# *Digital Communications*

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**Spread Spectrum -**
**It's not just for breakfast anymore!**

Don't blame me, the title is the work of this month's guest columnist, Steve Bible, N7HPR (n7hpr@tapr.org). While cruising the net recently, I noticed a sudden bump in the number of times Spread Spectrum (SS) techniques were mentioned in the amateur digital areas. While QEX has discussed SS in the past, we haven't touched on it in this forum. Steve was a frequent cogent contributor, so I asked him to give us some background. Steve enlisted in the Navy in 1977 and became a Data Systems Technician, a repairman of shipboard computer systems. In 1985 he was accepted into the Navy's Enlisted Commissioning Program and attended the University of Utah where he studied computer science. Upon graduation in 1988 he was commissioned an Ensign and entered Nuclear Power School. His subsequent assignment was onboard the USS Georgia, a trident submarine stationed in Bangor, Washington. Today Steve is a Lieutenant and he is completing a master's degree in computer science at the Naval Postgraduate School in Monterey, California. His areas of interest are digital communications, amateur satellites, VHF/UHF contesting, and QRP. His research area closely follows his interest in amateur radio. His thesis topic is Multihop Packet Radio Routing Protocol Using Dynamic Power Control. Steve is also the AMSAT Area Coordinator for the Monterey Bay area. Here's Steve, I'll have some additional comments at the end.

**Steve Spreads It On**
**(ok, that one was Harold)**

The column title says it all. What was once a communications mode shrouded in secrecy has entered the consumer market in the form of wireless ethernet links, cordless telephones, global position service (GPS), Personal Communications System (PCS), and digital cellular telephony (CDMA). And what are radio amateurs doing with spread spectrum today? Perhaps very little since AMRAD performed early experiments in amateur spread spectrum in the 1980's and formed the early regulatory rules that govern amateur radio today. In this column I would like to reintroduce the topic of amateur spread spectrum communications, discuss what it is and how we can experiment with spread spectrum today. Hopefully this column will prod you into thinking again about spread spectrum communications and see that there are several low cost building blocks available on the market today. Interspersed throughout the column I'll throw in the Part 97 rules and regulations that deal directly with amateur spread spectrum.

**Historical Background**

In 1980, the FCC expressed a desire to extend spread spectrum communications outside of the military-only realm and allow radio amateurs to experiment with spread spectrum communications. The FCC in following Title 47, Section 303 of the Code of Federal Regulations (CFR) shall ...

*(g) Study new rules for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest...*

What this meant was that a new mode of communications was opening up for experimentation and exploration by radio amateurs.

In 1980 AMRAD took the lead and forged the beginnings of amateur spread spectrum experimentation. The results of their experimentation were documented in the AMRAD Newsletter, QEX, QST, and compiled into a single book entitled "The ARRL Spread Spectrum Sourcebook." This is a good book and recommended for anyone learning about spread spectrum communications. Though it is becoming a bit dated by today's standards and advances in technology since the late 1980's, it is nonetheless a good guide and provides a historical perspective into the merging of SS into amateur radio. At the end of the column I will include a selected bibliography so that you can find other sources of information ranging from the practical to theoretical.

**What is Spread Spectrum?**

A spread spectrum system is one in which the transmitted signal is spread over a wide frequency band, much wider, in fact, than the minimum bandwidth required to transmit the information being sent (ref. 1). Spread spectrum communications cannot be said to be an efficient means of utilizing bandwidth. However, it does come into its own when combined with existing systems occupying the frequency. The spread spectrum signal being "spread" over a large bandwidth can coexist with narrowband signals only adding a slight increase in the noise floor that the narrowband receivers see. As for the spread spectrum receiver, it does not see the narrowband signals since it is listening to a much wider bandwidth at a prescribed code sequence which I'll explain later.

First, let's introduce five types of spread spectrum techniques:

**Direct Sequence Systems** - Direct sequence is perhaps one of the most widely known and utilized spread spectrum systems and it is relatively simple to implement. A narrow band carrier is modulated by a code sequence. The carrier phase of the transmitted signal is abruptly changed in accordance with this code sequence. The code sequence is generated by a pseudorandom generator that has a fixed length. After a given number of bits the code repeats itself exactly. The speed of the code sequence is called the chipping rate, measured in chips per second (cps). For direct sequence, the amount of spreading is dependent upon the ratio of chips per bit of information. At the receiver, the information is recovered by multiplying the signal with a locally generated replica of the code sequence. See figure 1.

**Frequency Hopping Systems** - In frequency hopping systems, the carrier frequency of the transmitter abruptly changes (or hops) in accordance with a pseudo random code sequence. The order of frequencies selected by the transmitter is dictated by the code sequence. The receiver tracks these changes and produces a constant IF signal. See figure 2.

**Time Hopping Systems** - A time hopping system is a spread spectrum system in which the period and duty cycle of a pulsed RF carrier are varied in a pseudorandom manner under the control of a coded sequence. See figure 3. Time hopping is often used effectively with frequency hopping to form a hybrid time-division, multiple-access (TDMA) spread spectrum system.

**Pulsed FM (Chirp) Systems** - A pulsed FM system is a spread spectrum system in which a RF carrier is modulated with a fixed period and fixed duty cycle sequence. At the beginning of each transmitted pulse, the carrier frequency is frequency modulated causing an additional spreading of the carrier. The pattern of the frequency modulation will depend upon the spreading function which is chosen. In some systems the spreading function is a linear FM chirp sweep, sweeping either up or down in frequency.

**Hybrid Systems** - Hybrid systems use a combination of spread spectrum methods in order to use the beneficial properties of the systems utilized. Two common combinations are direct sequence and frequency hopping. The advantage of combining the two methods is to capitalize on characteristics that are not available from a single method.

**Why Spread Spectrum?**

To answer the question "why should I use spread spectrum" could easily degenerate into a simple listing of advantages and disadvantages. However, spread spectrum has many different unique properties that cannot be found in any other modulation technique. As radio amateurs, we should exploit these properties and search for useful applications. Think of spread spectrum as another useful tool in our repertoire of modulation methods toolbox. For completeness, I will list some advantages and disadvantages that you will see for typical spread spectrum systems. Bare in mind that these come about because of the nature of spread spectrum, not because they are direct attributes.

Advantages:

- Resists intentional and non-intentional interference
- Has the ability to eliminate or alleviate the effect of multipath interference
- Can share the same frequency band (overlay) with other users
- Privacy due to the pseudo random code sequence (code division multiplexing)

Disadvantages:

- Bandwidth inefficient
- Implementation is somewhat more complex.

**Other Properties**

There are several unique properties that arise as a result of the pseudo random code sequence and the wide signal bandwidth that results from spreading. Two of these are selective addressing and code division multiplexing. By assigning a given code to a single receiver or a group of receivers, they may be addressed individually or by group away from other receivers assigned a different code. Codes can also be chosen to minimize interference between groups of receivers by choosing ones that have low cross correlation properties. In this manner more than one signal can be transmitted at the same time on the same frequency. Selective addressing and Code Division Multiple Access (CDMA) are implemented via these codings.

A second set of properties is low probability of intercept (LPI) and anti-jamming. When the intelligence of the signal is spread out over several megahertz of spectrum, the resulting power spectrum is also spread out. This results in the transmitted power spread out over a wide frequency bandwidth and makes detection in the normal sense (without the code), very difficult. Though LPI is not a typical application for radio amateurs, it would best to rename this property as “reduction of interference.” Thus spread spectrum can survive in an adverse environment and coexists with other services in the band. The anti-jamming property results from the wide bandwidth used to transmit the signal. Recall Shannon’s Information-rate theorem

$$C = W \log (1 + S/N)$$

C = capacity in bits per second
W = bandwidth
S = signal power
N = noise power

where the capacity of a channel is proportional to its bandwidth and the signal-to-noise ratio on the channel. By expanding the bandwidth to several megahertz and even several hundred megahertz, there is more than enough bandwidth to carry the required data rate and have even more to spare to counter the effects of noise. This anti jamming quality is usually expressed as “processing gain.”

So for the radio amateur, the properties of code division multiplexing, coexistence in an adverse environment, and processing gain, are all excellent reasons to experiment with and find useful applications for spread spectrum in the amateur radio service. Coupled with these reasons, amateurs can also enjoy increased data rates in digital data (packet radio) that cannot be done with conventional amateur or commercial radios due to physical (i.e. bandpass filters) and rules restrictions. For example, narrowband systems in the 70 cm band are limited to a maximum data rate of 56 kbps and a bandwidth of 100 kHz, there are no such restrictions in the 33 cm band and up.

Perhaps one of the most important reasons to use spread spectrum is its ability discriminate against multipath interference. A RAKE[1] receiver implementation for direct sequence allows

[1] RAKE is not an acronym. It is called RAKE because the filter arrangement of the receiver is like a garden rake

individual signal paths to be separately detected and the coherently combined with other paths. This not only tends to prevent fading but also provides a path diversity effect resulting in very rugged links in terrestrial mobile communications (ref. 2).

**Building Blocks**

Spread spectrum signals are demodulated in two steps: 1) the spectrum spreading (direct sequence, frequency hopping) modulation is removed, and 2) the signal is demodulated. The process of despreading a signal is called correlation. The spread spectrum signal is despread when the proper synchronization of the spreading code between the transmitter and receiver is achieved. Synchronization is the most difficult aspect of the receiver. More time, research, effort, and money has gone into the development and improving of synchronization techniques than in any other area of spread spectrum. The problem of synchronization is further broken down into two parts: initial acquisition and tracking.

There are several methods to solve the synchronization problem. Many of these methods require a great deal of discrete components to implement. But perhaps the biggest break-through has been from Digital Signal Processing (DSP) and Application Specific Integrated Circuits (ASIC). DSP has provided high speed mathematical functions that can slice up in many small parts and analyze the spread spectrum signal to synchronize and decorrelate it. ASIC chips drive down the cost by using VLSI technology and creating generic building blocks that can be used in any type of application the designer wishes. With the fast growing Part 15 and Personal Communications System (PCS) spread spectrum market, many ASIC manufactures have been designing and selling ASIC chips that take care of the most difficult problem in spread spectrum -- despreading and synchronization. With a few extra components, the amateur can have a fully functioning spread spectrum receiver.

One manufacture of a spread spectrum demodulator ASIC is UNISYS (Unisys Communications Systems Division, DSP Components, Dept. 9065, M/S F1F12, 640 North 2200 West, Salt Lake City, Utah 84116-2988; Phone: (801) 594-4440; Fax: (801) 594-4127). Their PA-100 performs the functions of despreading and demodulation, carrier recovery loop (frequency or phase), Pseudo Noise (PN) code detection, PN code tracking loop, data synchronization, and automatic gain control. It is programmable and offers a wide range of choices in data rates, modulation types, processing gains, PN codes, loop bandwidths, and tracking and acquisition procedures. It is capable of chipping rates up to 32 Mcps and data rates up to 64 Mbps. The PA-100 is controlled via a simple 8-bit interface. The chip is a 208-pin plastic Metrix Quad Flat Package (MQFP). The cost of the chip is $167.00 in single qty and $67.00 in lots of 1000.

**Where does Part 15 fit into all this?**

Many of the spread spectrum devices on the market today are listed as Part 15 devices. This refers to the device operating under the provisions of Title 47 Section 15.247 of the Code of Federal Regulations (CFR). There are three frequency bands allocated to this service:

902 - 928 MHz (26 MHz bandwidth)
2400 - 2483.5 MHz (83.5 MHz bandwidth)
5725 - 5850 MHz (125 MHz bandwidth)

Operation under this provision of this section is limited to frequency hopping and direct sequence spread spectrum. No other spreading techniques are permitted. Section 15.247 defines the technical standards that these systems must operate under. For example, the maximum peak output power of the transmitter shall not exceed 1 watt. If transmitting antennas of directional gain greater than 6 dBi are used, the power shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. This equates to a maximum transmitter EIRP of +6dBW (1 watt into a 6 dBi gain antenna)

Part 15 equipment operates on a secondary basis. Users must accept interference from other transmitters operating in the same band and may not cause interference to the primary users in the band. Primary users are government systems such as airborne radiolocation systems that emit a high EIRP; and Industrial, Scientific, and Medical (ISM) users. Thus the Part 15 device manufacturer must design a system that will not cause interference with and be able to tolerate the noisy primary users of the band. And this is where spread spectrum systems excel because of their low noise transmissions and ability to operate in an adverse environment.

Amateurs should realize that under the present Part 97 rules and regulations governing amateur spread spectrum today, taking a Part 15 spread spectrum device and adding an amplifier to it would break the rules. Even though it would be transmitting within the amateur spectrum, it more than likely would not be using one of the specified spreading codes assigned to amateur operation (refer to Sec. 97.311 Section (d) - SS emission types). However, this should not deter the radio amateur from using Part 15 devices in their experimentation or use in the amateur service. The device should be monitored to ensure that it remains under the Part 15 regulations and as such, no Part 97 regulations apply. Amateur traffic can flow though Part 15 devices, and they do not require a callsign since they do not require a license. However, the radio amateur should realize that when the traffic enters the amateur bands, for example, through a gateway, then Part 97 rules begin to apply.

**Further Part 97 Rules and Regulations**

Any radio amateur contemplating experimentation of spread spectrum in the amateur bands (excluding Part 15 devices) should become familiar with the present Part 97 rules and regulations governing it. Here are some excerpts that bare emphasizing:

**Sec. 97.119 Station identification**

*(a)(5) By a CW or phone emission during SS emission transmission on a narrow bandwidth frequency segment. Alternatively, by the changing of one or more parameters of the emission so that a conventional CW or phone emission receiver can be used to determine the station call sign.*

**Sec. 97.305 Authorized emission types.**

*Spread Spectrum is permitted on the following bands (over the entire band unless otherwise indicated):*

*UHF: 70 cm (420-450 MHz), 33 cm (902-928 MHz), 23 cm (1240-1300 MHz), 13 cm (2300-2310 and 2390-2450 MHz*)*

*SHF: 9 cm (3.3-3.5 GHz), 5 cm (5.650-5.925 GHz), 3 cm (10.00-10.50 GHz), 1.2 cm (24.00-24.25 GHz)*

*EHF: 6 mm (47.0-47.2 GHz), 4 mm (75.5-81.0 GHz), 2.5 mm (119.98-120.02 GHz), 2 mm (142-149 GHz), 1mm (241-250 GHz), Above 300 GHz*

*Operation on all of the above bands are on a secondary basis. No amateur station transmitting in these bands shall cause harmful interference to, nor is protected from interference due to the operation of the primary service.*

(*Note: Recent rule making has allocated 2390-2400 MHz and 2402-2400 MHz to the Amateur community on a primary basis.)

**Sec. 97.311 SS emission types**

[Note: Sections (a) through (d) set the technical standards for spread spectrum emissions.]

*(e) The station records must document all SS emission transmissions and must be retained for a period of 1 year following the last entry. The station records must include sufficient information to enable the FCC, using the information contained therein, to demodulate all transmissions. The station records must contain at least the following:*

*(1) A technical description of the transmitted signal;*

*(2) Pertinent parameters describing the transmitted signal including the frequency or frequencies of operation and, where applicable, the chip rate, the code rate, the spreading function, the transmission protocol(s) including the method of achieving synchronization, and the modulation type;*

*(3) A general description of the type of information being conveyed, (voice, text, memory dump, facsimile, television, etc.);*

*(4) The method and, if applicable, the frequency or frequencies used for station identification; and*

*(5) The date of beginning and the date of ending use of each type of transmitted signal.*

*(f) When deemed necessary by an EIC to assure compliance with this part, a station licensee must:*

*(1) Cease SS emission transmissions;*

*(2) Restrict SS emission transmissions to the extent instructed;*

*and*

*(3) Maintain a record, convertible to the original information (voice, text, image, etc.) of all spread spectrum communications transmitted.*

*(g) The transmitter power must not exceed 100 W.*

**Rules Reform**

Needless to say, by today's standards, practices, and improvements in technology, the above Part 97 rules and regulations on amateur spread spectrum are extremely restrictive especially in the case of the few fixed spreading codes dictated by section 97.311 (d)(1). The ARRL is reviewing the suggestions from the ARRL Futures Committee for changes to these rules and regulations to allow less restriction and freer experimentation.

**Getting Around the Rules - Legally**

In the mean time there is a Special Temporary Authority (STA) to allow amateur spread spectrum experimentation. Under this STA Section 97.305(c) is waived to the extent that particular amateur stations are authorized to transmit spread spectrum emissions on frequencies in the 6 meter (50 - 54 MHz), 2 meter (144 - 148 MHz), and 1.25 meter (222 - 225 MHz) bands. Section 97.311(c) is waived for these stations to the extent that the prohibition against hybrid spread spectrum emissions is lifted; and Section 97.311(d) is waived for these stations to use other spreading codes.

To participate in this STA it is requested that you have a bonafide purpose of experimenting and advancing the art of amateur spread spectrum. Contact Robert Buaas, K6KGS, 20271 Bancroft Circle, Huntington Beach, California 92646. Please include your name, address, callsign, expiration date of your license, and the details of your experiment. Do include an abstract of the project and a proposed set of goals you are trying to obtain. The information that you collect through your experimentation will be helpful in the advancement of Amateur spread spectrum but will also be useful for justification for rules changes before the FCC.

**Areas to expand and research**

Typical SS applications such as wireless ethernet use point-to-point communications. They link two subnets over distances of several miles with external Yagi antennas and less than one watt of power. Amateurs would rather use the traditional CSMA/CA technique they are familiar with in today's packet radio. However, with the requirement of correlating the spreading code it would require a network node to have multiple receivers to listen in on the channel and detect when an outlying node is trying to communicate with it. Here's where amateur radio experimentation can advance the art of spread spectrum, by creating a CDMA spread spectrum packet radio network. By using the techniques employed by GPS, relatively short codes can be use to minimize receiver acquisition time. These codes would also need to have good cross-correlation properties to minimize multiple access interference between nodes.

Power control is required to control the reuse of the frequency beyond code division multiplexing. It also behooves us to explore good power control to limit interference and to reduce the power consumption and drain on batteries.

Routing of packets through a network is typically a software issue, but with the ability to do code division multiplexing, how do we route packets from one subnet to another when they do not use the same code sequence?

Driving cost down has always been a top goal of any designer, and even more so since the Amateur is experimenting with their own money. Amateurs tend to be a frugal lot and will find any means available to build a system that costs as little as possible. This spawns innovative and creative methods to achieve this means. Then these means tend to be passed back to the commercial sector and benefit everybody.

CDMA is not the exclusive province of direct sequence systems; CDMA can also be used with frequency hopping. TDMA is not the exclusive province of narrowband systems; TDMA can also be used with direct sequence or frequency hopping.

**This isn't new**

In the 1982 AMRAD letter (reprinted on page 4-11 of the ARRL SS Handbook), Hal Feinstein, WB3KDU, wrote,

*Spread spectrum has found its way into packet radio. Spread spectrum allows each node to have a unique code which acts as a hard address. Another node in the system can send data to that node by encoding that data with the spread spectrum address for the receiving node. Traffic for other nodes does not interfere because it would have a different code. Among the reasons cited for employing spread spectrum for packet switching are privacy, selected addressing, multipath protection and band sharing. But it is interesting to note that a load is taken off the contention collision approach because now a single frequency is not in contention among the nodes wishing to transmit. The load is divided among the nodes addresses, and each that is interested in sending data to a target node competes for that node only.*

This is the CDMA part of SS. This is one of those areas the FCC really wants hams to experiment with. I think the paper has a lot of insight and it was even written over 13 years ago.

**PANSAT - A Spread Spectrum Satellite**

The Space Systems Academic Group (SSAG) at the Naval Postgraduate School (NPS) in Monterey, California is actively designing and building an amateur satellite named PANSAT (see figure 4). PANSAT is the acronym for Petite Amateur Navy Satellite. PANSAT is to become a packet digital store-and-forward satellite vary similar in capabilities as the existing PACSATs in orbit today. The tentative launch date of PANSAT is late 1996, early 1997 as a Get Away Special (GAS) payload from the Space Shuttle.

One big difference between today's PACSATs and PANSAT is that PANSAT will use direct sequence spread spectrum as the communications up and downlink.

PANSAT is being designed from the ground up as an amateur satellite. The only military mission of PANSAT is as a training vehicle for the education of military officers in the Space Systems Curricula by the design, fabrication, testing and operation of a low-cost, low earth orbit (LEO), digital communications satellite. One of the engineering objectives of PANSAT includes the evaluation and performance of spread spectrum packet radio communications using the Amateur community as the user base.

In order to facilitate the evaluation of spread spectrum performance the SSAG is designing a low cost spread spectrum modem and RF package to be presented to the amateur community in a kit form. The goal is to have the design of the spread spectrum radio/modem available before the launch of PANSAT to allow Amateurs to build and become operational via terrestrial means. This presents an exciting exchange of technology and the ability for the Amateur to build a low cost unit to experiment with. As the design and development progresses they will be presented in the Amateur press.

**Future and Summary**

Now is the time to begin experimenting with spread spectrum communications on a wider scale. Technology has advanced to the point where Amateurs can afford to build systems. The building blocks are available now in the form of Application Specific Integrated Circuits. The recent flood of consumer devices that employ spread spectrum has also driven the price down. In many cases the Amateur can either use these devices under their present type acceptance or modify them for Amateur operations. However, the Amateur should remain aware of the rules and regulations governing the particular device whether it falls under Part 15 or Part 97 of the FCC Rules and Regulations and remain within their guidelines. If the Amateur wishes to expand beyond the present Part 97 rules in bonafide experimentation, they are encouraged to join in the Special Temporary Authority.

Spread spectrum systems exhibit unique qualities that cannot be obtained from conventional narrowband systems. There are many research avenues exploring these unique qualities. Amateurs in their inherent pioneering nature can and will find new and novel applications for spread spectrum communications that the commercial sector may not even think of. And due to the frugal propensity of the Radio Amateur, they will certainly find the least expensive way to implement it, thus driving down the cost.

Amateurs should realize that there is plenty of room to explore spread spectrum techniques. All that remains now is to pick up a few good books on the subject and warm up the soldering iron. And as you progress upon this road less traveled, make sure you take notes along the way. Then share your discoveries with your fellow Amateur to help all of us expand the horizon with this exciting mode of communications call spread spectrum. It is no longer shrouded in secrecy and it's not just for breakfast anymore!

**WEB Crawling**

Here are two WEB pages of interest. I've started a general amateur radio SS page, http://www.tapr.org/ss.

See also the PANSAT page at http://www.sp.nps.navy.mil/pansat/pansat.html

**Selected Bibliography**


**Books -**

***Extensive research oriented analysis -***

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***Intermediate level -***

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R.E. Ziemer and R.L. Peterson, *Introduction to Digital Communications*, New York, Macmillan, 1985.

***Practical -***

R.C. Dixon, *Spread Spectrum Systems*, John-Wiley & Sons, 1984.

**Journals -**

There have been several special issues of IEEE publications that are devoted to spread spectrum systems. IEEE Transactions on Communications: August 1977 and May 1982. IEEE Journal of Selected Areas in Communications: May 1990, June 1990, and May 1992.


**References**


(1) R.C. Dixon, Spread Spectrum Systems, John-Wiley & Sons, 1984, page 7.

(2) K. Gilhousen, Qualcomm Inc., USENET newsgroup discussion.

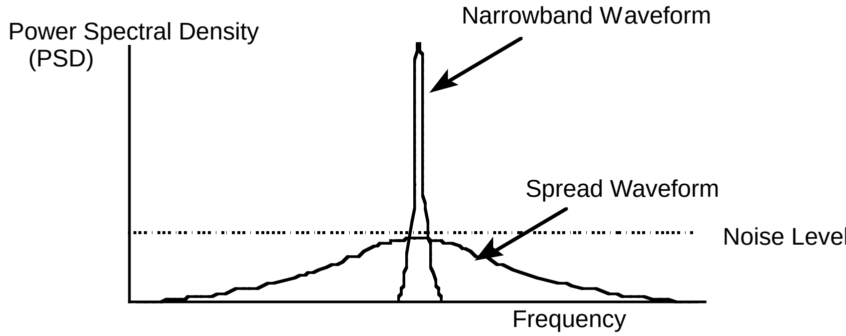


Figure 1. Comparison of a narrowband signal with a Direct Sequence Spread Spectrum signal. The narrowband signal is suppressed when transmitting spread spectrum.

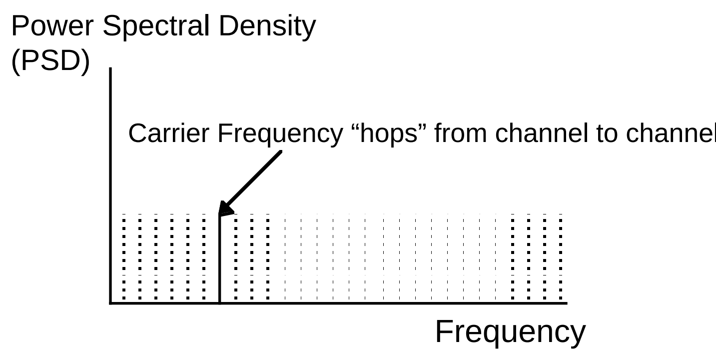


Figure 2. An example of Frequency Hopping Spread Spectrum signal.

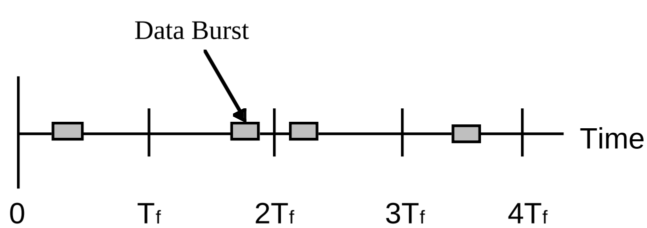


Figure 3. Time Hopping Spread Spectrum. Each burst consists of *k* bits of data and the exact time each burst is transmitted is determined by a PN sequence.

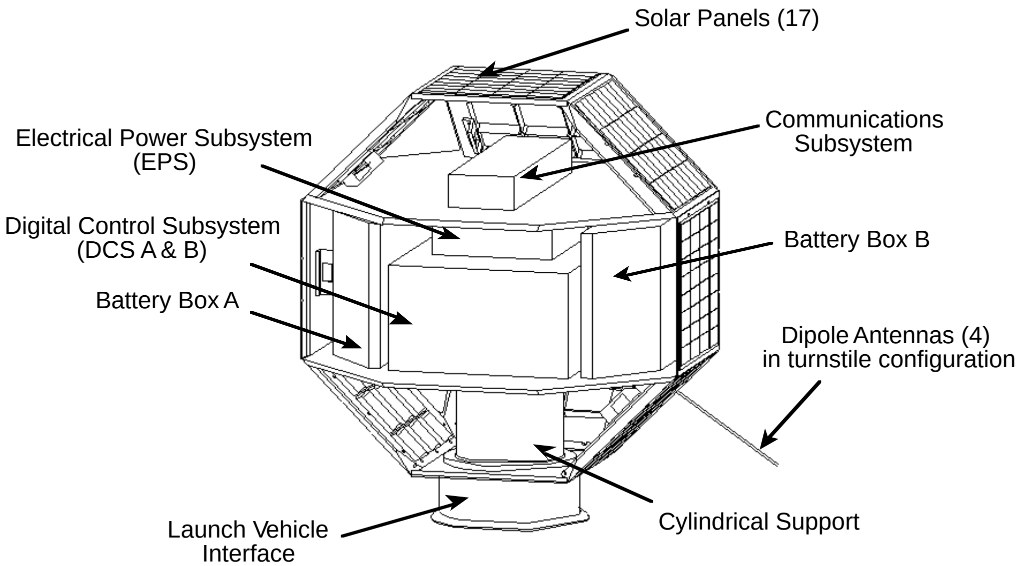


Figure 4. A cut away view of PANSAT, a Direct Sequence Spread Spectrum satellite being designed and built at the Naval Postgraduate School in Monterey, California.