filtering is employed to confine the spread-spectrum signal to the amateur band. (B) At the receiver end of the link, the filtered spread-spectrum signal is apparent only as a 10-dB hump in the noise floor. (C) Despread signal at the output of the receiver DBM. The original carrier—and any modulation components that accompany it—has been recovered. The peak carrier is about 45 dB above the noise floor—more than 30 dB above the hump shown at B. (These spectrograms were made at a sweep rate of 0.1 s/div and an analyzer bandwidth of 30 kHz; the horizontal scale is 1 MHz/div.)

cal rectangular pulses of constant width, but variable repetition rate, the latter always being some submultiple of the (constant) clock frequency. Because the modulating signal is a rectangular pulse (rich in harmonics), a multitude of sidebands is created. As the shift register advances, the varying repetition rate changes the *number* and *position* of the spectral lines. Neither the shape of the envelope nor the position of the nulls—which are functions of the pulse width (see Fig 3)—changes.

The envelope is so shaped because a rectangular pulse in the time-domain has a (sin x/x) Fourier transform in the frequency domain. Hence, the sidebands, or spectral lines, created by such a pulse have a (sin x/x) envelope.[4] As we are dealing with a signal proportional to the output *power* (that is, a function of the square of the output voltage), the resulting signal appears as a $(\sin x/x)^2$ spectrum when observed with a spectrum analyzer (Fig 2A). Note that the spectrum-analyzer display shows only the *envelope* of all the sidebands—that is, an *imaginary* curve joining the peaks of all the spectral lines.[5]

At the receiver end of the spread-spectrum link, the output of the DBM

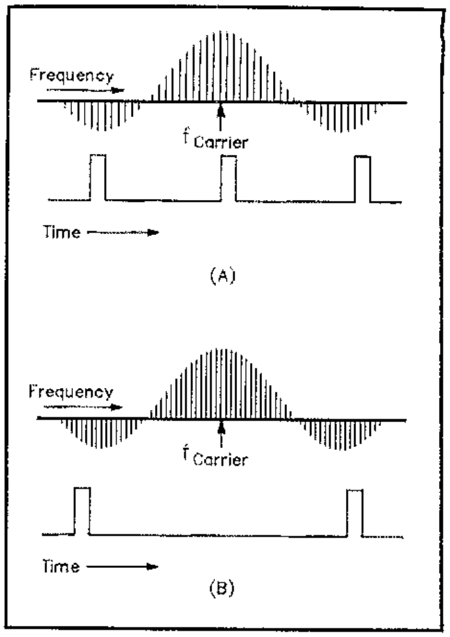
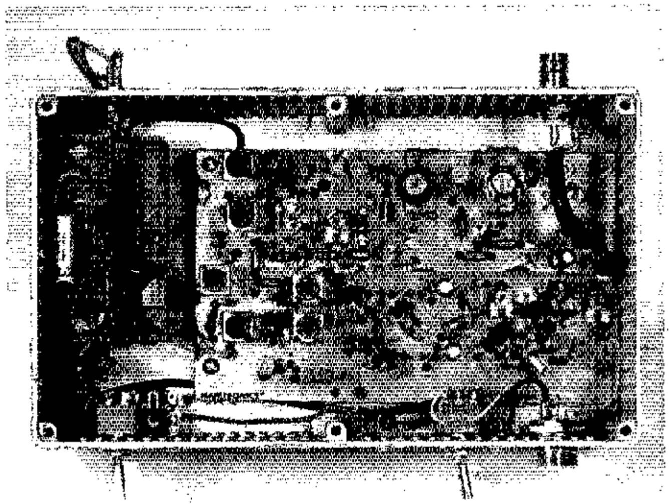
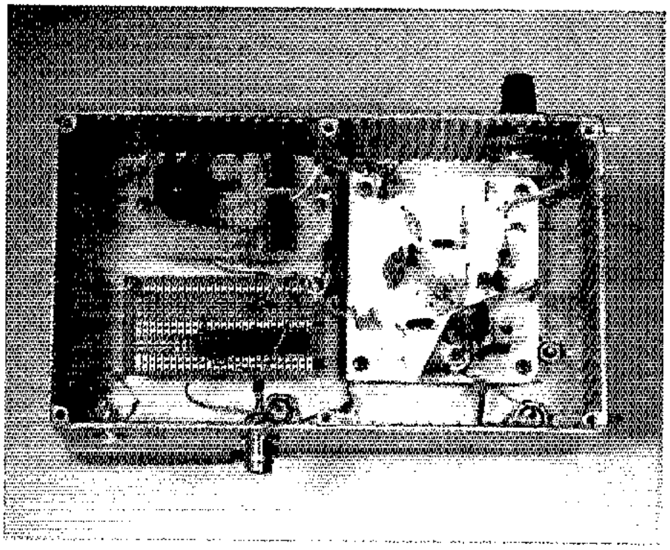


Fig 3—The PN signal (lower trace at A and B) consists of constant-width pulses that vary in repetition rate as the PN-generator shift register advances. Varying the PN-signal pulse rate changes the number and position of the spread signal's characteristic "spectral lines" (upper trace at A and B) without changing the shape of the signal envelope.



The spread-spectrum transmitter is based on a Hamtronics TA-451 446-MHz transmitter strip (Z1, right). The transmitter PN generator—the two piggybacked boards at left—uses 111.5-MHz energy from the TA-451 as the PN-sequence clock.



The heart of the spread-spectrum receiver is a synchronized oscillator (right) that recovers the transmitter PN-sequence clock from the received signal. The modules at left contain clock divider ICs (U8 and U9), a voltage regulator (U7) and the receiver PN generator (U10 and U11). R1, the OSC FREQ control, is at top right.

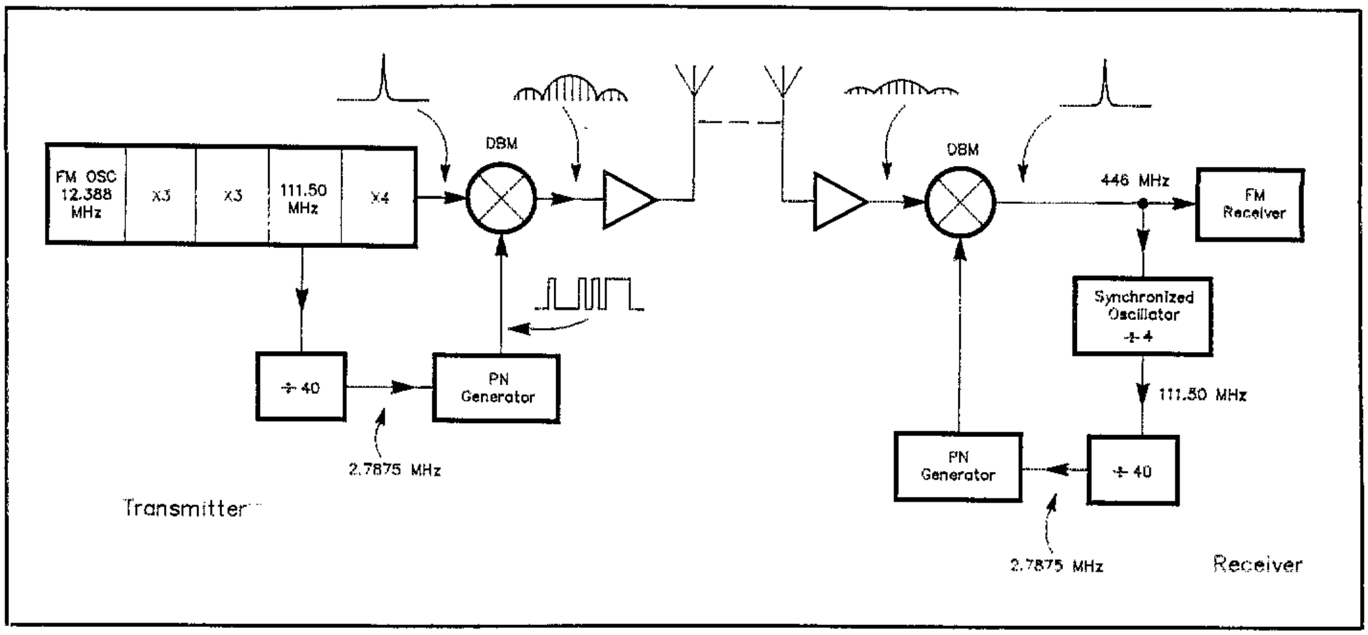
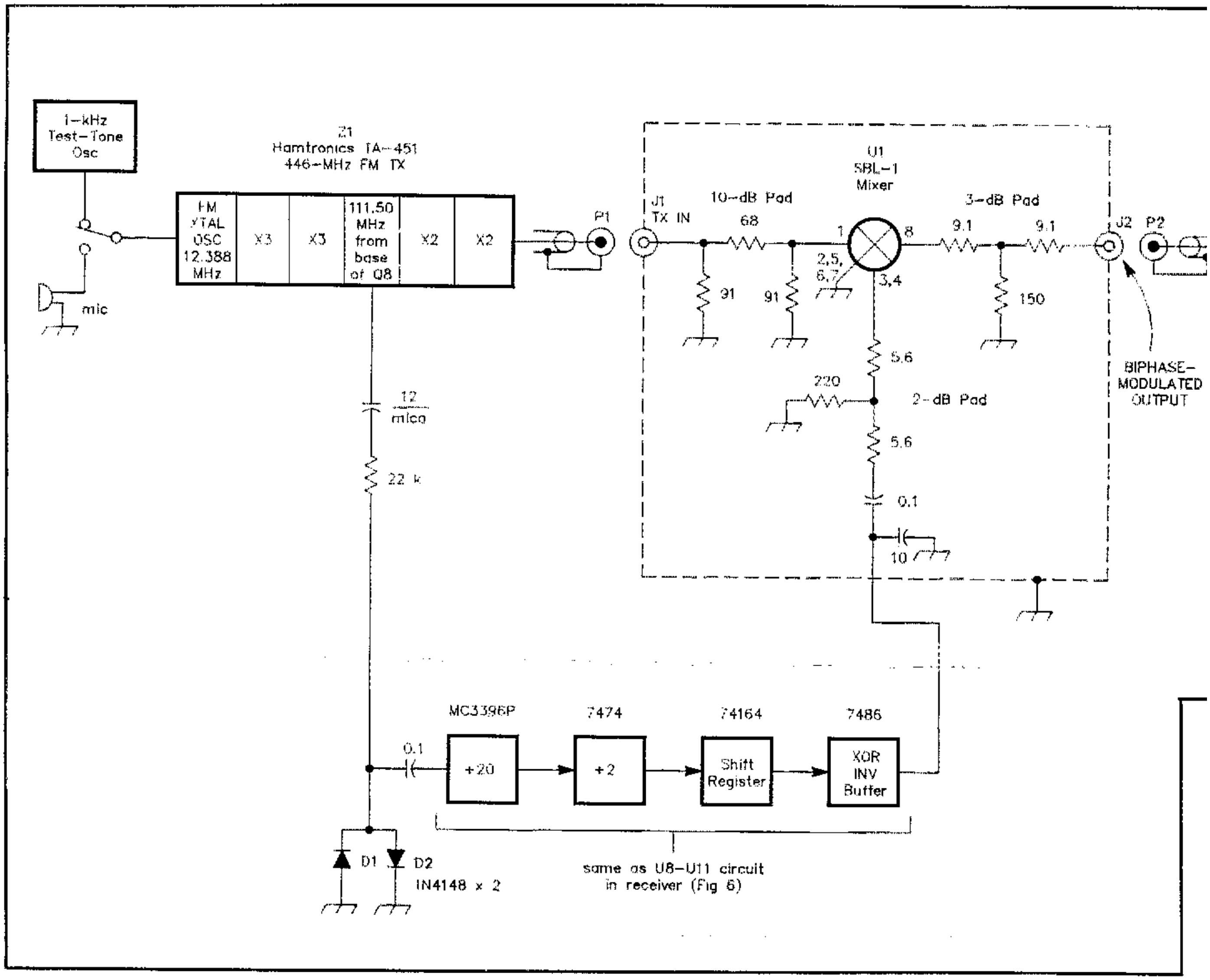


Fig 4—Block diagram of the practical spread-spectrum link. The success of this arrangement lies in the use of a synchronized oscillator (right) to recover the transmitter clock signal at the receiving site.



shows—in the absence of correlation—a slight rise in the noise floor, as shown in Fig 2B. If we now reintroduce PN identical in sequence, frequency and phase to that used at the transmitter, the received signal will be correlated or "despread," and the output of the DBM will be as shown at Fig 2C.

In Amateur Radio applications, the PN sequence is announced before spread-spectrum transmission begins[6] and can thus be easily duplicated at the receiver. A major problem—one common to all spread-spectrum systems—remains: that of synchronizing the receiver's PN sequence with that used at the transmitter. This can be done by recovering the transmitter clock frequency from the received signal. Because the received signal appears to be noise (Fig 2B), however, this can be a formidable challenge. Commenting on this problem, Robert Dixon writes that "...more time, effort and money has been spent developing and improving synchronizing techniques than any other area of spreadspectrum systems. There is no reason to suspect that this will not continue in the future."[7]

This article describes a simple solution to the synchronization problem. (Because of its simplicity, the solution does not offer all the antijamming properties of more sophisticated systems, but this should not be a concern to Amateur Radio operators.)

Overall Description of the Link

The UHF link described in this article was first demonstrated at the June 1988 AMRAD meeting. (Several members of AMRAD [the Amateur Radio Research and Development Corporation] have been involved in spread-spectrum experimentation since 1980.) Fig 4 shows the general arrangement used. The output of a 446-MHz transmitter is fed to one input port of a doubly balanced mixer. The other input port of the mixer is connected to a PN sequence generator that is clocked at a submultiple of the transmitter's carrier frequency.

At the receiver end of the link, a sliding correlator is used as follows: The output of a free-running "synchronized oscillator" [8] is divided to create a clock signal at a frequency close to that of the transmitter's clock. This locally generated clock is used to drive a PN generator identical to that used at the transmitter site. The resulting PN sequence is mixed with incoming RF in a doubly balanced mixer. The free-running frequency of the synchronized oscillator can be adjusted to run the receiver's PN sequence faster or slower than the transmitter's. The speed difference causes the receiver PN sequence to "slide by" the transmitter sequence (hence the name *sliding correlator).*

Because the transmitter and receiver sequences differ in speed, the PN sequence fed to the receiver's doubly balanced mixer will coincide with the transmitter sequence at some instant. Correlation, or *despreading,* then occurs, and the output of the DBM duplicates the original carrier as shown in Fig 2C. This carrier is fed to the input of the synchronized oscillator, which locks onto the incoming signal. The loop is now closed: The original clock has been recovered, and the system stays locked.

The Direct-Sequence Transmitter

As shown in Fig 5, I used a Hamtronics® model TA-451 transmitter strip (Z1), the output power of which is adjusted to 10 mW (+10 dBm), as an exciter. This transmitter is based on a

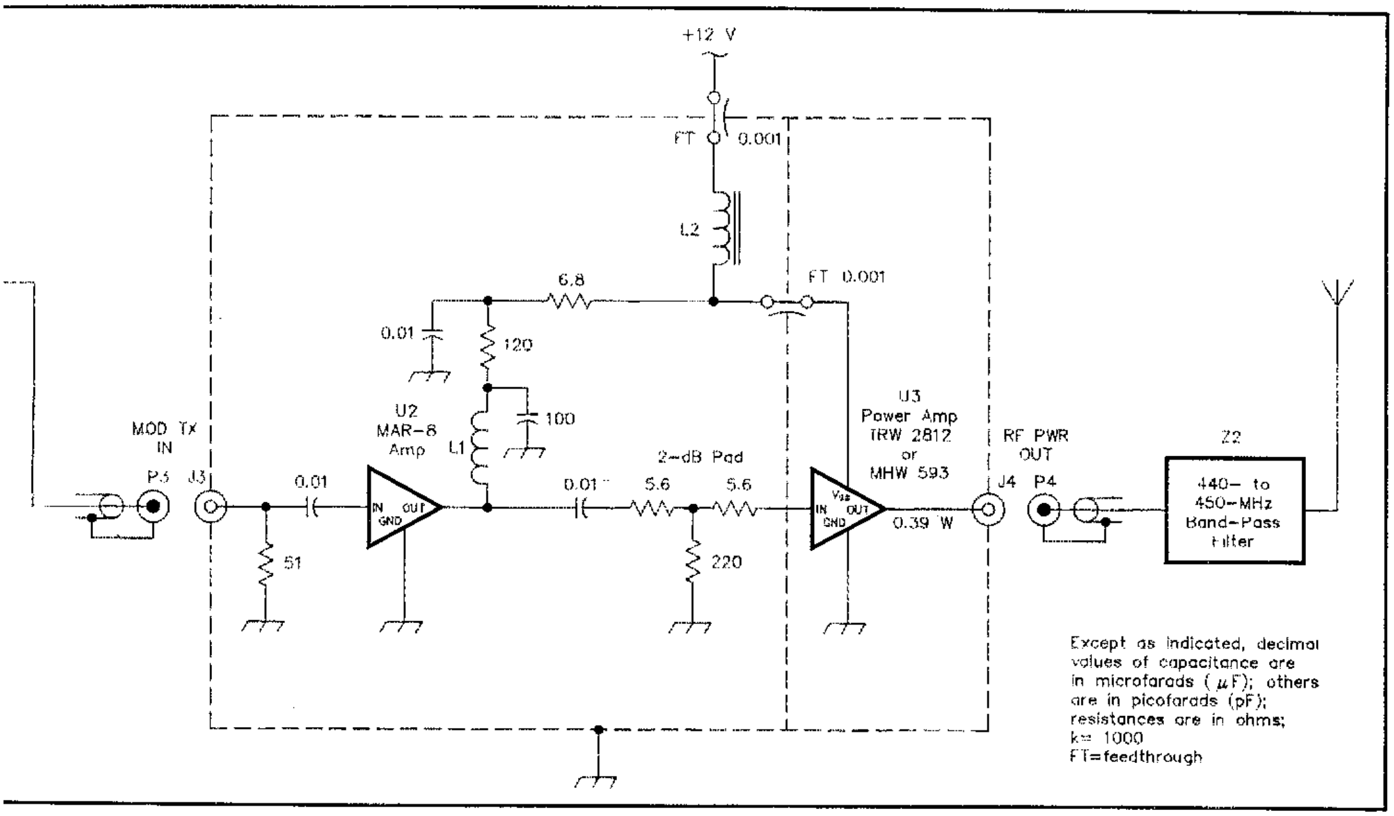


Fig 5—Schematic of the 440-MHz spread-spectrum transmitter. All capacitors under 0.001 μF are dipped mica; others are 50-V ceramic (0.1 μF units: monolithic ceramic) unless marked otherwise. Resistors are 5% tolerance, ¼- or ½-W carbon film or composition. Q8 (in the Z1 box) is a Hamtronics part designator. See Fig 6 for details on the PN generator. The 1-kHz tone generator, included to facilitate testing in the author's version of the link, is not described in this article.

D1, D2—1N4148 or equiv.

L1—10 close-wound turns of no. 30 KYNAR® -insulated (wire-wrap) tinned copper wire, 1 mm diam (use a no. 64 [0.036-in. diam] drill as a removable form).

L2—1 turn of no. 30 KYNAR-insulated wire through an Amidon FB-64-101 (Palomar FB-1-64, RADIOKIT FB64-101 also suitable) ferrite bead.

U1—Mini-Circuits SBL-1 mixer (Mini-Circuits, PO Box 350166, Brooklyn, NY 11235-0003, tel 718-934-4500).

U2—Mini-Circuits MAR-8 MMIC.

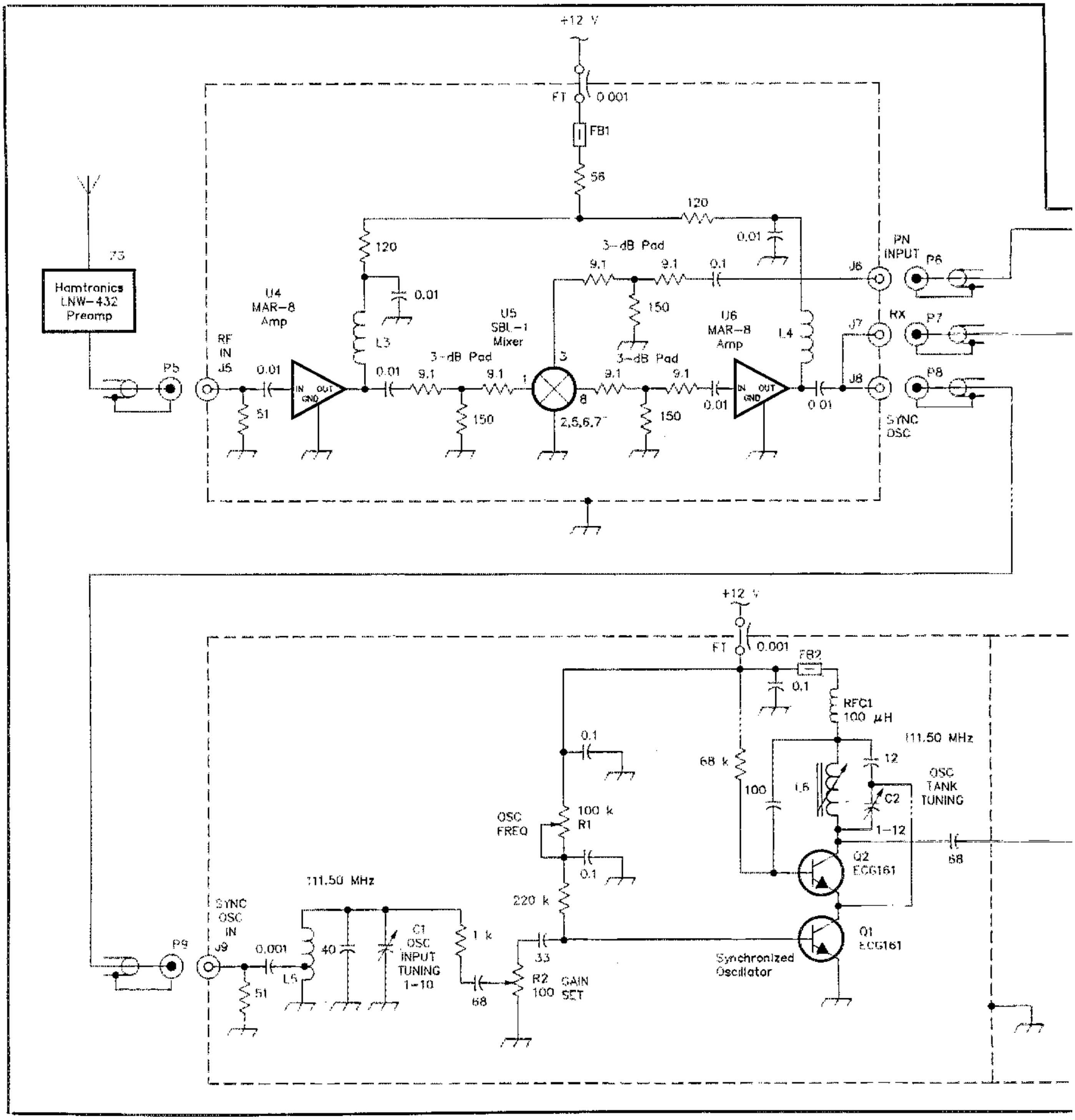
U3—TRW 2812 or Motorola MHW 593 amplifier module.

Z1—Hamtronics TA-451 446-MHz FM transmitter (Hamtronics, Inc, 65 Moul Rd, Hilton NY 14468-9535, tel 716-392-9430).

Z2—Hamtronics HRF-432 440- to 450-MHz, helical-resonator band-pass filter.

Fig 6—Mixer and PN-generator circuitry for the 440-MHz spread-spectrum link. Except for 0.1-µF units, all capacitors are 50-V ceramic unless marked otherwise; 0.1-µF capacitors are 50-V monolithic ceramic. Resistors are 5% tolerance, ¼- or ½-W carbon film or composition.

C1—1- to 10-pF, ceramic-dielectric piston trimmer.
C2—1- to 12-pF, air-dielectric trimmer.
FB1, FB2—Amidon FB-64-101 (Palomar FB-1-64, RADIOKIT FB64-101 also suitable) ferrite bead.
L3, L4—10 close-wound turns of no. 30 KYNAR-insulated (wire-wrap) tinned copper wire, 1 mm diam (use a no. 64 [0.036-in. diam] drill as a removable form).
L5—2½ turns of no. 16 tinned copper wire, ¼ in. diam. Tap ¾ turn from ground end. Use a ¼-in.-diam drill as a form. After winding the coil, remove the drill and spread the turns to make a coil ½ inch long.
L6—4 space-wound turns of no. 20 enam copper wire on a ¼-in. diam, slug-tuned plastic form. Nominal inductance, approx 0.2 µH.
R1—100-kΩ, linear-taper control.
RFC1—100-µH miniature molded choke.
U4, U6—Mini-Circuits MAR-8 MMIC.
U5—Mini-Circuits SBL-1 doubly balanced mixer.
U7—7805 regulator IC
U8—MC3396P divide-by-20 prescaler IC.
U9—7474 dual-D, positive-edge-triggered flip-flop IC.
U10—74164 8-bit, parallel-output shift register, asynchronous clear IC.
U11—7486 quad two-input exclusive-OR gate IC.
Z3—Hamtronics LNW-432 preamplifier adjusted for an input response flat from 430 to 460 MHz. See text.
Z4—446-MHz FM receiver, or transceiver in receive mode.



12.388-MHz crystal oscillator, the output of which is multiplied by 36 to produce output at 446 MHz. The link clock is based on transmitter energy sampled at one-fourth the output frequency (111.5 MHz, at the base of Q8 in the Hamtronics transmitter). This signal is fed to a divide-by-40 chain consisting of a MC3396P and a 7474. The divider chain produces a series of pulses at 2.7875 MHz. These pulses are used to clock a seven-stage shift register composed of a 74164 and a 7486. (This circuit, described in detail in the reference cited at note 9, is identical to that used in the link receiver [Fig 6].) This shift register, the PN generator, drives one input port of a doubly balanced mixer (U1). Attenuators are used on all ports of the DBM to reduce the effects of impedance mismatch and keep IMD products at a low level.

The output of the DBM, a biphase-modulated signal, is then amplified by an MMIC (U2), and a UHF amplifier module (U3) that produces about 0.39 W in the 440- to 450-MHz range. The output spectrum of the transmitter (ahead of the band-pass filter, Z2) is shown at Fig 2A.

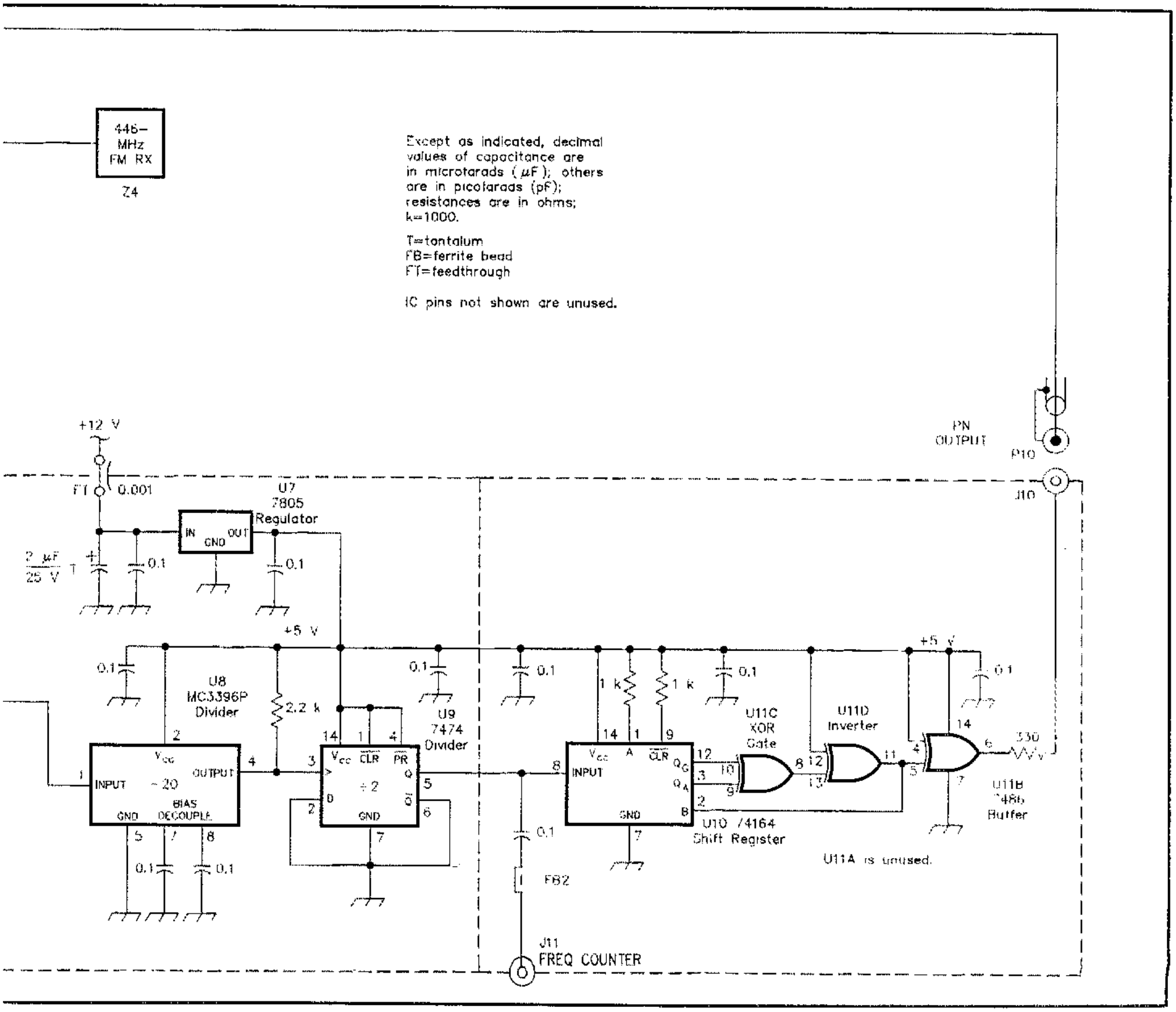
Because about 90% of the output power appears between the two first nulls (located at 443.2125 MHz [446.00 − 2.7875] and 448.7875 MHz [446.00 + 2.7875], respectively) the use of a band-pass filter (Z2) to attenuate the signal below 440 MHz and above 450 MHz does not appreciably affect reception of the radiated signal. (Reliable lock was obtained over a distance of more than a mile of fairly flat terrain using 0.39 W output and a quarter-wave groundplane antenna.)

As Fig 5 shows, the link clock is slightly frequency modulated by the audio signal. This does not introduce jitter or cause false synchronization because a peak deviation of 5 kHz at 446 MHz translates to a shift of only 15 Hz at the clock frequency (2.7875 MHz)—a negligible variation. (As an alternative approach, the clock could be derived directly from the transmitter's crystal oscillator, ahead of the phase modulator. This would, of course, require a different divider chain at the receiver end of the link.)

The Direct-Sequence Receiver and Synchronizer

See Fig 6. Signals from the antenna are fed to a Hamtronics Model LNW-432 preamplifier (Z3) aligned for a flat response from 430 to 460 MHz, an arrangement that provides some limited RF selectivity. The output of Z3 is boosted another 20 dB by a Mini-Circuits MAR-8 MMIC (U4) and then applied to one port of an SBL-1 Mini-Circuits DBM (U5). The output of the DBM is further amplified by a second MAR-8 (U6), the output of which feeds Z4, a 446-MHz narrow-band-FM receiver (in my system, a Yaesu FT-708R transceiver), and the input of a synchronized oscillator.

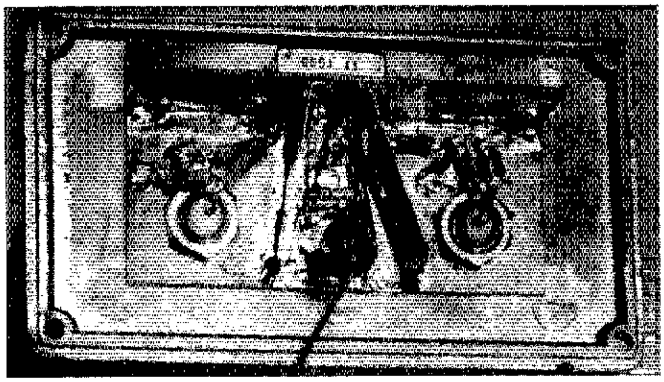
The synchronized oscillator is a deceptively simple-looking circuit that is unfortunately as yet little-known in amateur circles. Q2 is a modified Colpitts oscillator that, in this application, free-runs at approximately 111.5 MHz, or one-fourth



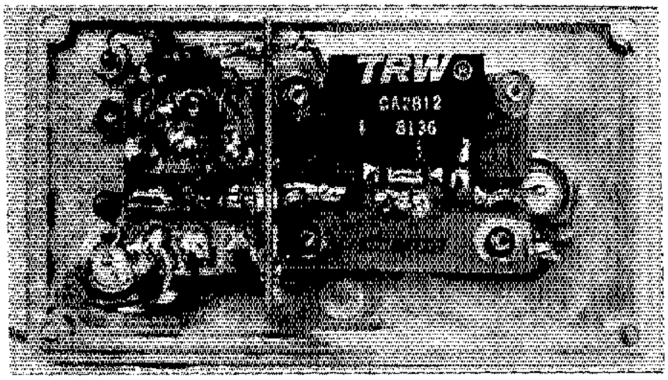
Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms; k=1000.

T=tantalum
FB=ferrite bead
FT=feedthrough

IC pins not shown are unused.



Construction of the transmitter biphase modulator. J1, TX IN, is at left; the SBL-1 DBM, U1, at top center; and J2, BIPHASE-MODULATED OUTPUT, at right. U1 receives PN-generator injection via the wire in the foreground.



The transmitter MMIC (U2) and power (U3) amplifiers. J3, MOD TX IN, is to the lower left; J4, RF POWER OUT, to the right. U3, a TRW 2812 amplifier module, commands the right two-thirds of this view; U2, a Mini-Circuits MAR-8, is the tiny black pill above and to the right of J3.

of the expected input frequency. Because Q2 operates in class C, it draws supply current only during a small portion of each cycle of its output sine wave. The resulting pulsating emitter current develops a pulsating voltage across Q1. Because there is no voltage drop across Q1 when Q2 is cut off, Q1 operates as an amplifier only on the peaks of Q2's output sine wave. Thus, an RF synchronizing signal applied to Q1's base will be allowed to steer Q2's oscillation frequency only for the brief periods during which Q2 conducts. R1, OSC FREQ (labeled TUNING in the title photo), allows adjustment of Q1's base current and, hence, Q2's free-running frequency.

In practice, the synchronized oscillator provides the function of a phase-locked loop (PLL) while offering several advantages over a PLL. The synchronized oscillator, which uses only two transistors, is simpler to implement. Unlike a PLL, which depends on a multistage feedback loop (phase detector, loop filter and so on) to achieve and hold lock, the synchronized oscillator locks onto the input signal directly. Further to its advantage, the synchronized oscillator can operate with very noisy input signals.[10,11,12]

The output of Q2 is thus a sine wave at 111.50 MHz. It is divided by 20 in U8 (a MC3396P prescaler) and then again by 2 in U9 (a 7474 flip flop), the output of which—a 2.7875-MHz square wave—feeds a seven-stage shift register (U10, a 74164), the application of which is described in more detail in the work cited at note 9. This arrangement exactly duplicates that used at the transmitter end of the link.

The output of the PN generator is connected to the IF port of the DBM (U5). This constitutes a sliding correlator in the sense that the transmitter and receiver PN sequences—identical, but running at slightly different speeds—slide by each other within the DBM. At the instant the receiver PN sequence coincides with that of the transmitted signal, correlation takes place in the DBM, and the DBM delivers a despread signal (Fig 2C). This despread signal, recognized by the synchronized oscillator as a valid input, forces the oscillator into lock and keeps it there.

Construction of the Link Prototype

As shown in the photographs, the various elements of the circuit were built in individual die-cast aluminum boxes. This provides ample interstage shielding; it also allowed flexibility during development of the link. A second version could no doubt be made much simpler mechanically.

Adjustments

The Hamtronics transmitter (Z1 in Fig 5) requires only one adjustment specific to its use in this application: *Its output must be reduced to 10 mW.* If you do not own an RF-power meter capable of measuring this level accurately, you can easily construct one as follows. Build a dummy load by connecting a 1.5-V, 25-mA lamp (one of the two identical lamps available as Radio Shack® no. 272-1139) in series with a 1- to 8-pF variable capacitor. Connect this dummy load to the Hamtronics transmitter via a sensitive SWR indicator. Turn on the transmitter and adjust the capacitor to minimize the SWR

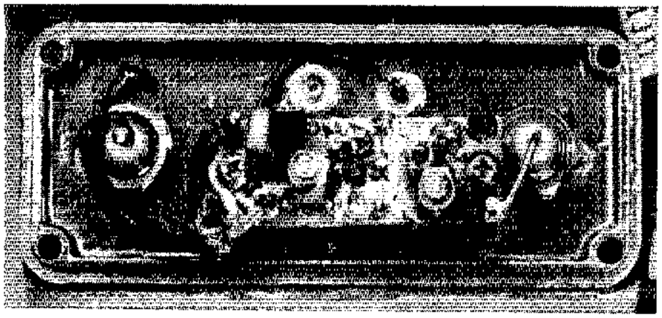
What's Spread Spectrum?

The useful energy in a conventional AM, FM or PM signal—including CW, RTTY, AMTOR, SSB and packet-radio transmissions—is concentrated narrowly around a center frequency. The bandwidth of such signals is directly related to the modulating frequency (and, where applicable, frequency deviation and modulation rate). The efficiency of these and other conventional modulation schemes is often equated with how tightly they concentrate signal energy for a given information rate.

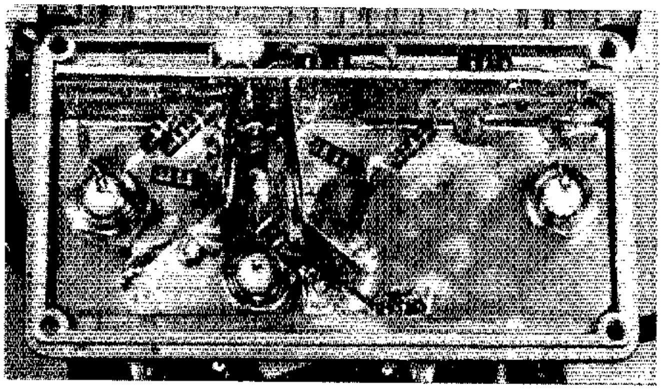
Spread-spectrum communication doesn't follow these rules. In spread-spectrum work, the signal energy is *intentionally spread* over a wide bandwidth. Because of this, spread-spectrum signals are largely immune to interference from, and less likely to cause interference to, nonspread signals. Spread spectrum offers the additional advantages of better noise rejection than nonspread systems, the possibility of hiding the communication channel in the ambient noise, and the possibility of conducting multiple communications at the same time on the same frequency (code-division multiplexing). Also, spread spectrum is highly resistant to jamming and can be used for precise ranging—characteristics that make it valuable in space communications.

Signal spreading can be done in several ways. In a *frequency hopping (FH)* system, the center frequency of a conventional signal is varied many times per second according to a predetermined table of frequencies. *Direct sequence (DS)* spreading is done by varying the phase of an RF carrier with a very fast, pseudorandom binary bit stream called pseudo-noise (PN). In *chirp* spread spectrum, the signal carrier is swept over a range of frequencies. (The USAF over-the-horizon-backscatter HF radar is a chirp spread-spectrum system.) In *time hopping* spread spectrum, a carrier is keyed on and off with a PN sequence. Many commercial and military spread-spectrum systems are *hybrids* of two or more of these spreading techniques, but current FCC rules limit amateur spread-spectrum work to FH *or* DS—FH-DS hybrids are not allowed.

To learn more about spread-spectrum communication, see chapter 21 of the 1989 *ARRL Handbook*, back issues of *QEX* and the amateur spread-spectrum rules in ARRL's *FCC Rule Book*. Watch for ARRL's upcoming spread-spectrum book. And stay tuned to *QST*: This month, André Kesteloot describes what we believe to be *the first practical amateur spread-spectrum communication system*—an *affordable* system that's simple to adjust and based on components readily available to experimenters. Amateur spread spectrum is here—and *you* can be a part of it.—*Ed.*



The receiver preamp, Z3, a Hamtronics LNW-432 module, fits neatly into its own die-cast box.



The three ICs in the receive-mixer module are contained on a single PC board. U4 is at left (above J5, RF IN); U5 is almost hidden from view by the disc-ceramic capacitor at top, and U5 is at the right (above J8, SYNC OSC). (In this model, a coaxial tee is used at J8 in lieu of mounting J7, RX, on the box.) The jack at center is J6, PN INPUT.

presented by the dummy load to the transmitter. Connect the second 272-1139 lamp across a 1.5-V cell in series with a 50-Ω adjustable resistor, and place this lamp so that you can simultaneously view it and the dummy-load lamp. Adjust the current through the dc-fed lamp so that the lamp dissipates 10 mW. Turn on the transmitter and adjust R37 (on the transmitter) so that the RF-fed lamp glows at the same brightness as the dc-fed lamp. This simple comparison method yields surprisingly accurate results. No other adjustments are required at the transmitter site.

method yields surprisingly accurate results. No other adjustments are required at the transmitter site.

At the receiver site, the only adjustments necessary concern the synchronized oscillator (Fig 6). Using a dip meter coupled to L5 as a resonance indicator, adjust C1, OSC INPUT TUNING, for resonance at 111.5 MHz. (Because R2 loads the tuned circuit, you may have to temporarily disconnect the 68-pF capacitor from the R2 wiper to obtain a discernible dip.) Connect a frequency counter to the output of the divide-by-40 chain via J11, FREQ COUNTER. Adjust R1, OSC FREQ, to the center of its range. Adjust the wiper of R2, GAIN SET, to the ground end of its range. Set C2, OSC TANK TUNING, to the center of its range, and adjust L6 for a reading of approximately 2.78 MHz on the frequency counter. Note that this reading can be varied by adjusting the OSC FREQ control.

Operation

After identifying your station on the link carrier frequency in accordance with §97.84(g)(5) of the FCC rules (identification by means of a narrow-band emission—AFSK or voice—is the easier option to implement) and stating the characteristics of your PN sequence, you may turn on the spread-spectrum transmitter.[13]

At the receiver end of the link, adjust the wiper of R2 (Fig 6) to about 30° from the ground end of its range. (Further advancing this control only "oversynchronizes" the oscillator and produces distortion at its output, and could lead to false triggering of the divide-by-20 stage.) Connect a frequency counter to J11 and adjust R1 for a counter indication of about 2.7875 MHz. Assuming that the received signal is sufficiently strong, you should observe that the counter suddenly displays exactly 2.7875 MHz as you adjust R1. When this happens, the receiver PN sequence has locked to the transmitter sequence.

The synchronized oscillator should be able to achieve lock at free-running frequencies from about 2.7860 to 2.7890 MHz. In my version, the receiver stays in lock for hours without needing readjustment of R1 once the synchronized-oscillator enclosure has stabilized (about 30 minutes after turn-on).

Summary

This article has described a direct-sequence spread-spectrum UHF link that uses readily available components and does not require sophisticated equipment for adjustments and tuning. As it stands, the system transmits and receives voice, or packets by means of AFSK. Work is currently proceeding to modify the system to allow direct data transmission.

Radio amateurs should expect spread-spectrum technology to become rapidly prominent in the field of amateur high-speed data transmission. I hope that this description of a practical spread-spectrum link will encourage others to undertake their own experiments on one of Amateur Radio's newest frontiers.

Acknowledgments

Vasil Uzunoglu, codeveloper of the synchronized oscillator, deserves much credit for clarifying my understanding of his circuit, and I thank Chuck Phillips, N4EZV, for his constant encouragement and support.

Notes

[1] Radio amateurs are now authorized by the FCC to transmit spread-spectrum emission using frequency hopping or direct-sequence spreading, but not a combination of both, at frequencies above 420 MHz. This article describes a direct-sequence 446-MHz link that uses a seven-stage shift register with feedback taps at stages 7 and 1. Because the FCC rules pertaining to amateur spread-spectrum operation contain logging, identification and technical-standards provisions that differ greatly from those regulating operation with "standard" emissions, radio amateurs contemplating spread-spectrum operation are urged to familiarize themselves with Part 97's spread-spectrum rules before putting their own spread-spectrum systems on the air.—*Ed.*

[2] R. Dixon, *Spread Spectrum Systems,* 2nd ed, (New York: Wiley, 1984), pp 114-125.

[3] A. Kesteloot, "Practical Spread Spectrum: Achieving Synchronization with the Slip-Pulse Generator," *QEX*, May 1988, pp 6-11.

[4] MIT School Staff, *Principles of Radar* (New York, McGraw-Hill, 1946), pp 4-12.

[5] A. Kesteloot, "Of Weltanschauung, Jitter and Amplitude Modulation," *AMRAD Newsletter 1987*, Vol XIV, No. 4, pp 4-7.

[6] FCC rules currently require that amateur spread-spectrum emissions be identified by means of narrow-band emissions, or by altering one or more parameters of a spread-spectrum emission in a fashion such that CW or SSB or narrow-band FM receivers can be used to identify the sending station (§97.84 (g) (5)). The current FCC rules do not require that the station ID include details concerning the spreading method and sequence in use, but interoperability of amateur spread-spectrum stations is facilitated when this information is given as part of the ID.—*Ed.*

[7] Dixon, p 214.

[8] V. Uzunoglu and M. White, "The Synchronized Oscillator: A Synchronization and Tracking Network," *IEEE Journal of Solid State Circuits,* Vol SC-30, No 6, Dec 1985, pp 1214-1224.

[9] A. Kesteloot, "Practical Spread Spectrum: A Simple Clock Synchronization Scheme," *QEX*, Oct 1986, pp 4-7.

[10] See note 8.

[11] A. Kesteloot, "Extracting Stable Clock Signals from AM Broadcast Carriers for Amateur Spread-Spectrum Applications," *QEX*, Oct 1987, pp 5-9.

[12] An ambiguity is introduced by the fact that the synchronized oscillator divides by 4. It is thus theoretically possible for the oscillator to lock onto any one of the four RF cycles that can produce the correct frequency relationship at the receiver end of the link. In practice, though, the receiver tends to lock onto the proper cycle very reliably. (This ambiguity will be resolved once it becomes possible to [1] build a synchronized oscillator capable of operating reliably at 446 MHz, or [2] find a reasonablypriced phase-locked loop capable of operating at 446 MHz.)

[13] I identify my spread-spectrum transmissions by speaking into a hand-held FM voice transceiver tuned to the link carrier frequency.