

Introduction to Spread Spectrum Communications

The aspects involved in spread spectrum techniques.

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What is meant by spread spectrum? Many electrical engineers ask that question (especially "non-RF" engineers), even though literature and books on the subject abound, and explanations can be found at various websites. Indeed, simple explanations are not readily available without first developing some complex ideas through the use of equations. Some papers dwell exclusively on certain aspects of the technique while ignoring others (the DSSS type, for instance, with extensive focus on PN-code generation). The following discussion attempts to popularize spread-spectrum techniques by highlighting most of the aspects involved.

Theoretical Justification for SS

Spread spectrum (SS) is apparent in the Shannon and Hartley channel-capacity theorem:

$$C = B \cdot \log_2 (1+S/N).$$

In that equation, C is the channel capacity in bits per second (bps), which is the maximum data rate for a theoretical bit-error rate (BER). B is the required channel bandwidth in Hz, and S/N is the signal-to-noise power ratio. To be more explicit, one assumes that C, which represents the amount of information allowed by the communication channel, also represents the desired performance. Bandwidth (B) is the price to be paid, because frequency is a limited resource. S/N ratio expresses the effect of environmental conditions and physical characteristics such as obstacles, presence of jammers, interference, etc.

An elegant interpretation of this equation that is applicable to difficult environments (those with a low S/N ratio caused by noise and interference) says that one can maintain or even increase communication performance (high C) by allowing or injecting more bandwidth (high B), even when the resulting signal power is below the noise floor. (The equation does not forbid that condition!)

The application of a few mathematical tools, such as McLaurin's series for log functions, simplifies and reduces the Shannon expression:

$$C/B \sim 1.433 \cdot S/N.$$

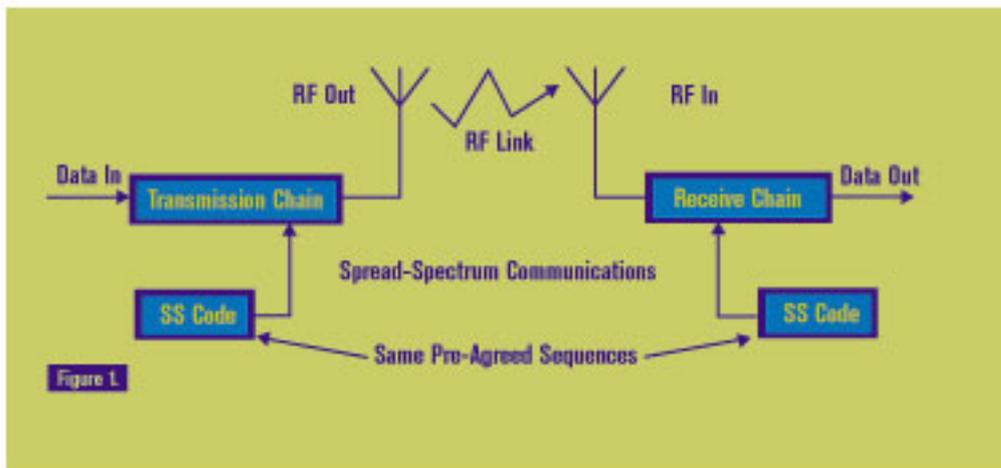
Very roughly, $C/B \sim S/N$, or

$$N/S \sim B/C.$$

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Thus, to send error-free information for a given noise-to-signal ratio in the channel, we need only perform the fundamental SS signal-spreading operation: increase the transmitted bandwidth. That principle seems simple and evident, but its implementation is complex (mainly because spreading the baseband (by a factor that can be several orders of magnitude) forces the electronics to act and react accordingly).



Definitions

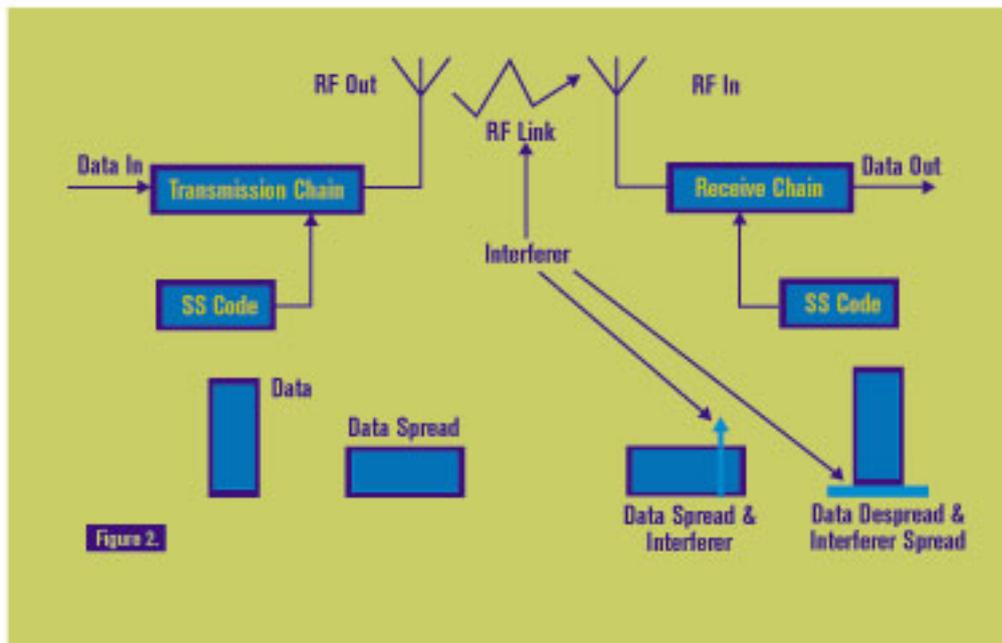
The formal definition of SS is more precise: SS is an RF communications technique in which the baseband signal bandwidth is intentionally spread over a larger bandwidth by injecting a higher-frequency signal. As a direct consequence, transmission energy is spread over a wider bandwidth and appears as noise. The ratio (in dB) between the spread baseband and the original signal is called processing gain. Typical SS processing gains run from 10 dB to 60 dB.

To apply an SS technique, simply inject the corresponding SS code somewhere in the transmitting chain (that injection is called the spreading operation). Conversely, you can remove the SS code (despreading operation) at a point in the receive chain before data retrieval. The effect of a despreading operation is to reconstitute the information in its original bandwidth. Obviously, the same code must be known in advance at both ends of the transmission channel. (In some circumstances, it

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should be known only by those two parties.)



Resistance to interference (anti-jamming effects) - Jamming signals and interference (whether intentional or unintentional) are rejected because they do not contain the SS key. That is the real beauty of SS. Only the desired signal, which has the key, will be seen at the receiver when the despreading operation is exercised.

SS and (de)coding keys - The codes of modern communications are digital sequences, which are made to appear "noise-like" by making them as long and as random as possible. In any case they must remain reproducible, so at best the sequence is "nearly random." Such codes are called pseudo-random numbers (PRNs). The hardware most frequently used to generate pseudo-random codes is just a feedback shift register, a chain of RS-flip-flops with EXOR gate feedback.

To guarantee efficient SS communications, PRN sequences must respect certain rules such as length, auto-correlation, cross-correlation, orthogonality, and bits balancing. The more popular PRN sequences have names: Barker, M-Sequence, Gold, Hadamard-Walsh, etc. Keep in mind that a more complex sequence provides a more robust SS link, but the price paid for that advantage is more complex electronics (both in speed and behavior), mainly for the SS despreading operation. SS despreading chips can contain several million equivalent 2-input NAND gates, switching at several tens of megahertz.

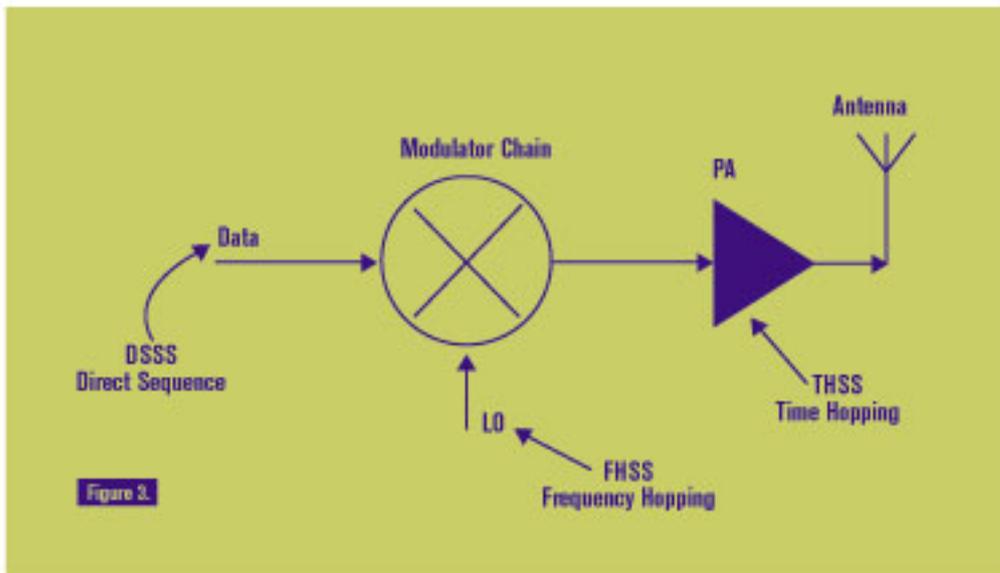
Modulation (spreading) techniques for SS - Different SS techniques are distinguished according to the point in the communication channel at which the PRN is inserted.

If the PRN is inserted at the data level, we have the direct sequence form of spread spectrum (DSSS). (In practice, the pseudo-random sequence is mixed or multiplied

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with the information signal, giving an impression that the original data flow was "hashed" by the PRN.) If the PRN acts at the carrier-frequency level, we have the frequency hopping form of spread spectrum (FHSS). Applied at the LO stage, FHSS PRN codes force the carrier to change or hop according to the pseudo-random sequence. If the PRN acts as an on/off gate to the transmitted signal, we have a time hopping spread spectrum technique (THSS). One can mix all the above techniques to form a hybrid SS technique such as DSSS + FHSS. DSSS and FHSS are the techniques most in use today.



Implementations and Conclusions

A complete SS communication link requires various advanced and up-to-date technologies and disciplines: RF antenna, powerful and efficient power amplifier (PA), low-noise, highly linear low-noise amplifier (LNA), compact transceivers, high-resolution analog-digital and digital-analog converters (ADCs and DACs), rapid, low-power digital signal processing (DSP), etc.

The area of most difficult technical challenge is the receiver path, especially at the despreading level for DSSS, because the receiver must be able to recognize the message and synchronize with it in real time. Because correlation is performed at the digital-format level, the tasks are mainly complex arithmetic calculations including fast, highly parallel binary additions and multiplications. More time, effort, research, and money has gone toward developing and improving synchronization techniques than toward any other aspect of SS communications.

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