the abdus salam
international centre for
theoretical physics

Spread Spectrum Radio Technologies

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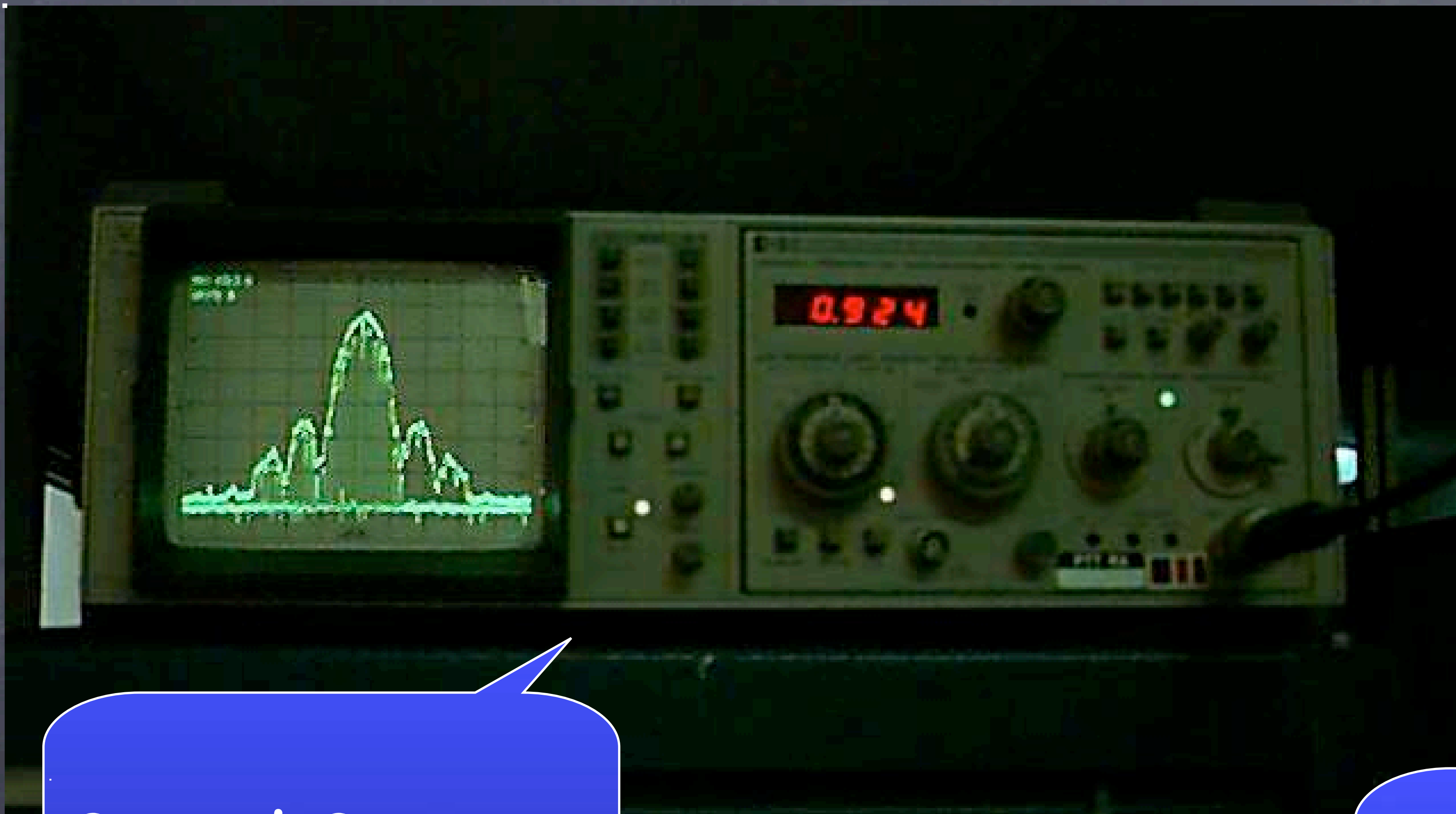
We will speak about

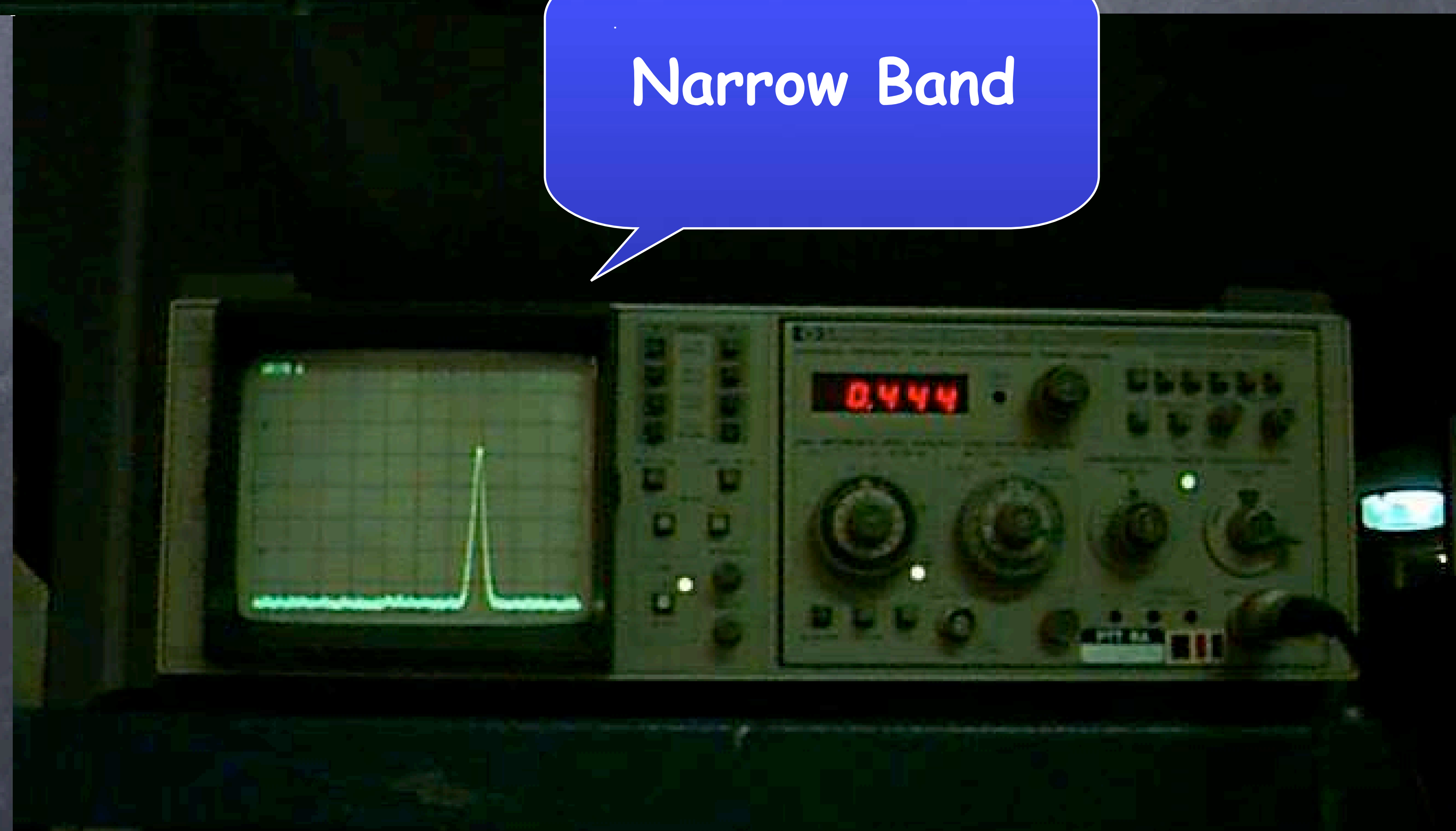
- Spread Spectrum vs. Narrow Band
- Benefits of Spread Spectrum
- Direct Sequence Spread Spectrum
- Frequency Hopping Spread Spectrum
- Frequency Hopping vs. Direct Sequence
- Antenna Basics
- Power Budget Calculation

Spread Spectrum vs. Narrow Band

- Spread Spectrum Signal Characteristics
  - The bandwidth of the transmitted signal is much greater than the original message bandwidth
  - The bandwidth of the transmitted signal is determined by a spreading function (code), independent of the message, and known only to transmitter and receiver

Spread Spectrum vs. Narrow Band





Spread Spectrum vs. Narrow Band

	Narrow Band Data Modulation	Spread Spectrum Data Modulation
Power Density	The energy of the transmitted signal is concentrated close to the carrier frequency. High energy in a part of the band	The energy of the signal is distributed (spread) in all the frequencies. Low energy in all the band
Actual Power Density	The actual power density is determined by the data signal (to be transmitted)	The actual power density is determined by the data and a specific (data independent) code (redundant transmission)
Geographical Coverage	Concentration of energy => High energy level => Greater coverage	Spread Energy => Low power density => Small coverage
Bandwidth (Round Figures)	Small BW AM=4kHz FMw=15kHz FMn=8kHz TV=5MHz	Large BW 902-928 MHz 2.400 2.485 GHz 5.720 5.850 GHz
System Colocation	Archived by frequency allocation. There's a limit of system for a given BW and band	Archived by using different codes (CDMA) There's in any case a limit
Noise Immunity	Archived by increasing the power of the carrier	The information is present all over the band in a reduntand way. The system use the code "to look for" his partners. Is a very unlucky situation to have noise at the same time in the whole band, therefore information can be reconstructed.

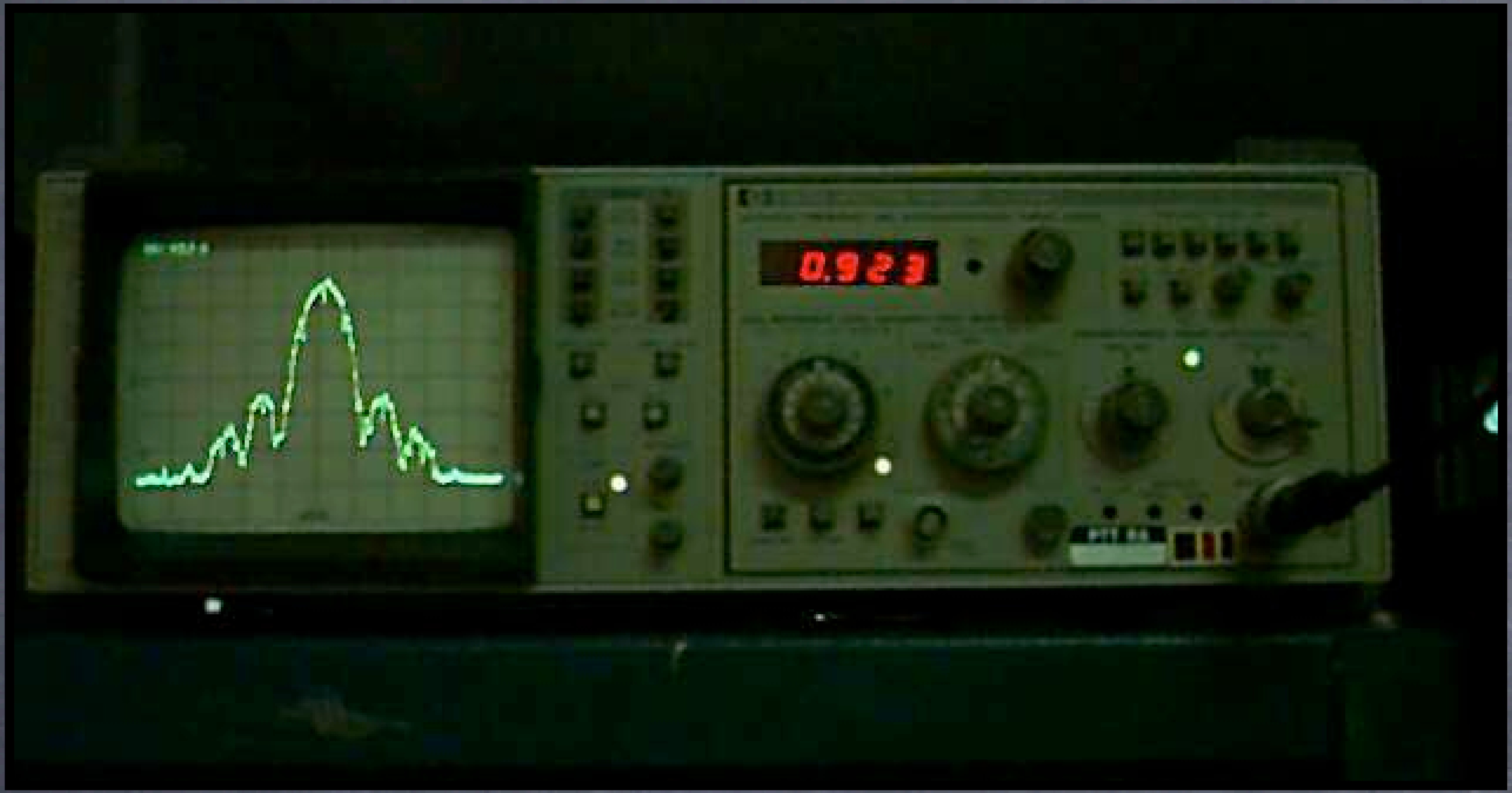
Benefits of Spread Spectrum

- Do not interfere with other signals (spread or narrow)
- Are immune to interference generated by other signals (spread or narrow) present in the frequency band
- Hard to intercept (CODE)
- Can be physically co-located
- License free operation (CEPT TR-1001)
- Resistance to jamming

Direct Sequence Spread Spectrum

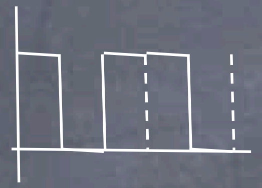
- **May be seen as result of two processes**
  - Data is multiplied with a higher rate digital sequence (spreading code). The sequence has many "chips" for every data bit;
  - The resultant signal modulate the RF carrier.
- **Effects of Direct Sequence spreading**
  - Data bit information is carried in every "chip";
  - If the noise do not affect all the "chips", the information can be recovered. Chips are done in a way that they are easily recognizable;
  - The capacity of a system to reconstruct data is a function of the ratio Tbit/Tchip=Process Gain (Usually PG>10);
  - Multiple system can co-exist in the same band if they use different (orthogonal) spreading sequence;
  - Spreading seq. tend to be very long, requiring high BW.

Direct Sequence Spread Spectrum



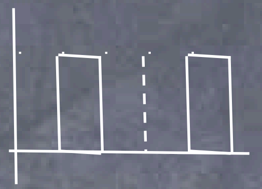
Direct Sequence Spread Spectrum

To transmit a 0 the station use a unique “chip sequence”:



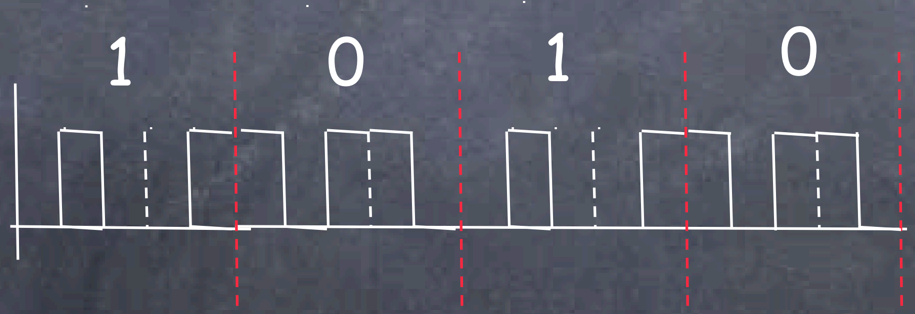
1 0 1 1 0

To transmit a 1 the station use the one’s complement of its chip sequence:



0 1 0 0 1

Therefore if data is 1010 it will transmit:



Direct Sequence Spread Spectrum

- It is more convenient to use a bipolar notation where 0 = -1 and 1 = +1.
- With this new notation the two chip sequences becomes:

  (+1,-1,+1,+1,-1)

  (-1,+1,-1,-1,+1)
- As we said before if another group of stations wants to share the same band they have to use different chip sequences :

  S= sequence for 0 of group A $\overline{\mathbf{S}}$= sequence for 1 of group A

  T= sequence for 0 of group B $\overline{\mathbf{T}}$= sequence for 1 of group B
- They must be pairwise orthogonal therefore the normalized inner product must be 0:

$$S \bullet T \equiv \frac{1}{m} \sum_{i=1}^{m} S_i \cdot T_i = 0$$

- In practice as many pairs are the same as are different
-
- Important notice: S * T = 0 , S * $\overline{T}$ = 0 , S * S = 1 , S * $\overline{S}$ = -1

Direct Sequence Spread Spectrum

- A good sequence with all this features is the so called Pseudo Noise sequence (PN)
- A PN sequence of a given length is orthogonal (CROSS CORRELATION COEFFICENT =0) with all the other PN sequences of the same length
- It has a good AUTO CORRELATION behavior, in fact the CORRELATION COEFFICENT of a sequence, correlated to a shifted version of itself, is close to 0 (this is a very important factor during synchronization)

Direct Sequence Spread Spectrum

When two or more stations transmit simultaneously (using different codes) the bipolar signals add linearly, like adding voltages;

To recover the bit stream of an individual station, the receiver has to :

know the chip sequence used by that station

compute the inner normalized product between the received sequence and the chip sequence of the station; let's assume that:

station A transmit $\mathbf{S}$

station B transmit $\overline{\mathbf{T}}$

we ,station C, receive $(\mathbf{S}+\overline{\mathbf{T}})$

we want to see what A was transmitting:

$(\mathbf{S}+\overline{\mathbf{T}})*\mathbf{S}=\mathbf{S}*\mathbf{S}+\mathbf{S}*\overline{\mathbf{T}}=1+0=1$

As we see station A was transmitting a 1

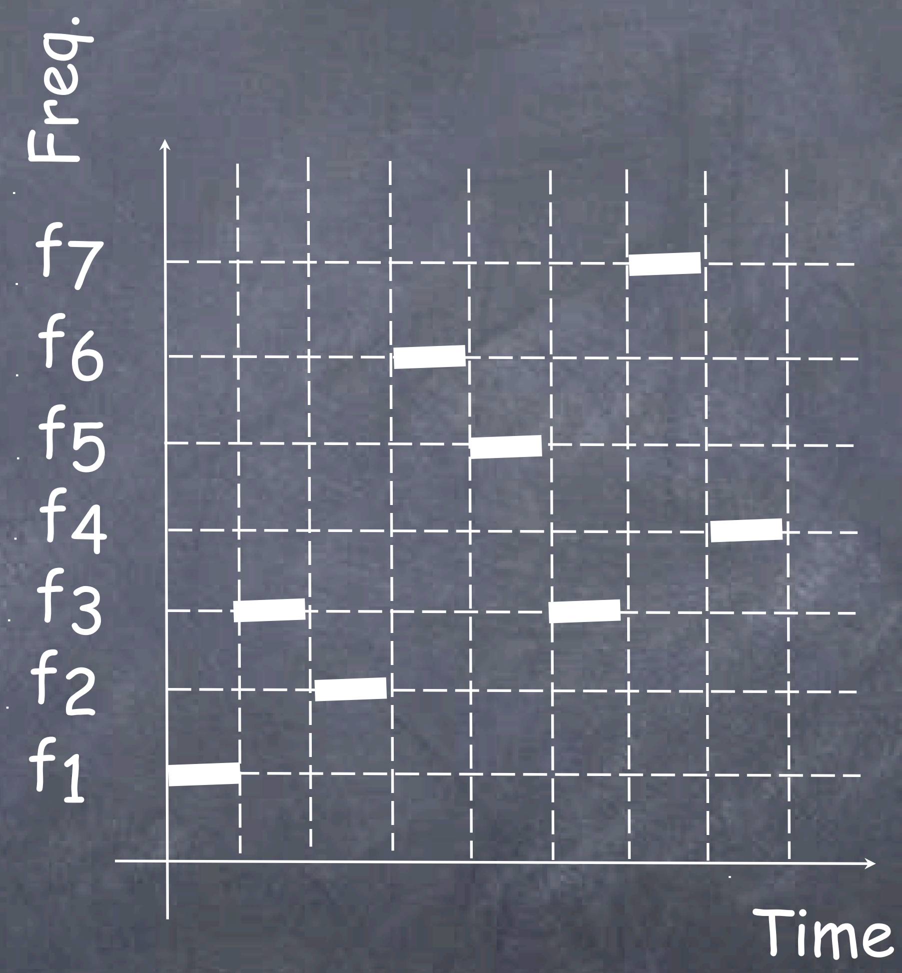
This, in any case, is an ideal situation because we assumed that the tree station where perfectly synchronized and there were no noise ... in any case up to a certain extent the decoding algorithm works quite well ...

Frequency Hopping Spread Spectrum

- May be seen as result of two processes
  - Data modulate the RF carrier;
  - The center frequency of the RF carrier is modified based on a spreading sequence.
- Effects of Frequency Hopping spreading
  - Data is carried on all the frequency hops;
  - If the noise do not affect all the hops, the information can be recovered;
  - Multiple system can co-exist in the same band if they use different spreading sequences.

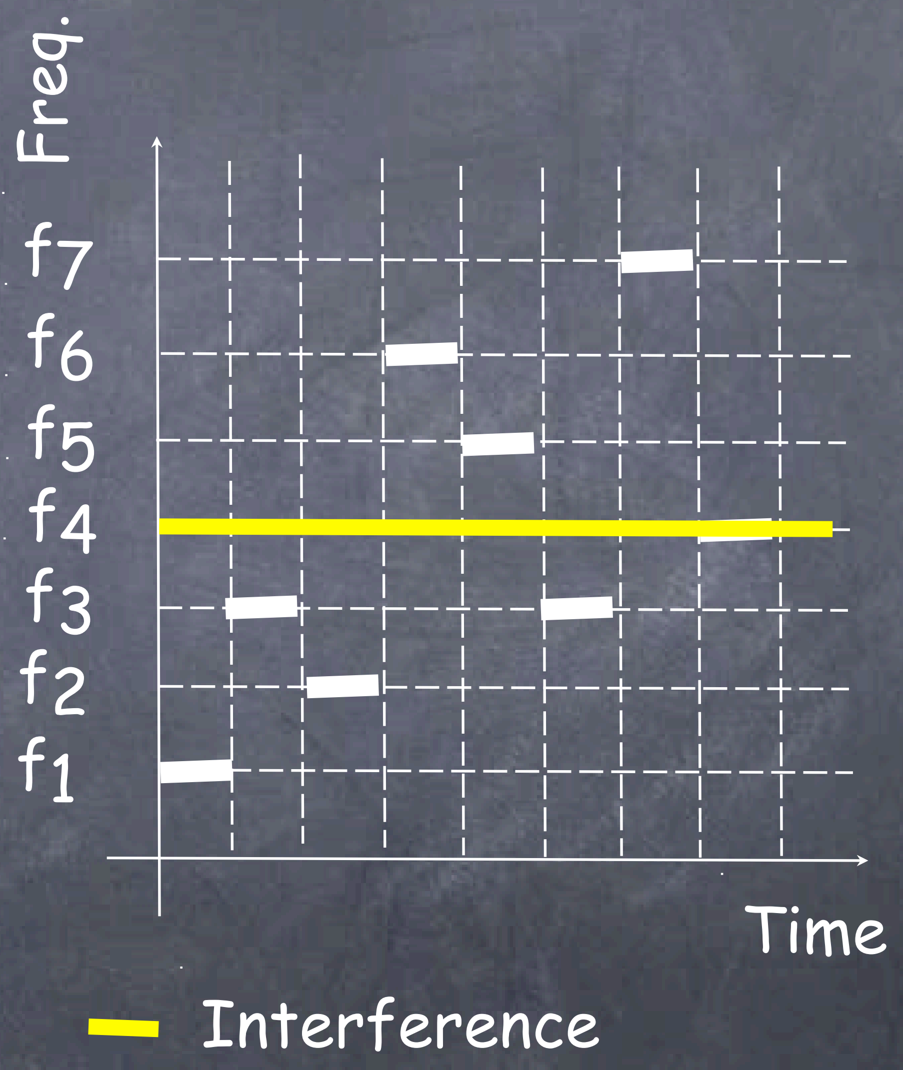
Frequency Hopping Spread Spectrum

- Transmitted signal is spread over a wide range of frequencies. (i.e. 2.400-2.485 GHz)
- Transmission usually hop 35 times per second.



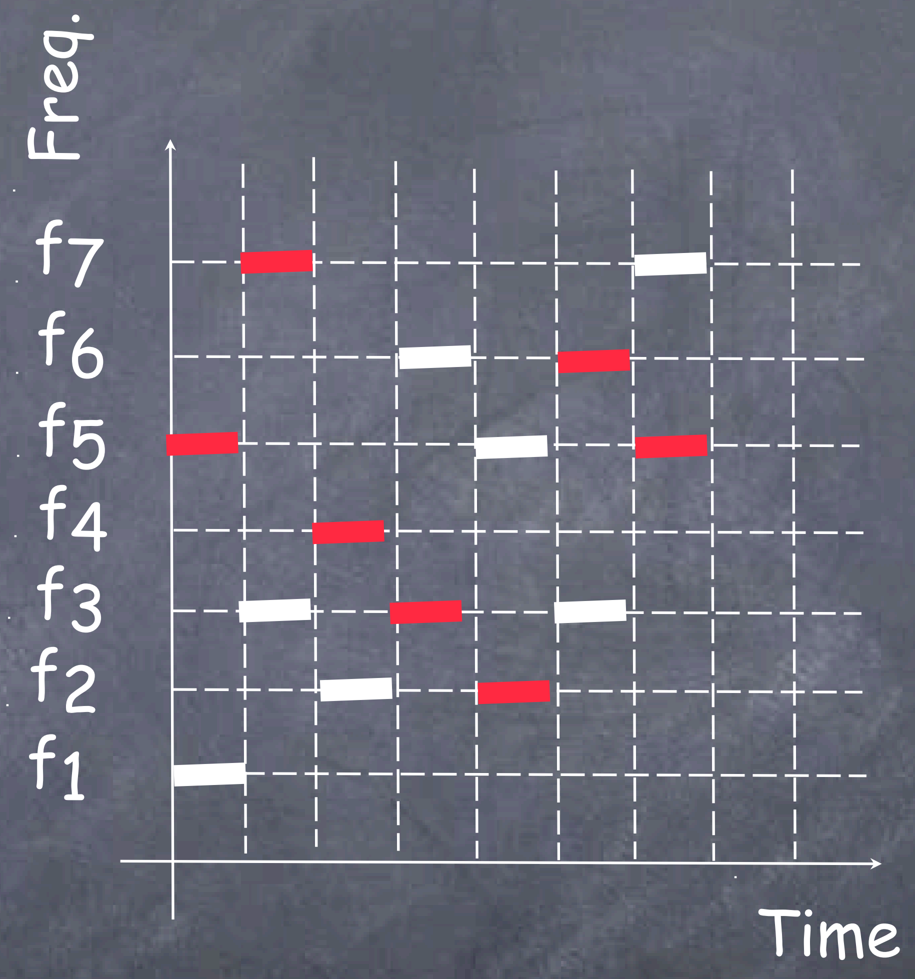
Frequency Hopping Spread Spectrum

- Low probability of interception.
- Jamming and interference immunity.

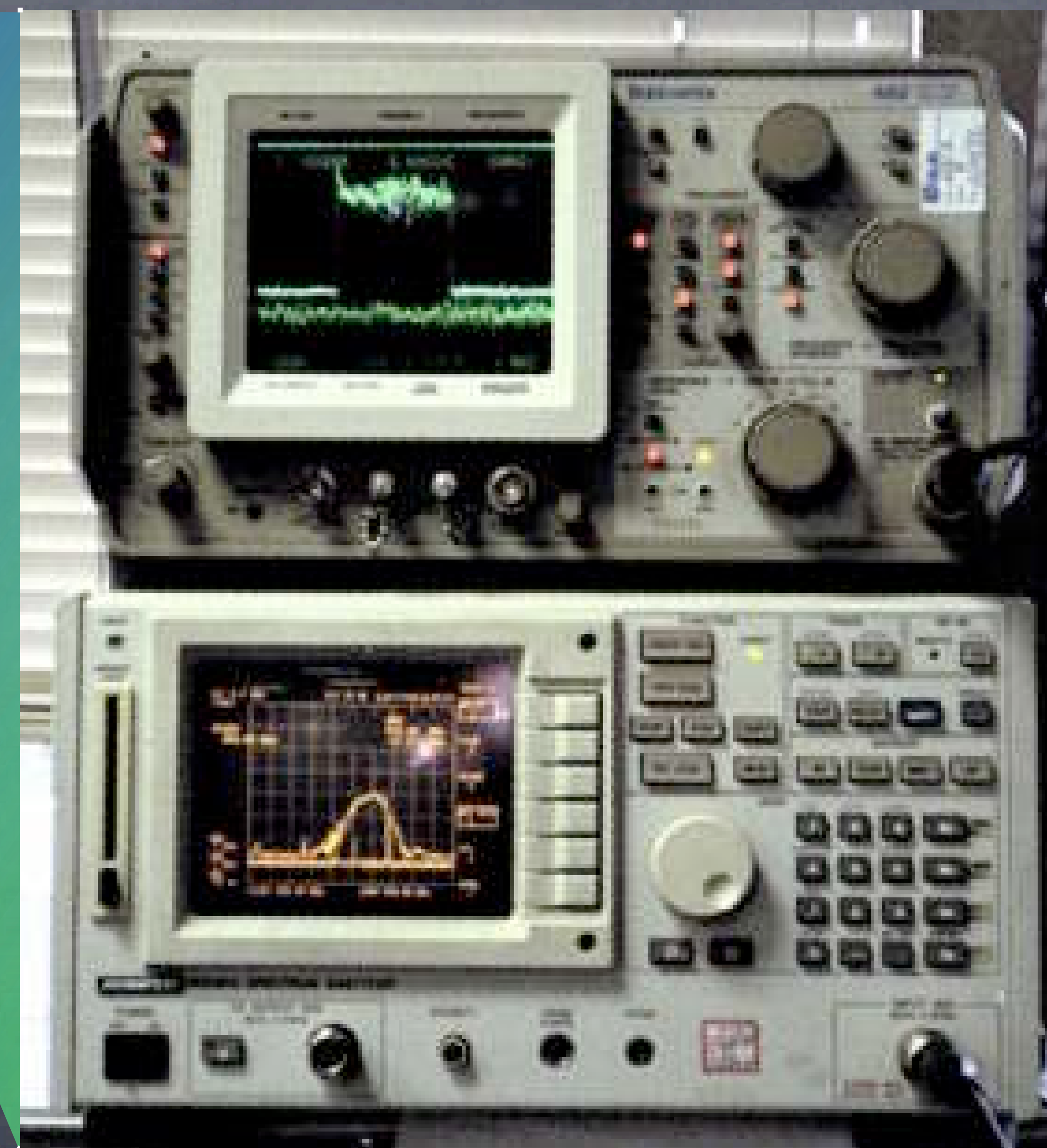


Frequency Hopping Spread Spectrum

- Co-existence of two systems.
- No near/far problem.



FHSS



Frequency Hopping
vs.
Direct Sequence

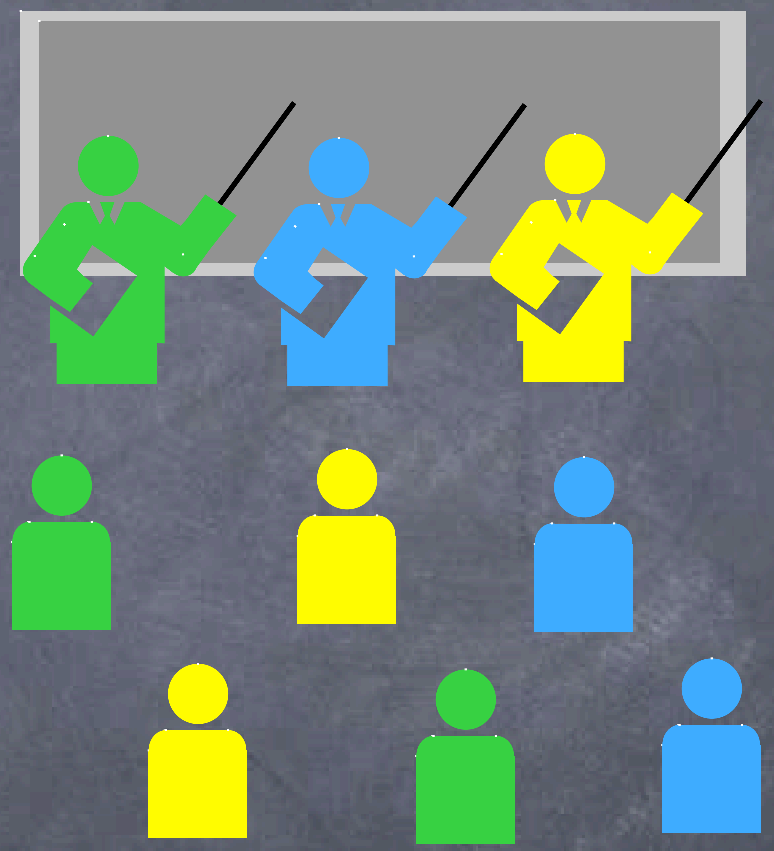
DSSS

Frequency Hopping vs. Direct Sequence

- System co-location
  - DS require very high speed for the “spreading code”, much higher that the transmitted data.
- Interference rejection
  - DS systems accept levels of interference a little bit higher that those accepted by FH systems;
  - However if the interference is higher than the limit the DS stop to work but the FH try to use unaffected frq. and continue to work.

Frequency Hopping vs. Direct Sequence

- DS systems are affected by high levels of interference created by other DS systems using the same band but different codes.
- FH can always use unblocked hops.



Frequency Hopping vs. Direct Sequence

- Multipath
  - DS systems use very high transmission rates => very short symbols that are more sensitive to echoes and delays.
- Throughput
  - DS systems transmit continuously (PSK). FH spend some time to re-synchronize and for hopping (FSK);
  - DS systems may have a better throughput for same data rate over the air.
- Radio Complexity
  - DS use more complex radios.

Antenna Basics

Antenna Basics

- Transmission Line
  - The device used to guide the RF energy from one point to another.
- Radio Antenna
  - The structure associated with the region of transition from a guided wave to a free space wave, radiating RF energy.

Antenna Basics - UNITS

- How do we measure power:

  [dBm]=10 Log [mW]

dbm	watt
0	0.001
10	0.01
20	0.1
30	1
40	10

Antenna Directivity

- Isotropic Antenna:
  - Radiates the energy fed into it in the whole space.
- Non Isotropic Antenna:
  - Radiates energy fed into it only in part of the space.

Antenna Directivity and Gain

- Non isotropic antennas are characterized by their capability to radiate more strongly in some directions than in others; this is called directivity.
- The ratio of the maximum power density to the average power density over the entire space is the numerical measure of directivity that is:

$$D = \frac{P}{P_{av}} \qquad D[dBi] = 10 Log_{10}\left[\frac{P}{P_{av}}\right]$$

Antenna Directivity and Gain

- The gain is closely related to directivity. In this case you have to take into account the efficiency (k) of the antenna:

$$G = k\frac{P}{P_{av}}$$

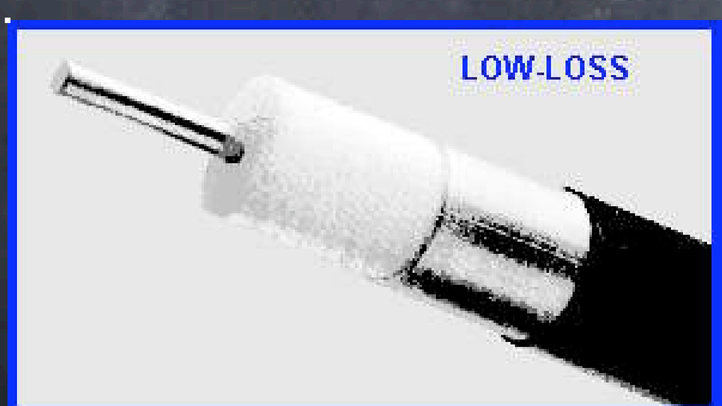
For most of the antenna systems used, efficiency is quite high, in such cases the gain is essentially equal to directivity

Antenna Types

Omni Directional Antenna

YAGI Directional Antenna

Transmission Lines ,Cables and Connectors

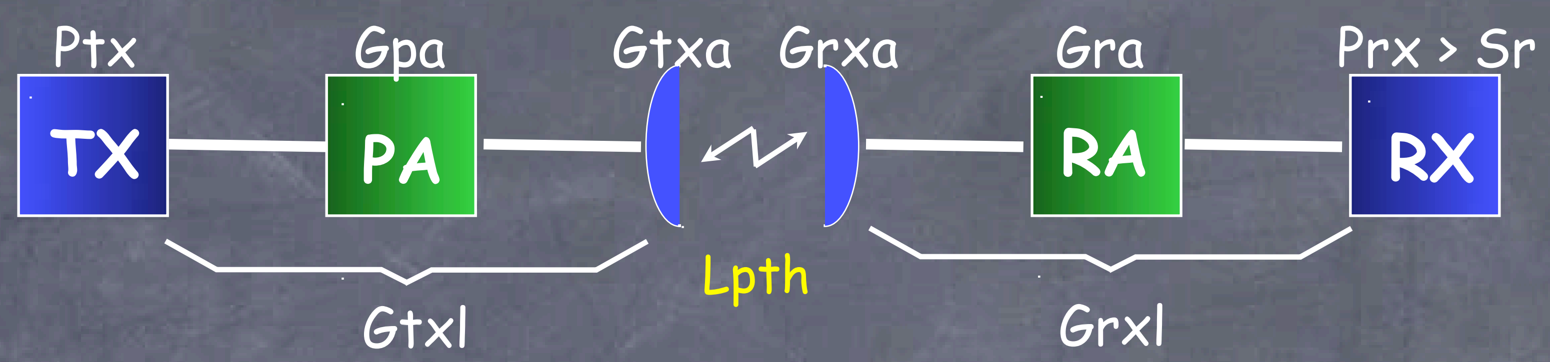


Type	Typycal attenuation @ 2.400GHz
RG58	1 dB/m
RG214	0.6 dB/m
Heliax	0.14 dB/m

Power Budget Calculation

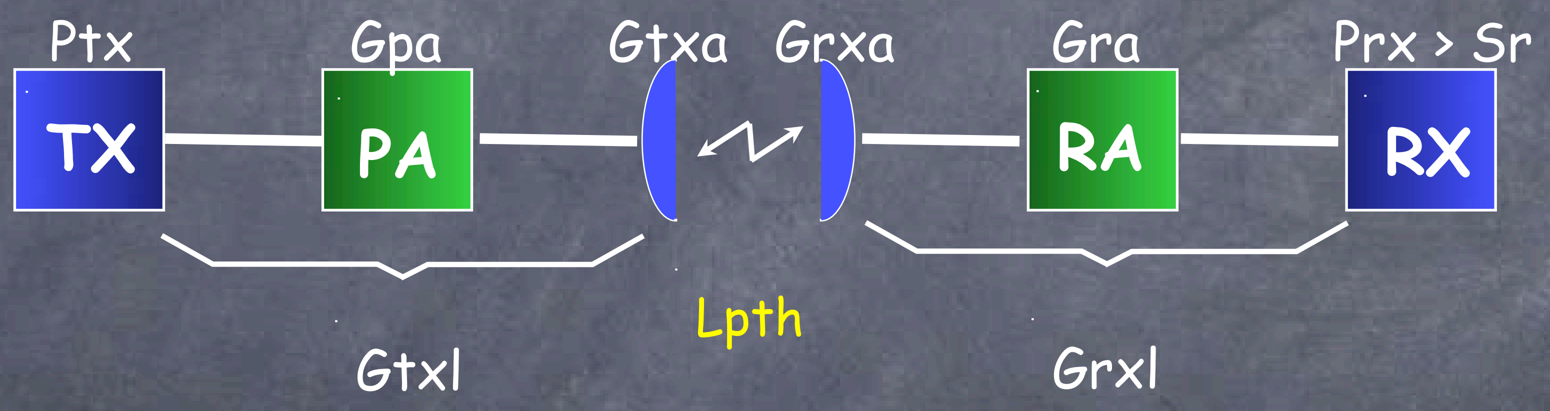
- What is the distance limitation for RADIO LINKS ?
  - Generally, transmission range is limited to "unobstructed line-of-sight" The transmission range is influenced by the
  - transmitter power
  - type and location of the antenna
  - frequency
  - length of the antenna feed line (the cable connecting the radio to the antenna).
  - Another factor influencing the transmission range is the existence of obstructions (hills, groups of buildings ,etc).

Power Budget Calculation



- Ptx[dBm]=Power generated by TX
- Gpa[dB]=Gain of the Power Amplifier
- Gtxl[dB]=Gain (loss) of transmission line
- Gtxa[dBi]=Gain of TX antenna
- Lpth[dB]=Loss of the transmission medium
- Grxa[dBi]=Gain of RX antenna
- Grxl[dB]=Gain (loss) of receiving line
- Gra[dB]=Gain of the Receive Amplifier
- Prx[dBm]=Power received
- Sr[dBm]=Sensivity of receiver Gtxl

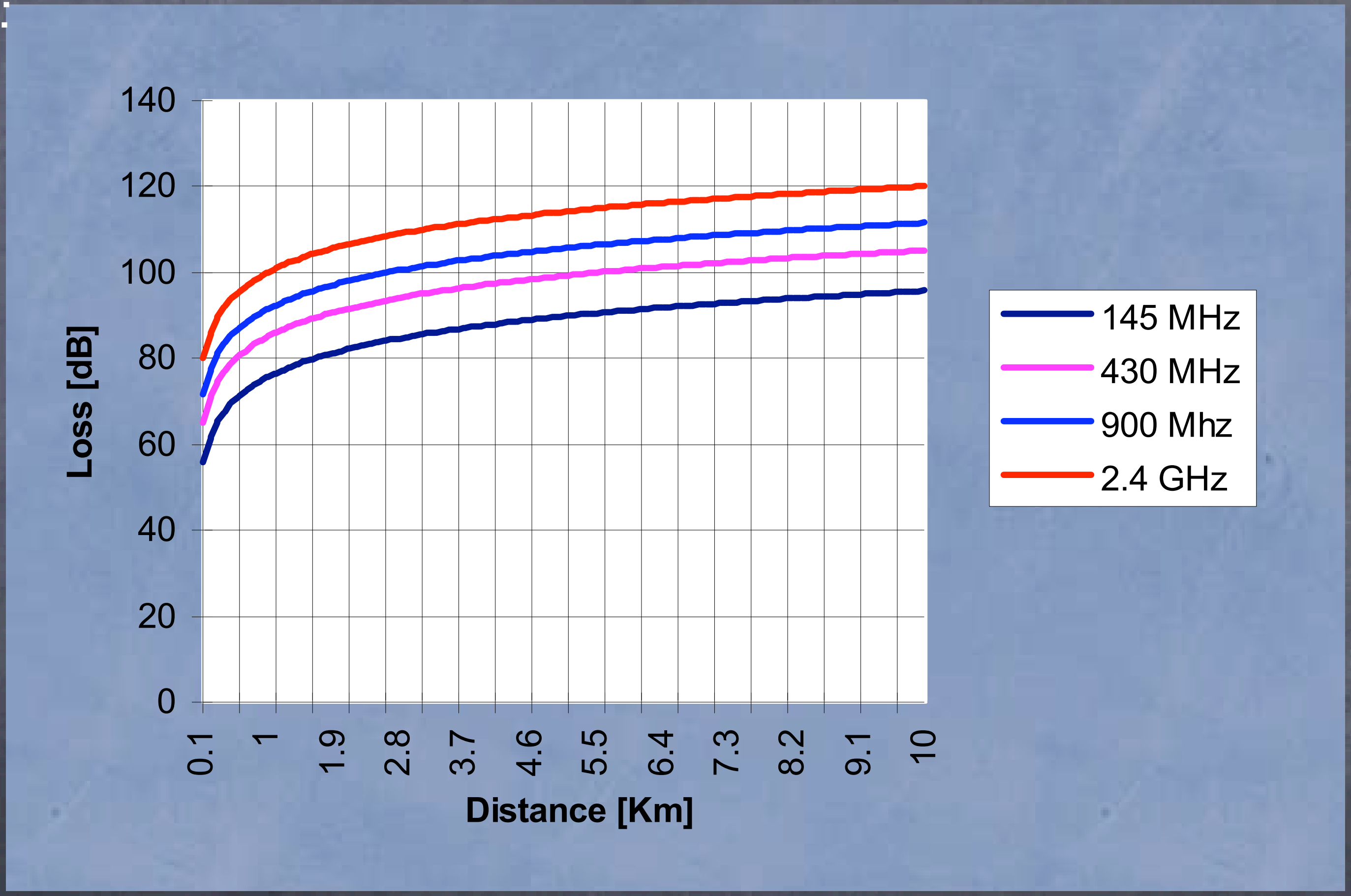
Power Budget Calculation



- Prx=Ptx+Gpa-Gtxl+Gtxa-Lpth+Grxa+Gra-Grxl
- Prx > Sr

Power Budget Calculation

- Loss of TRANSMISSION medium:



$$Lpth[dB] = 92.5 + 20 \cdot Log_{10} f[GHz] + 20 \cdot Log_{10} d[Km]$$

Spread Spectrum Radio Technology

The end. Relax