SPREAD SPECTRUM TECHNIQUES

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Feb. 1st 2005
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Hedy Lamarr
25-Year Old Hollywood Star
Frequency Hopping

WESTERN EUROPE EDITION

THE STARS AND STRIPES

Unofficial Newspaper of U.S. Forces in the European Theater

Vol. 2—No. 128 1 Fr. Monday, Nov. 19, 1945

Hedy Adds New Twist to War

Actress Invents Control Device While Toying With Torpedo Idea, Has Patent to Prove It

Hedy Lamarr

HOLLYWOOD, Nov. 18 (AP).—It could not have been a press agent's stunt, because the timing was too perfect, but the report from London that film actress Hedy Lamarr had patented a radio steering device for torpedoes at least had a patent to back it up.

In an interview, Hedy modestly admitted she did only "creative work on the invention," while the composer and author, George Antheil, "did the really important chemical part."

Hedy was not too clear about how the device worked, but she remembered that she and Antheil sat down on her living room rug and were using a silver match box with the matches simulating the wiring of the invented "thing".

She said that at the start of the war "British fliers were over hostile territory as soon as they crossed the channel, but German aviators were over friendly territory most of the way to England... I got the idea for my invention when I tried to think of some way to even the balance for the British. A radio controlled torpedo, I thought would do it."

Hedy asserted that the "control" device works on aerial as well as submarine torpedoes.

She said it works on anything and added that it was "lots of fun planning the invention and watching them pick, sort and put together all the little thingamabobs that went into the device." She said it was lots more fun being scientific than going to the movies.

She coyly dodged a query as to whether any company was interested in producing the device but did admit that as far as she knew nobody has ever used it yet for any practical purpose.

"Not Just a Pretty Face"

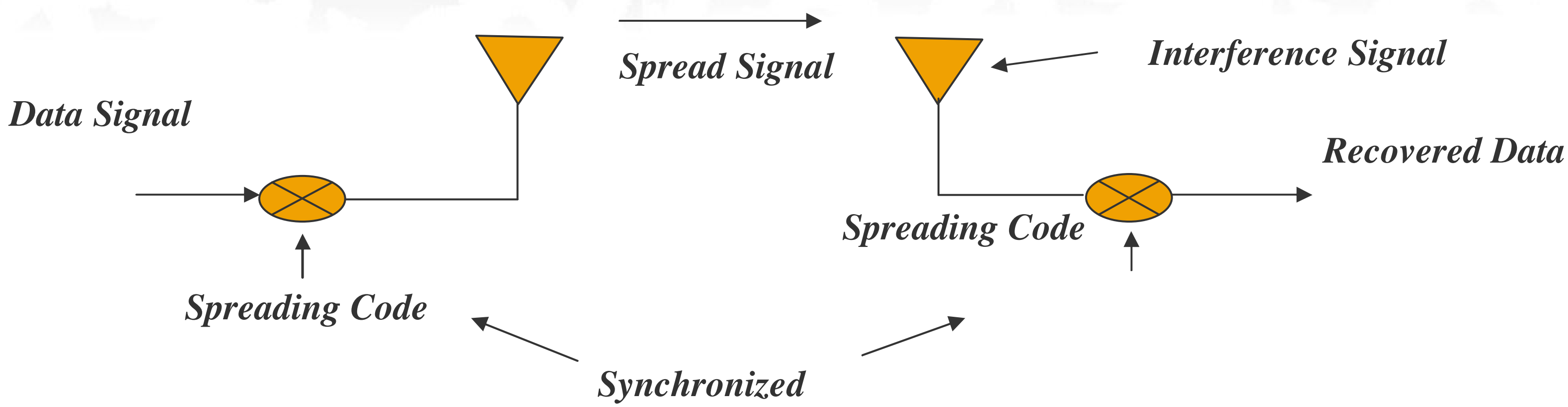
Hedy Lamarr - Story Continued

- Today, spread spectrum devices using micro-chips, make pagers, cellular phones, and, yes, communication on the internet possible. Many units can operate at once using the same frequencies.
- Most important, spread spectrum is the key element in anti-jamming devices used in the government's 25 billion Milstar system. Milstar controls all the intercontinental missiles in U.S. weapons arsenal.
- Fifty-five years later, Lamarr was recently given the EFF (Electronic Frontier Foundation) Award for their invention. The co-inventor, Antheil was also honored; he died in the sixties.

Why Spread Spectrum ?

- 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.

Basic Spread Spectrum Technique (1/2)

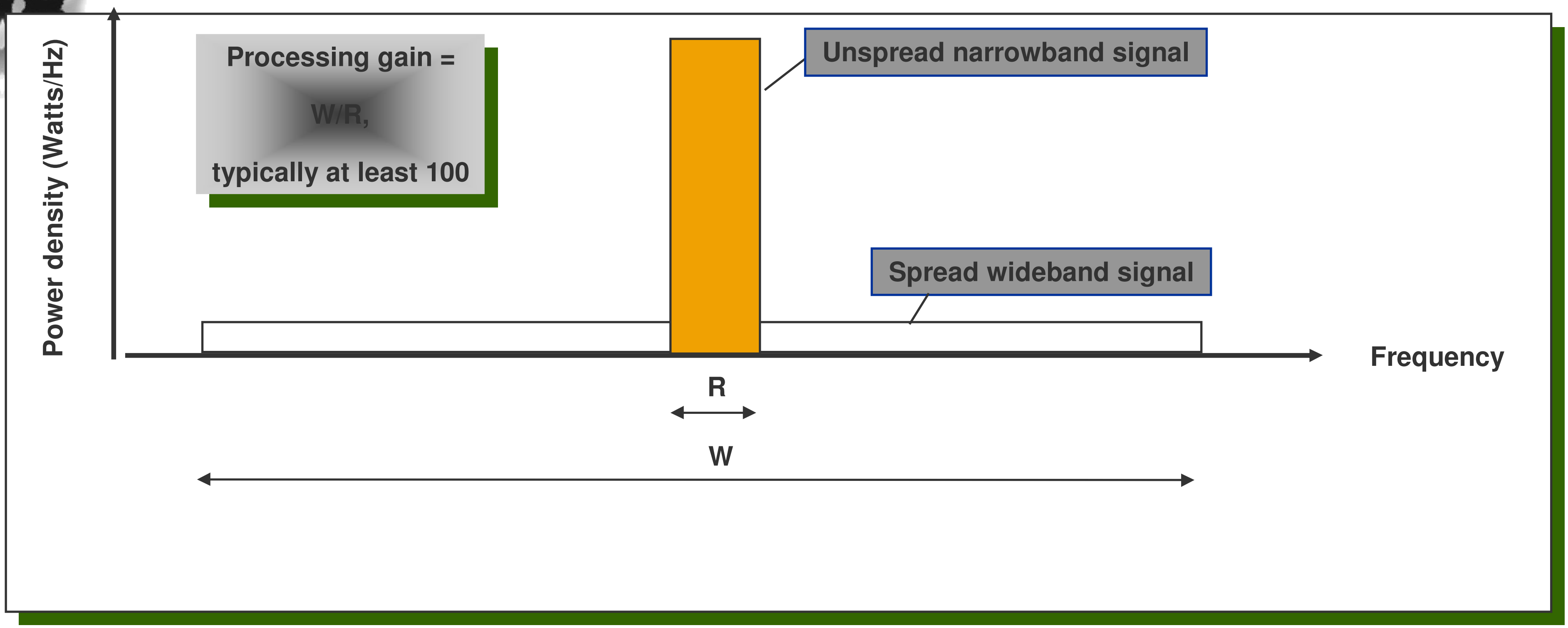


DEFINITION:

Spread spectrum (SS) is a means of transmission in which:

1. The transmitted signal occupies a bandwidth which is much greater than the minimum necessary to send the information.
2. Spreading is accomplished by means of a spreading signal called a ‘code’ signal, which is independent of the data.
3. At the receiver, despreading is done by correlating the received SS signal with a synchronized replica of the spreading signal.

Basic Spread Spectrum Technique (2/2)



A narrowband signal is spread to a wideband signal (example: CDMA):

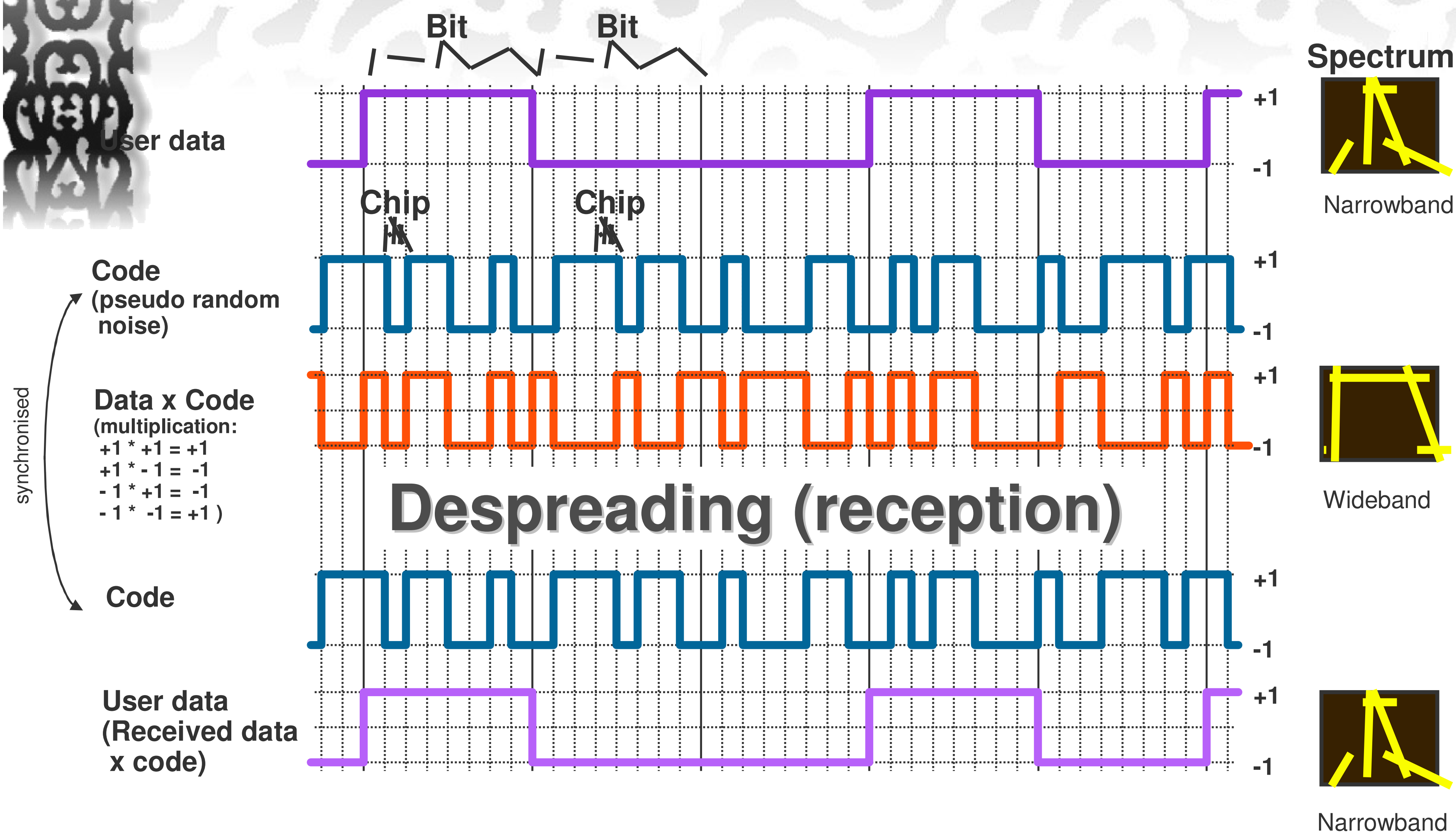
Spread-Spectrum Theoretical Justification

- SS is apparent in the Shannon and Hartley channel-capacity theorem:

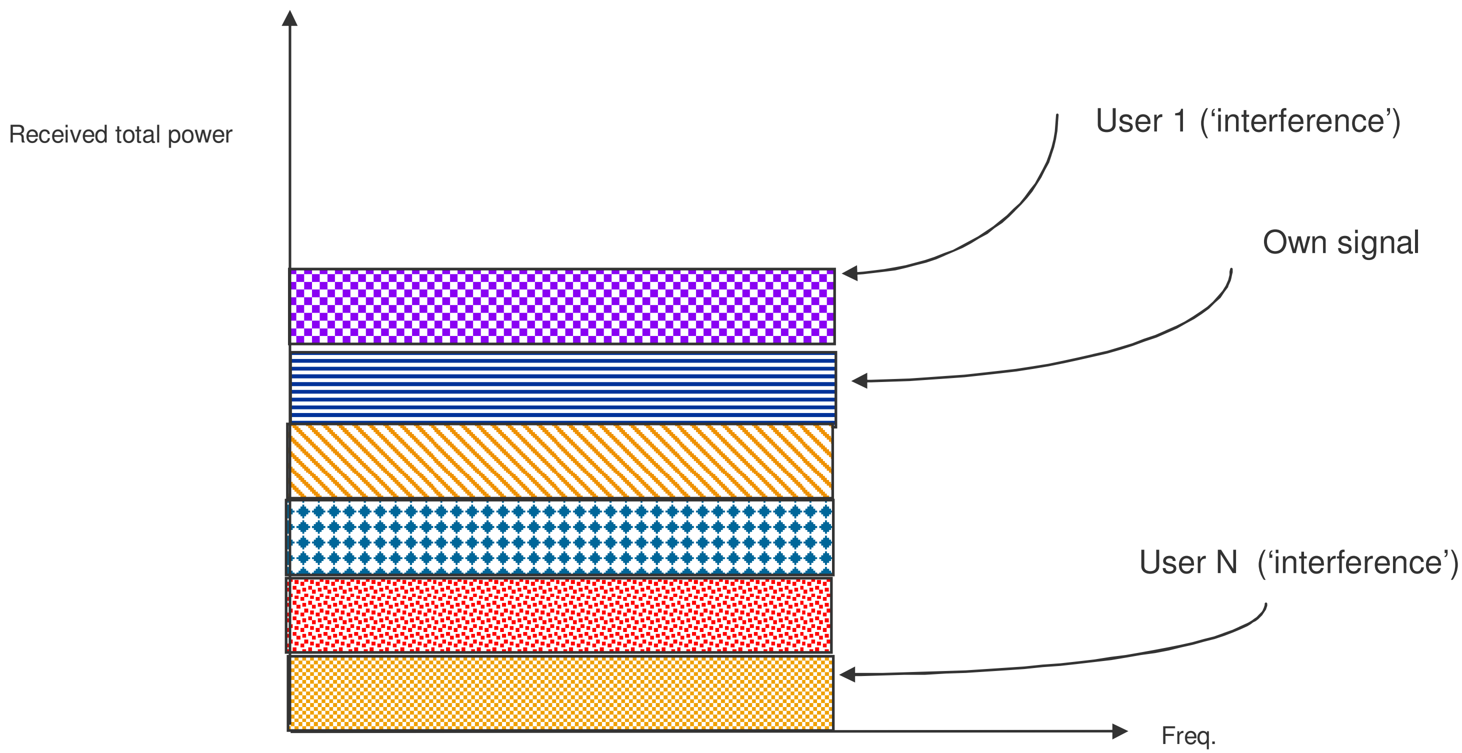
- $C = B \ \text{Log2}\ (1+ S/N)$
  - C is the channel capacity in bits per second (bps), which is the maximum data rate for a theoretical bit-error rate (BER).
  - B is the required channel bandwidth in Hz,
  - S/N is the signal-to-noise power ratio.

- => Very roughly, $C/B \cong S/N$ (see reference 2), which means:
- To send error-free information for a given signal-to-noise ratio in the channel, therefore, we need only perform the fundamental SS signal-spreading operation: increase the transmitted bandwidth.

Spreading (Transmission)



Detecting Own Signal, Correlator

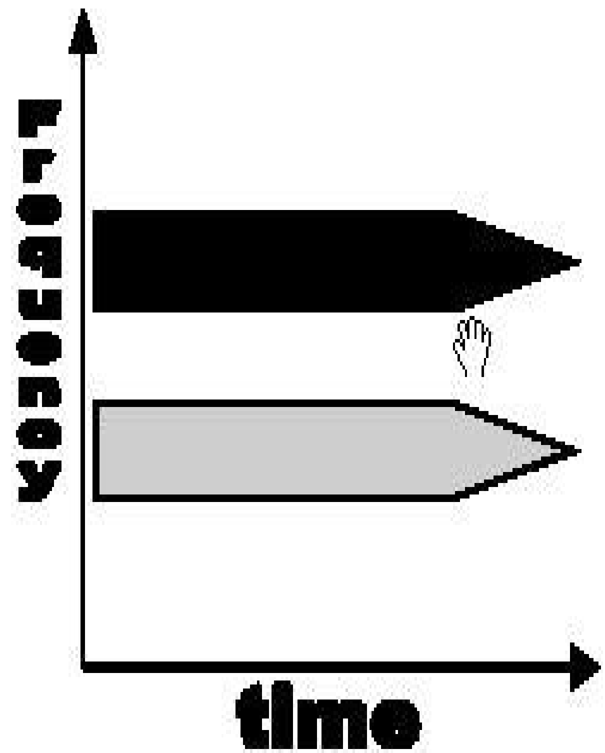


Spread Spectrum Technology Family

- Direct Sequence (DS) - A carrier is modulated by a digital code sequence in which bit rate is much higher than the information signal bandwidth.
- Frequency Hopping (FH) - A carrier frequency is shifted in discrete increments in a pattern dictated by a code sequence.
- Time Hopping (TH) - Bursts of the carrier signal are initiated at times dictated by a code sequence.
- Hybrid Systems - Use of combination of the above.

Direct Sequence Spread Spectrum (DSSS) Technology (1/2)

- Most widely recognized technology for spread spectrum.
- This method generates a redundant bit pattern for each bit to be transmitted. This bit pattern is called a chip.
- The longer the chip, the greater the probability that the original data can be recovered, and the more bandwidth required.



Direct Sequence Spread Spectrum (DSSS) Technology (2/2)

- Even if one or more bits in the chip are damaged during transmission, it can be recovered the original data by using statistical techniques without the necessary for retransmission.
- To an unintended receiver, DSSS signals are received as low-power wideband noise.

Process Gain
- Definition, Meaning, Explanation (1/2)

- In a spread spectrum system, the process gain (or ‘processing gain') is the ratio of the spread bandwidth to the unspread bandwidth. It is usually expressed in decibels (dB).

- The process gain is the ratio by which unwanted signals or interference can be suppressed relative to the desired signal when both share the same frequency channel.

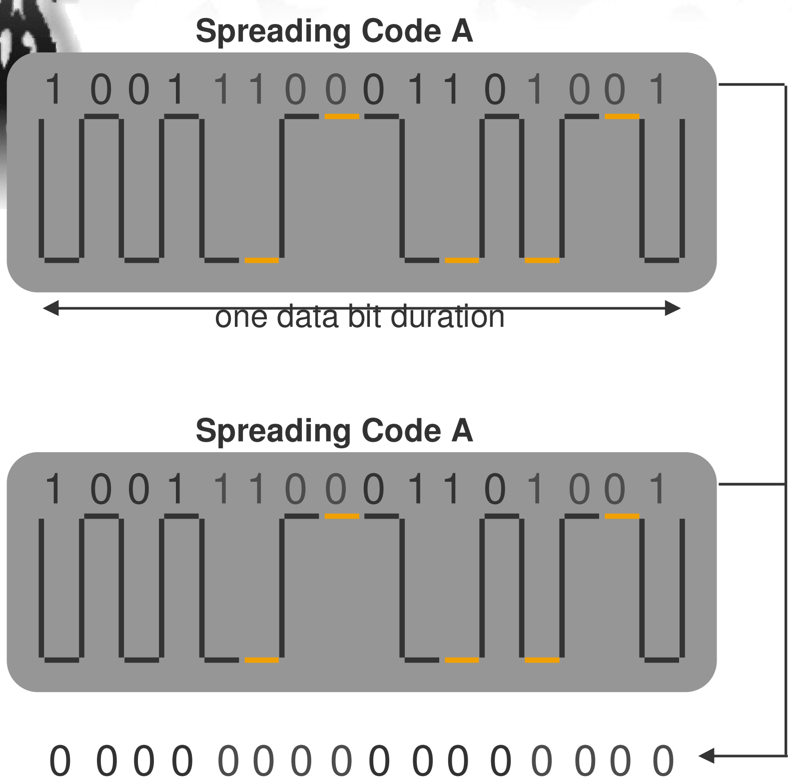
- Note that process gain has no effect on wideband thermal noise.

Process Gain
- Definition, Meaning, Explanation (2/2)

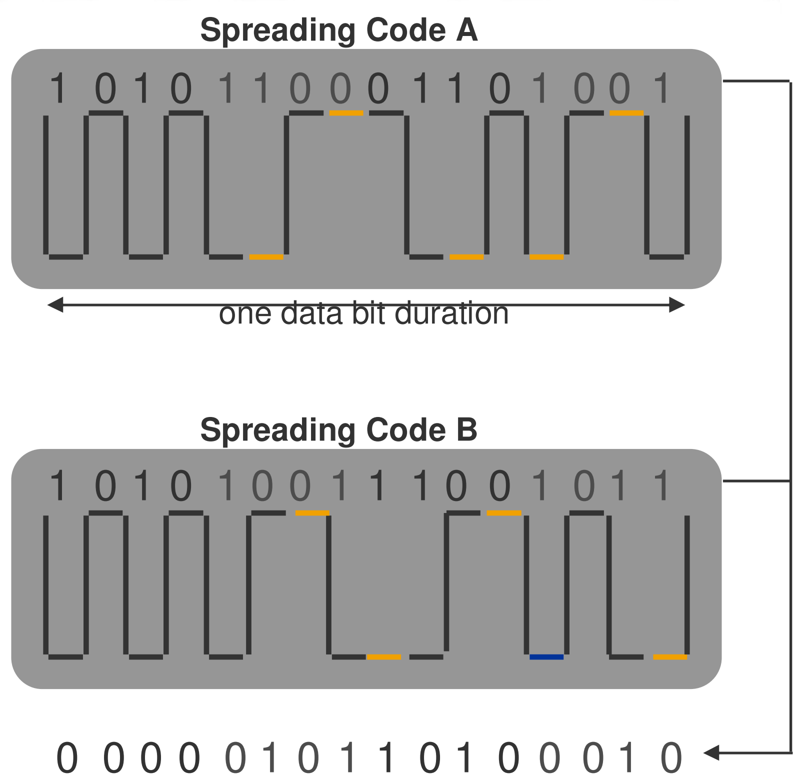
- Example:

  If a 1 KHz signal is spread to 100 KHz, the process gain expressed as a numerical ratio would be 100,000/1,000 = 100. Or in decibels, 10log10(100) = 20 dB.

Spreading Codes
- Self-Correlation & Cross-Correlation

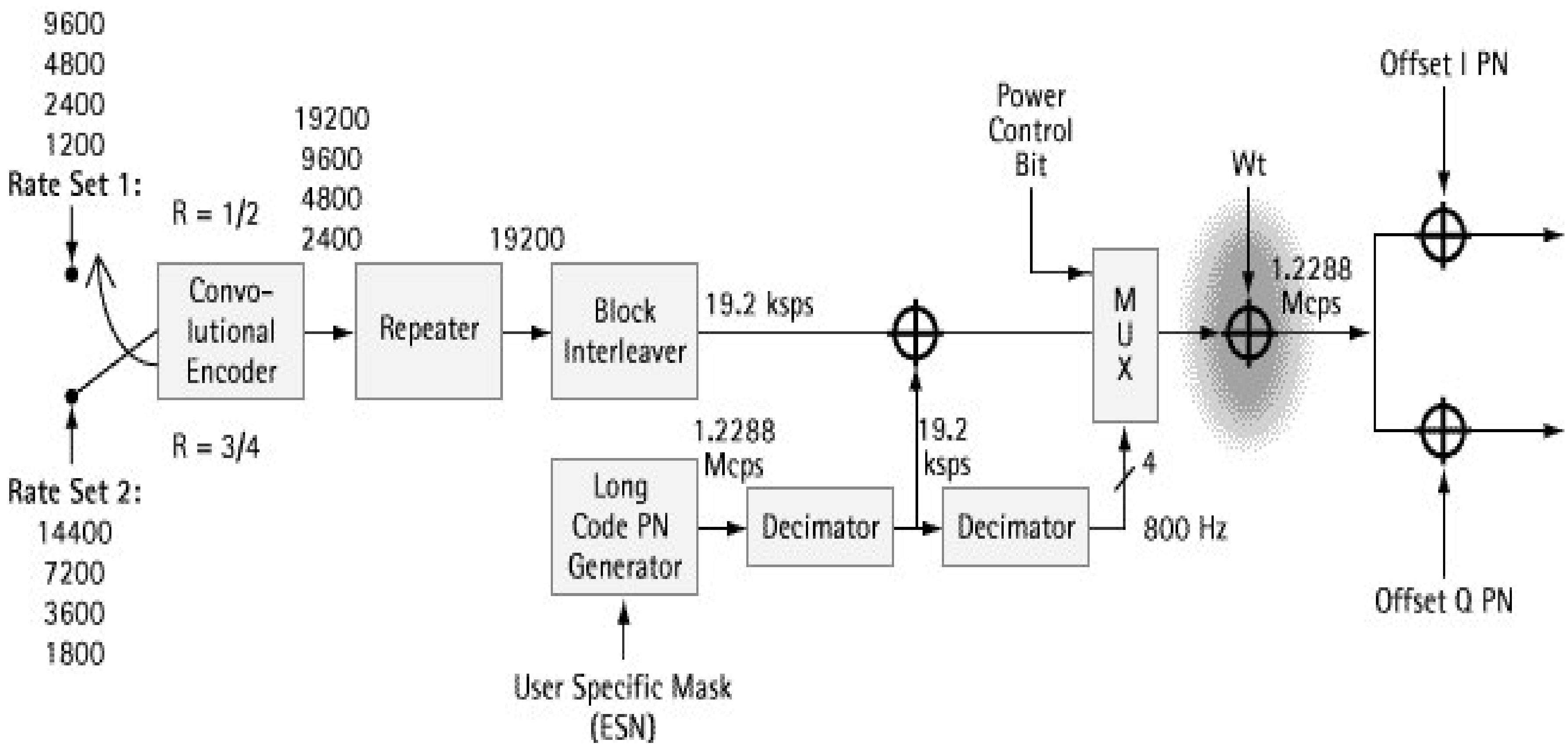


Self-Correlation
for each code is 1.



Cross-Correlation
between Code A and Code B = 6/16

Description of Code (CDMA)



Spreading codes
- Preferable Codes

In order to minimize mutual interference in DS-CDMA , the spreading codes with less cross-correlation should be chosen.

- Synchronous DS-CDMA:
  - Orthogonal Codes are appropriate (e.g. Walsh-Hadamard code etc.) in down-link
- Asynchronous DS-CDMA:
  - Pseudo-random Noise (PN) codes / Maximum sequence
  - Gold codes

Walsh-hadamard Code

- **Walsh Code:** One of a group of specialized PN codes having good autocorrelation properties but poor cross-correlation properties. Walsh codes are the backbone of the CDMA One and cdma2000 cellular systems, and are used to support the individual channels used simultaneously within a cell. Walsh codes are generated in firmware by applying the Hadamard transform on 0 repeatedly.

Gold Code

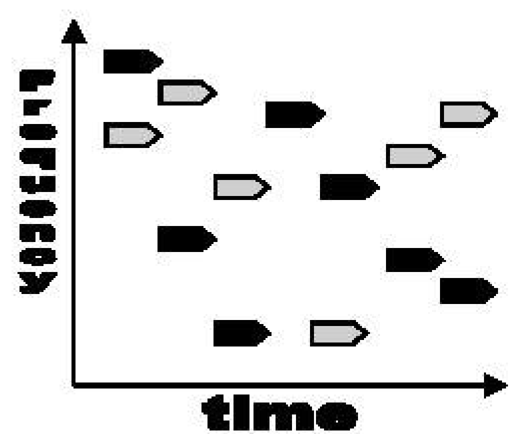
- **Gold Code:** One of a family of pseudo-noise codes that exhibits minimal, well defined, cross-correlation levels with all other members of the family. This property is often exploited in CDMA spread spectrum systems. A Gold code is normally generated through modulo-2 addition of two PN codes of equal length. Distinct members of a Gold code family are determined by the chip (bit) offset of one code relative to the other. Preferred pairs of PN codes, which exhibit optimal performance, have been thoroughly studied and documented. A balanced Gold code is one in which the number of ones exceeds the number of zeros by one, a trait shared by all m-sequences.

Frequency Hopping Spread Spectrum (FHSS) Technology (1/2)

- Frequency hopping
  - Data signal is modulated with a narrowband carrier signal that hops from frequency to frequency as a function of time over a wide band of frequencies
  - Relies on frequency diversity to combat interference
    - This is accomplished by

multiple frequencies, code selection

and Frequency Shift Keying methods



Frequency Hopping Spread Spectrum (FHSS) Technology (2/2)

- Hopping pattern is known to both transmitter & receiver.
- In order to properly receive the signal, the receiver must be set to the same hopping code and listen to the incoming signal at the right time and correct frequency.
- The net effect is to maintain a single logical channel if synchronizing sender and receiver properly.
- Unintended receiver see FHSS to be short time impulse noise.

Frequency Hopping Spread Spectrum - Slow Frequency Hopping

- One or more data bits are transmitted within one Frequency Hop.

- Advantage:

  Coherent data detection is possible.

- Disadvantage:

  If one frequency hop channel is jammed, one or more data bits are lost. So we are forced to use error correcting codes.

Frequency Hopping Spread Spectrum - Fast Frequency Hopping

- One data bit is divided over more Frequency Hops.
- Advantage:
  - Now error correcting codes are not needed.
  - Diversity can be applied. Every frequency hop a decision is made whether a -1 or a 1 is transmitted, at the end of each data bit a majority decision is made.
- Disadvantage:
  - Coherent data detection is not possible because of phase discontinuities. The applied modulation technique should be FSK or MFSK.

Jamming Margin (1/2)

- The level of interference (jamming) that a system is able to accept and still maintain a specified level of performance, such as maintain specified bit-error ratio even though the signal-to-noise ratio is decreasing.

- The ratio of [J/S] is a figure of merit that provides a measure of how invulnerable a system is to interference .The larger the [J/S] ,the greater is the systems is to interference but forces to employ a greater processing gain.

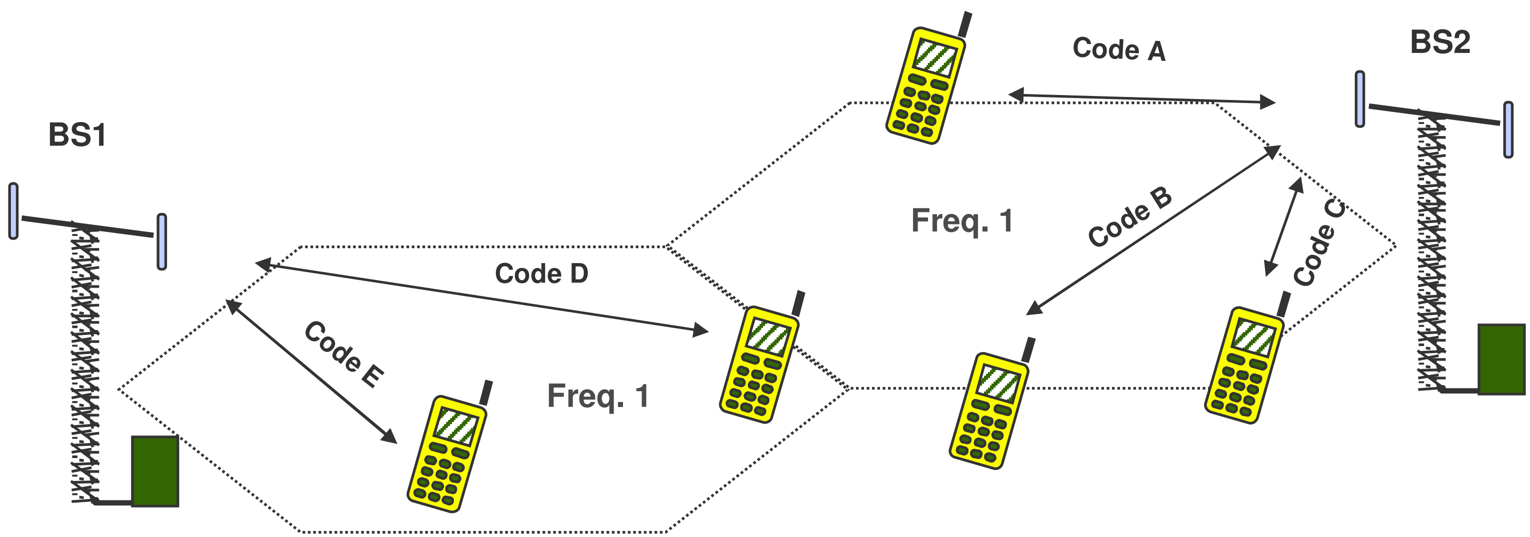
Jamming Margin (2/2)

- Although the process gain is directly related to the interference rejection properties, a more indicative measure of how a spread spectrum system will perform in the face of interference is the jamming margin (Mj). The process gain of a system will always be greater than its jamming margin.

- $M_j = G_p - [L_{system} + (S/N)_{out}]$ dB
  - where L_{system} is the system implementation loss (dB); G_p is process gain (dB): $(S/N)_{out}$ is the signal to noise ratio at the information output (dB).
- A spread spectrum system with a 30 dB process gain, a minimum required output signal to noise of 10 dB and system implementation loss of 3 dB would have a jamming margin of 30 - (3+10) dB which is 17 dB. The spread spectrum system in this example could not be expected to work in an environment with interference more than 17 dB above the desired signal.

CDMA Principles

- Users are separated by codes (code channels), not by frequency or time (in some capacity/hierarchical cell structure cases, also difference carrier frequencies may be used).
- Signals of other users are seen as noise-like interference
- CDMA system is an interference limited system which averages the interference (ref. to GSM which is a frequency limited system)



Important Advantages of CDMA

- Many users of CDMA use the same frequency.
- Multipath fading may be substantially reduced because of large signal bandwidth.
- There is no absolute limit on the number of users in CDMA. Rather the system performance gradually degrades for all users as the number of users is increased.

Drawbacks of CDMA

- Self-jamming is a problem in a CDMA system. Self-jamming arise because the PN sequence are not exactly orthogonal, non-zero contributions from other users in the system arise
- The near- far problem occurs at a CDMA receiver if an undesired user has high detected power as compared to the desired user.

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Abbreviation

- DS: Direct Sequence
- DSSS: Direct Sequence Spread Spectrum
- FH: Frequency Hopping
- FHSS: Frequency Hopping Spread Spectrum
- PN: Pseudo-Noise
- SS: Spread Spectrum

Thank you very much!

Questions?

Assignment

- Explanation of the process gain and jamming margin, what is the relationship between them?