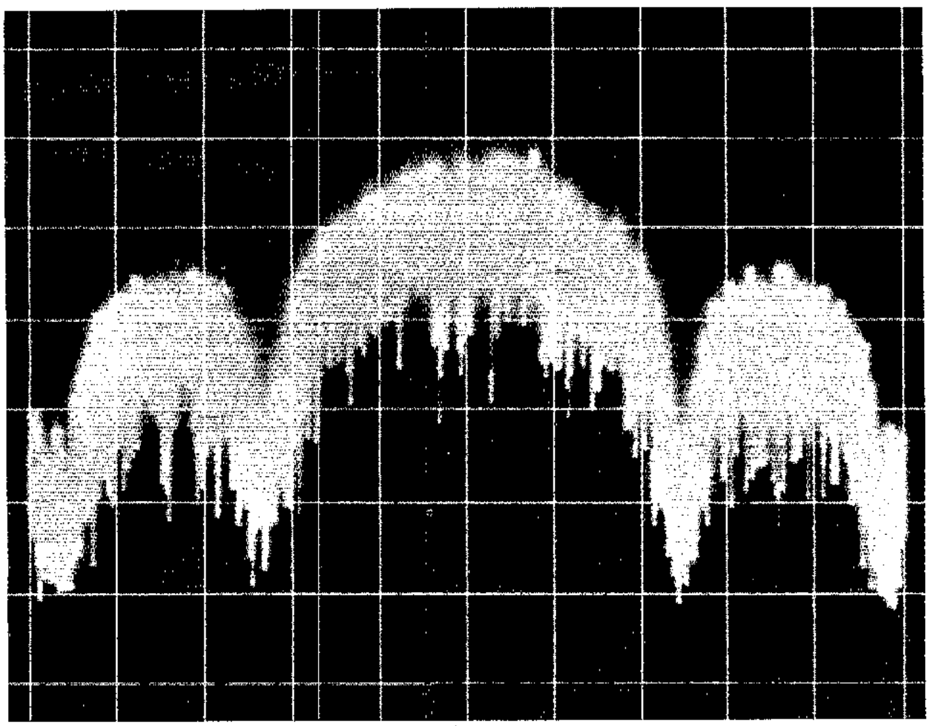
Spread Spectrum and the Radio Amateur

Spread-spectrum signals are unlike any emissions presently used by radio amateurs. But we stand at the threshold of what may be a new mode for amateur communications.

By Paul L. Rinaldo,* W4RI



A modulation technique that has been in development since the late 1940s, spread spectrum (SS) has, until recently, been virtually unthinkable for use by radio amateurs for a number of reasons. First, SS occupies bandwidths far in excess of the necessary bandwidth; that would be illegal! By using a pseudo-random digital sequence to scatter energy over a wide band, there is only a small amount of energy in any one hertz; that would make it an unauthorized code. SS systems have been complex and expensive; that would be beyond the resources of radio amateurs. Much of the development has been conducted under government contract; most hams knew little or nothing about the subject. There were more than enough reasons to deter hams from even dreaming about an SS rig in their shacks.

The situation has changed greatly in recent years! SS technology has progressed to the point where affordable systems can be built for amateur and other non-governmental uses. The replacement of the Federal Communications Commission's Office of the Chief Engineer with the Office of Science and Technology (OST) carried with it the mandate to encourage the use of new technology. The FCC's OST sees the Amateur Radio Service as a test bed for new techniques. Some at the FCC feel that the long-term retention of amateur frequencies, in competition with other radio services, depends largely on continued technological advancements by amateurs. We may be entering an "experiment or expire" era.

Why the sudden interest in SS? The reasons are many. First, there is the simple technical imperative, meaning that the technology is there as a result of many years of government-sponsored development, so why not use it for civilian applications? Another reason is that a number of SS users, say in the Land Mobile Service, could be overlaid on top of an existing band already "full" of mobile users employing conventional frequency modulation. Similar overlays could be tried by amateur experimenters in the ham bands. If this is done with care, the preexisting users wouldn't even detect the presence of the SS overlay. Yet another possibility is the creation of new bands, maybe a 900-MHz band, which would use SS exclusively to accommodate

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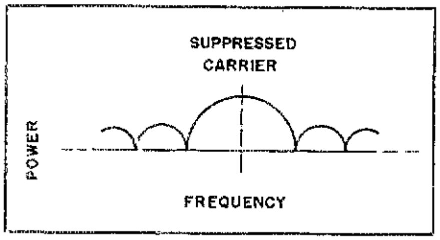


Fig. 1 — Power vs. frequency for a direct-sequence-modulated spread-spectrum signal. The envelope assumes the shape of a $\left(\frac{\sin x}{x}\right)^2$ curve. With proper modulating techniques, the carrier is suppressed.

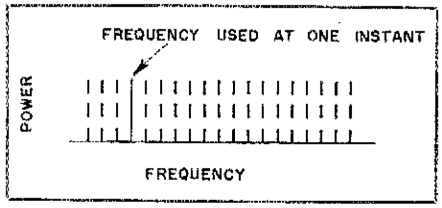


Fig. 2 — Power vs. frequency for frequency-hopping spread-spectrum signals. Emissions jump around in pseudo-random fashion to discrete frequencies.

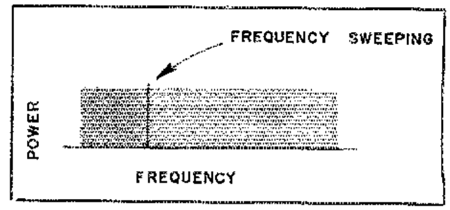


Fig. 3 — Power vs. frequency for chirp spread-spectrum signals. The carrier is repeatedly swept, continuously, from one end to the other in a given band.

thousands of users. Moreover, SS could afford these users both privacy and immunity from interference through proper code settings. In general, SS offers possibilities for more extensive sharing of frequencies while minimizing interference.

Spread-Spectrum Fundamentals

SS systems employ radio-frequency bandwidths that greatly exceed the bandwidth necessary to convey the intelligence. Bandwidths for SS systems generally run from 10 to 100 times the information rate. By spreading the power over a wide band, the amount of energy in any particular hertz or kilohertz is very much smaller than for conventional narrow-band modulation techniques. Depending upon the transmitter power level and the distance from the transmitter to the receiver, the SS signal may be below the noise level.

SS systems also use coding sequences to modulate and demodulate the transmission. Receivers with the wrong code will not demodulate the encoded SS signal and will be highly immune to interference from it. On the other hand, receivers with the right code are able to add all the spread energy in a constructive way to reproduce the intended modulation. In fact, the use of coherent correlation can yield some process gain. Changing the code to another sequence effectively creates a new "channel" on which a private conversation can take place. Many good code combinations could be made available on a single chip and selected by means of thumbwheel switches on the SS transceiver.

Types of Spread Spectrum

There are four basic types of spread spectrum: direct sequence, frequency hopping, pulse-fm and time hopping. In addition, there are hybrids consisting of combinations of two or more of the above basic types.

Direct Sequence (DS): Direct sequence SS is produced by modulation of a carrier with a digitized code stream. This type of modulation is also known by the terms pseudo-noise (PN), phase hopping (PH), direct spread, or direct code. Phase-shift keying (psk) is usually used to produce the marks and spaces, but frequency-shift keying (fsk) could also be used. The wide rf bandwidth arises from the use of a high-speed code. Of course, if the transmitter were allowed to rest on the mark frequency, there would be a steady carrier in one place whenever there is no modulation. This would produce interference to a narrow-band user on that frequency. It would also pose problems for other SS users of the same band, particularly if they did the same thing. So it is conventional for SS systems to include techniques to continue a pseudo-random code sequence even during intervals when intelligence is not being transmitted.

The power spectrum for a DS signal (as might be seen on a spectrum analyzer) is not uniform across the band, but has a main lobe and sets of sidelobes as illustrated in the title photo and in Fig. 1. The bandwidth of the main lobe as measured from null to null is two times the clock rate of the code sequence. The bandwidth of the side lobes is equal to the clock rate. To receive a DS signal, the receiver must collapse or "despread" it to the original bandwidth of the information. This is done by using a replica of the code sequence used by the transmitter.

Frequency Hopping (FH): As the name implies, frequency hopping is simply jumping to a number of different frequencies in an agreed sequence. The code sequence is usually at a slower rate than for direct sequence and is normally slower than the information rate. The hopping rate may also be determined by practical considerations, such as how long it takes for a particular frequency synthesizer to settle down on a new frequency.

Actual modulation of the frequencies uses normal narrow-band techniques such as frequency modulation. At any instant, an FH transmitter is emitting all of its power on a specific frequency slot and potentially could interfere with someone else using a narrow-band system on that frequency. However, the FH dwell time on that particular frequency is so short that most narrow-band users would not be bothered. Mutual interference between two or more FH users sharing the same band could be extremely low, depending upon the design of the code sequences. Fig. 2 illustrates the power spectrum for an FH signal.

Pulse-FM (Chirp): A chirp spread-spectrum system sweeps its carrier frequency over a wide band at a known rate. Again, conventional narrow-band modulation of the sweeping carrier is used to convey the intelligence. The receiver uses a matched, dispersive filter to compress the signal to a narrow band. Chirp systems typically do not use a code sequence to control the sweep generator. Sweep time can be largely independent of the information rate. Normally, a linear-sweep pulse is used, similar to that produced by a sweep generator. The power spectrum for a chirp system is illustrated in Fig. 3.

Time Hopping (TH): Time hopping is a form of pulse modulation using a code sequence to control the pulse. As in other pulse techniques, the transmitter is not on full time and can have a duty cycle of 50% or less. Several systems can share the same channel and function as a time-division multiple-access (TDMA) system. TH is more vulnerable to interference on its center frequency than other SS systems. Seldom seen in its pure form, TH is typically used in hybrid systems using frequency hopping as well.

Hybrids: In addition to the TH/FH hybrid system just mentioned, there are also DS/FH and DS/TH combinations. Hybrid systems are typically designed to accommodate a large number of users and to provide a higher immunity to interference. They also produce better results at practical code sequence rates governed, for example, by how fast a frequency synthesizer can be switched. Also, hybrids can produce greater spreads than those which are practical for pure SS systems.

Some Considerations

Synchronization: In the design of a spread-spectrum system, usually the toughest problem is synchronization of the code sequence at the receiver with that of the incoming signal. If sync is not attained, even just one bit off, nothing but noise can be heard. The problem becomes worse when more than two stations are trying to communicate in a net. This is because of the different propagation delays between stations; i.e., it takes a different time for a signal to travel over paths A-B, A-C, or B-C if the stations are not equidistant. These differences may be only slight but just enough to degrade the signal-to-noise ratio of the received signal.

Glossary of Spread Spectrum Terms

Chirp — Same as pulse-fm.
Code sequence — A series of 1 or 0 bits arranged in a known pattern.
Direct code — Same as direct sequence.
Direct sequence — A type of spread-spectrum modulation using a code sequence to modulate a carrier, normally using phase-shift keying.
Direct spread — Same as direct sequence.
Frequency hopping — A type of spread spectrum which employs rapid switching between a large number of discrete frequencies.
Hybrid — A spread spectrum system that combines two or more basic types of spread spectrum.
Phase hopping — Same as direct sequence.
Pseudo-noise — Same as direct sequence.
Pulse-fm — A type of spread spectrum that uses a swept carrier.
Spread spectrum — A class of modulation types that produce bandwidths far in excess of the bandwidth necessary to convey the intelligence.
Time hopping — A type of spread spectrum using a form of pulse modulation in which the pulses are controlled by a code sequence.

In addition to the time uncertainty related to propagation, there is also a frequency uncertainty in trying to keep oscillators at two or more stations from drifting.

Because the stations cannot be expected to synchronize on their own with no reference, it is normal for at least one station to transmit an initial reference for sync purposes. Upon reception, the receiving stations can generate the code sequence at a rate different from the code sequence used at the transmitter. Eventually, the two code streams will slide into phase with one another and may then be locked up. After initial synchronization, maintaining sync presents another problem which can be solved in different ways. One is to use a code sequence preamble at the beginning of each transmission. Another is to use ultra-stable clocks at all stations to ensure that the code-sequence clock frequency does not change. Numerous other schemes have been devised and implemented with varying degrees of difficulty. The exception is that chirp systems do not have this problem because the matched filter used in demodulation inherently achieves sync on each pulse transmitted.

Transmitter and Receiver Design: One difference between SS and conventional rf equipment is that SS requires transmitters and receivers that have 10 to 100 times the bandwidth of narrow-band systems. That may pose some problems at lower frequencies, but in the 420-MHz band the amateur television (ATV) experimenters already have equipment that can handle wideband signals. The transmitter design, which should be well within amateur capability, amounts to taking care in broadbanding the rf stages after modulation to maintain amplitude linearity, and in keeping the antenna system VSWR very low. Receivers must not only have wideband front ends but must have good dynamic range and linearity to handle both the desired signal and any interference. Where an i-f is used, the frequency chosen must be higher than for conventional transceivers. In practice, 70 MHz is a common SS i-f. Components (such as filters) are available for this frequency to build SS i-f modems (modulator/demodulators).

Amateur SS Experimentation

The Amateur Radio Research and Development Corporation (AMRAD) has formed a group to experiment with several different types of SS systems. Before on-the-air tests are conducted, it will be necessary to obtain a Special Temporary Authorization (STA) from the FCC. Readers wishing to participate should contact AMRAD via the author.

The continued existence of the Amateur Radio Service depends, in part, on amateurs' contributions to the state of the art through experimentation. Spread spectrum is fertile ground for amateur investigation. While SS has been developed extensively for military and other governmental applications, civil uses are virtually unexplored. Hams have the capacity to build SS systems which are practical and inexpensive. There is no guarantee that SS will prove itself worthy of regular use in civilian radio services, but the technology is ripe for Amateur Radio experimentation. QST

[The title photo, a spectrum analyzer display of a direct-sequence spread-spectrum signal, is reprinted through the courtesy of Robert Dixon and John Wiley & Sons, Inc. The photo appears on the cover of *Spread Spectrum Systems.* — Ed.]

Selected Bibliography

Reading material on spread spectrum may be difficult to obtain for the average amateur. Below are references that can be mail ordered. Spread spectrum papers have also been published in IEEE Transactions on Communications, on Aerospace and Electronic Systems and on Vehicular Technology.

Dixon, *Spread Spectrum Systems,* 1976, Wiley-Interscience, 605 Third Ave., New York, NY 10016, $29.50.

Dixon, *Spread Spectrum Techniques,* IEEE Service Center, 445 Hoes La., Piscataway, NJ 08854, IEEE member prices $19.45 clothbound, $12.95 paperbound; nonmembers $29.95 clothbound.

Brumbaugh, et al., *Spread Spectrum Technology,* a series of papers presented at the 1980 Armed Forces Communications Electronics Association show printed in the August 1980 issue of *Signal,* available from AFCEA, Skyline Center, 5205 Leesburg Pike, Falls Church, VA 22041.

Current published searches on spread spectrum are available from the U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161 for $30 each:

Spread Spectrum Communications (99), May 79 NTIS/PS-79/0494/9.

Spread Spectrum Communications (188), May 79 (El) NTIS/PS-79/0495/6.

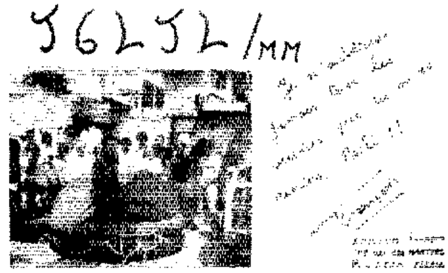
Strays

HAMS RESCUE HAM IN BERMUDA TRIANGLE

☐ Three seagoing Amateur Radio operators recently had an unusual rendezvous. Captain Emerson Hiller, KA1CYA, master of the research vessel *Knorr,* and Bill Edwards, K5CN, radio officer on the *Knorr,* brought Francois Erpicum, J6LJL/MM aboard the ship where he was a guest for almost a month.

Francois was certainly maritime mobile when he was found in the Bermuda Triangle area where he had been adrift in a life raft for four days and nights. His sailing vessel, the *Nanesse,* had been struck, holed and sunk within seconds after being hit on May 20. He was rescued just after midnight on May 24, when the watch on the *Knorr* sighted his red flare. He never learned what it was that struck his vessel. Word of his rescue was sent to the U.S. Coast Guard and over amateur frequencies.

Francois departed the *Knorr* upon its arrival in Ponta Delgada, Azores, where he was met by Belgian officials who assisted him in matters of immigration, missing passport and the like. During a continuation of his cruise, aboard another sailing vessel, he plans to write a magazine article and a book about his experiences. Keep your ears open for Francois, J6LJL/MM, from the far reaches of the Pacific. It will help if you speak French, but when last seen, Francois was picking up English quite rapidly. — *Bill Edwards, K5CN, McAllen, Texas*



The covered life raft, featured on this unique QSL card, is one reason why Francois Erpicum, J6LJL/MM was in excellent condition after four days and nights adrift in the Bermuda Triangle.

I would like to get in touch with . . .

☐ someone interested in a game of chess via OSCAR 7, mode B. Albert Weiss, K6VU, 2461 Crestview Dr. S., Salem, OR 97302.