Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Security of Wireless Networks
Lecture 6

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From *past lectures*

Eavesdropping is easy, the attacker needs:

- A high-gain antenna, a sensitive receiver
- Knowledge of communication frequencies, modulation

Insertion is easy, the attacker needs:

- A high-gain antenna, powerful transmitter
- Knowledge of communication frequencies, modulation

Eavesdropping/insertion have implications even if the communication is confidential and authentic! (example of the passive keyless entry and start systems)

Physical Layer Security

Jamming

Communication Jamming

Definition: *Entirely preventing or reducing the ability of communicating parties to pass information by the deliberate use of EM signals.*

- The term has been broadly used in a number of contexts and can also refer to unintentional prevention of communication.

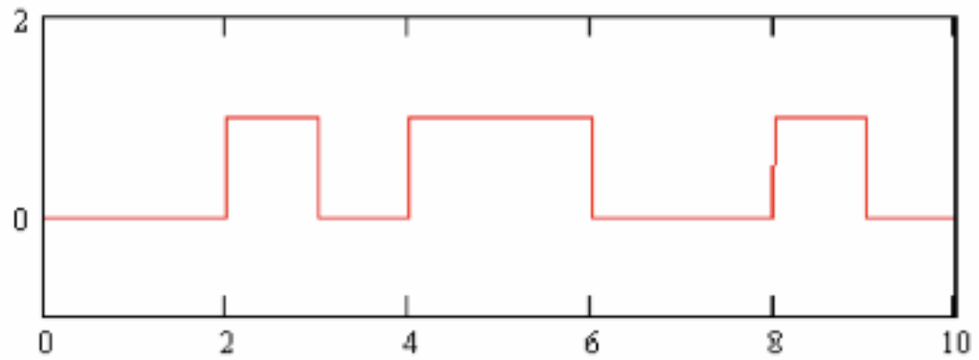
Communication Jamming

Carrier: an RF signal that "carries" information

Information signal is modulated onto the carrier signal.

- Carrier typically has a much higher frequency than the information (baseband) signal

Baseband (information) signal: m(t)



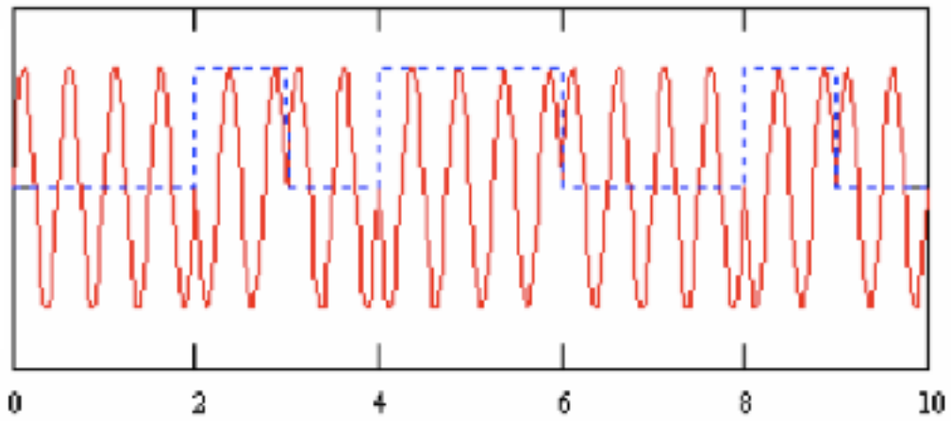
Carrier: $\sin(2\pi \mathbf{f} t)$ *(or* $\cos(2\pi \mathbf{f} t)$*)*

Modulated signal:

BPSK(t) = $\sin(2\pi f t)$, b=1

= $\sin(2\pi f t+\pi)$, b=0

Binary Phase Shift Keying (BPSK)



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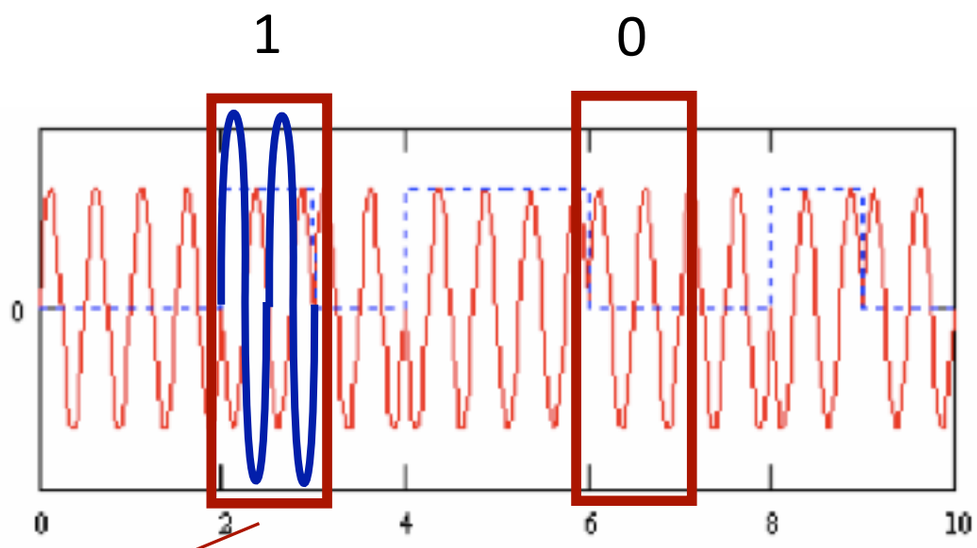
Note: $\sin(2\pi f t)=\cos(2\pi f t+\pi/2)$

Communication Jamming

Symbols

- Can carry one or more bits of information, depending on the modulation scheme.

```
   Modulated signal:
BPSK(t)  = sin(2πft),b=1
         = sin(2πft+π),b=0
Binary Phase Shift Keying
```



symbol (carrying bit 1)

Symbol Jamming: corrupt symbols such that the receiver

- cannot interpret them or
- interprets them incorrectly

Communication Jamming: corrupt enough bits such that the information cannot be reconstructed *(despite Error Correction)*

Communication Jamming

Jamming individual symbols

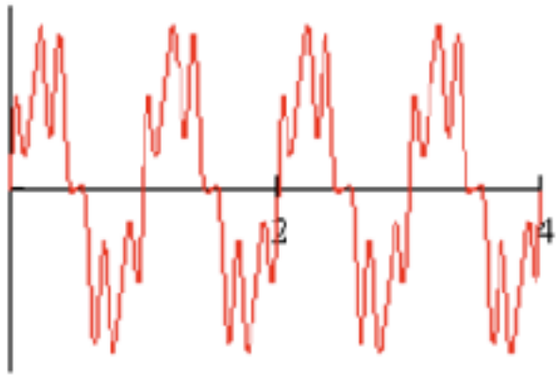
- Individual symbols or bits are jammed
- Most communication systems will do error detection and correction
- Beyond a certain threshold of corrupted bits (given for each ECC scheme) the messages cannot be recovered

- Targeted low-power jamming of individual bits is not easy and might require synchronization

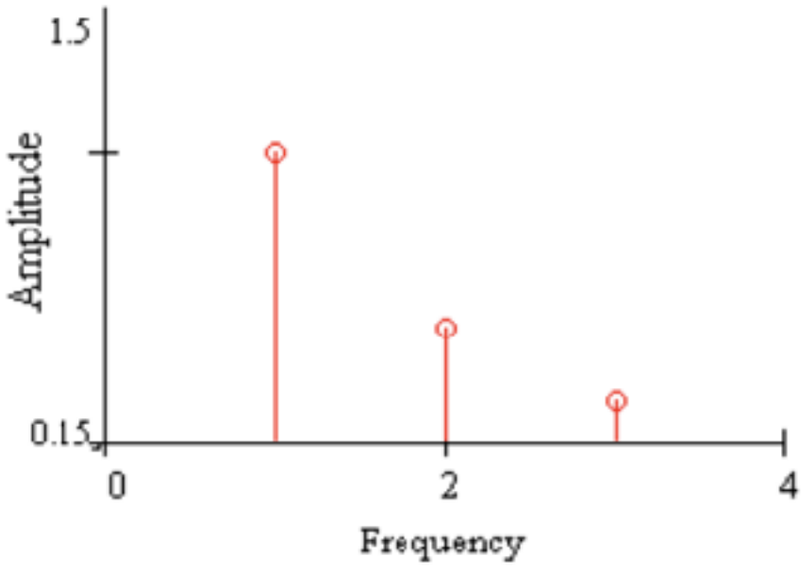
Communication Jamming

Frequency representation of signals:

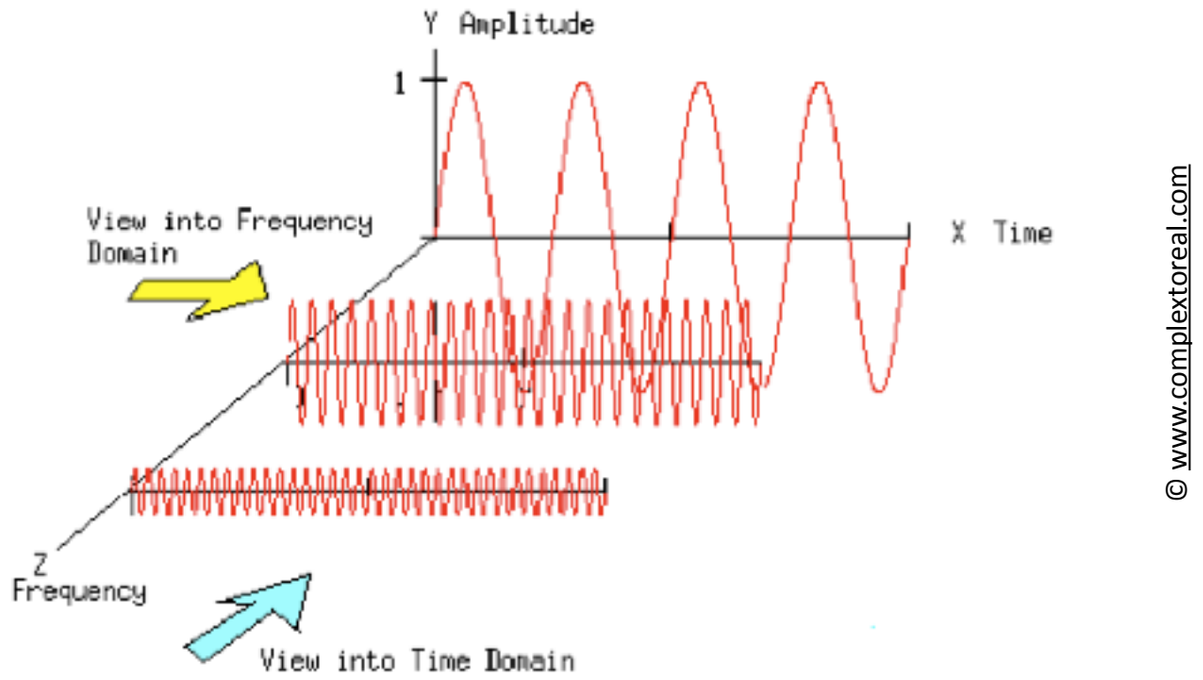
- It is important to understand which RF frequencies are used in communication



periodic signal



signal spectrum



decomposed to its *basic frequency and its harmonics*

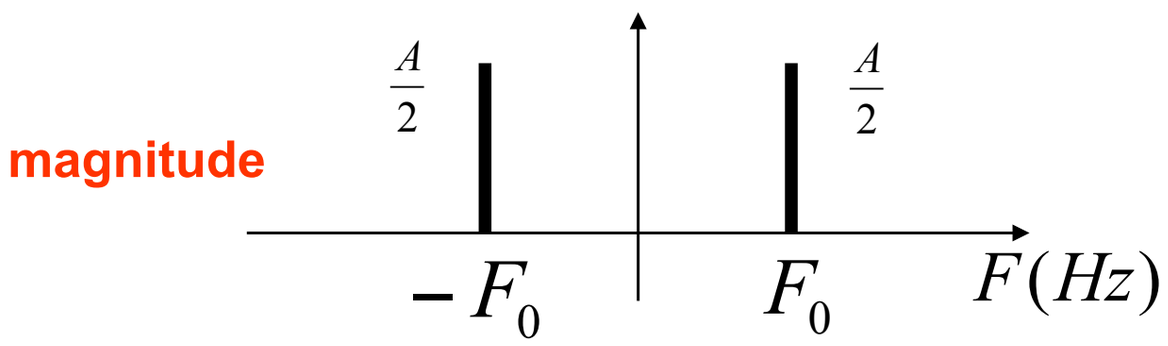
Communication Jamming

Frequency representation of signals:

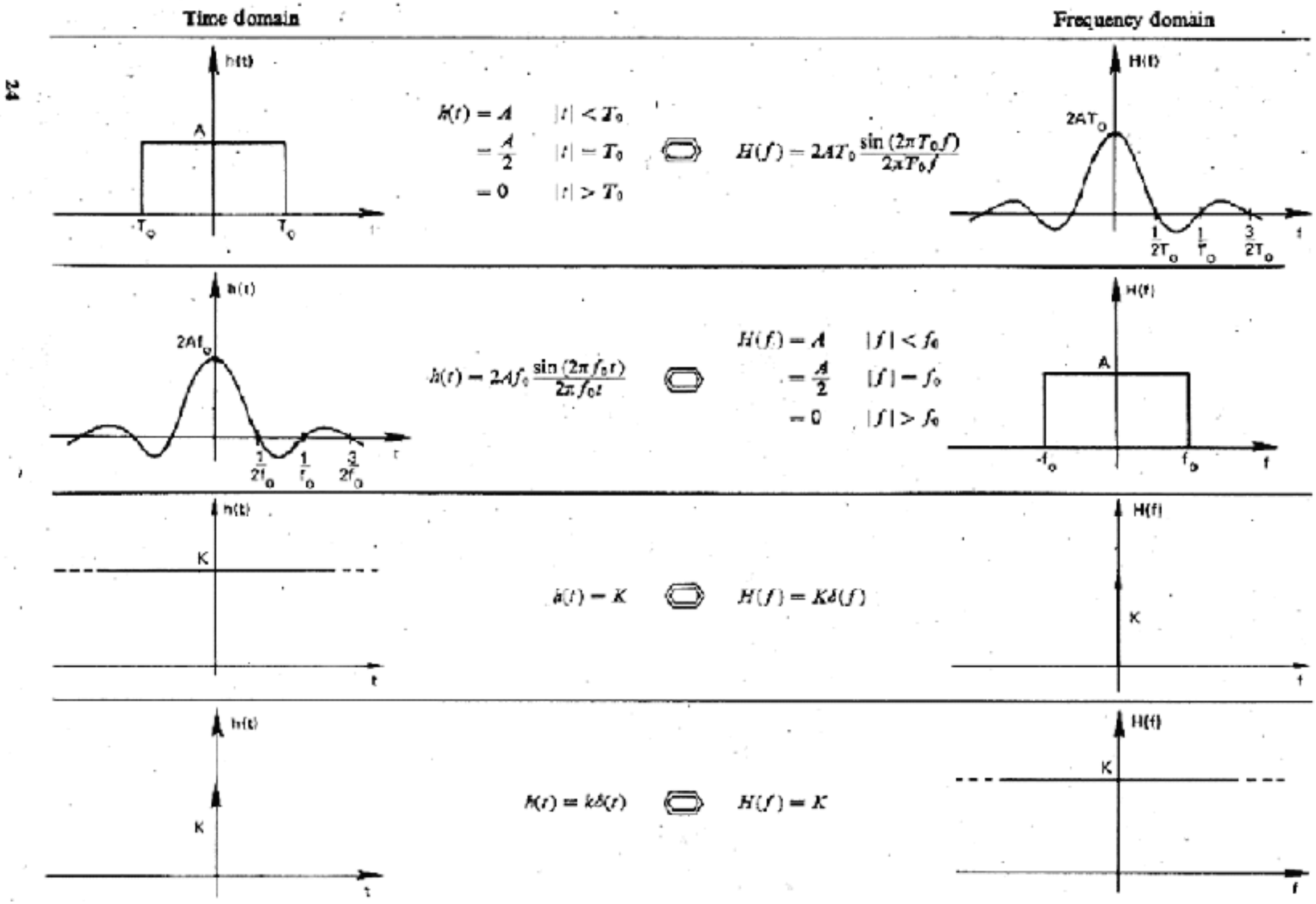
- complex representation

$$x(t) = A\cos(2\pi F_0 t + \alpha)$$

$$= \left(\frac{A}{2}e^{j\alpha}\right)e^{j2\pi F_0 t} + \left(\frac{A}{2}e^{-j\alpha}\right)e^{-j2\pi F_0 t}$$

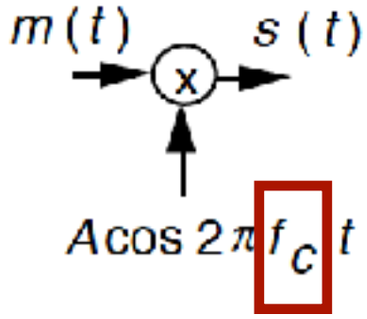


Frequency Representation



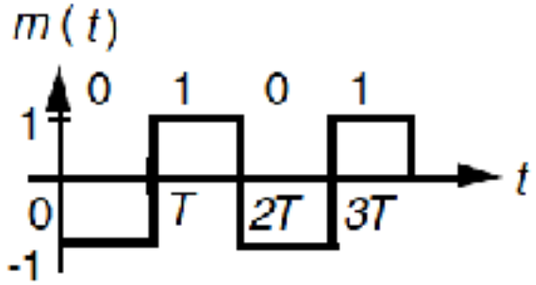
Communication Jamming

Example spectrum

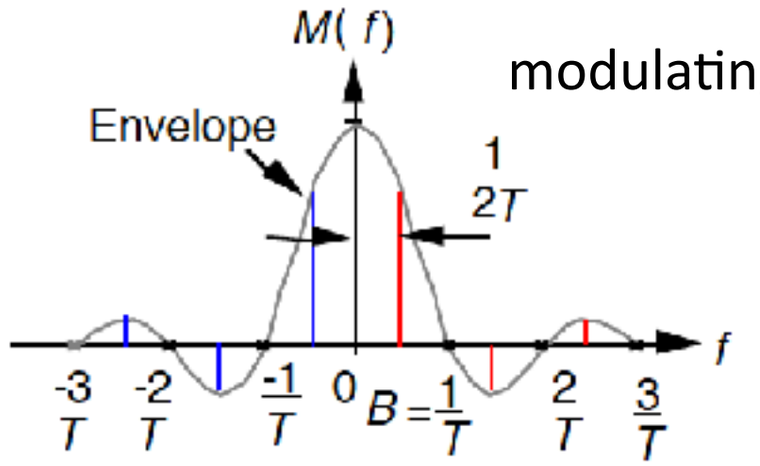


carrier frequency

message (modulating signal)

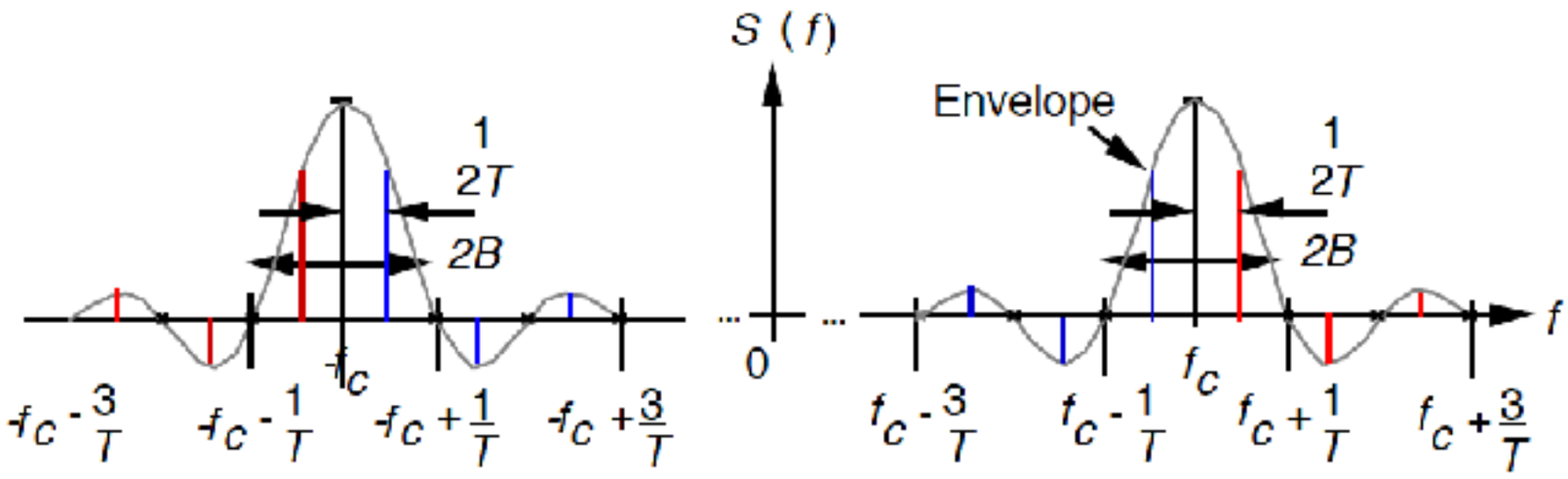


(a)



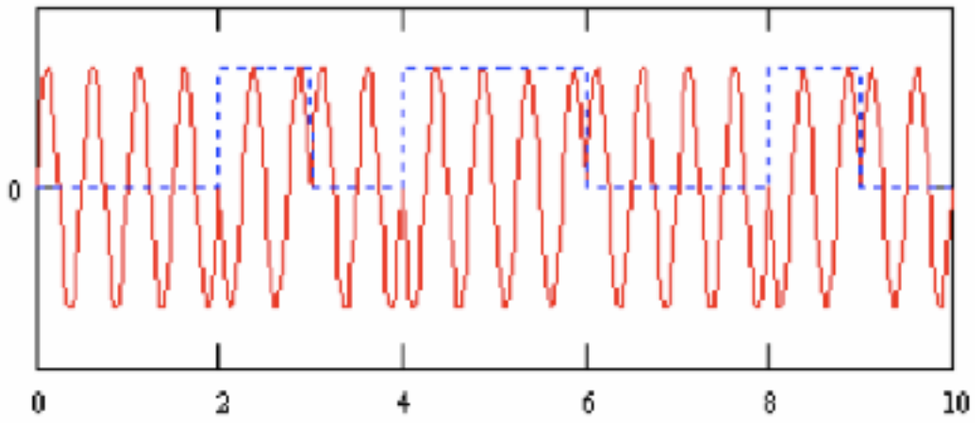
(b)

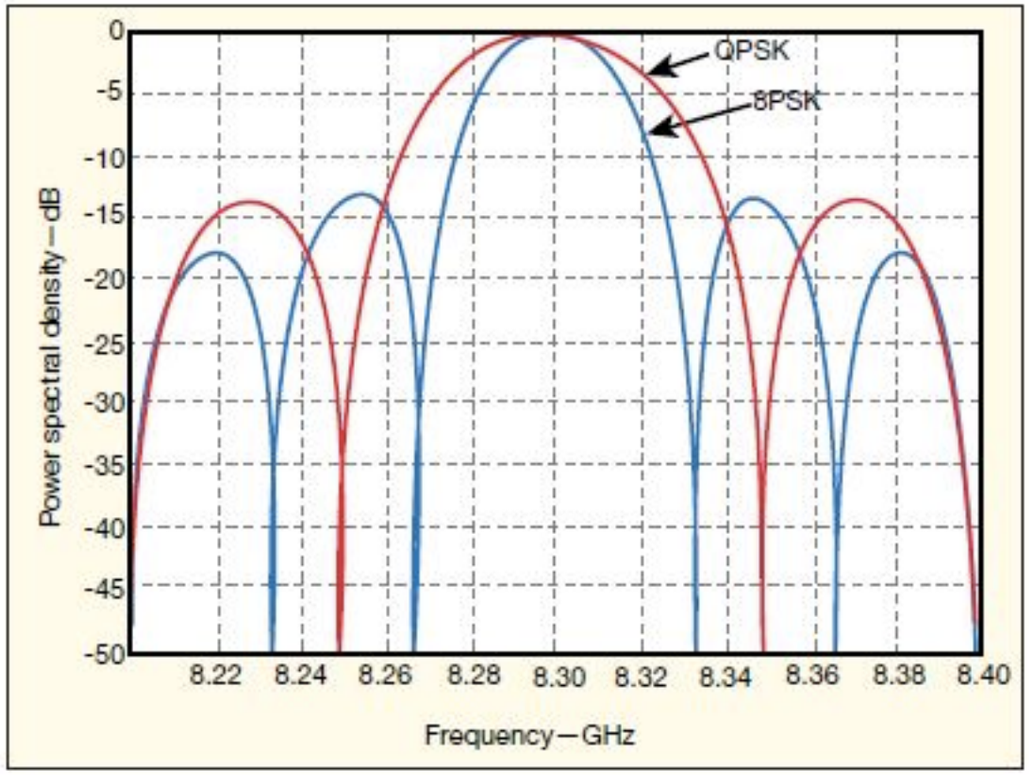
modulating signal spectrum



Communication Jamming

Example spectrum (BPSK)





Communication Jamming

Frequency:

- To jam, the attacker needs to *transmit on the right frequencies during the right time. (e.g., all)*
- Partial jamming might not prevent communication (the receiver might still reconstruct the signal)

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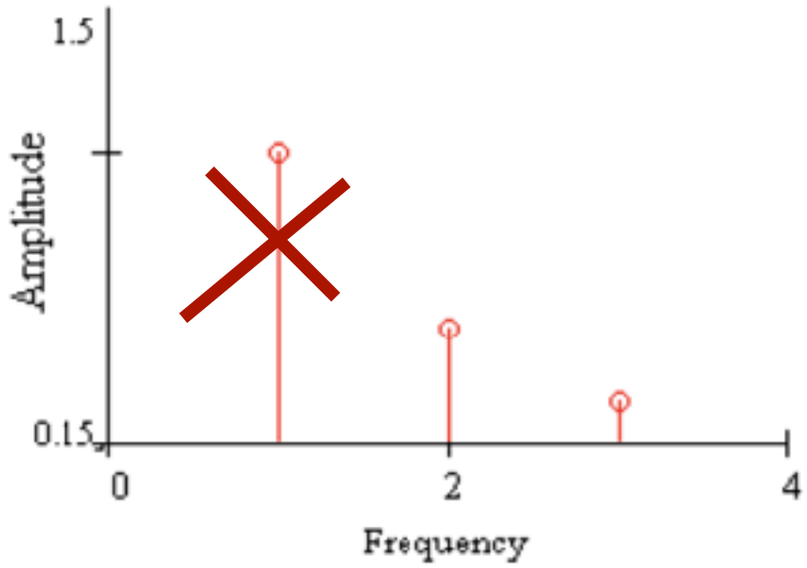


example spectrum

P – transmitted power
G - antenna gain
F – communication frequency
D - distance

Communication Jamming

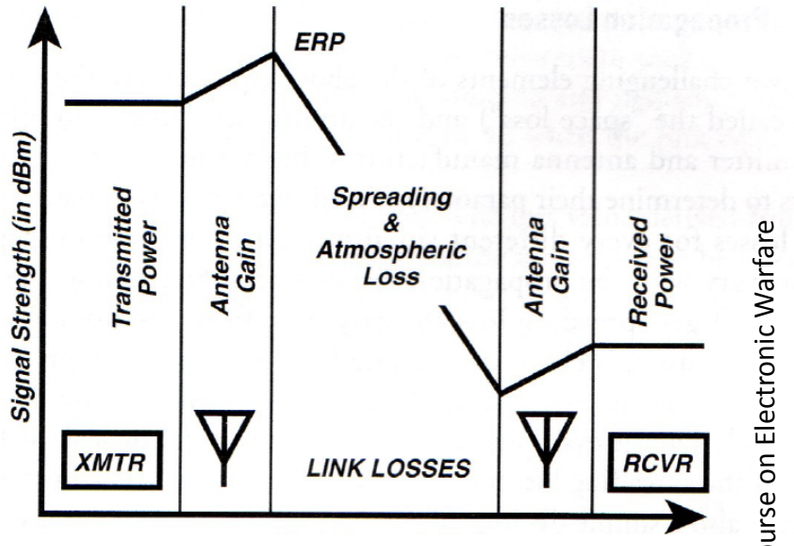
Assuming that the attacker uses the full signal spectrum.

- It is all about power!

$$S = P_T + G_T - 32 - 20\log(F) - 20\log(D_S) + G_R$$

$$J = P_J + G_J - 32 - 20\log(F) - 20\log(D_J) + G_{RJ}$$

spreading losses — directional gain



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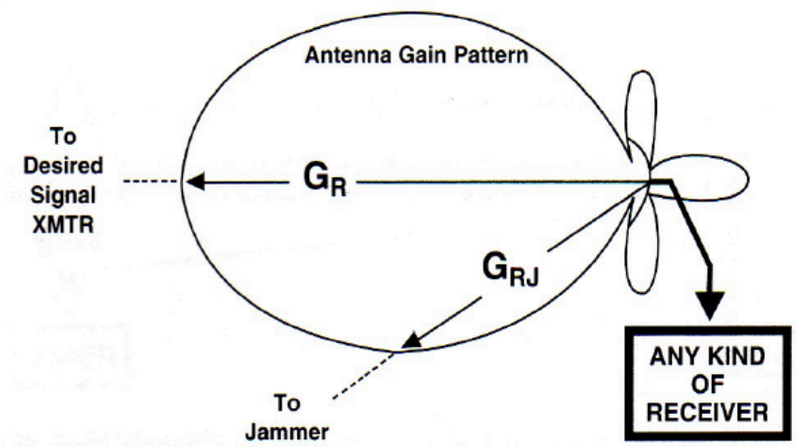
Jamming-to-Signal ratio (J/S):

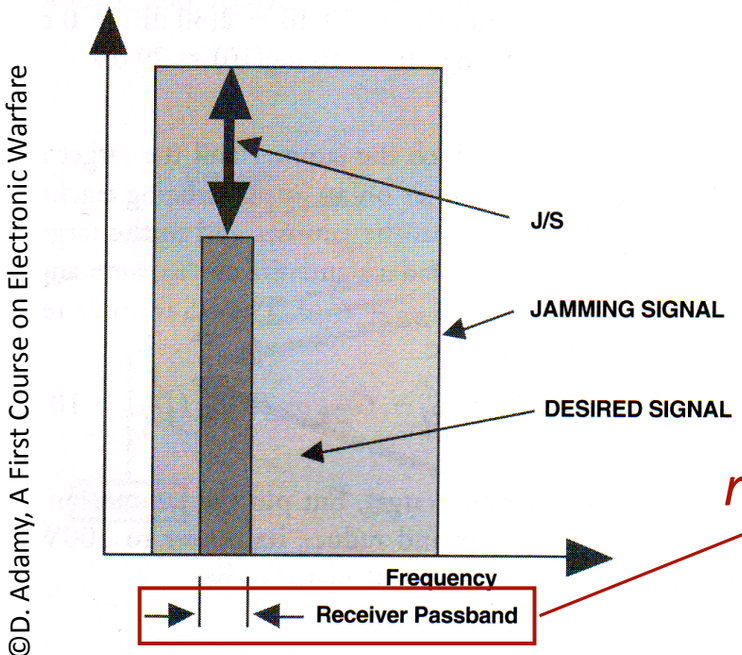
- `J/S = J-S (dB)`
- In most communication systems `J/S=0` results in successful jamming



If the receiving antenna is not omnidirectional, its gain to the jamming signal will be different (usually less) than its gain to the desired signal.

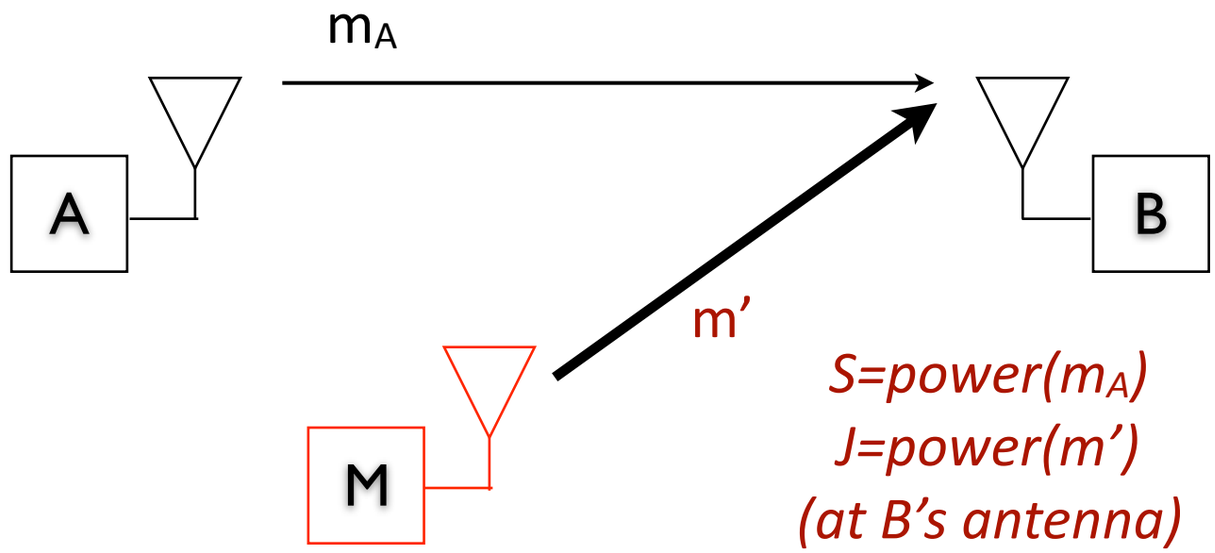
P – transmitted power
G - antenna gain
F – communication frequency
D - distance

Communication Jamming



The jamming-to-signal ratio is simply the ratio of the power of the two received signals within the frequency passband of the receiver.

receiver filters



S=power(m_A)
J=power(m')
(at B's antenna)

$$S = P_T + G_T - 32 - 20\log(F) - 20\log(D_S) + G_R$$

$$J = P_J + G_J - 32 - 20\log(F) - 20\log(D_J) - G_{RJ}$$

spreading losses — directional gain

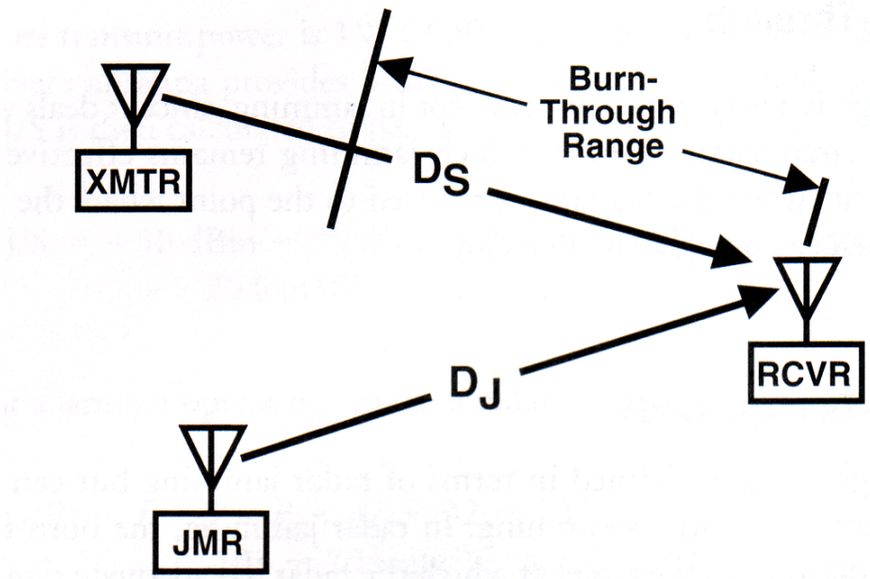
Example:

- jammer uses 100W (50dBm), antenna gain 10dB, distance 30km
- transmitter uses 1W (30dBm), antenna gain 3dB, distance 10km
- J/S = 17dB => probably successful jamming

Communication Jamming

A bit of terminology: *Burn-through range*

- The range from which the sender succeeds in communicating with the receiver, despite jamming.



12 The equivalent of radar burn-through against communications jamming occurs when the range from the desired transmitter to the receiver is reduced to the point at which the signal is received with adequate quality.

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Communication Jamming

A bit of terminology: *Other types of jamming*

Types of Jamming

Type of Jamming	Purpose
Communications jamming	Interferes with enemy ability to pass information over a communications link
Radar jamming	Causes radar to fail to acquire target, to stop tracking target, or to output false information
Cover jamming	Reduces the quality of the desired signal so it cannot be properly processed or so that the information it carries cannot be recovered
Deceptive jamming	Causes a radar to improperly process its return signal to indicate an incorrect range or angle to the target
Decoy	Looks more like a target than the target does; causes a guided weapon to attack the decoy rather than its intended target

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Communication Jamming

Parameters that influence jamming

The Effect of Each Parameter in the Jamming Situation on J/S

Parameter (Increasing)	Effect on J/S	Type of Jamming
Jammer transmit power	Directly increases on J/S dB for dB	All
Jammer antenna gain	Directly increases J/S dB for dB	All
Signal frequency	None	All
Jammer-to-receiver distance	Decreases J/S as the distance^2	All
Signal transmit power	Directly decreases J/S dB for dB	All
Radar antenna gain	Decreases J/S dB for dB	Radar (self-protect)
Radar antenna gain	Decreases J/S 2 dB per dB	Radar (stand-off)
Radar-to-target distance	Increases J/S as the distance^4	Radar
Radar cross-section of target	Directly increases J/S dB for dB	Radar
Transmitter-to-receiver distance	Increases J/S as the distance^2	Comm
Transmit antenna gain	Directly decreases J/S dB for dB	Comm
(Directional) receiver antenna gain	Directly decreases J/S dB for dB	Comm

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Communication Jamming: Implications

Jamming has implications beyond Denial of Service attacks:

Example: *Public WiFi Localization Systems*

- (Access Point MAC, Location Pairs) stored in a database.
- Mobile device detects APs and retrieves their locations.
- Based on these locations, computes its location.

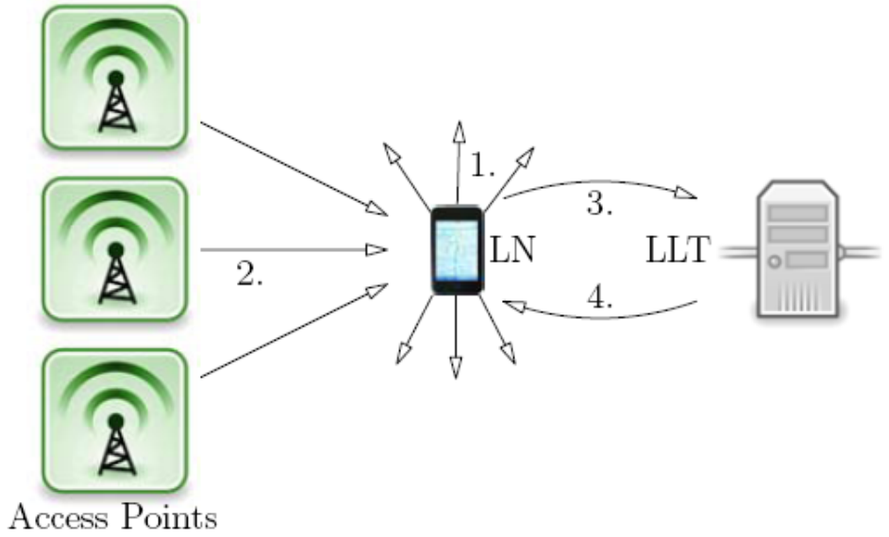


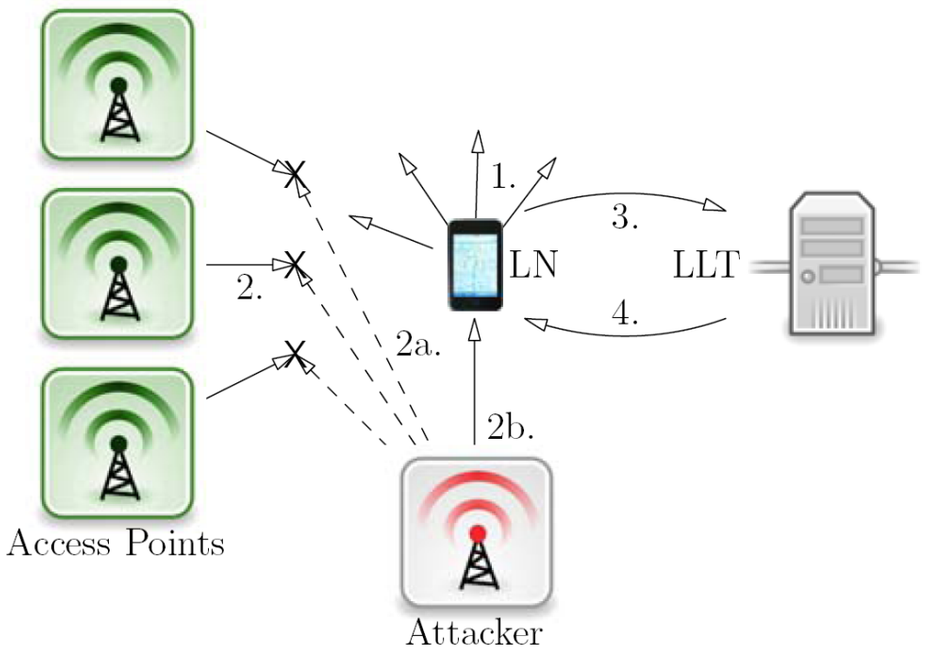
Figure 1: The Skyhook localization process. 1. The LN broadcasts a probe request frame. 2. APs reply with a response beacon frame. 3. The LN queries the LLT server. 4. The server returns data about observed APs. 5. The LN computes its location.

http://www.syssec.ch/press/location-spoofing-attacks-on-the-iphone-and-ipod

Communication Jamming: Implications

Example: *Public WiFi Localization Systems*

- When a Mobile is localized,
  - ***jam legitimate APs***
  - insert MACs of APs from another location
- This results in the Mobile displaying an incorrect location



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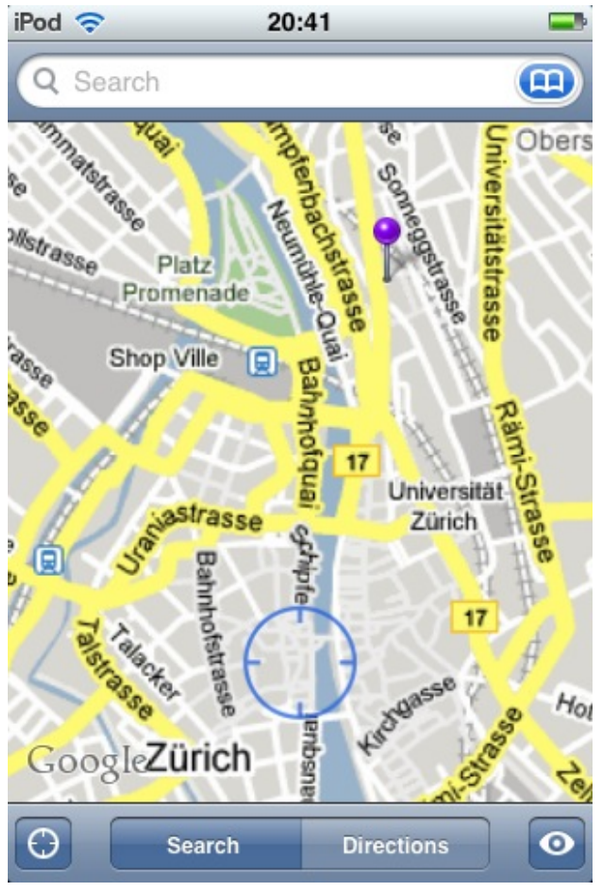


Physical Layer Security

Jamming-resistant communication

Jamming Resistant Communication

Basic principle of Jamming Resistant Communication:

- If you cannot fight, *RUN and HIDE*

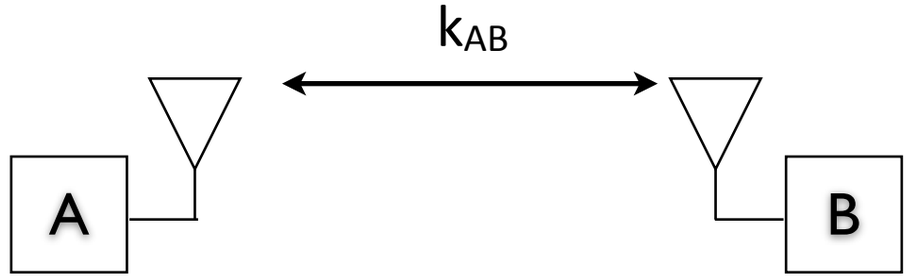
Techniques for Jamming Resistant Communication:

- Frequency Hopping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)
- Chirp

Jamming Resistant Communication

Basic principle of Jamming Resistant Communication:

- If you cannot fight, *RUN and HIDE*
- But we need an advantage over the attacker:
  a shared secret key between the sender and the receiver

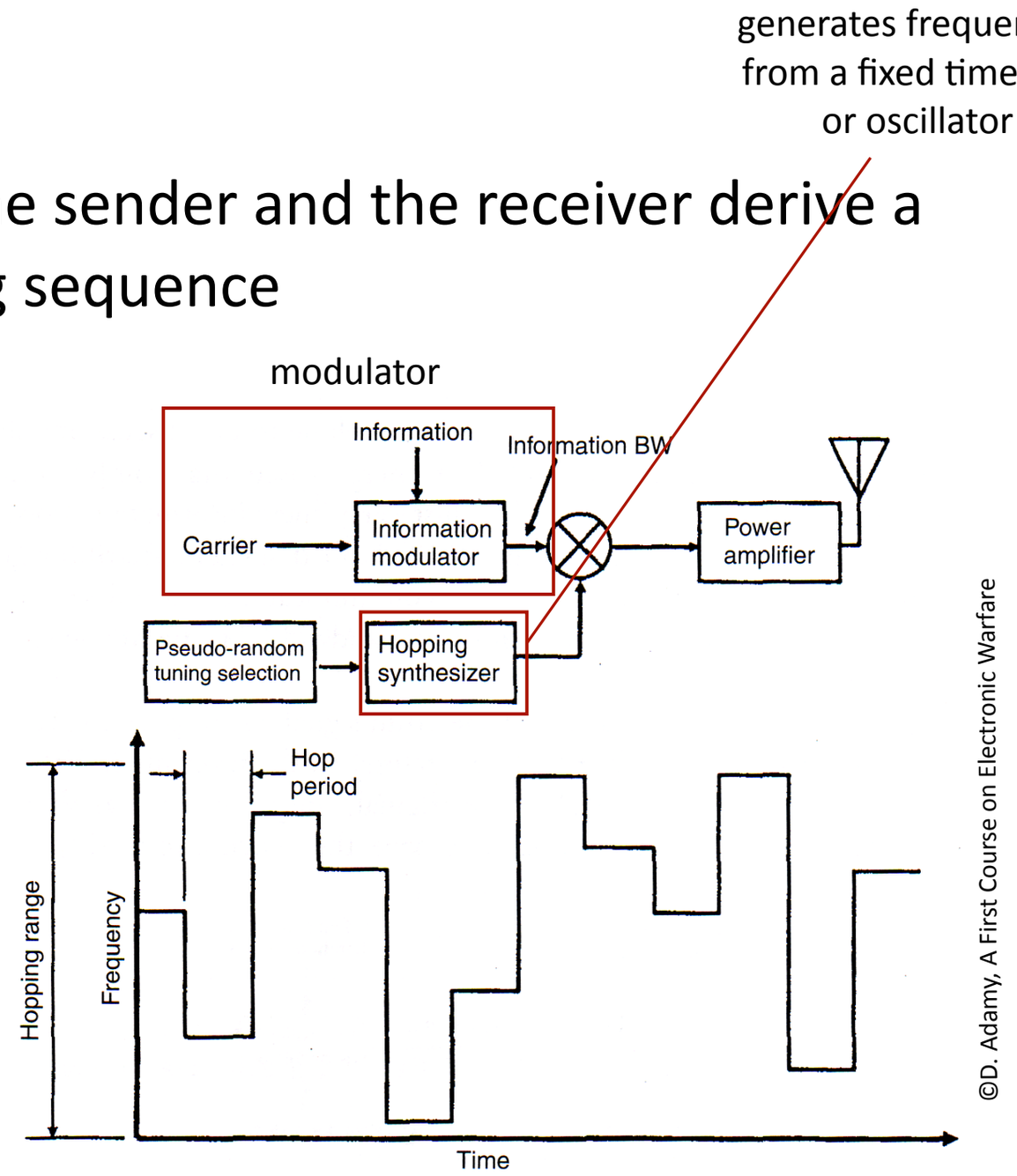


Frequency Hopping Spread Spectrum

FHSS

- Using the shared key, the sender and the receiver derive a pseudorandom hopping sequence
- Sender and receiver are synchronized
- *The attacker cannot guess the next hop or detect-and-jam*

First mentioned by Nikola Tesla (1903) in two US patents. US patent by actress Hedy Lamarr and composer George Antheil (1942)

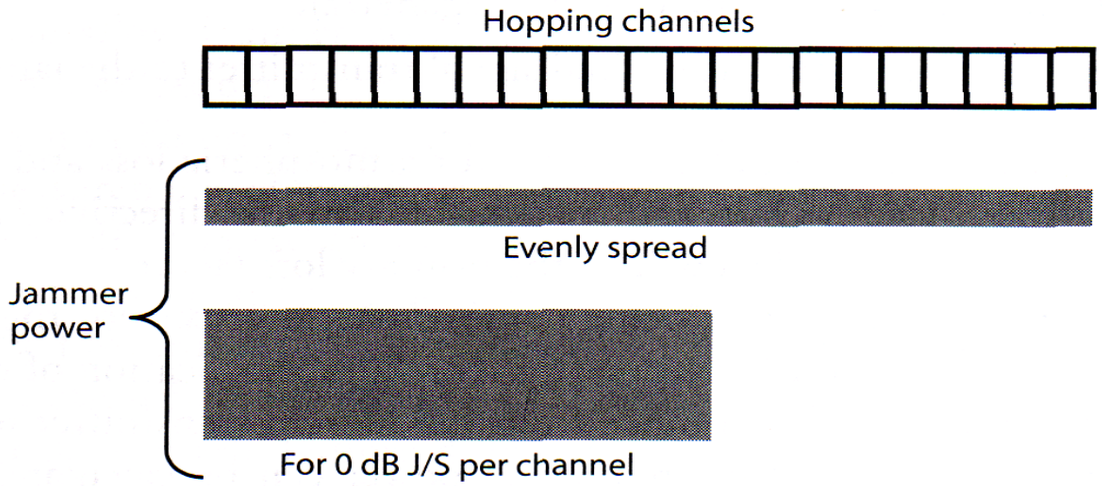


Frequency-hopped signals hop between randomly selected frequencies over a wide frequency range.

Frequency Hopping Spread Spectrum

FHSS Partial Band Jammer

- Distributes its power such that the jamming power per channel is equal to the received signal strength
- `J/S=0dB` provides sufficient Bit Error Rate



A partial-band jammer distributes its available power to achieve 0 dB J/S in each jammed channel at the jammed receiver.

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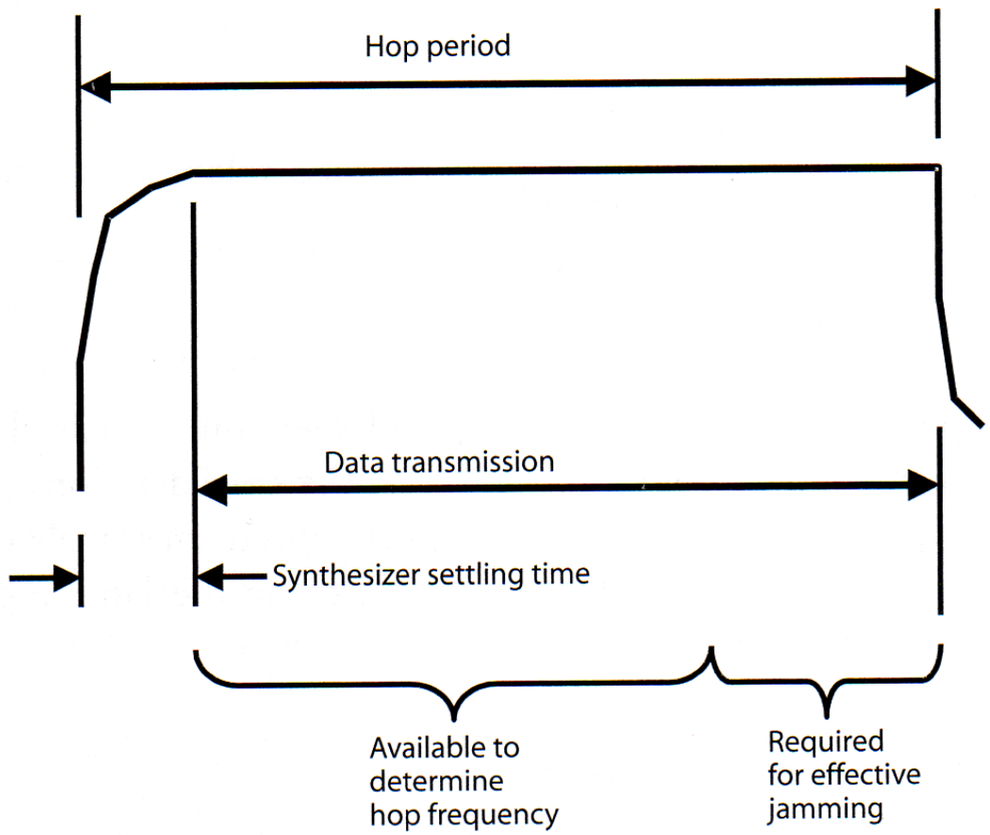
Frequency Hopping Spread Spectrum

FHSS Follower Jammer

- First detects on which frequency communication is taking place and then jams.
- Protection: message encodings that enable message recovery despite of x% of it being corrupted



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A follower jammer must determine the frequency of the hop and set its jamming frequency during 67% of the data transmission time.

Bluetooth:

79 channels, 1MHz each

1000 hops/second

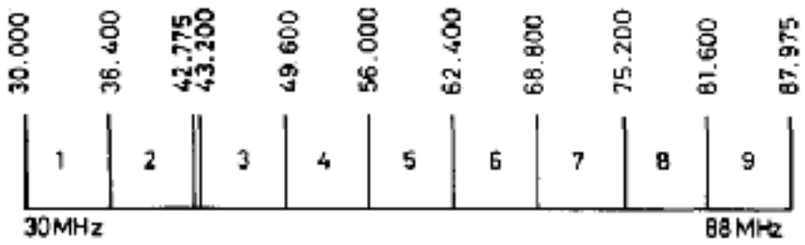
Jaguar V system:

50W

2320 channels

50-500 hops/second

Jaguar-V frequency-hopping radio system
IEEPKOC, Vol. 129, Pt. F, No. 3, JUNE 1982

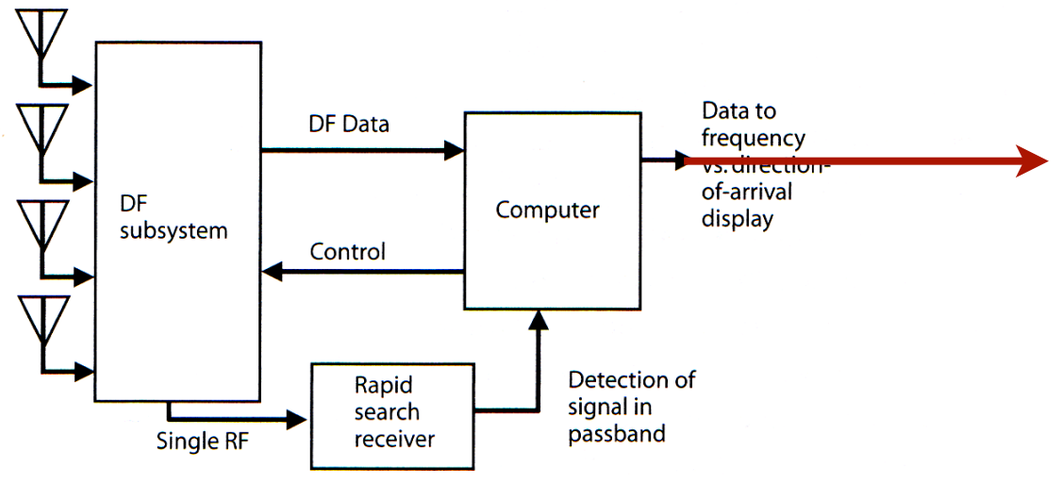


1 hop band =256 channels spaced by 25kHz
=6.4 MHz

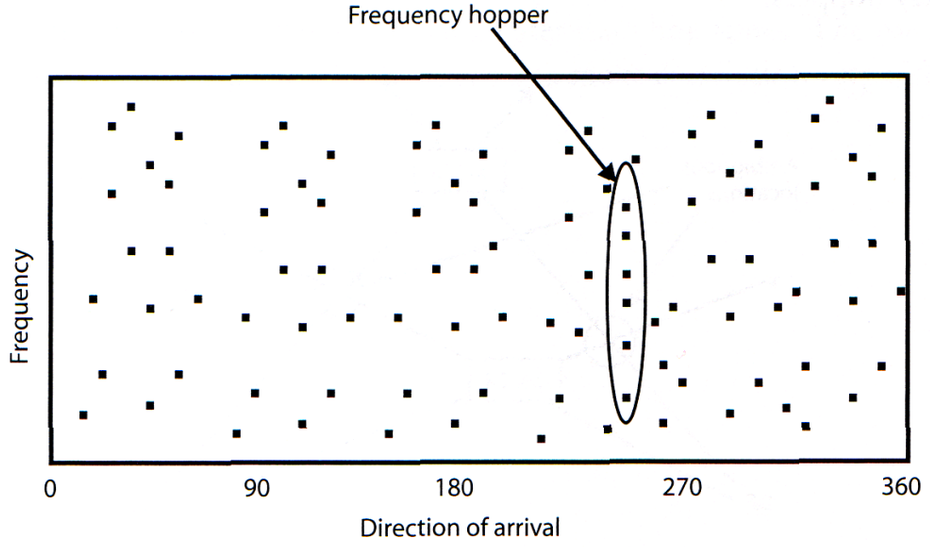
Frequency Hopping Spread Spectrum

Detectability / Localization of FHSS transmitters

- FHSS transmitters do not really “hide”
- Using AoA detection can be detected
- Other possible techniques include differential RSS localization, TDoA, etc ...



9 A sweeping DF system for frequency hoppers includes a rapid search receiver to detect occupied channels. Then the search is stopped while a DF is taken.



i.40 When collected DOA data shows multiple frequencies at one angle of arrival, a frequency hopper is identified.

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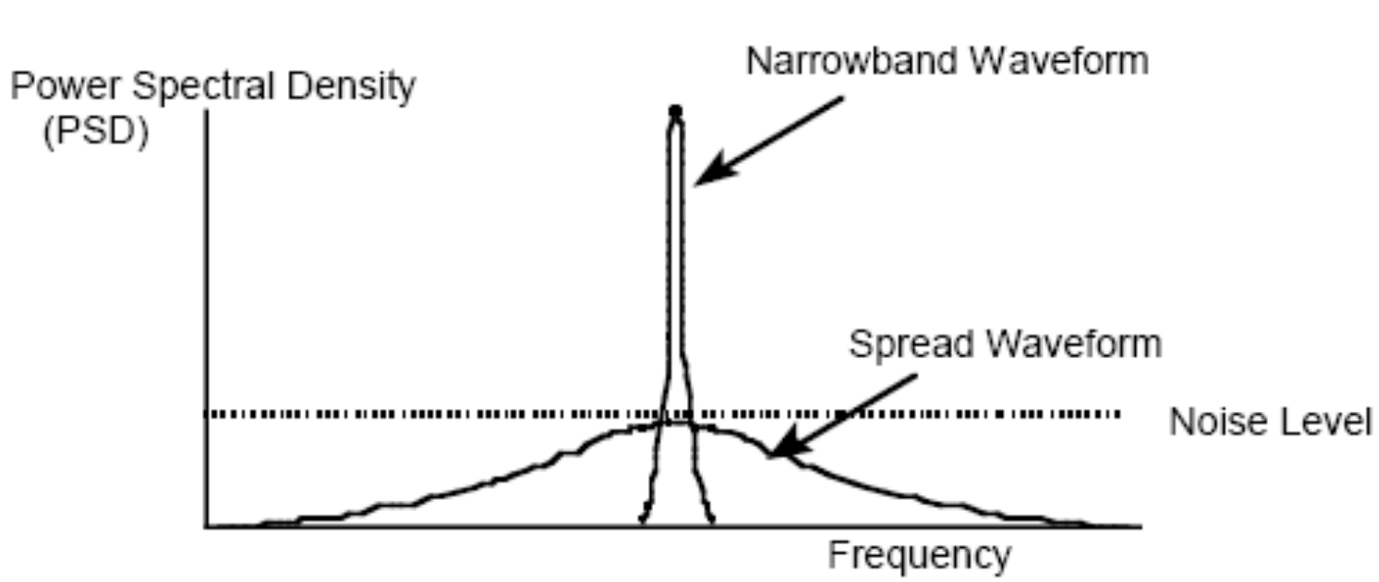
Direct Sequence Spread Spectrum

DSSS

- Spread the signal using a secret code (derived from a key)
- Signal is “hidden” in noise *(we need noise)*



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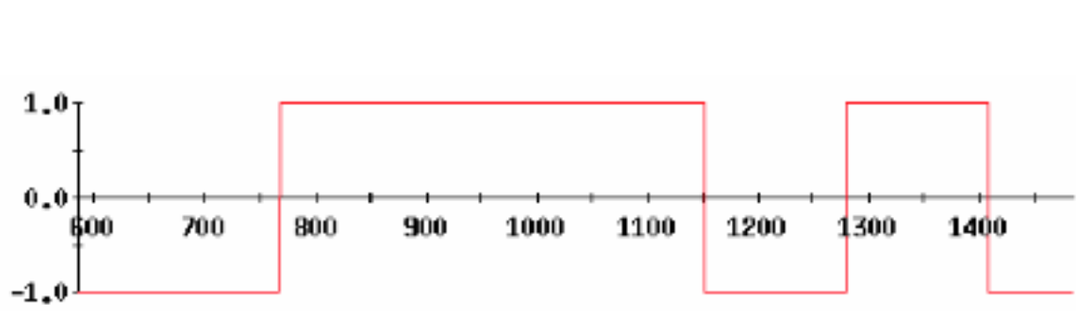
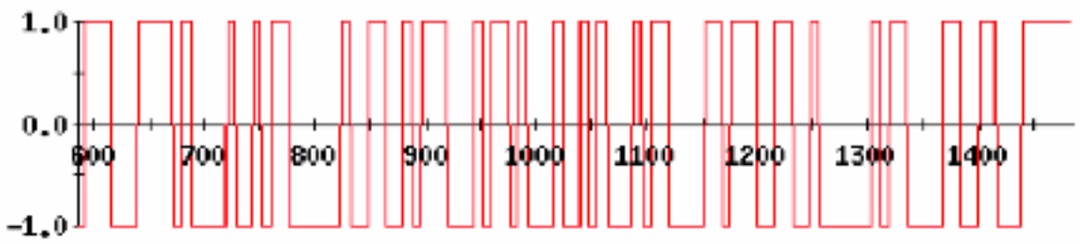
Direct Sequence Spread Spectrum

DSSS

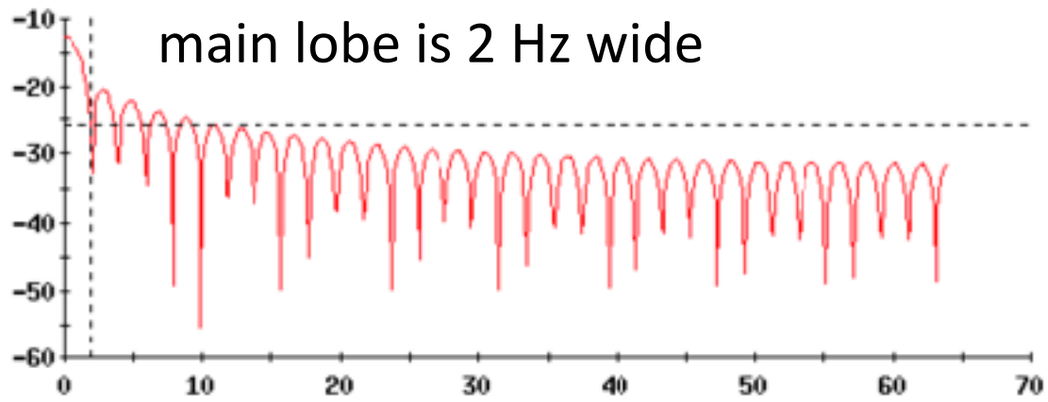
- Spreading (baseband)
- To spread we therefore need to transmit with a higher symbol (bit) rate. *Makes sense?*



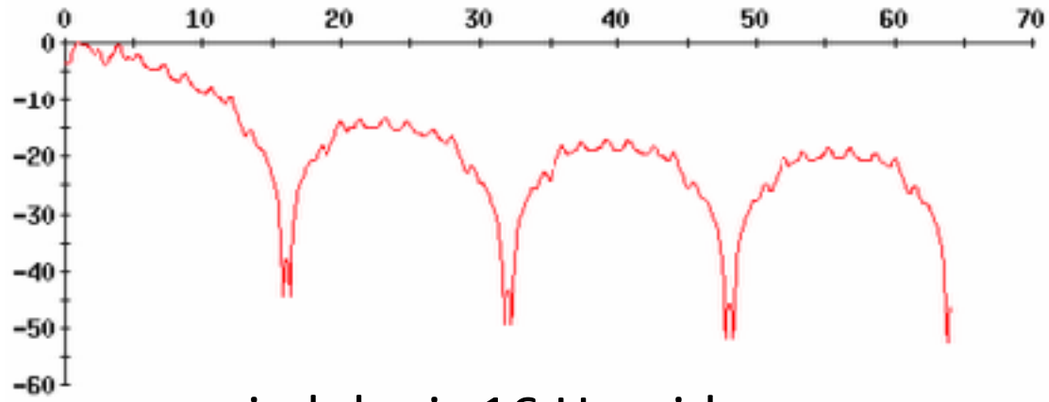
symbol rate is 2



symbol rate is 16

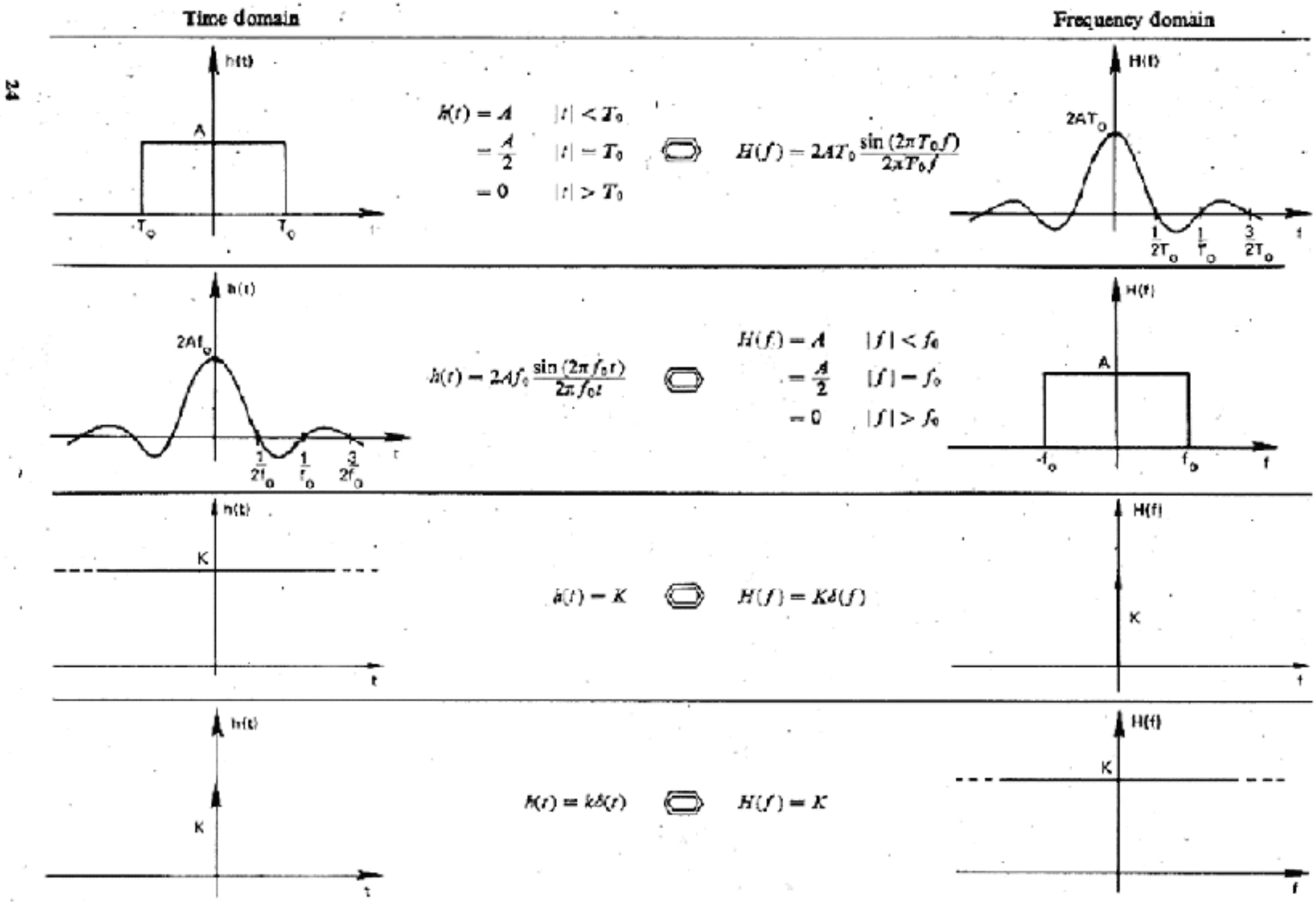


main lobe is 2 Hz wide



main lobe is 16 Hz wide

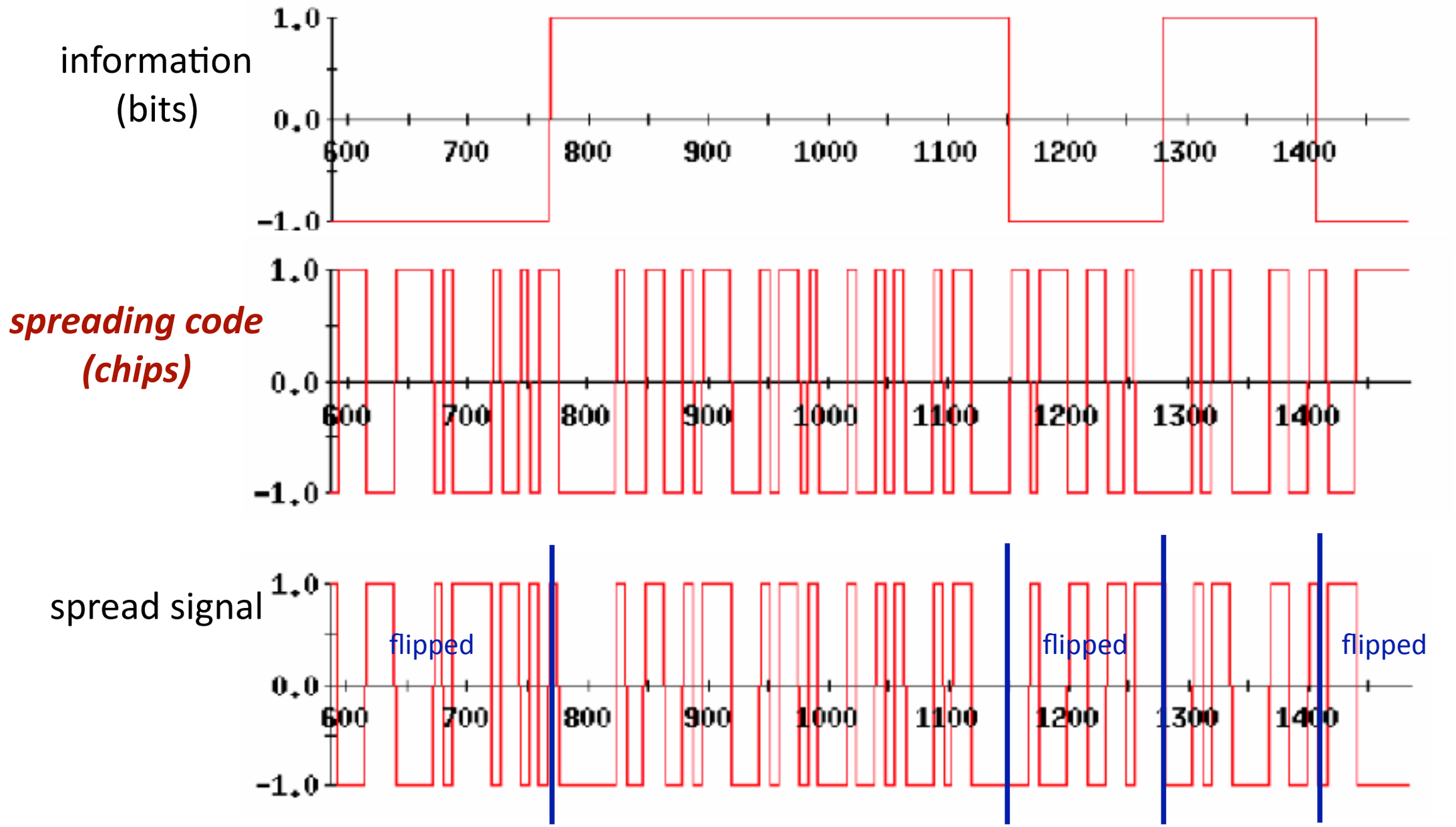
Frequency Representation



Direct Sequence Spread Spectrum

The ratio of the chip rate to the information bit rate is the *processing gain (PG)*

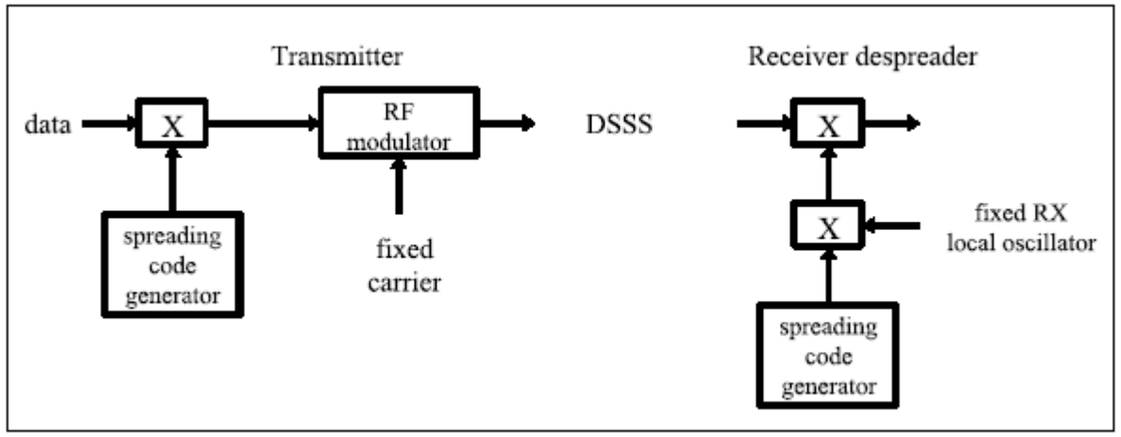
DSSS



Direct Sequence Spread Spectrum

DSSS

- Spreading and Modulation

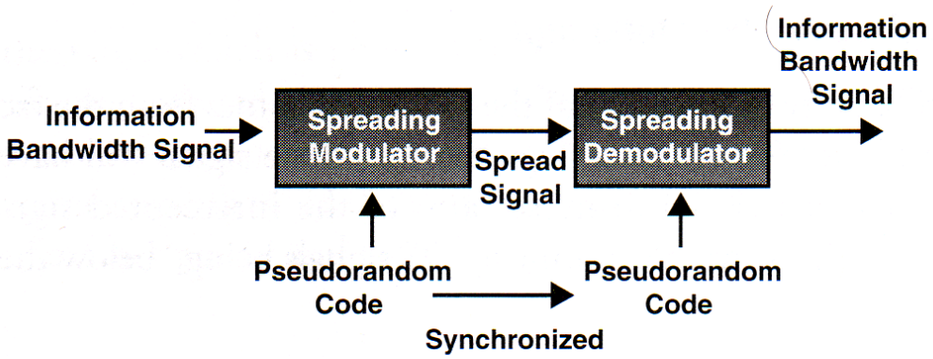


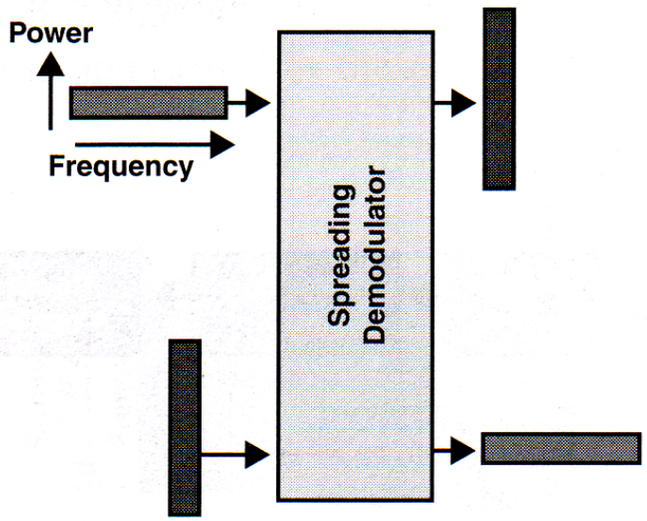
- Spreading code is produced by a spreading code generator
- Some systems operate with public spreading codes (to mitigate interference)
- For anti-jamming purposes, pseudo random sequences need to be long and infrequently repeat (wide spread)
- They need to have *good auto and cross correlation properties*

Direct Sequence Spread Spectrum

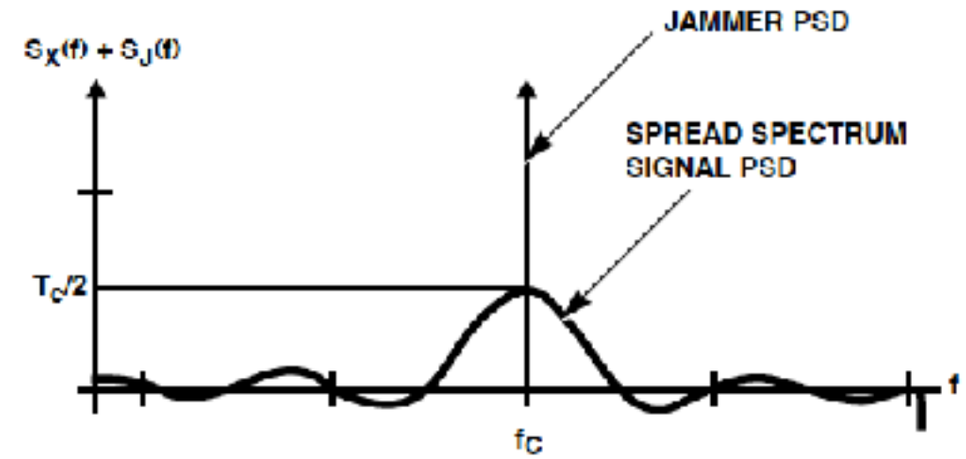
DSSS under Narrow-band Jamming

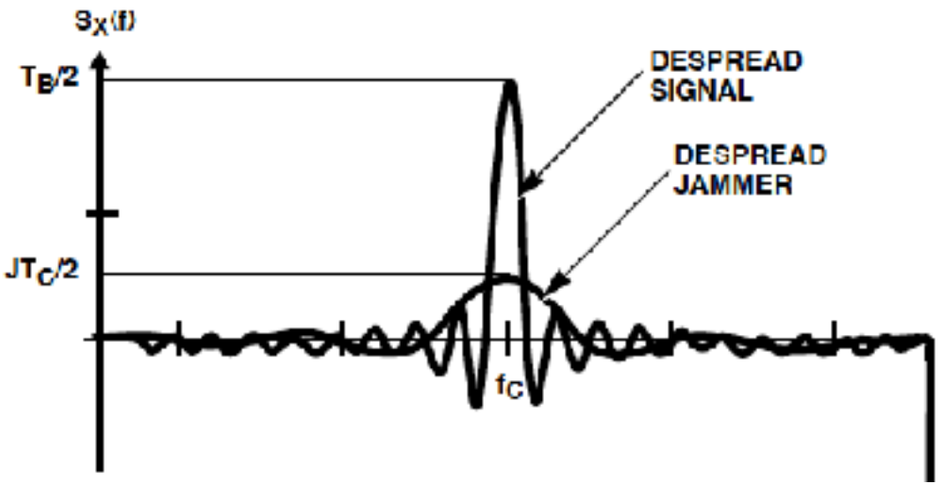
- Using a code on a narrow-band jamming signal spreads the signal (cross/auto correlation properties of the codes).





The same process that collapses the frequency spectrum of the spread-spectrum signal back to its information bandwidth spreads any nonsynchronized signal by the same factor.





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Direct Sequence Spread Spectrum

DSSS under Narrow-band Jamming

- Jamming margin

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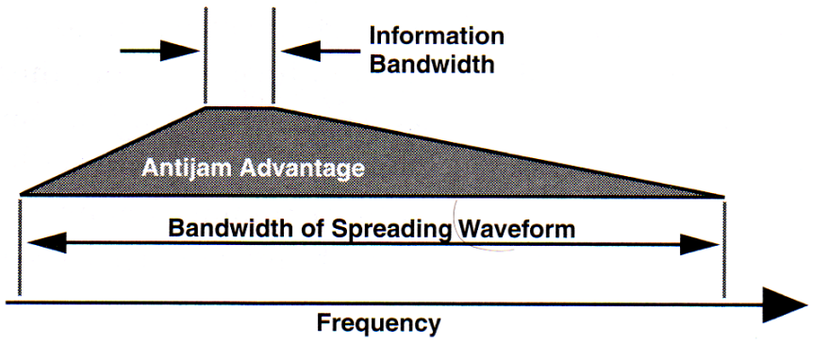
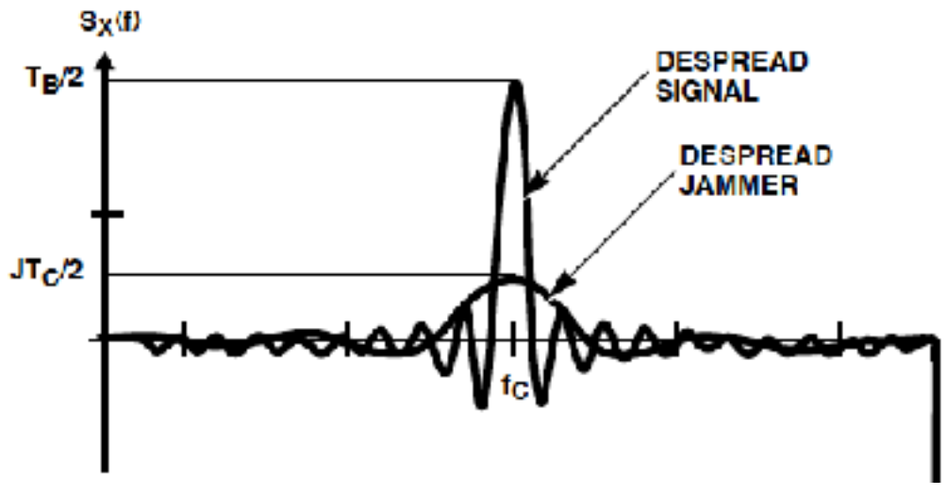


In order to jam a spread-spectrum signal, it is necessary to get sufficient jamming energy through the despreading process, which discriminates against nonsynchronized signals by the ratio of the spreading bandwidth to the information bandwidth.

Jamming margin: $M_J = G_P - L_{SYS} - SNR_{OUT}$

where

M_J = the jamming margin (in decibels);
G_P = the processing gain (in decibels);
L_{SYS} = the system losses (in decibels);
SNR_{OUT} = the required output SNR.



Direct Sequence Spread Spectrum

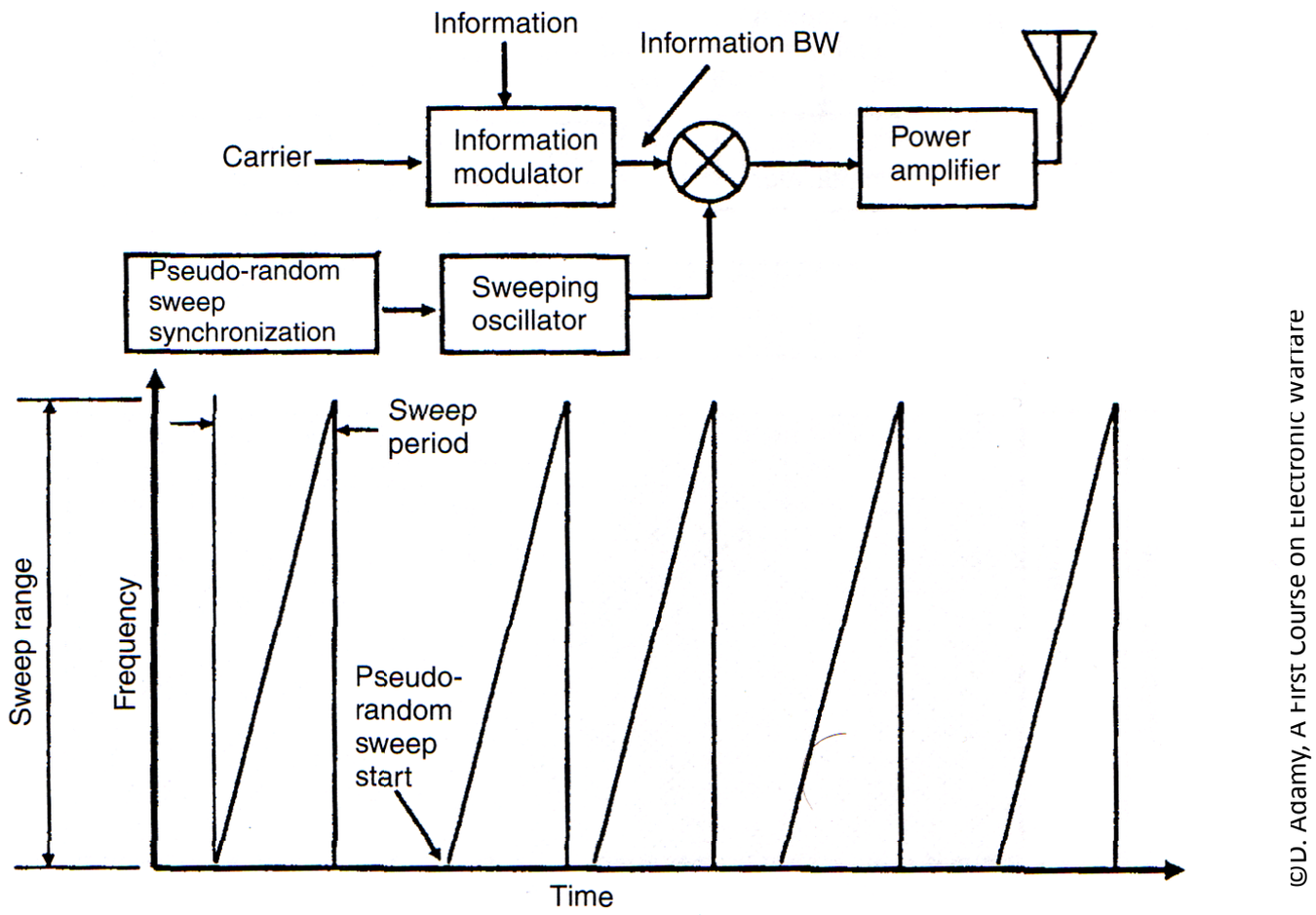
DSSS summary

- DSSS hides the signal in noise
- Signal detection is now more difficult (w/o code)
  - Can be done through energy detection (requires strong signal) or signal characteristic (constant chip rate)
    (Dillard&Dillard, Detectability of Spread Spectrum Signals, 1989)
- Signal interception/modification difficult - LPI
- Narrowband jamming now requires much higher power
- Broadband jamming still effective (if you have enough power)

Chirp Signals

Random start and then sweep ... (can be used with FH)

- Prevents narrow-band and partial-band jamming
- Follower jammers might be an issue



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Chirp signals are rapidly swept over a frequency much wider than the information bandwidth of the transmitted signals.

Jamming

Jamming is power play with hide and seek

- Difficult to defend against can be only made more difficult
- Typically combined with jammer detection and “neutralization”

e.g. Jamming 802.11b

802.11b uses DSSS

- spreading codes are publicly known
- e.g. Barker sequence for 802.11b at 1Mbps and 2Mbps = "1 0 1 1 0 1 1 1 0 0 0"
- spreading codes are the same for all channels

Jamming:

- jammer knows the codes and therefore can jamm any channel by transmitting symbols using the same codes ...
- even if the attacker uses adjacent channels the throughput will be affected
- there is no solution for this DoS attack on 802.11

Broadcast Jamming-Resistant Communication

Keys, some keys, no keys

Keys and Jamming-Resistant Communication

Broadcast

- Public key crypto doesn't help
- Shared Keys?
- Some shared keys?
- No keys?