Welcome to
Wireless Technology Overview

Modulation, access methods, standards and systems

Amplitude Modulation (Ye Olde Classiqúe)

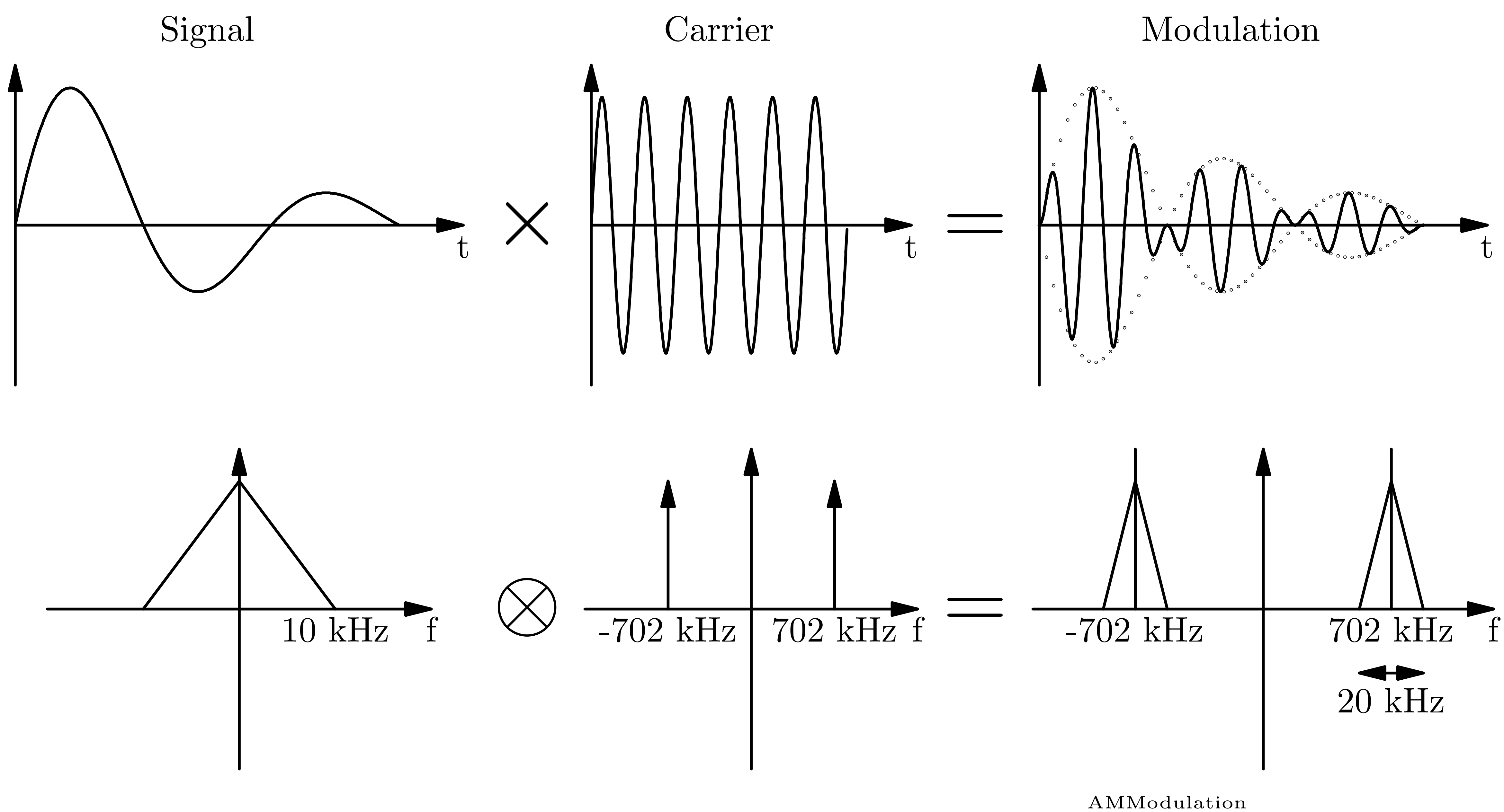


Figure 1.1: Amplitude Modulation (DSB-SC)

$$\phi(t) = f(t)\cos\omega_c t$$

- Best Proof of $-$ve frequencies!

AM Demodulation

$$f(t)\cos^2\omega_c t = \frac{1}{2}f(t) + \frac{1}{2}f(t)\cos(2\omega_c t)$$

- De-modulation achieved by multiplying again.
- (Must get Frequency right!)
- Easy to filter out the component at twice the carrier.
- All Terrestrial Noise sources affect the *amplitude* of Rx.

Standard, Goode Olde Fashioned Broadcast

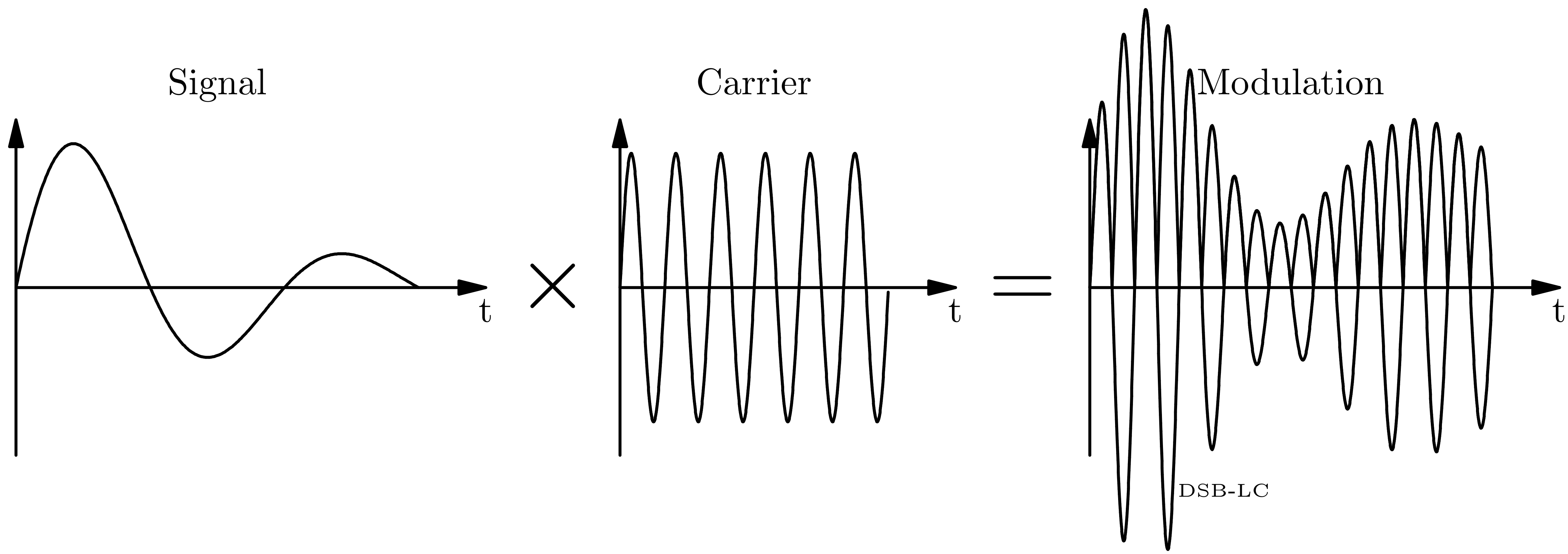


Figure 1.2: Large carrier AM, also showing a rectified overlay

- Cheap detection, expensive transmission.
- (Must accomdate largest −ve swing *above* carrier inversion.)

Frequency Modulation

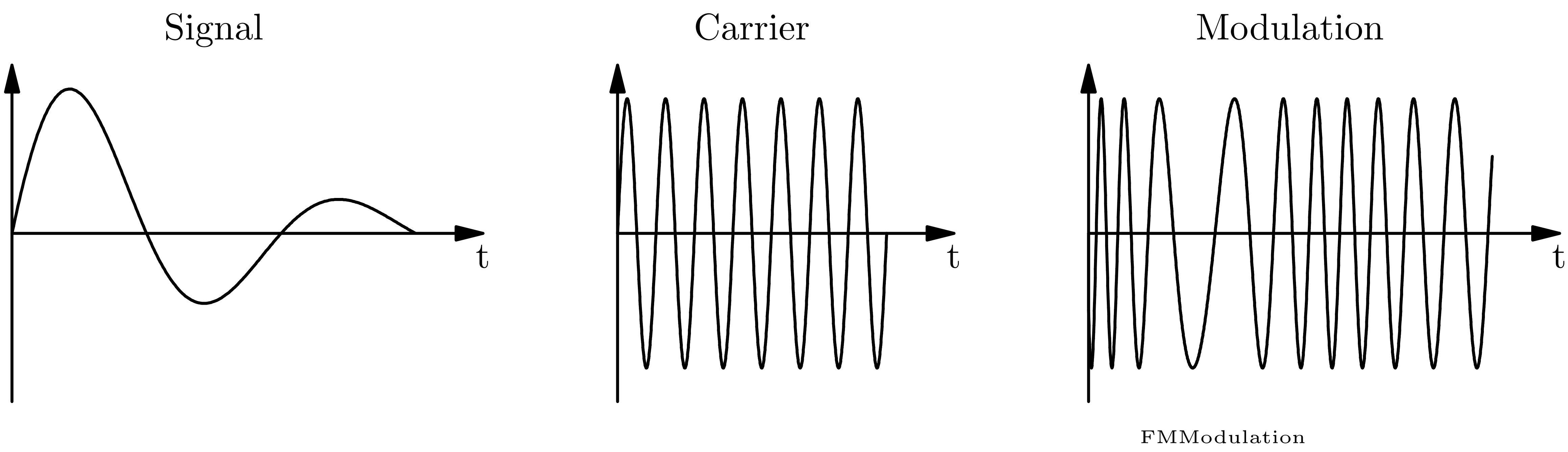


Figure 1.3: Frequency modulation

$$\Phi_{\mathrm{FM}}(t) = Ae^{j(\omega_c t + \beta \sin \omega_m t)}$$

$$\Phi_{\mathrm{FM}}(t) = Ae^{j(\omega_c t)} \left(1 + j\beta \sin \omega_m t - \frac{1}{2!}\beta^2 \sin^2 \omega_m t - j\frac{1}{3!}\beta^3 \sin^3 \omega_m t + \cdots \right)$$

Carsons Rule:

$$W \approx 2\omega_m(1 + \beta)$$

- Wide RF bandwidth required for small signal bandwidth.
- Stereo FM has much less SNR.
- Doppler Shift a problem for mobile users. (DAB to the rescue. . .)

Digital Modulation

- No you can't shove 1's and 0's onto your el-cheapo FM transmitter bug. 10101010 works until 11111111 :-)

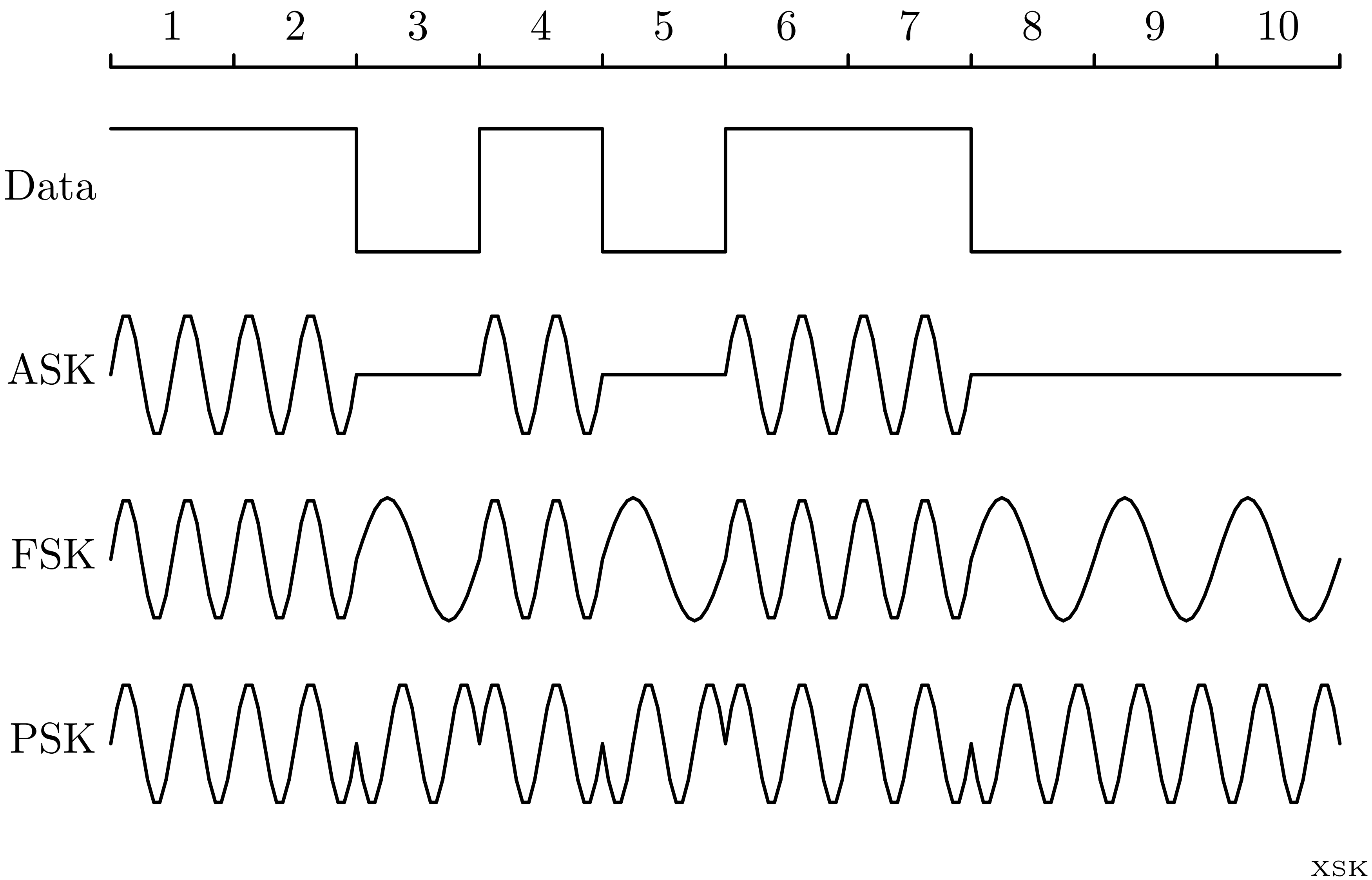


Figure 1.4: Simple digital modulation: Amplitude, Frequency and Phase Shift Keying

Baud and Bits...

symbol	bits	freq
a_1	00	f_1
a_2	01	f_2
a_3	10	f_3
a_4	11	f_4

- Channel bandwidth determines *symbol* rate, not bit rate!
- 56k??? Ha!

***I*n phase and *Q*uadrature phase**

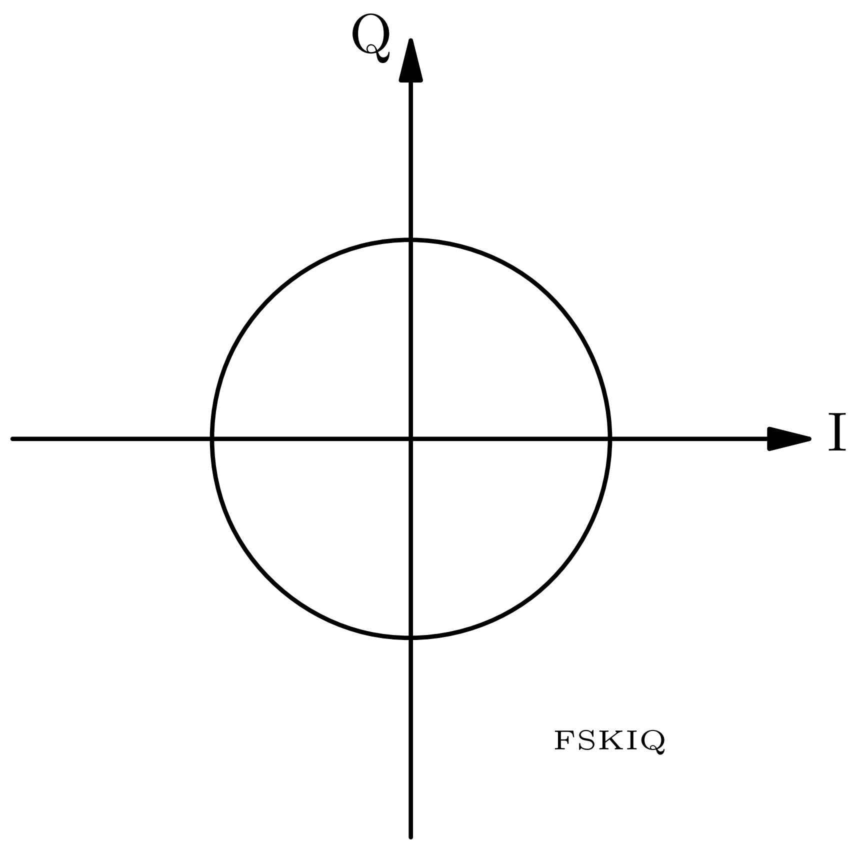


Figure 1.5: I/Q diagram of a slowly varying FSK signal.

- Signal amplitude change varies size of circle.

BPSK

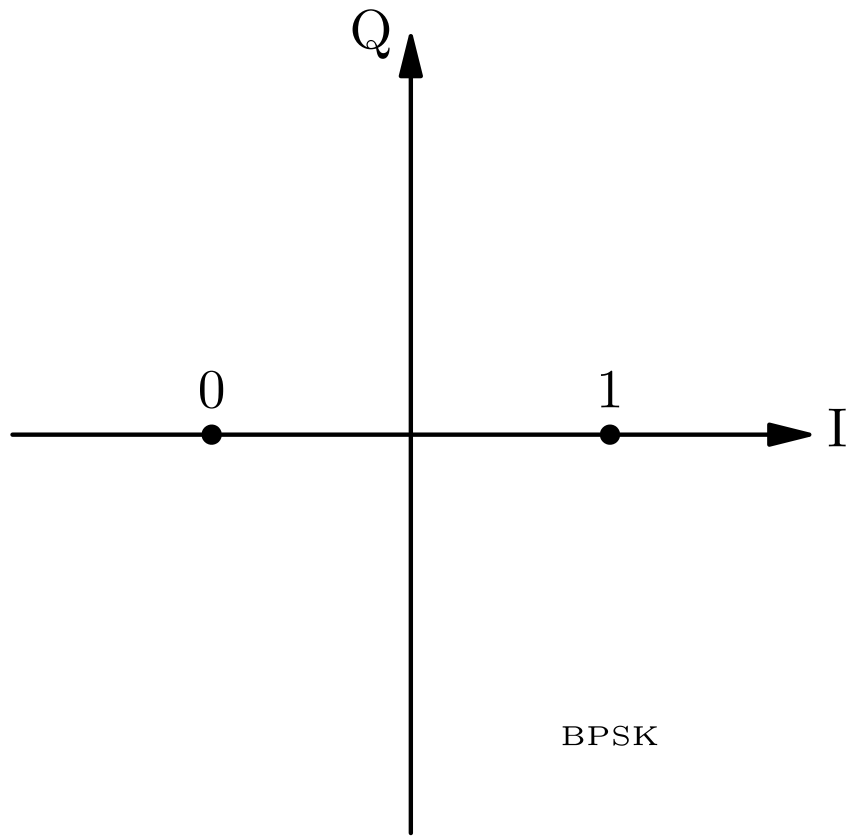


Figure 1.6: I/Q diagram of a Binary PSK

QPSK

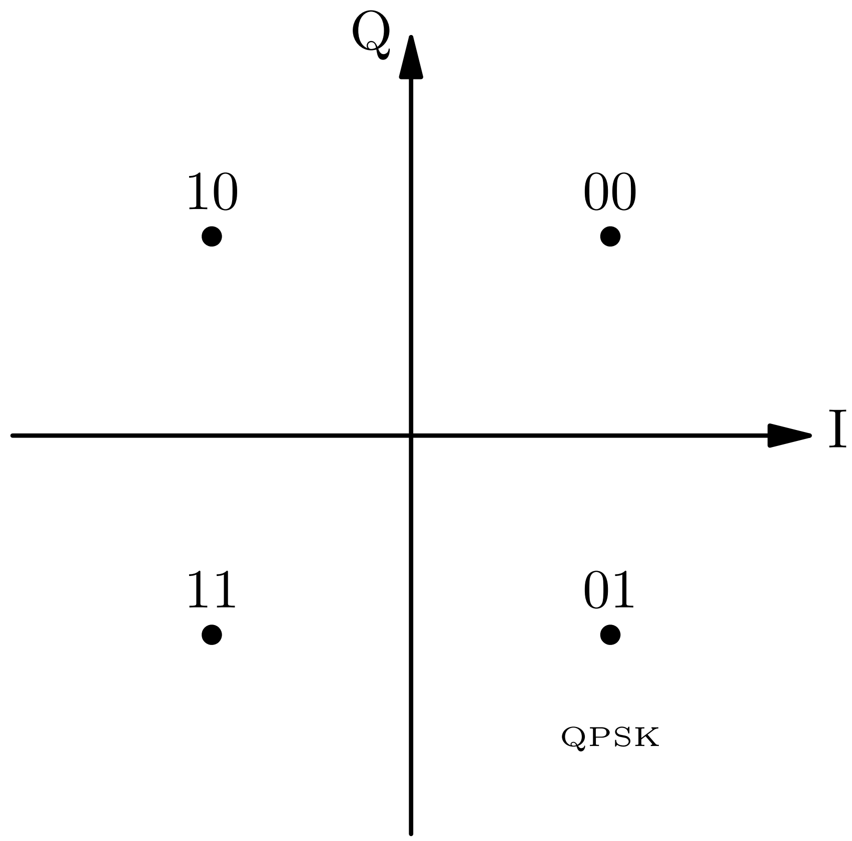


Figure 1.7: Quadrature Phase Shift Keying I/Q diagram.

- Additive noise convert dots into *areas*. . .
- Note zero crossing to get from 00 to 11 etc (any double-bit change).
- RF amplifiers. . .
- If no change in symbol, clock recovery difficult.

DQPSK

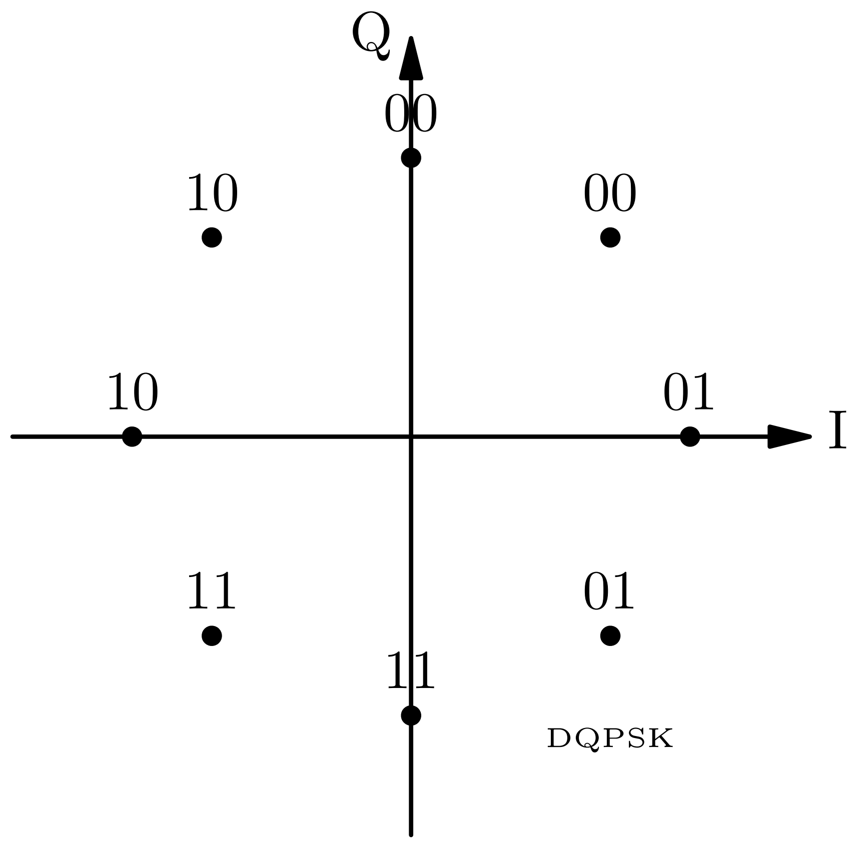


Figure 1.8: $\pi/4$ Differential Quadrature Phase Shift Keying

- Still only four states, *lessens* need to control RF amplitude.
- Every symbol involves a state change—clock recovery.

OBPSK

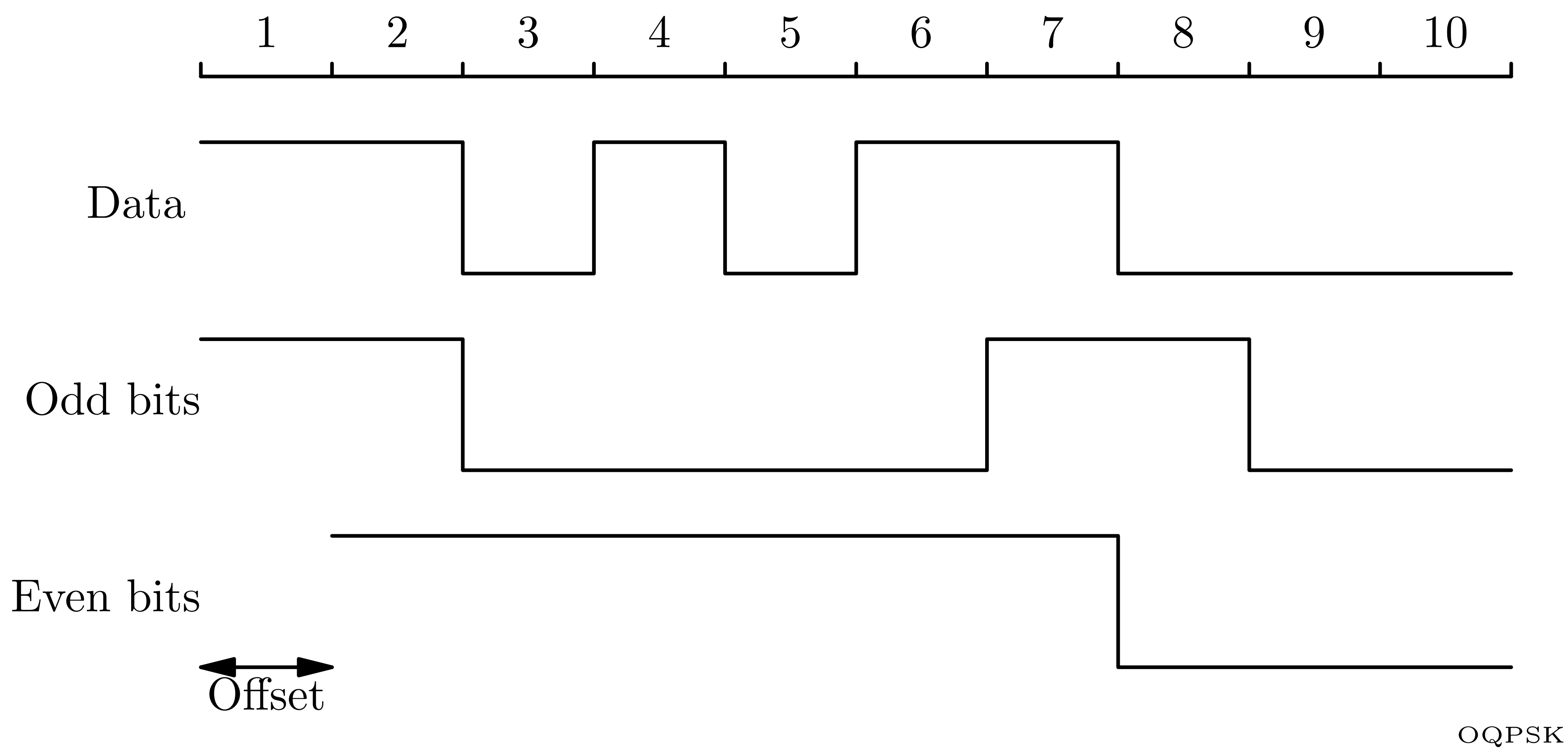


Figure 1.9: Offset Quadrature Phase Shift Keying

- Separate BPSK data streams on I and Q axes = QPSK.
- Ensures that 2 bits can't change simultaneously.
- Minimizes need to control RF amplitude.

M-ary

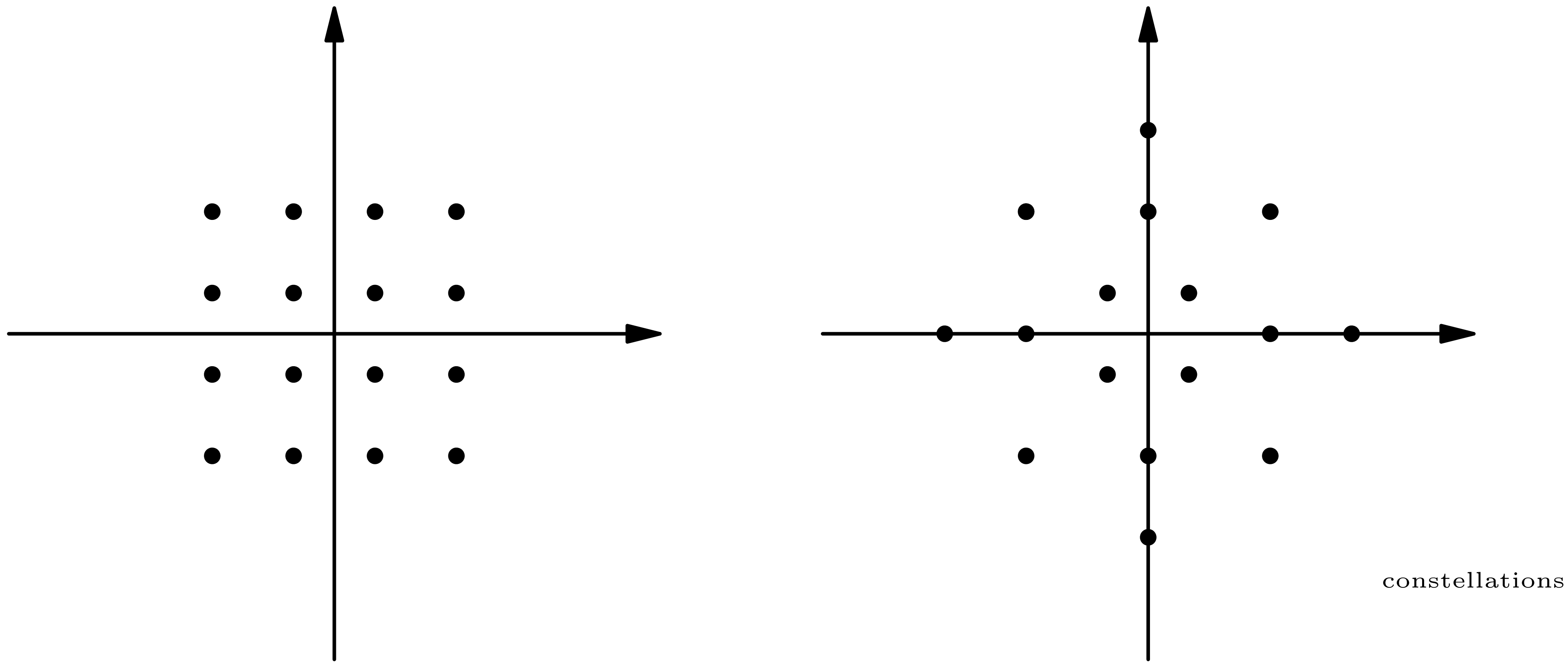


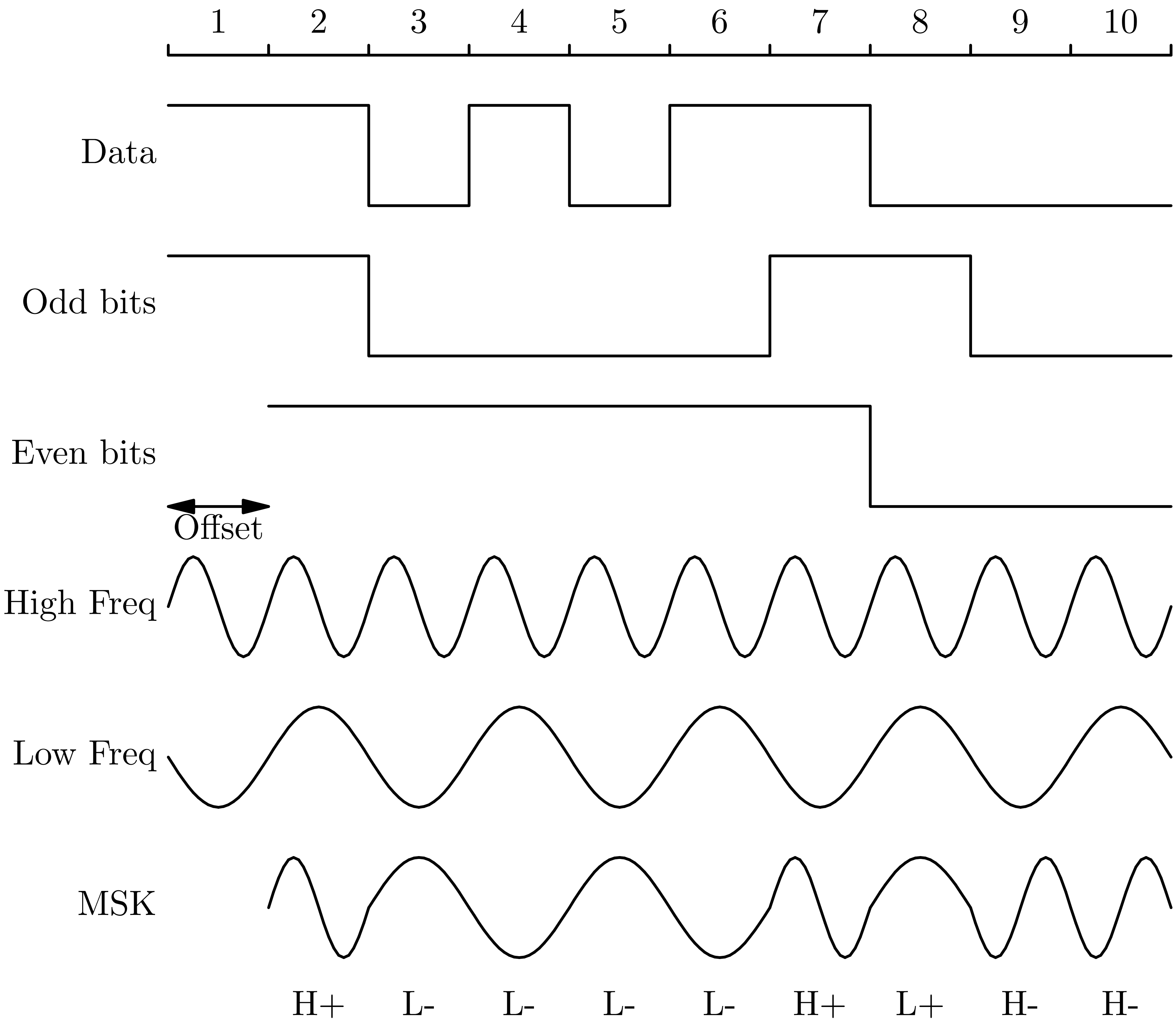
Figure 1.10: Two types of 16-ary Phase and Level shifted constellations.

- Higher data throughput, lower symbol rate.
- Ability to distinguish states drops, requiring higher SNR.

Minimum Shift Keying

Odd Bit	Even Bit	Freq	Sense
1	1	High	+
0	1	Low	−
1	0	Low	+
0	0	High	−

- Clever use of two frequencies, +ve and −ve.
- Overlaid on Offset QPSK.
- Add a Gaussian Filter to smooth things further: GMSK. (Class D amp OK!)



msk

Figure 1.11: Minimum Shift Keying

Noise considerations

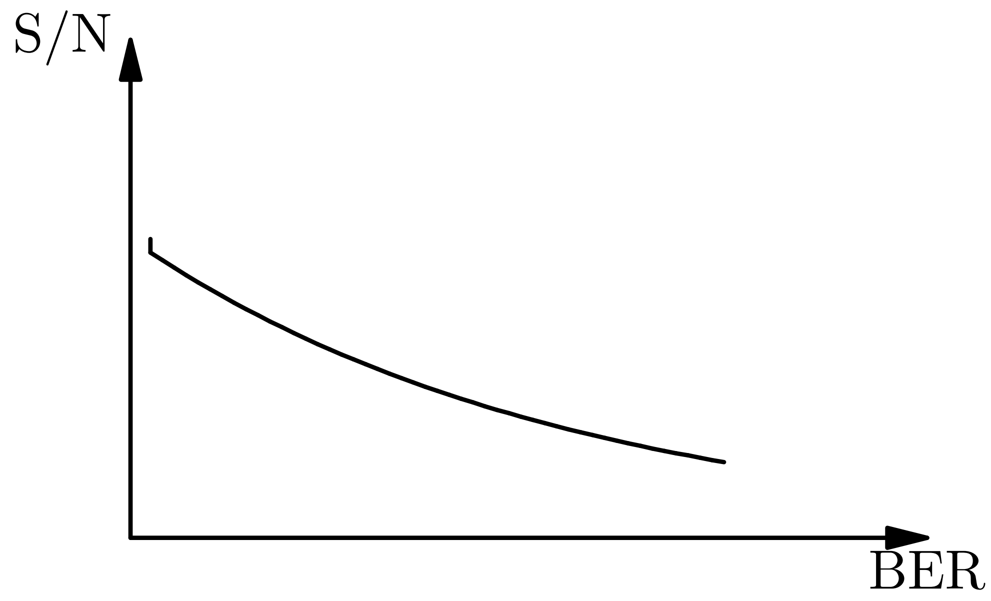
$$P_n = kTB$$

where $k = 1.38 \times 10^{-23} J/K$ (Boltzmann's constant), T is the temperature in Kelvin, and B is the bandwidth in Hz.

- Note that the wider the bandwidth, the higher the noise floor.
- Signal must exceed the noise floor by a margin (SNR).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi r)^2}$$

$$P_r = P_n(\text{dB}) + S/N(\text{dB})$$



BER

Figure 1.12: Bit Error Rate increases with decreasing S/N ratio.

Noise Temp & Figure

- Can therefore speak of Noise Temperature of a receiver.
- DSTV LNA at about 20K!
- Also Noise Figure:

$$NF = 10\log_{10}\left(\frac{T}{290K} + 1\right)$$

- 3dB = 290K (Room Temp)

BER vs SNR

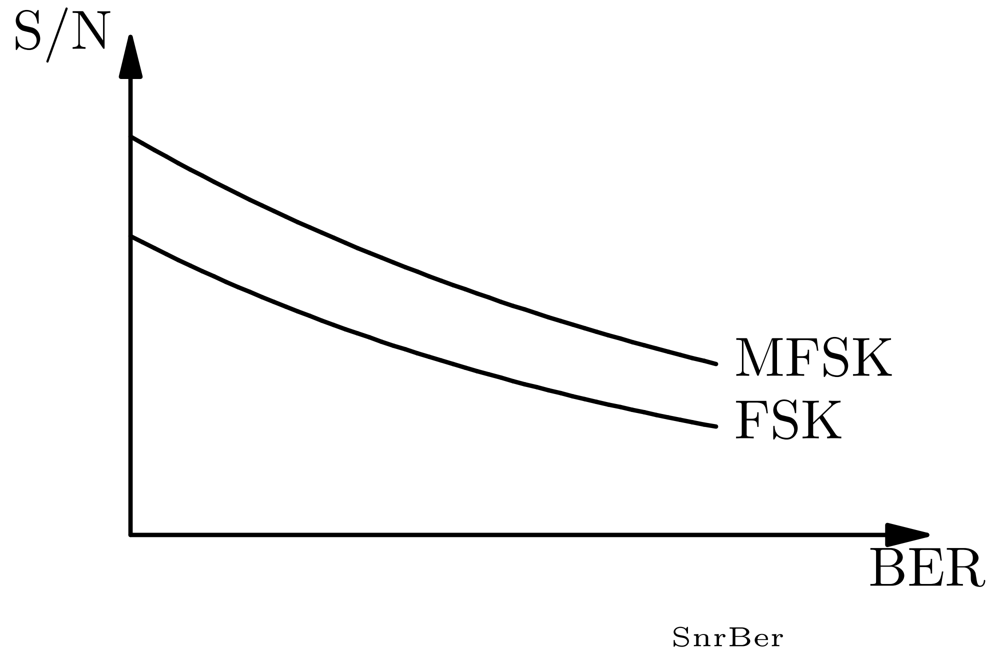


Figure 1.13: Bit error rates at Signal to Noise Levels.

In summary, as a rule-of-thumb:

1. Bandwidth Required $\approx 2\times$ Symbol Rate, for most modulation schemes, or:

$$\text{BW} \approx 2 \times \text{Baud}$$

2. For a scheme which uses 2^M bits per symbol, the Symbol Rate is the Bit rate over M, or:

$$\text{Baud} = \frac{\text{bps}}{M}$$

3. For the same Bit Error Rate, the Signal to Noise Ratio required increases as a factor of M, the number of Bits per Symbol, or:

$$\text{S/N}_{\text{Required for Multiple Bits/Symbol}} = M \times \text{S/N}_{\text{Required for 1 Bit/Symbol}}$$

In dB terms, this means an $M\times$ 3dB improvement in link budget requirement.

Chapter 2

Channel Access

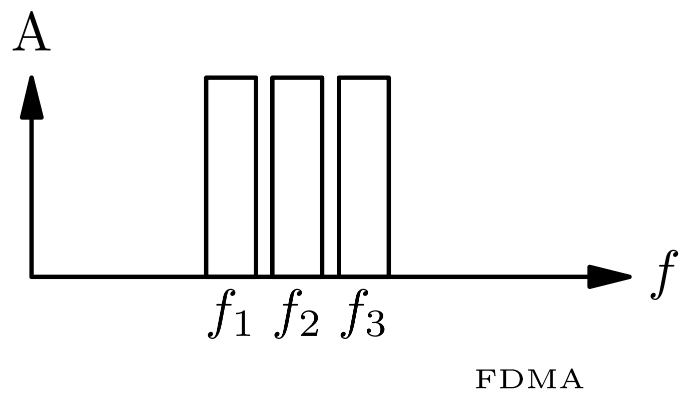


Figure 2.1: Frequency Division Multiple Access

- Classic Access method.
- Hogged all the time.
- Guard band
- BW $\approx 2\times$ datarate.

TDMA

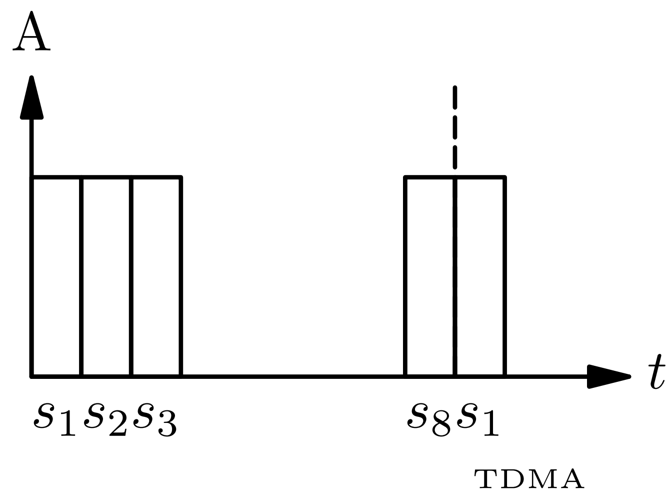


Figure 2.2: Time Division Multiple Access

- eg GSM 8 timeslots/frequency.
- GSM frame 4.6ms, 0.5ms /slot.
- Hence Breakthrough.
- GSM freq. spacing 200kHz
- Silent slots can be captured (Not GSM)
- To send 10kbps, 8 slots. Inst. rate 80kbps, 160kHz!

CDMA

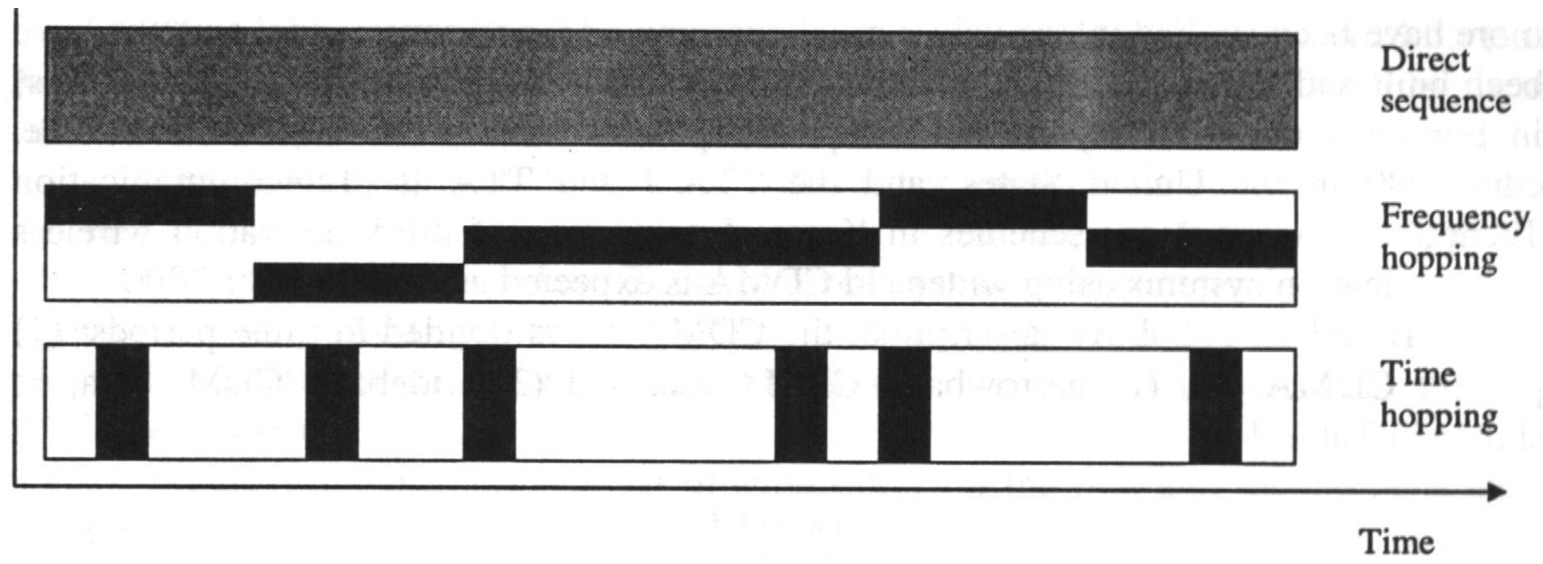


Figure 2.3: CDMA Classifications: Direct Sequence, Frequency Hopping and Time Hopping

- Not a “standard”
- DSSS
- FHSS (Fast and Slow)
- THSS
- Any combination!

CDMA

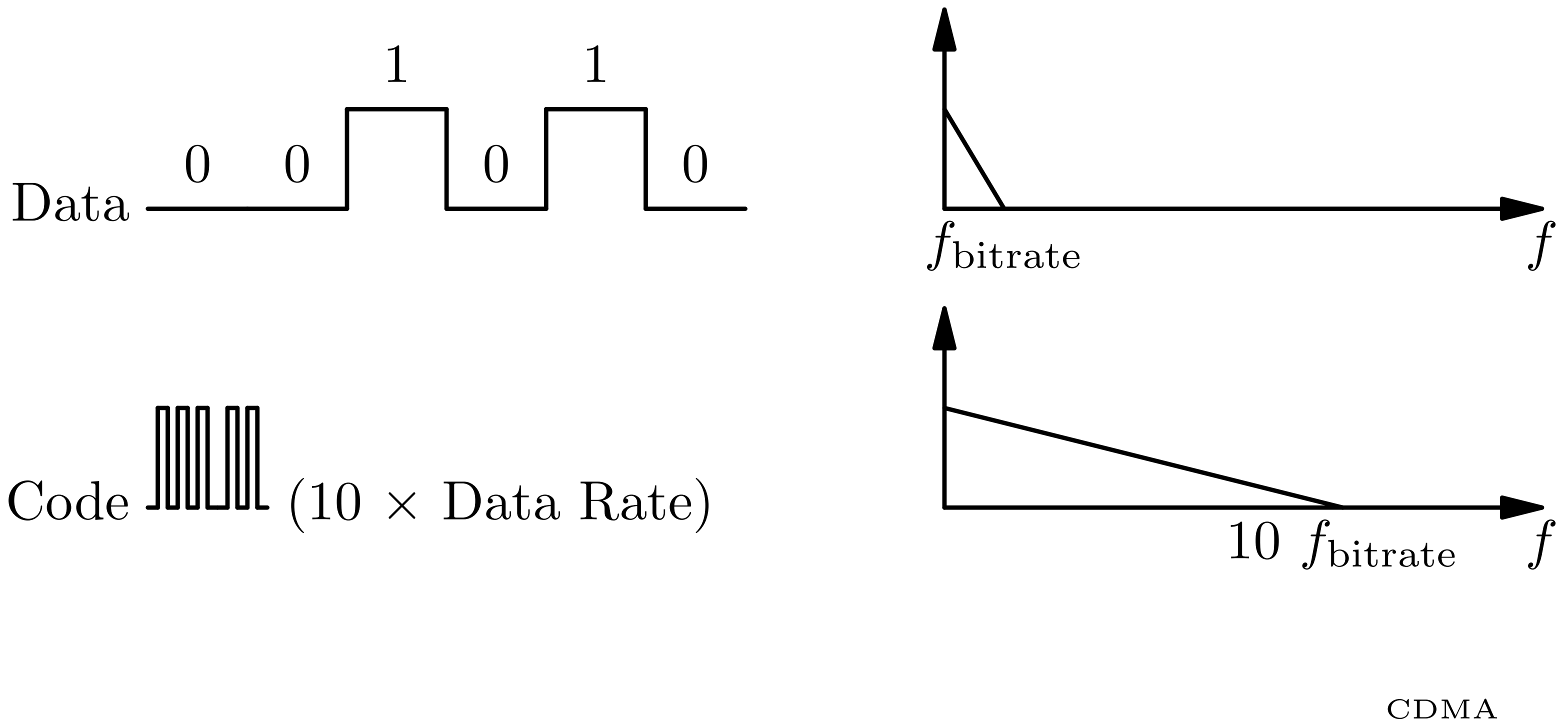


Figure 2.4: Code Division Multiple Access Spreads the Spectrum.

- PRN (linear shift register) or actual Orthogonal
- Code must have good Auto and bad Cross Correlation!
- "Sidelobes" in Auto may cause erroneous Code synch.
- Good Auto reqd for multipath.
- "Short" code—1 bit, "Long" several bits.
- Short is periodic, MUD, limited number.
- Long large number of codes, but MUD more difficult.
- BTS downlink synchronous, uplink asynchnoronous.

- “Soft” handover.
- WLAN, DAB, 3G
- (Less fading)

SDMA

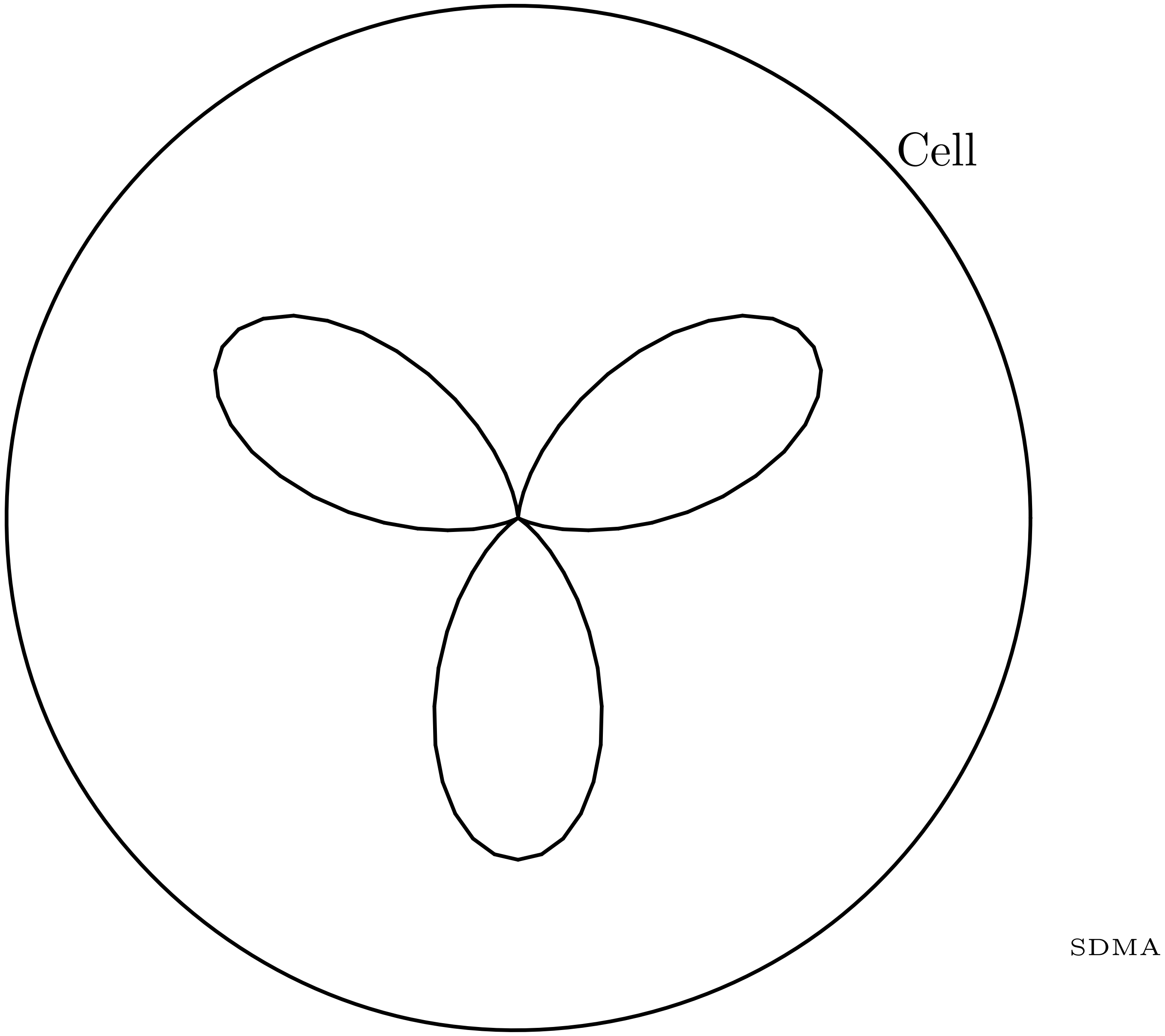


Figure 2.5: Space Division Multiple Access with "Smart" antennas.

- (Cells)
- "Smart" arrays.
- Hence higher freq.
- Reuse same freq *and* timeslot.
- Computationally intensive.

Fading

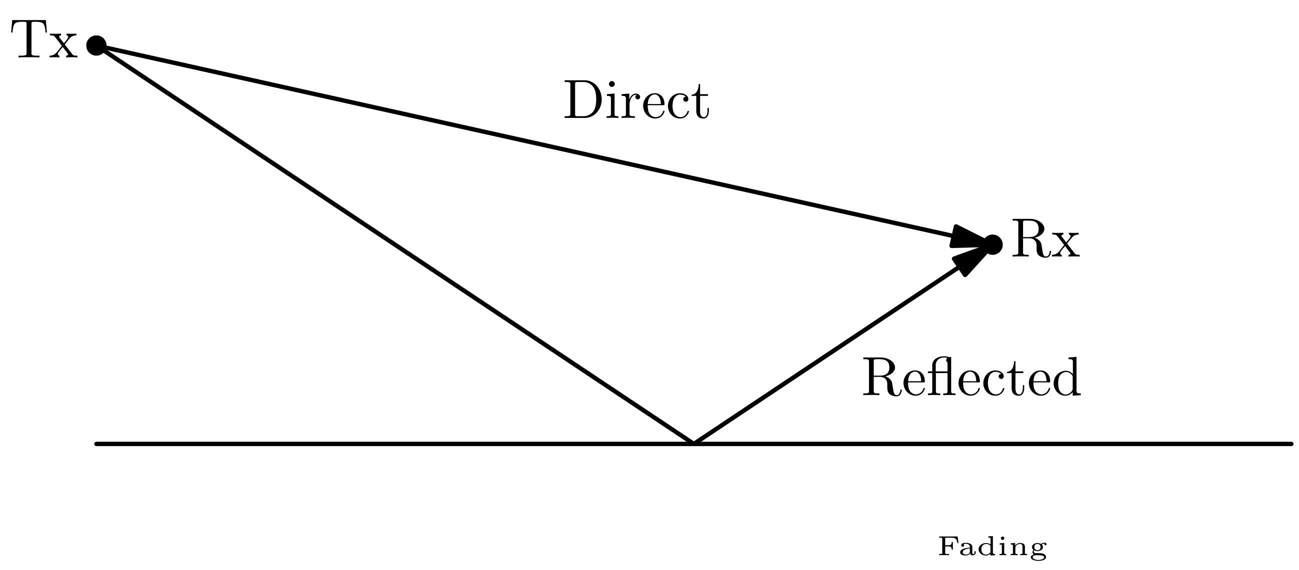


Figure 2.6: Fading due to Multipath Cancellation

- Space diversity. (BTS)
- Polarization Diversity.
- CDMA.
- Intersymbol Interference (Digital).
- Ghosting (Analogue)

Chapter 3

Cellular systems

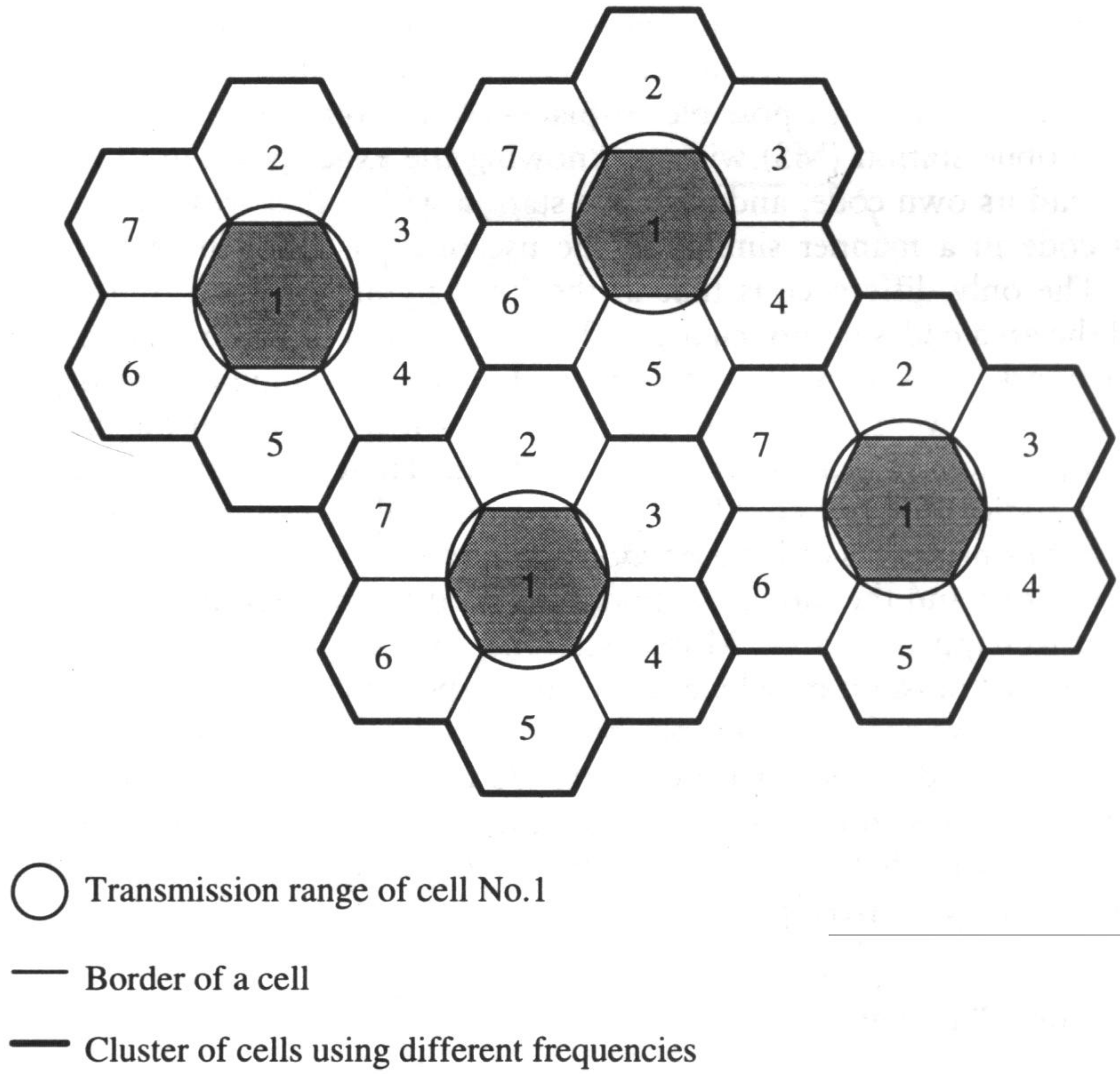


Figure 3.1: Cell structure and frequency re-use.

- eg GSM 300m–35km

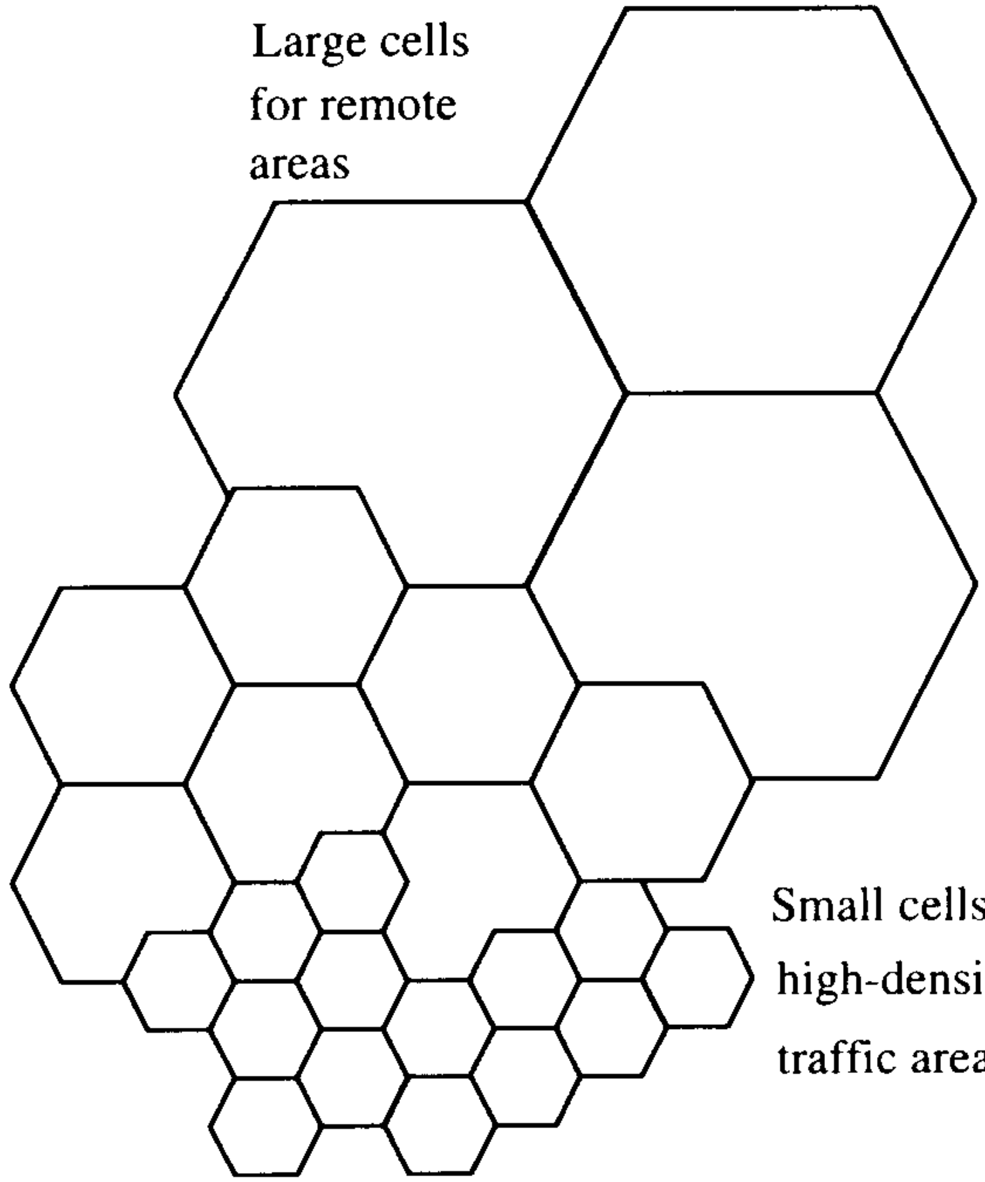


Figure 3.2: Splitting cells into smaller subcells when traffic rises.

- Cheaper initial Rollout.
- Split when traffic ($) increases!
- Micro and pico cells.
- Hence *Power Control* immensely important.

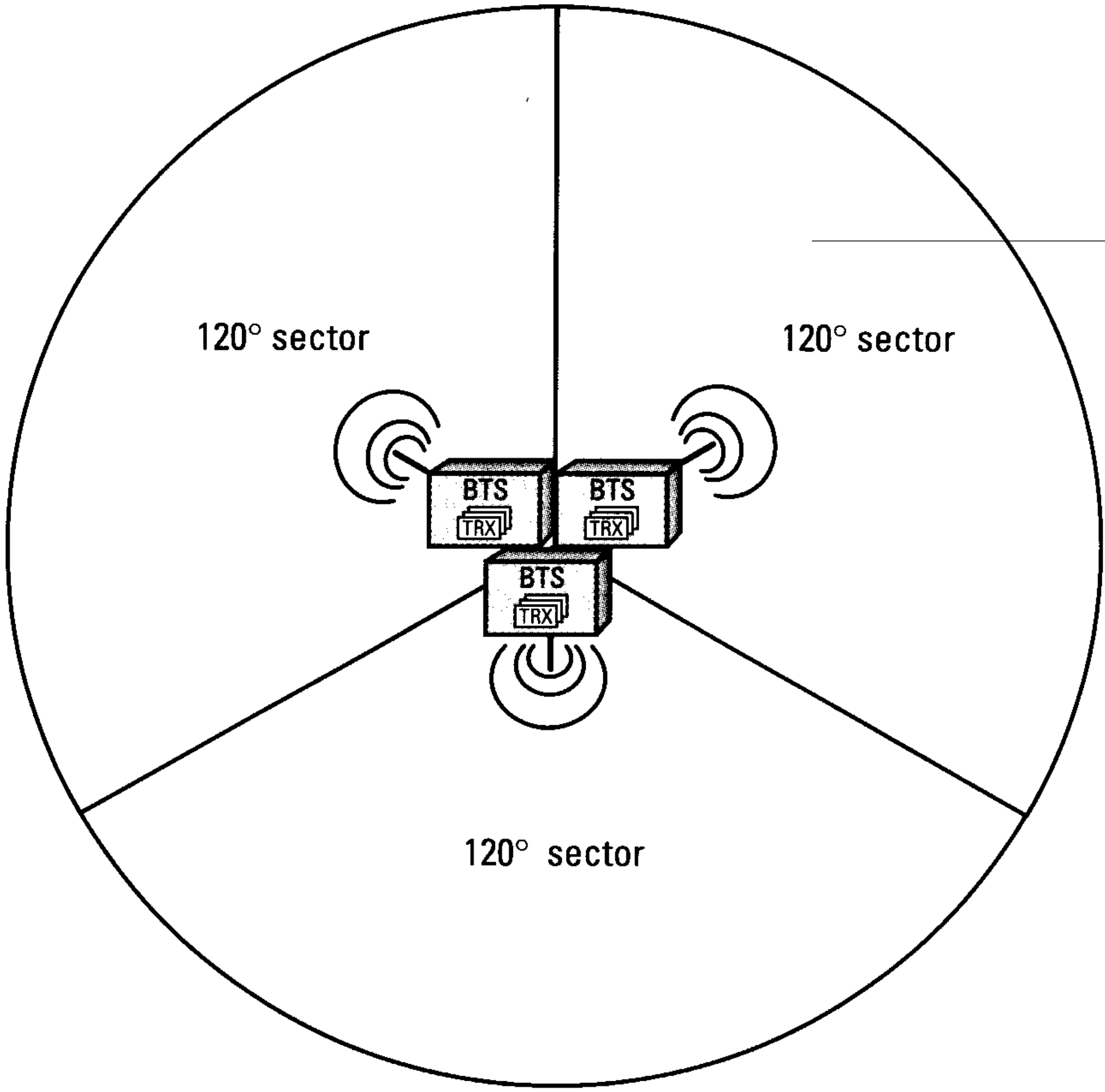


Figure 3.3: A sectorized cell.

- Mast etc already there!
- Can also have a directional cell.
- Umbrella cells for fast moving traffic.

- *Groupe Spéciale Mobile* $\Longrightarrow$ Global System for Mobile communication.
- European vs American methods.
- MOU in 1987, documentation 1991 (5k pages), 1M 1994, 500M 2001.
- Fullrate—8 timeslots/freq.
- Halfrate—16.

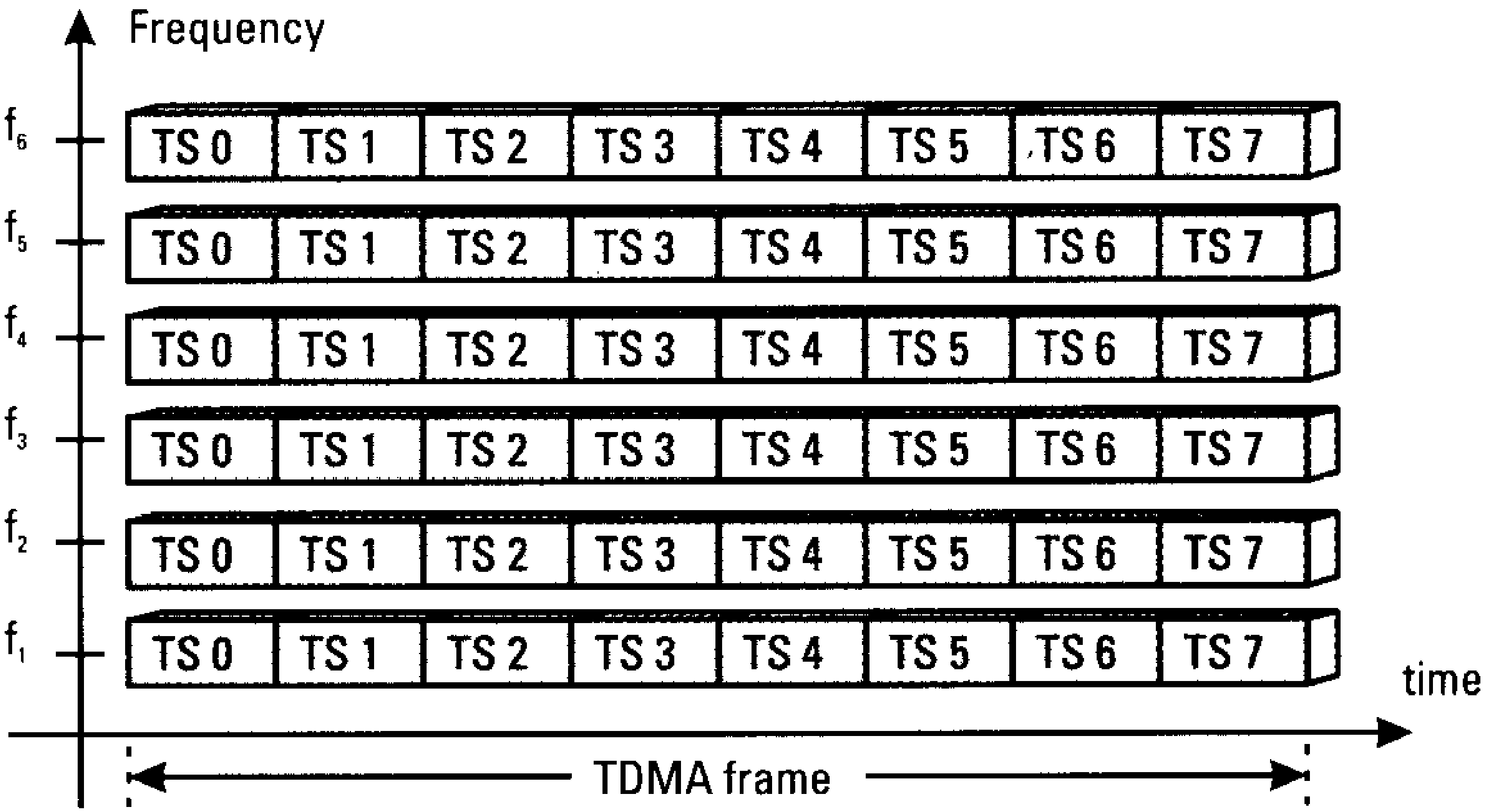


Figure 3.4: GSM time slots and frequency allocations

- Modulation GMSK.
- TDMA Power ramping

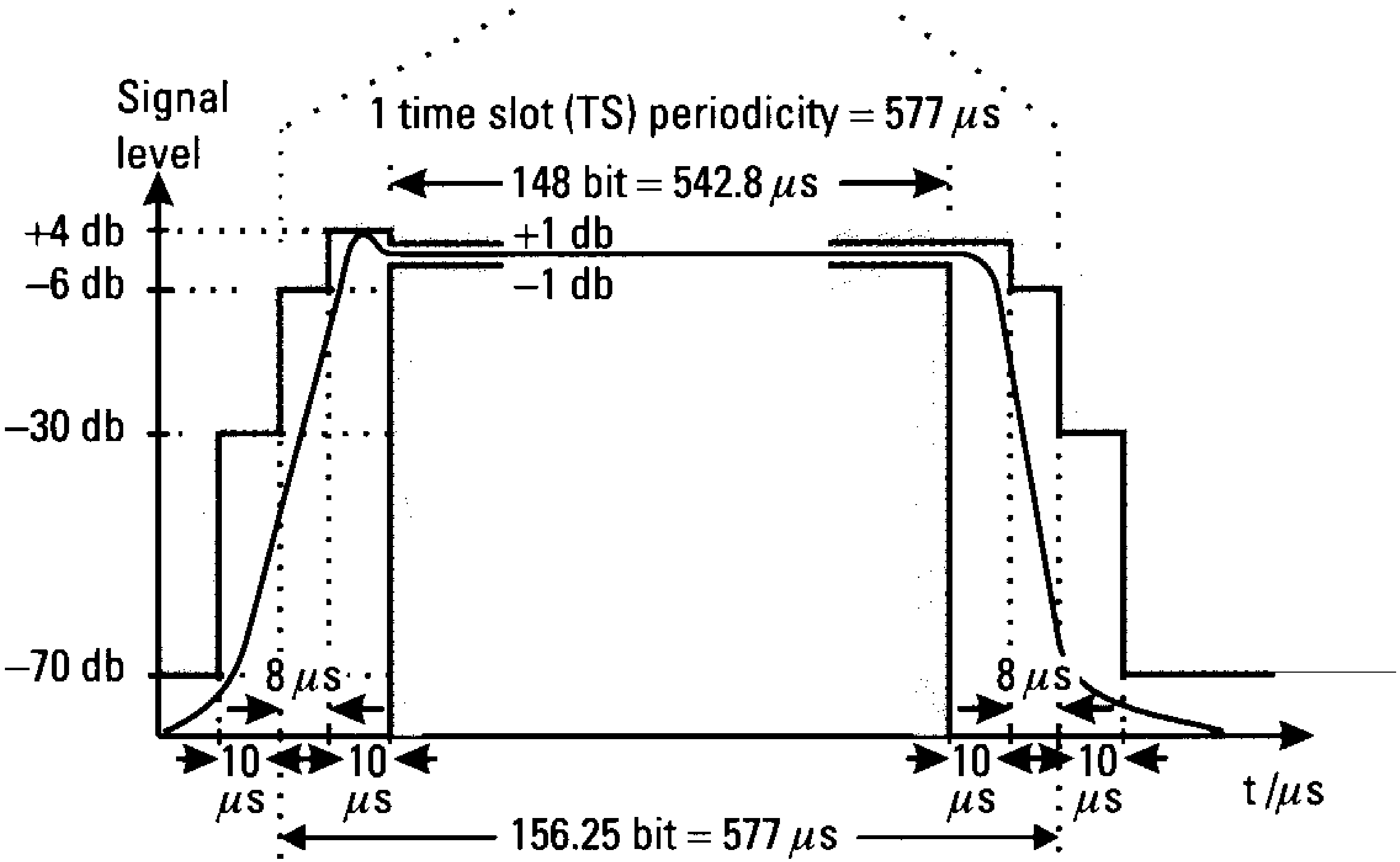


Figure 3.5: Time domain response requirement on the GSM transmission.

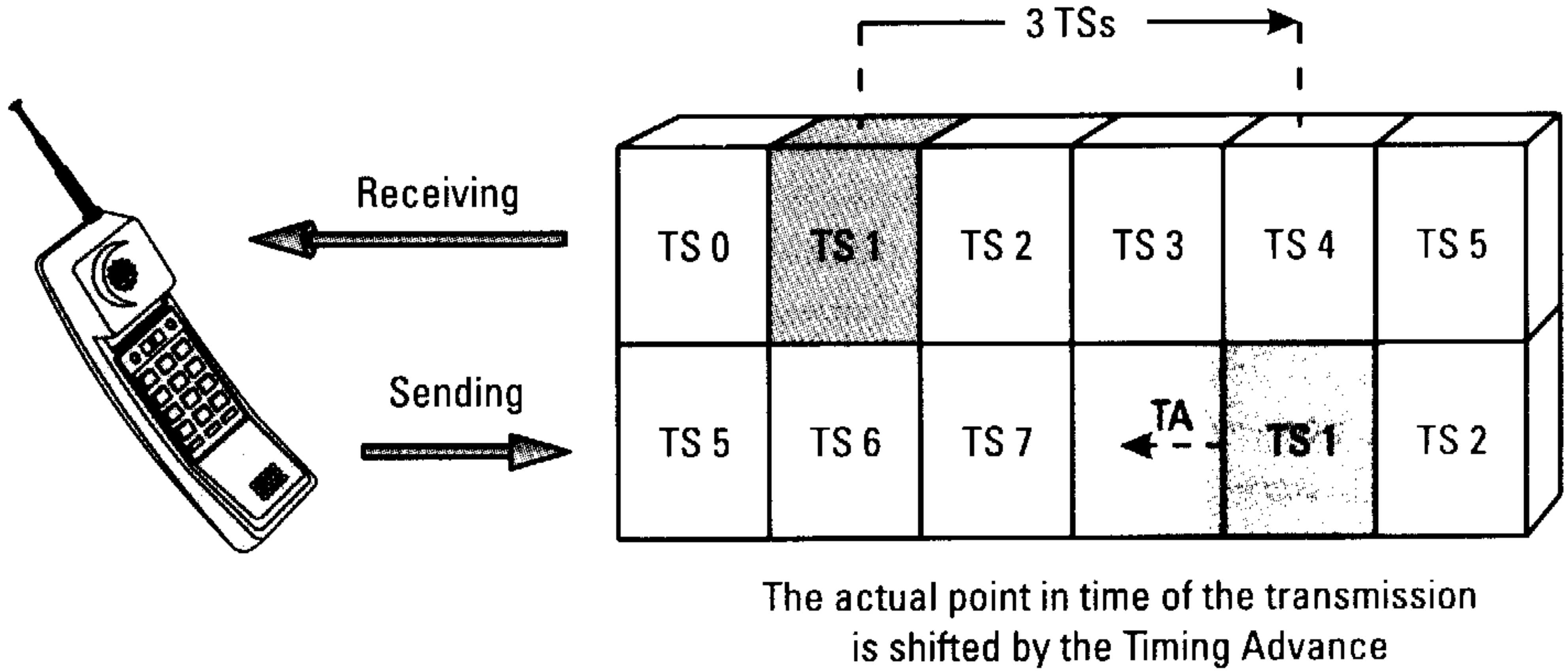


Figure 3.6: The Tx and Rx timeslots are offset. Timing advance causes the mobile to transmit earler than alloted to compensate from the finite velocity of propagation.

- Offset timeslots for Tx/Rx. (3TS)
- Must know which TS!
- Near/far ISI means TA.
- Max TA 63 bits (1bit=3.69μs)
- Hence Max cell size is 35km!
- Power control in steps of 2dB.

- Migrated from 900MHz to 1800MHz, 1900MHz, and even 450MHz.
- Speech Coding (Fullrate) 13.5kbps. PCM is 64kbps=wireline quality.
- (Hence 9k6 max *data* rate)
- Uses Regular Pulse Excitation, Long Term Prediction (RPE-LTP).
- DTX lessens RF interference and saves battery life.
- Codec must perform Voice Activity Detection in DSP.
- "Comfort" noise by SID frame every 480ms!

Future Trends 2.5G 3G UMTS Hot Air?

- UMTS 2Mbps, DSSS CDMA, using 2G infrastructure.
- EFR, WAP
- GPRS
- GPRS Rolled out in Canada. max 115kbps.

- *Digital European Cordless Telephone* $\Longrightarrow$ Digital Enhanced Cordless Telephone.
- Replacement for ord 50MHz CT.
- Evolved into replacement for PABX.
- Evolved to WLL.
- FDMA/TDMA
- Only 10 frequencies, 1728kHz wide from 1880.928 to 1898.208MHz.
- 12 Duplex (24 simplex) per freq.

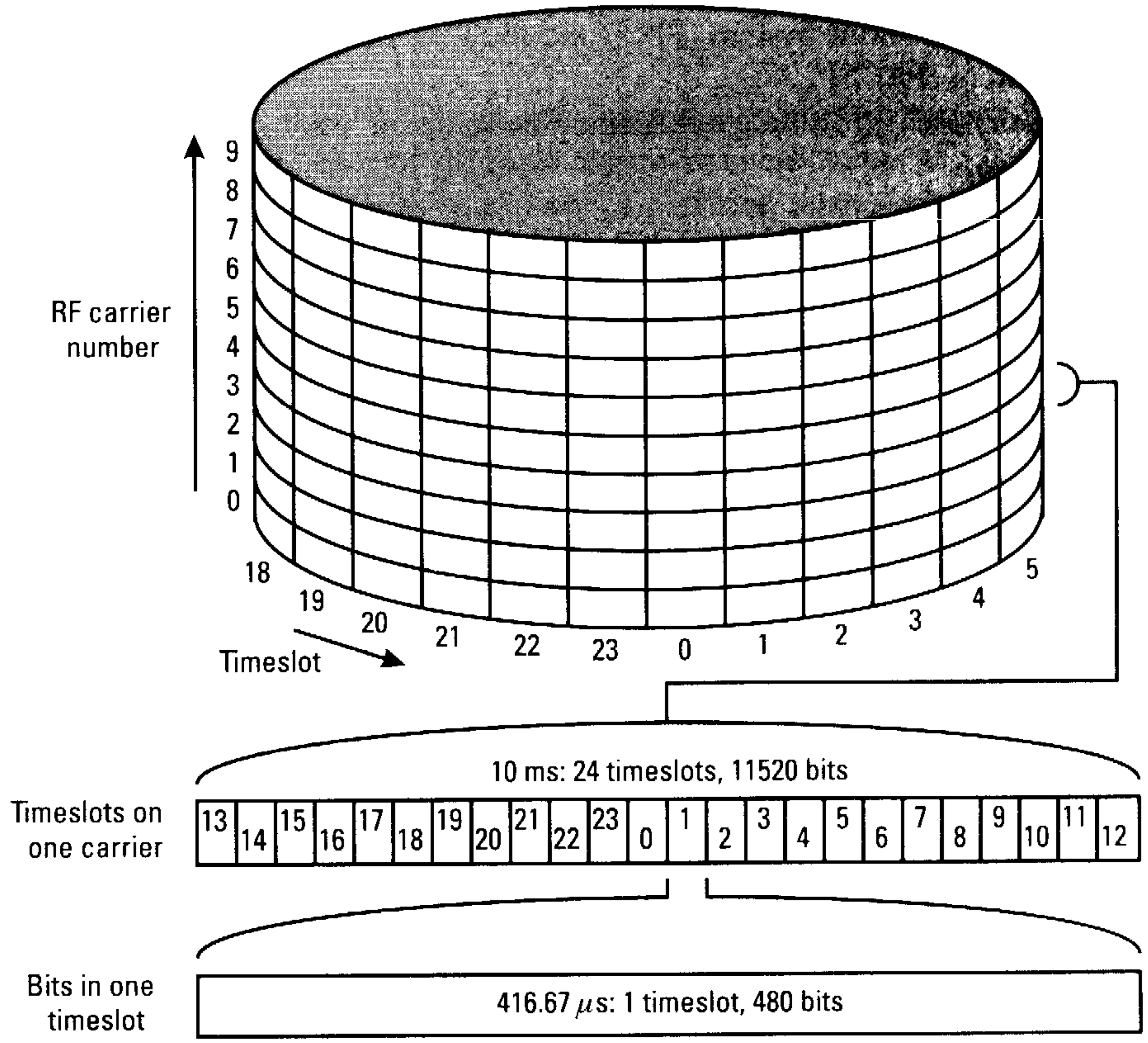


Figure 3.7: Timeslots and frequency channels of the DECT system.

- Cheaper 6 stations, or 1!!!
- TDMA timeframe 10ms
- aggregate bitrate 1153kbps (hence BW)
- Range 300m outdoors 50m indoors with equalizer
- Modulation GMSK

- Peak power 250mW.
- PWT DQPSK 8 channels, 90mW!
- Speech Coding 32kbps ADPCM

Future Trends

- Integrated GSM/DECT phones. (Already available)
- FEATURES!!

Figure 3.8: World map showing TETRA installations [www.tetramou.com: 2001]

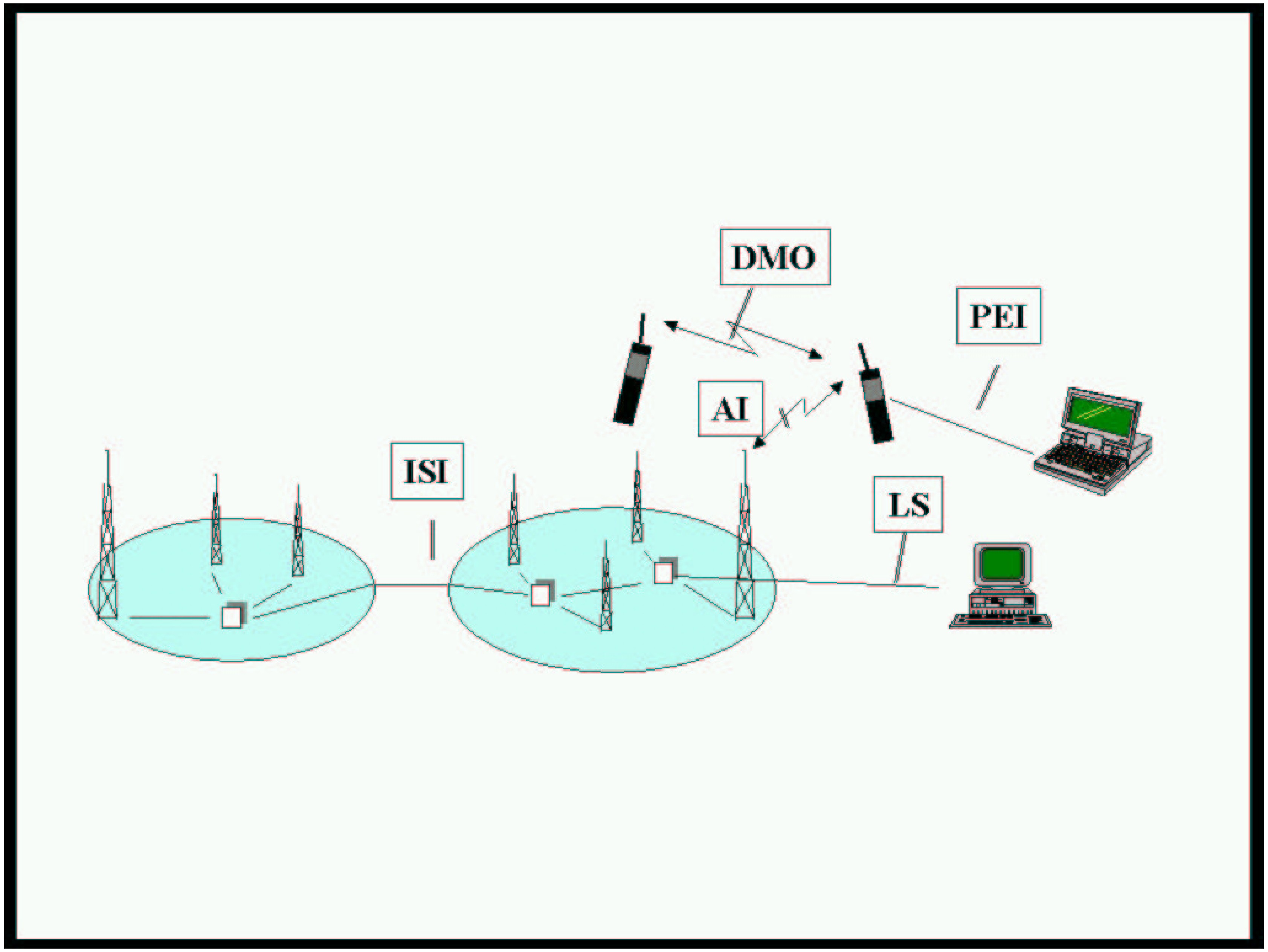


Figure 3.9: Overview of TETRA system operation.

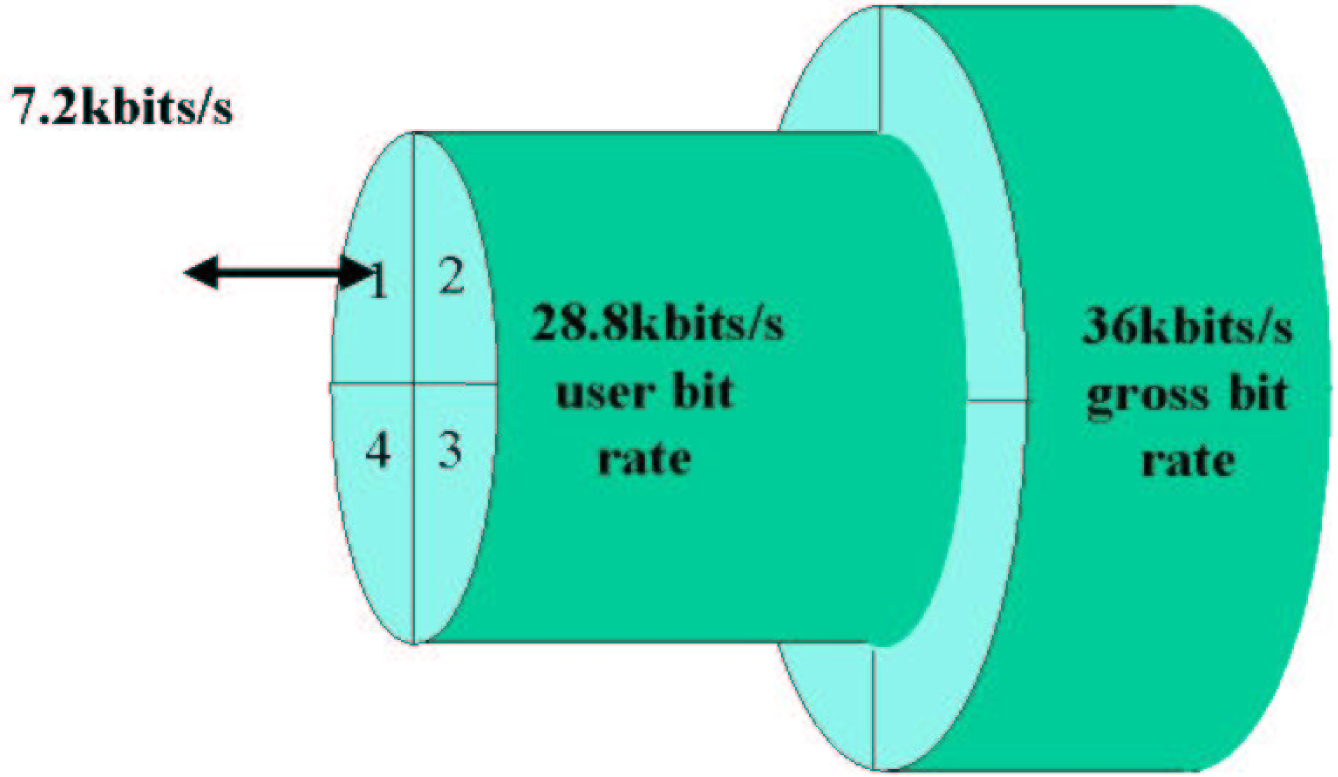


Figure 3.10: Overview of TDMA communication stream

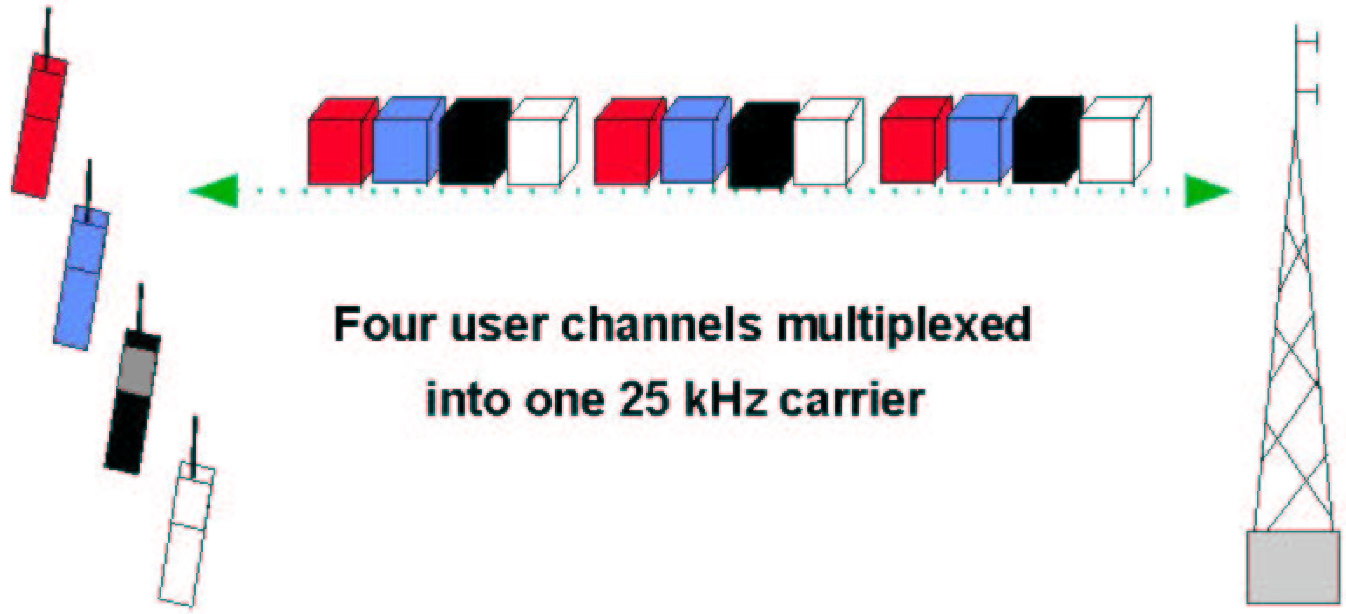


Figure 3.11: TDMA timeslot illustration

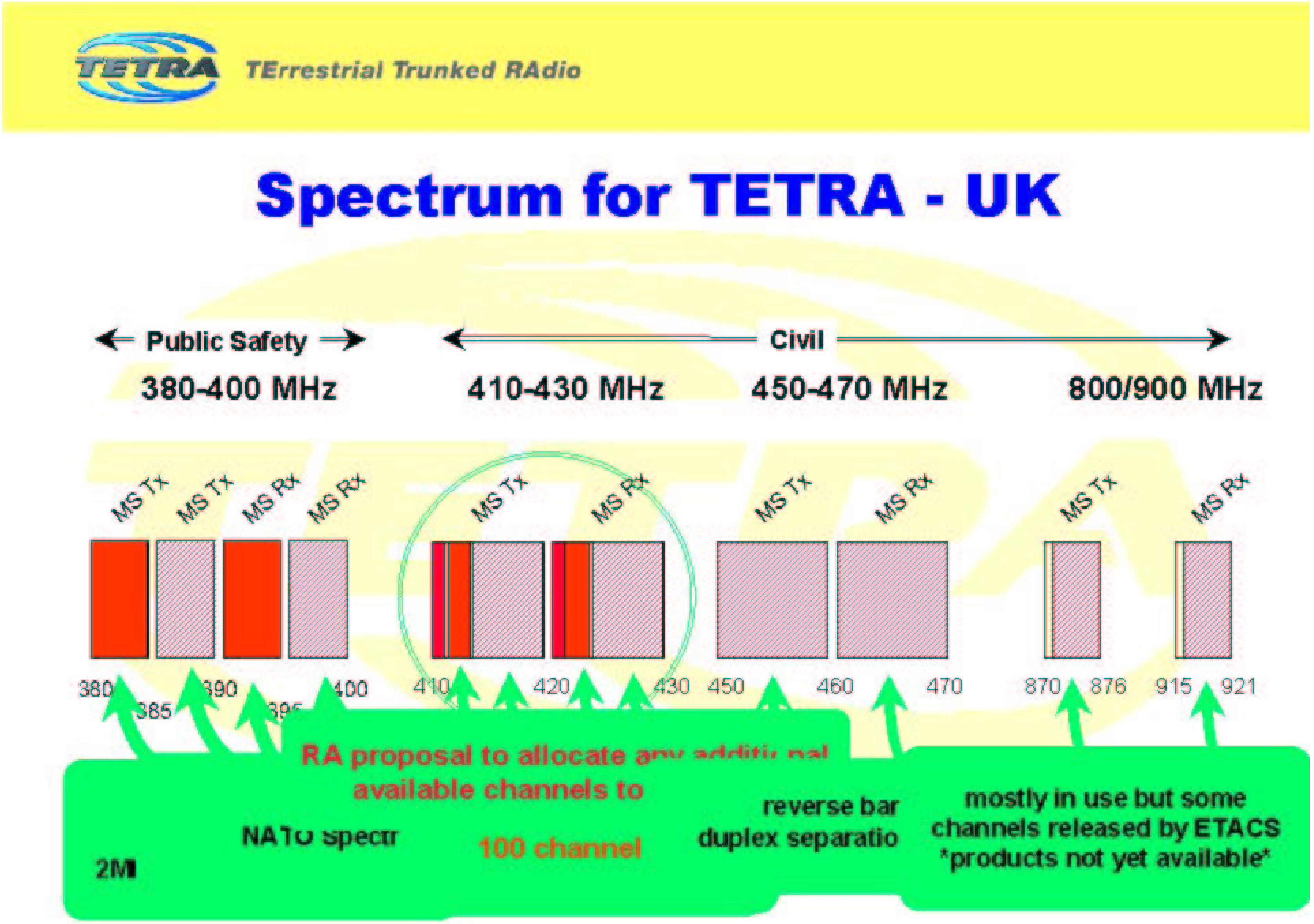


Figure 3.12: Overview of spectrum typically used for TETRA [from www.tetramou.com]

	Base station to vehicle mounted	Vehicle mounted to base station	Base station to handheld	Handheld to base station
TX power (dBm)	44	40	44	30
Tx cable & combiner loss (dB)	6	2	6	0
Tx antenna gain (dB)	10	2	10	-2,5
Peak EIRP (dBm)	48	40	48	27,5
Rx antenna gain (dB)	2	10	-9	10
Rx cable loss (dB)	2	2	0	2
Diversity gain (dB)	0	3	0	3
Rx sensitivity (dBm)	-103	-106	-103	-106
Maximum path loss (dB)	151	157	142	144,5

Figure 3.13: Overview of link budgetspectrum typically used for TETRA [from www.tetramou.com]

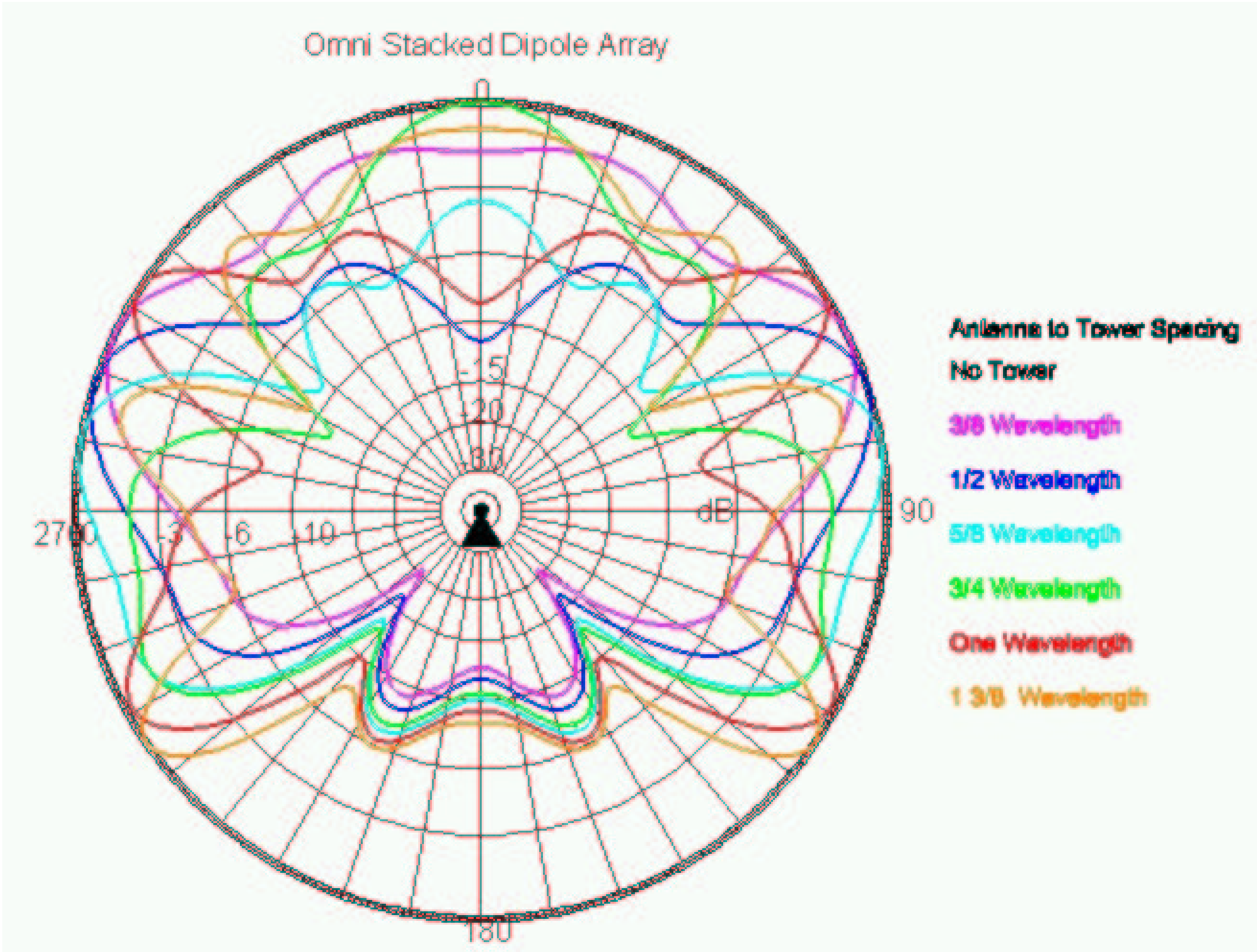


Figure 3.14: Omni antenna spaced from mast with spacings ranging from 3/8 λ to 1 and 3/8 λ

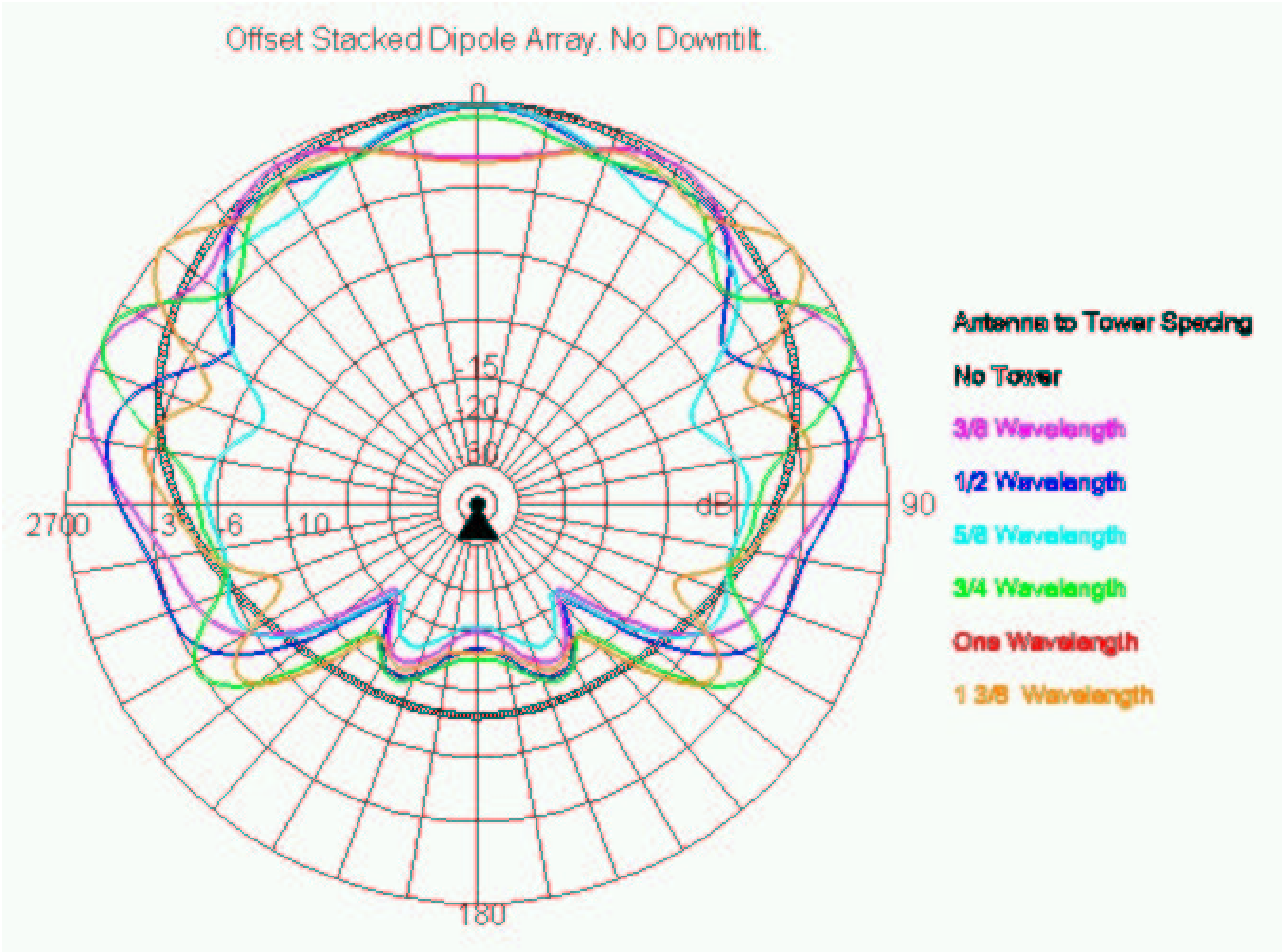


Figure 3.15: Directional antenna spaced from mast with spacings ranging from 3/8 λ to 1 and 3/8 λ

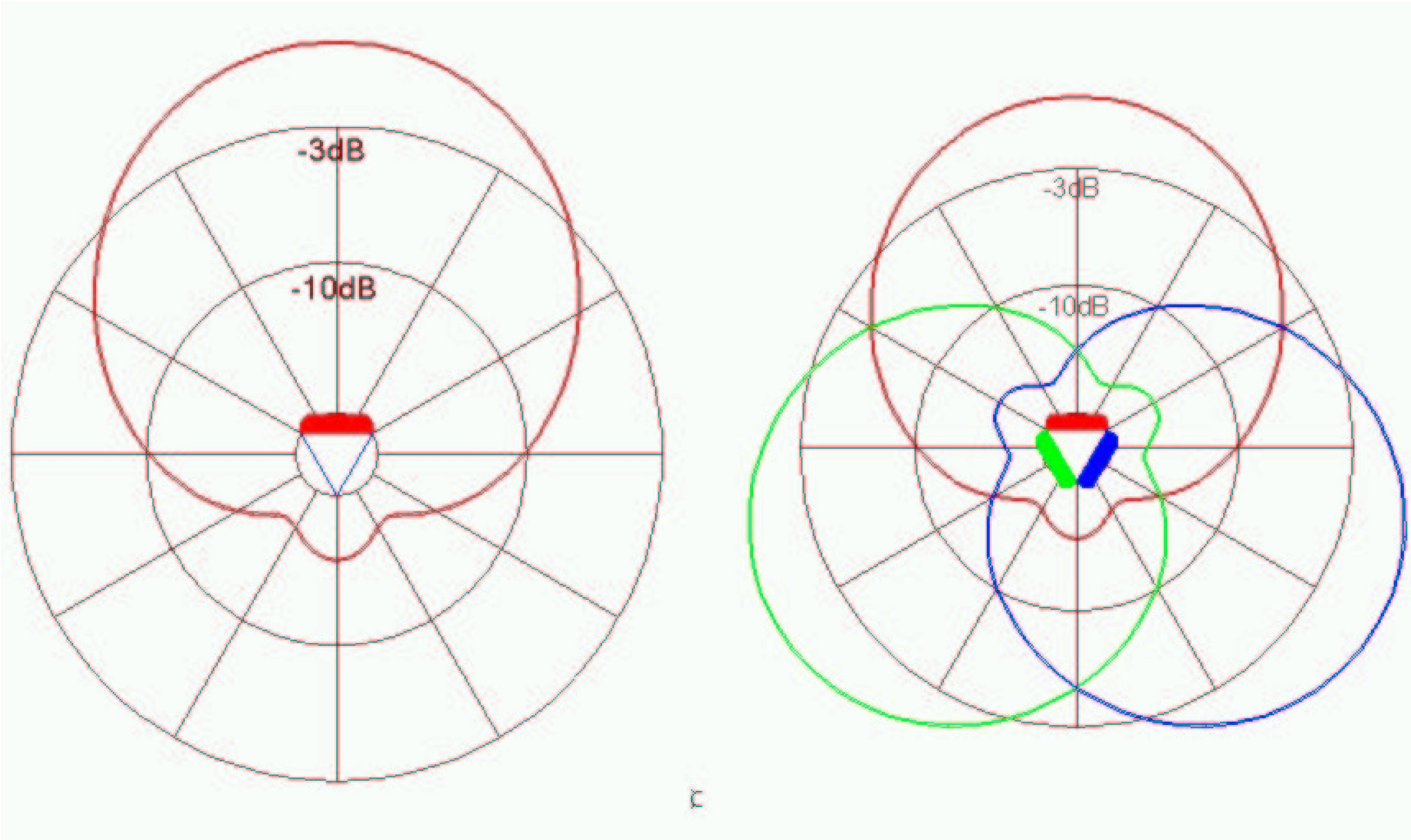


Figure 3.16: Typical antennas arranged to cover three sectors

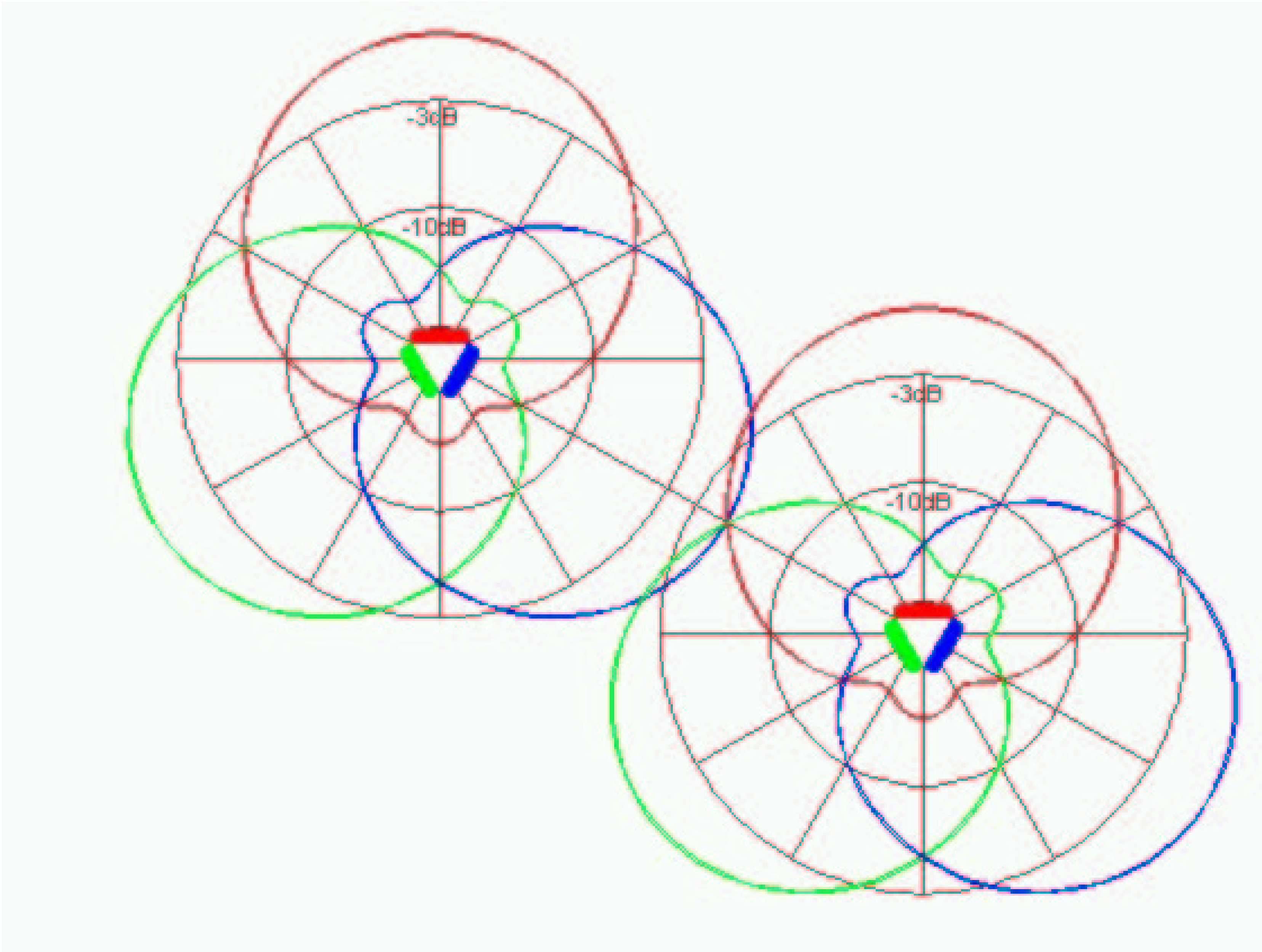


Figure 3.17: Combining the sectoral basestations shown in 3.16 to form a cellular system

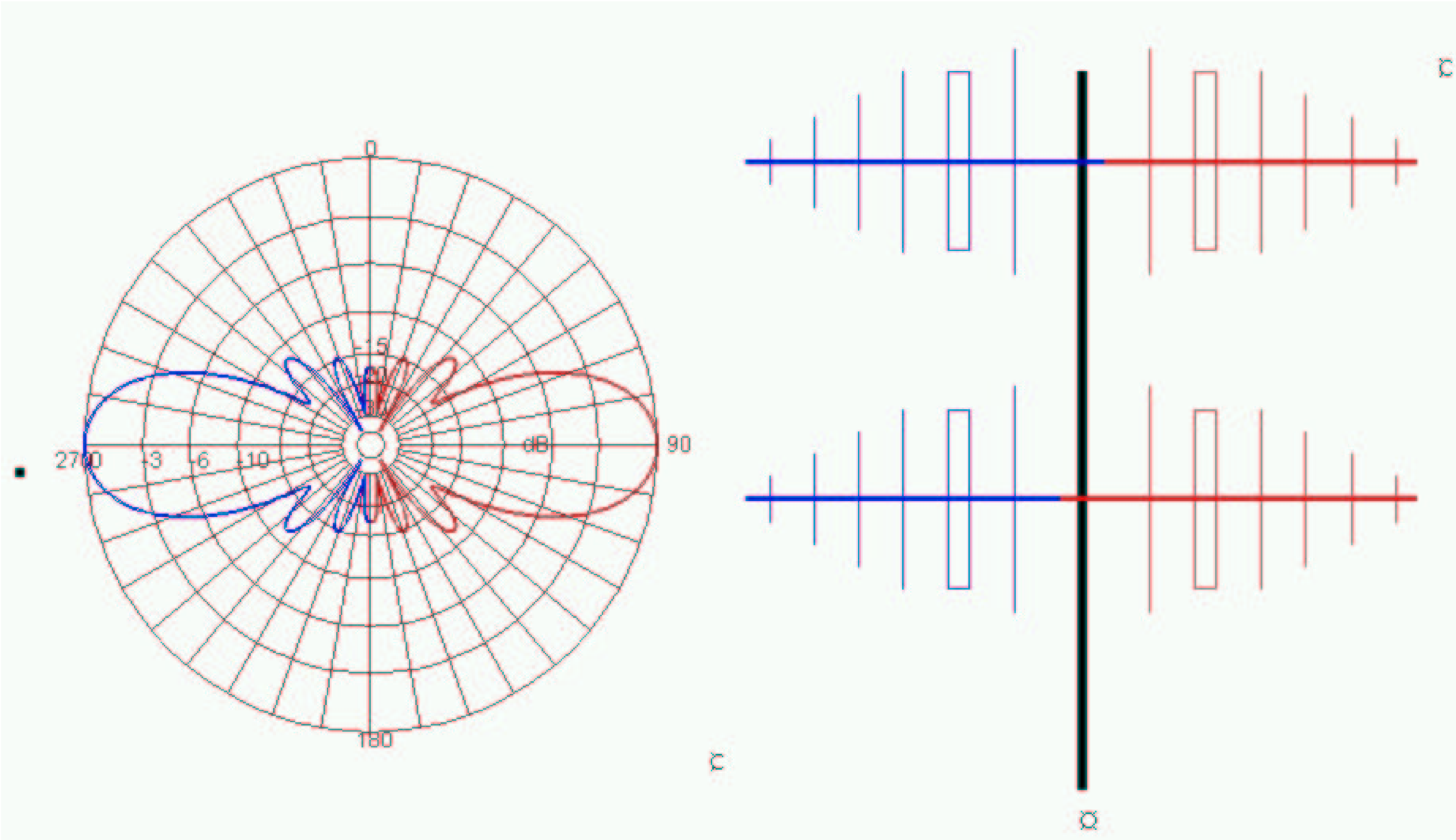


Figure 3.18: A two yagi base station configuration and pattern indication

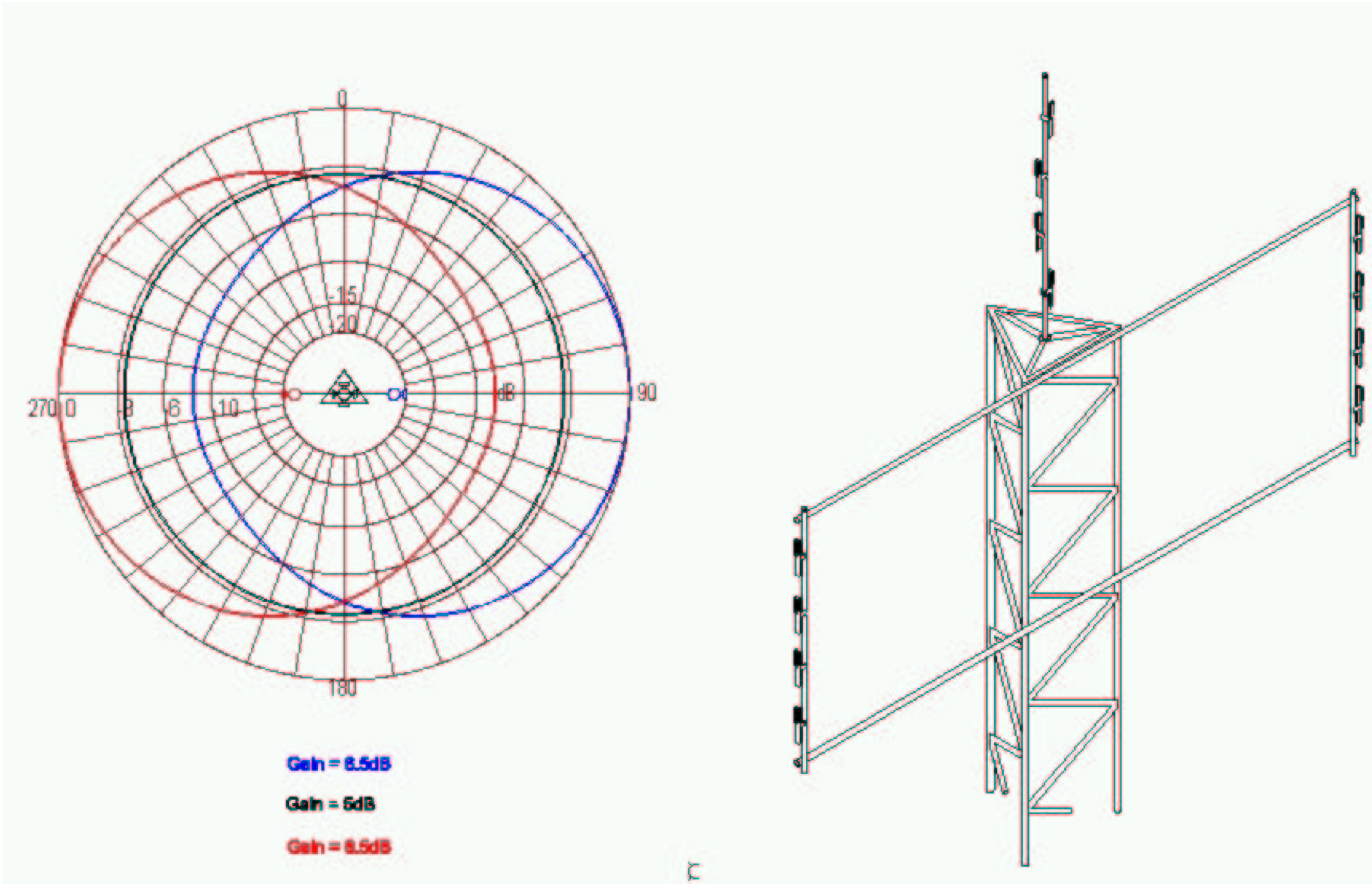


Figure 3.19: Top of mast omni plus two offsets [from Sinclair]

s

	BS-> MS		MS->BS	
Tx Power	42	dBm	35	dBm
Combiner/Filter Losses	-5	dB	-1	dB
Mobile Antenna Gain	1	dBi	1	dBi
Base Antenna Gain	5	dB	5	dB
Base Cable Losses	-2	dB	-2	dB
Diversity Gain	0	dB	0	dB
Rx Sensitivity	-112	dBm	-115	dBm
Resultant System Gain	**153**	**dB**	**153**	**dB**

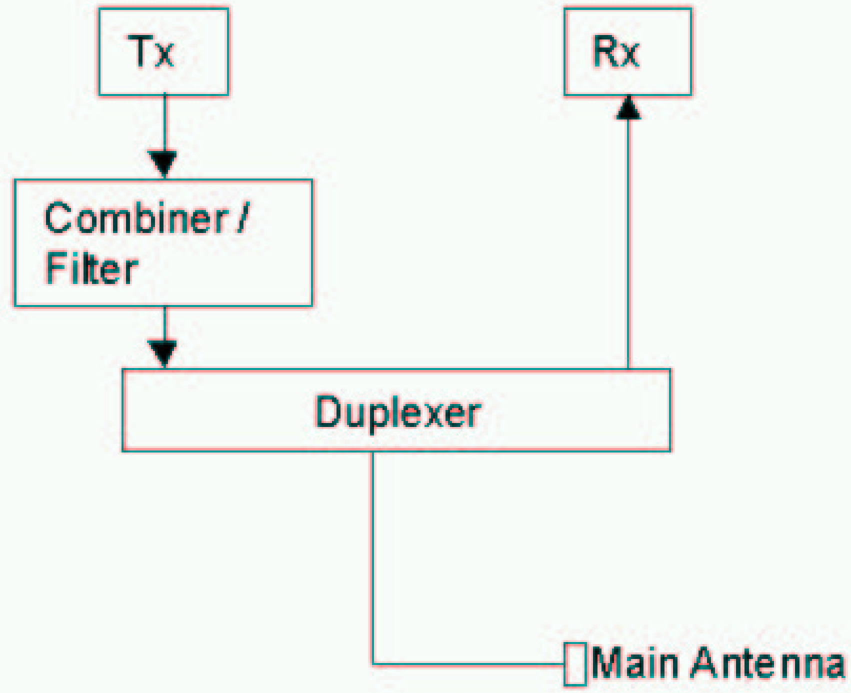


Figure 3.20: Schematic of system and budget for configuration in figure 3.19.

LMDS

- Local Multipoint Distribution Service
- Not a “standard”
- Not even a standard freq. band.
- Point-to-point or Multipoint.
- Generally Broadband Access.
- (Narrowband Ionica spectacular failure..)

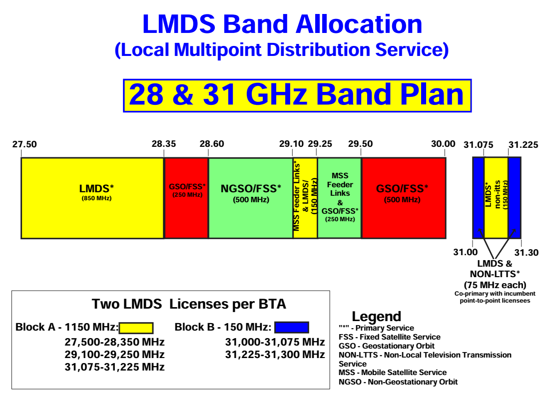


Figure 3.21: LMDS Frequency allocations

- Gigabits/second
- Several km.
- LOS, affected by rain.

- 802 family is Ethernet.
- WLAN traditionally VERY slow.
- Intersil PRISM.

Basic Service Set:

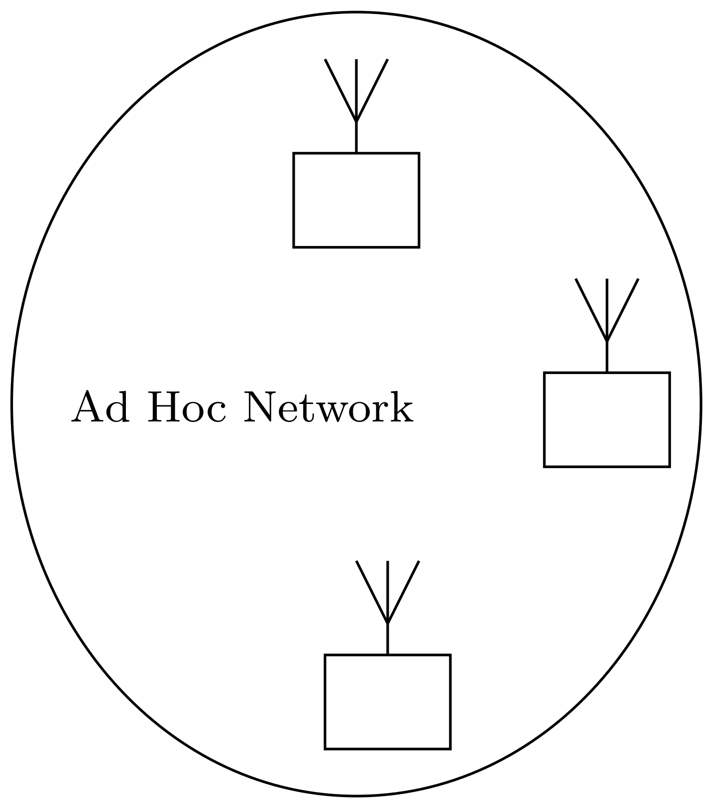


Figure 4.1: An Ad-Hoc network, with peer-to-peer networking

Extended Service Set: (With Access Point)

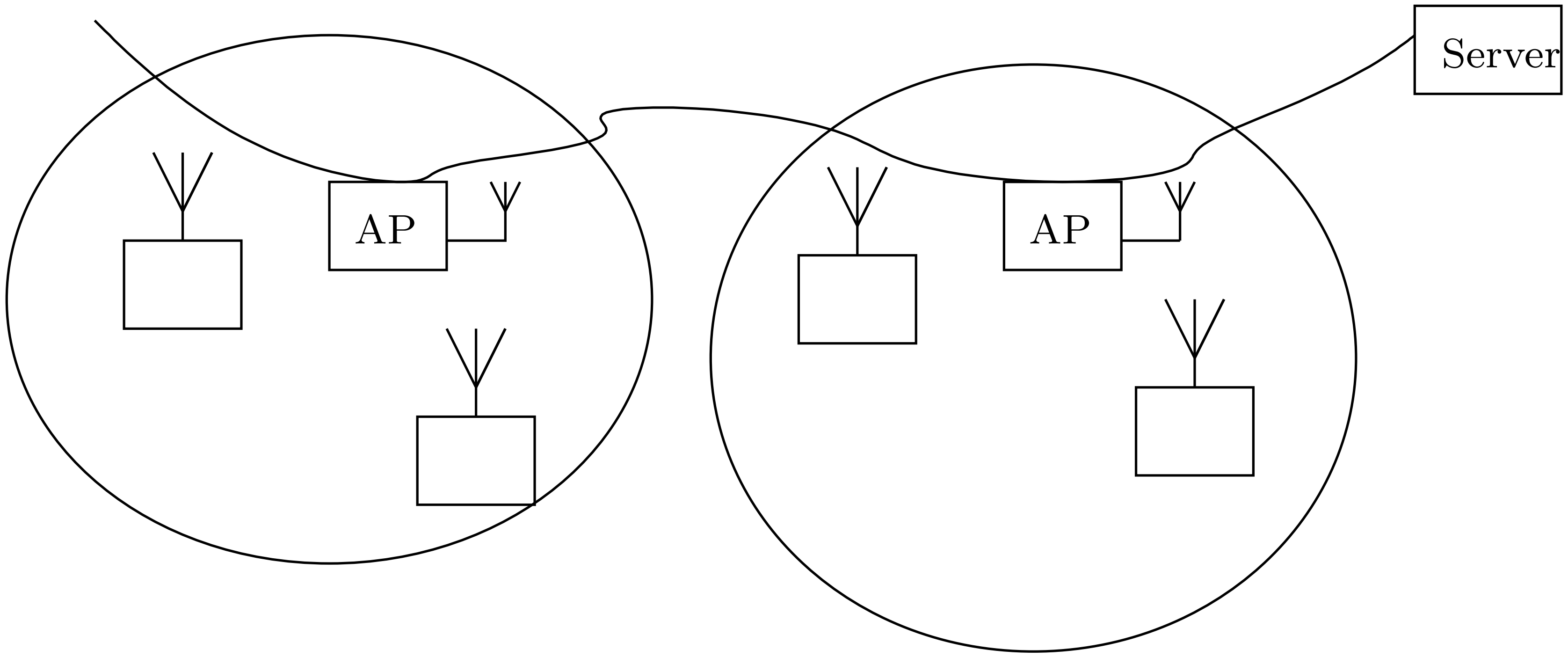


Figure 4.2: ESS provides campus-wide coverage.

- Allows comms between BSSs.
- All comms through AP.

Table 1: Global spectrum allocation at 2.4GHz

Region	Spectrum
USA	2.4000–2.4835 GHz
Europe	2.4000–2.4835 GHz
Japan	2.471—2.497GHz
Frace	2.4465–2.835GHz
Spain	2.445–2.475GHz

- In the worst case 2.471–2.475 GHz is the only common bandwidth!

- DSSS, FHSS (ISM band) and Infrared specified in standard.
- For DSSS, a one-symbol length Barker code (PRN), 11 chips.
- One station at a time!
- 1Mbps and 2Mbps in base standard 2.4GHz ISM.
- DBPSK and DQPSK, channel 20MHz.
- For FHSS, BFSK and 4FSK in 1MHz channels, ie 79 channels.
- 78 different hop sequences specified. 2.5 hops/sec.

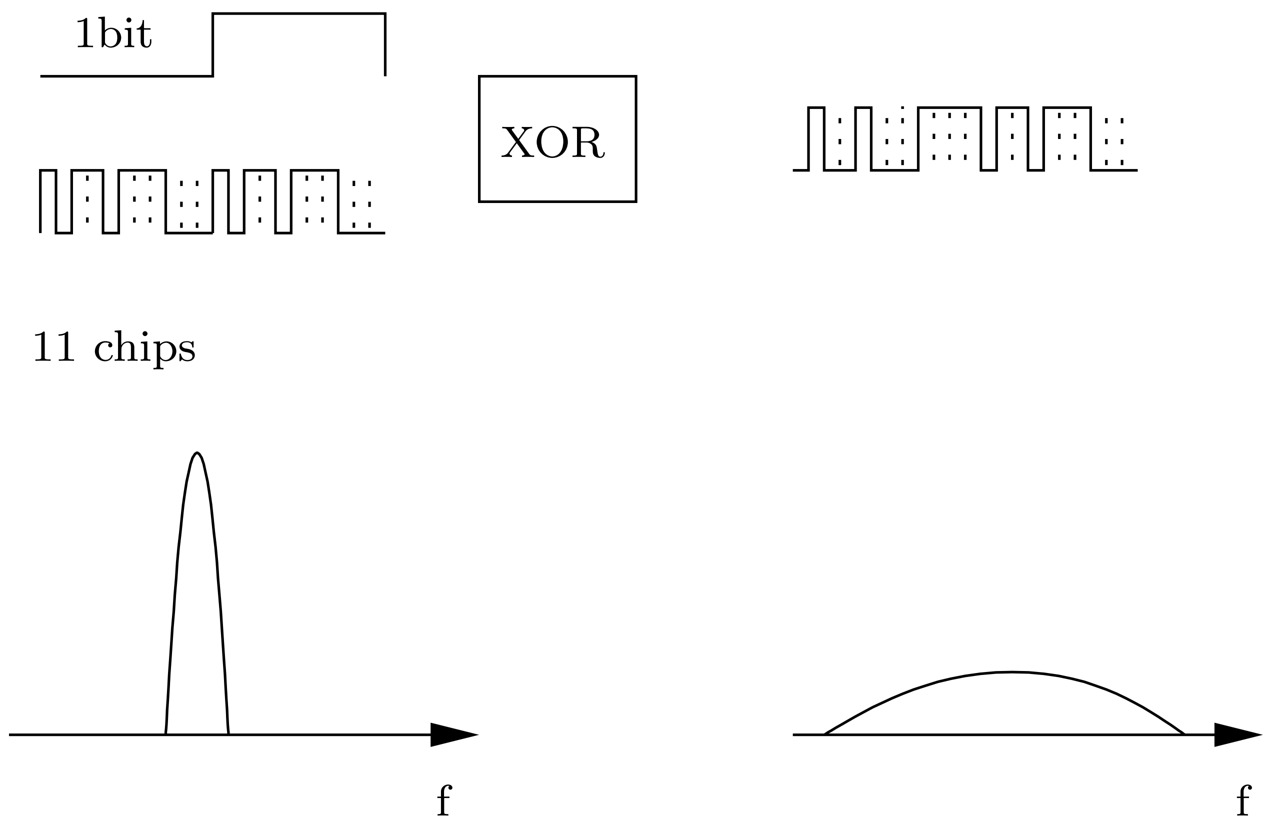


Figure 4.3: DSSS data and Barker code spreading.

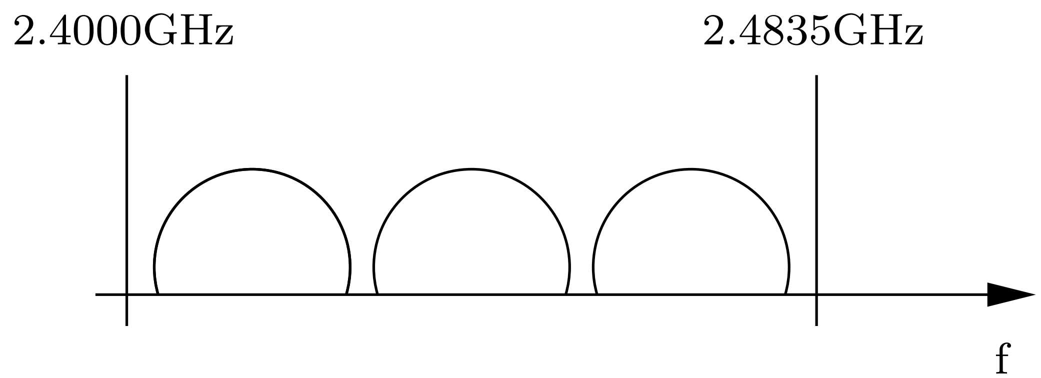


Figure 4.4: Three non-overlapping DSSS channels in the ISM band.

- Cannot do CSMA/CD since cant listen and talk!
- Random back off after Tx.
- Immediate ACK within contention window.
- Random back-off doubled if no ACK to max of 256 slot times.

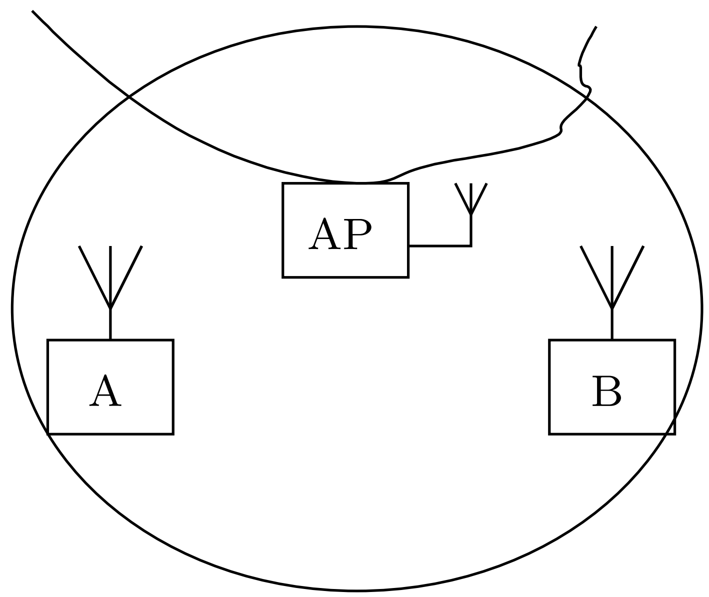


Figure 4.5: Possibility of a hidden node.

- RTS/CTS scheme informs all.
- Timing Synchronization to within 4μs by AP by Timing Beacons.
- Stations in doze wake up for beacons. Traffic queued.

Future Trends

- 802.11b is 11Mbps DSSS in 2.4GHz ISM.
- 5GHz ISM 54Mbps! Also DSSS.
- 500 Mbps (simplex) demonstrated.
- Roaming not specified, but IAPP has been agreed.

Pitfalls

- Designed as a Wireless ***LAN***
- Widely used as a WAN.
- WISP's too.
- Backhauls for GSM.
- Easily killed by FHSS, or any strong single Frequency.
- Cheap (yes, its a pitfall!)
- Uses the “Welding Band”

Bluetooth

- Much hyped, not a lot to show. (RSN)
- Replacement for IrDA.
- Seamless comms between "toys".
- 1Mbps GMSK modulation.
- 2.4–2.4835 GHz.
- FHSS in 79 channels.
- Class 1—100mW (20dBm) Power Control reqd to 0dBm
- Class 2—2.5mW (4dBm) Power Control to 0dBm
- Class 3—1mW (0dBm) no power control.
- NOT MEANT for WLAN's!
- Huge sales RSN :-)

NAVSTAR GPS

- 24 satellites in 6 orbital planes. Must be in line-of sight to at least three!
- MEO at about 17 000km.
- 1575.42 and 1227.6MHz, CDMA. Each satellite has a different code.
- Precise Positioning Service and Standard Positioning Service
- "Selective Availability" turned off on May 2 2000.
- Theoretically, can be turned back on again!
- Much commercial navigation dependant on GPS.

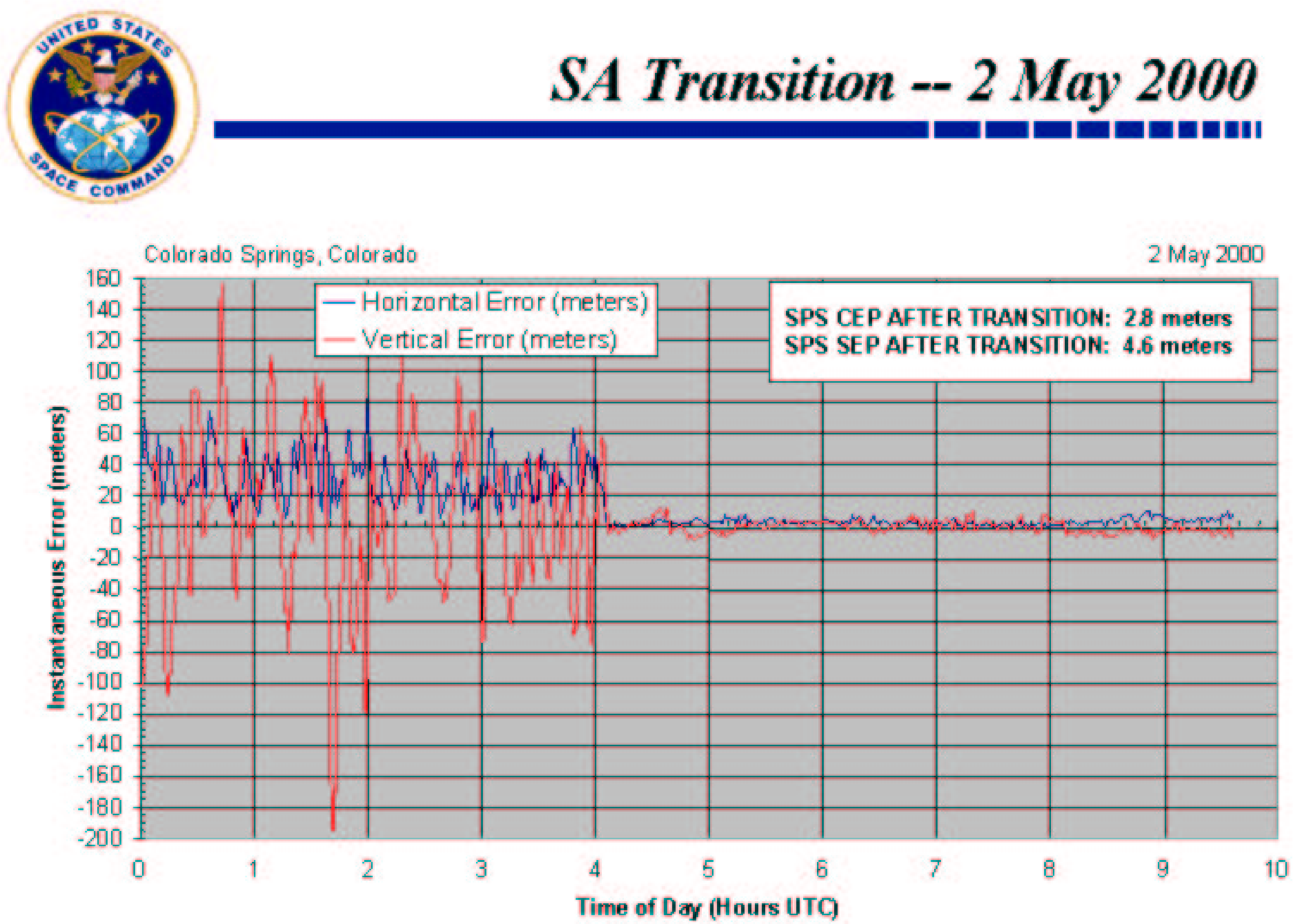


Figure 5.1: Position fixing before and after SA was turned off.

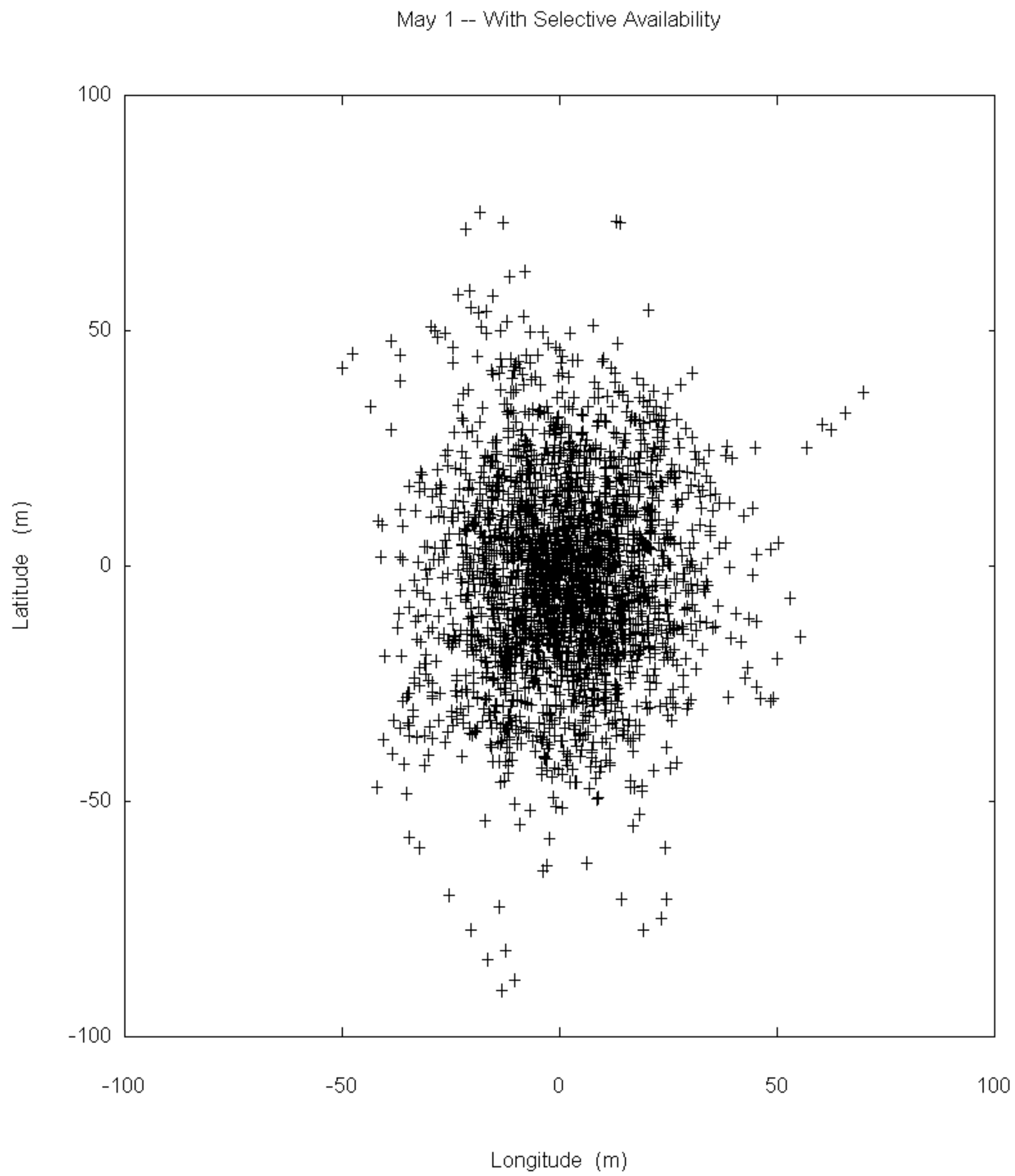


Figure 5.2: Before SA was turned off

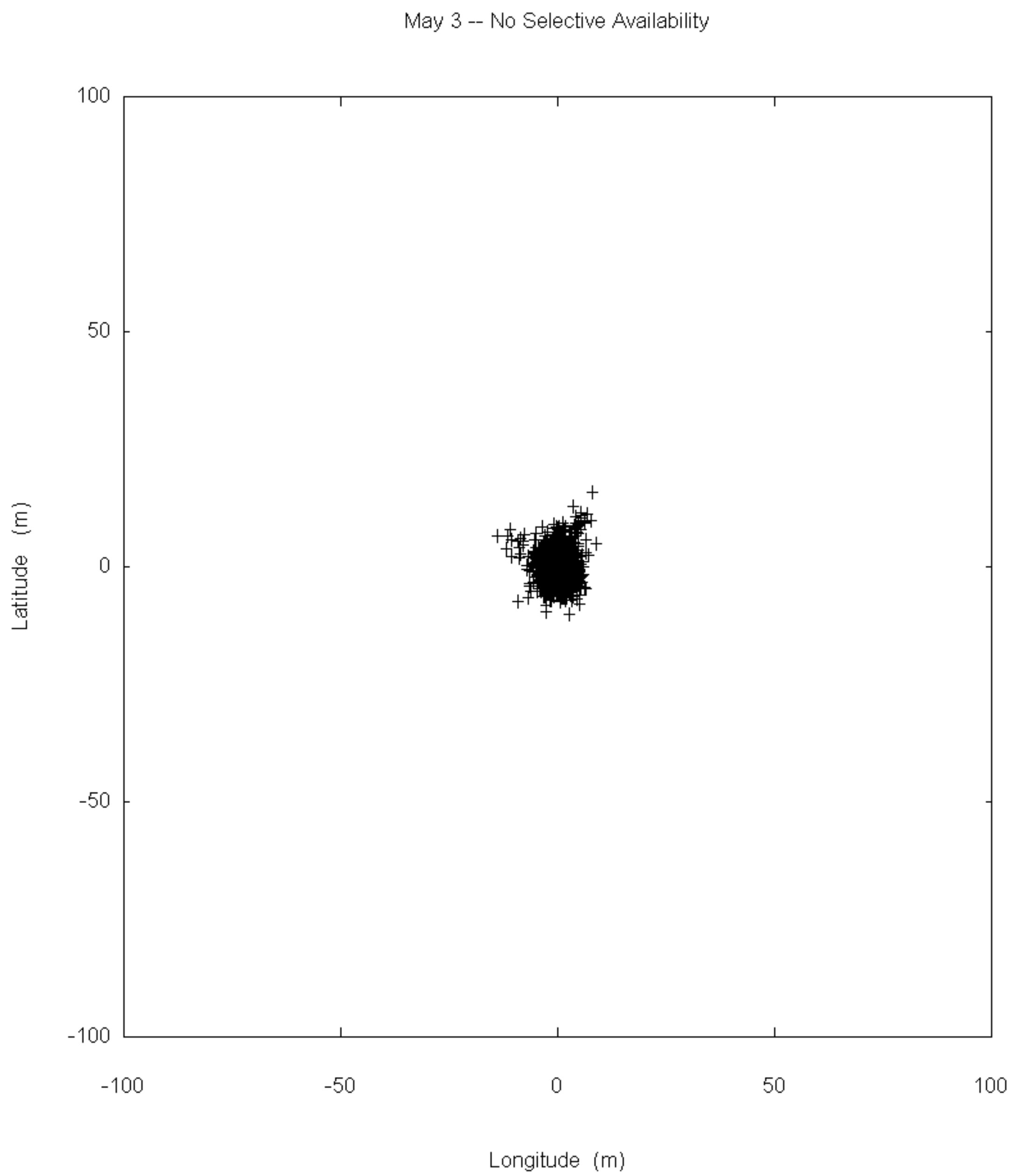


Figure 5.3: After SA was turned off.

- 22m accuracy in the horizontal plane, 27.7m in the vertical.
- Time within 200ns of UTC!
- With SA on, 100m horizontal and 156m vertical, 340ns.
- GLONASS 24 satellites in 3 orbital planes, FDMA. 26m Horizontal and 45m vertical. No SA.

Time of Arrival ranging.

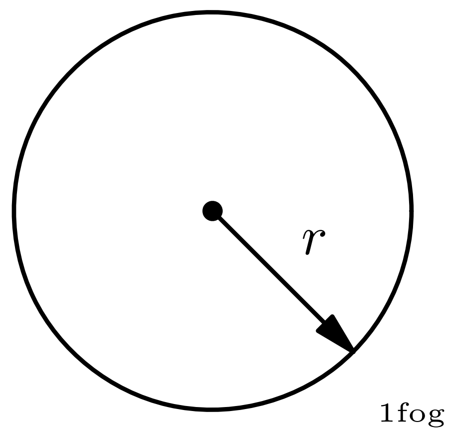


Figure 5.4: Ranging information from 1 foghorn.

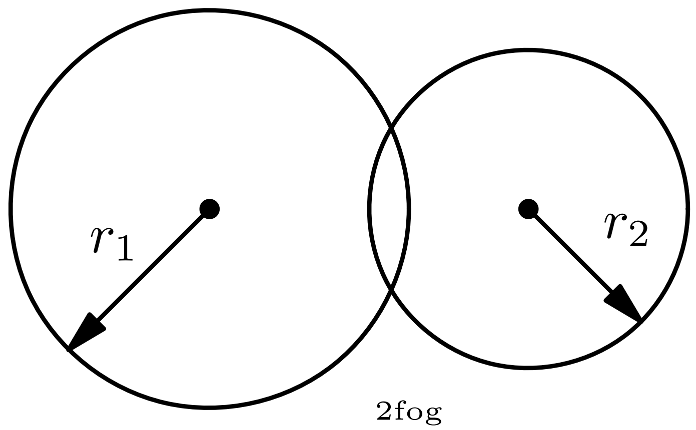


Figure 5.5: Ambiguity in position from 2 sources. User can be at either intersection point.

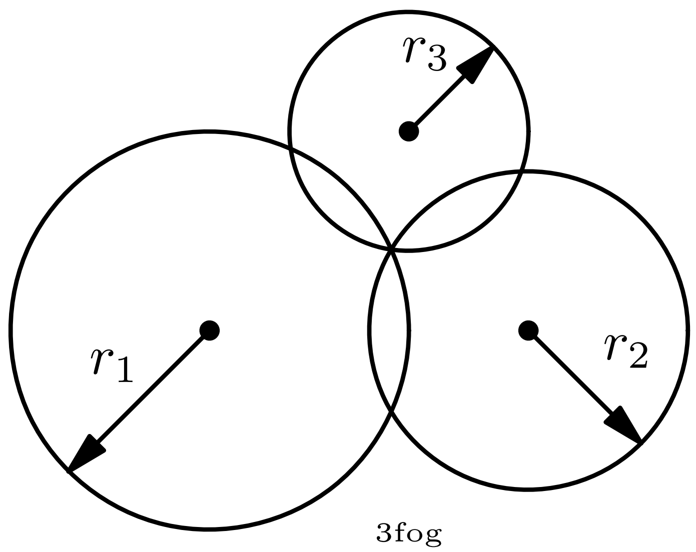


Figure 5.6: Using a 3rd foghorn to resolve the ambiguity.

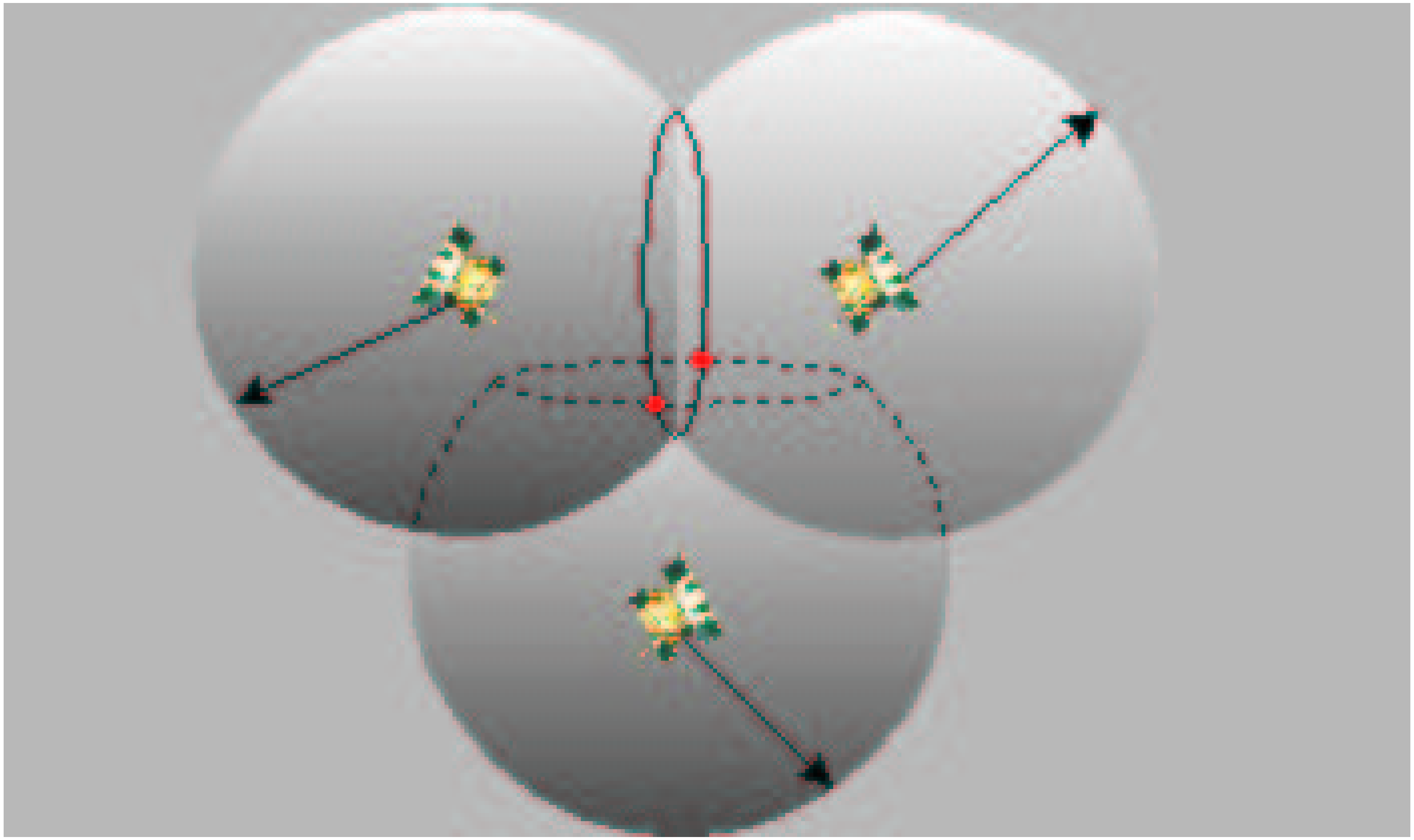


Figure 5.7: Three-dimensional 3-source TOA positioning.

Geodetic Reference

- Plataardevereniging?
- “Standard earth” ellipsoid. World Geodetic System 1984 (WGS-84)
- Equitorial Radius 6 378.137km
- Polar radius of 6 356.752km
- GPS computes height etc in reference to this ellipsoid.
- Can be at “sea-level” underwater :-)

Its all a matter of Time...

- Satellites must themselves know where they are wrt WGS-84 ellipsoid.
- Since MEO, earth is NOT a point source of mass. Mass variations actually affect the satellite positions.
- Fixed ground stations monitor their known position versus GPS and upload new ephemeris data to the satellites.
- "Ground segment" also responsible for synchronizing time.
- GPS time is a "paper" timescale (no leap-seconds) GPS now behind UTC by more than 10 seconds.
- Clock error of 1ns translates to 0.3m error!

Source of Error	Accuracy decrease
Ionosphere	0–30m
Troposhere	0–30m
Measurement	0–10m
Ephemeris data	1–5m
Satellite clock drift	0–1.5m
Multipath	0–1m
Now Defunct Selective Availability	0–70m

- Differential GPS can improve accuracies to sub metre level.