TEKNILLINEN KORKEAKOULU
TEKNISKA HÖGSKOLAN
HELSINKI UNIVERSITY OF TECHNOLOGY

# Cellular Network Planning and Optimization
# Part IV: Antennas

Jyri Hämäläinen,
Communications and Networking Department,
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# Basics

# Preliminaries

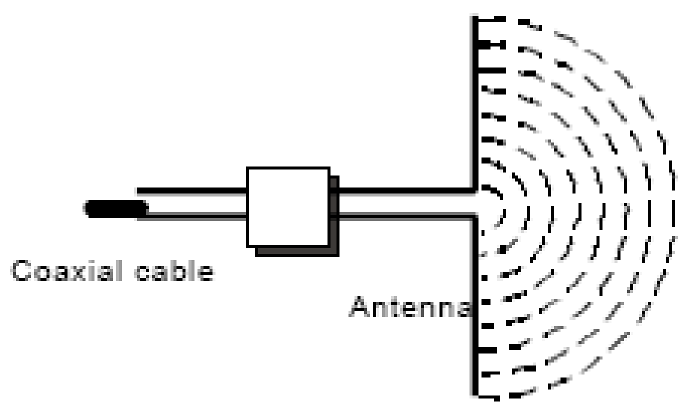
Note: In the following we concentrate on the base staton antennas. This is due the fact that mobile terminal antenna gains are usually small from link budget perspective (although antenna is critical element in mobile station)

Most common antenna gain measure is dBi = dB(isotropic). It is the forward gain of a certain antenna compared to the ideal isotropic antenna which uniformly distributes energy to all directions.
An other measure that is used is dBd = dB(dipole). It is the forward gain of an antenna compared to a half-wave dipole antenna.

# Preliminaries

First question: What is antenna?

An antenna is the converter between cable bounded electromagnetic waves and free space waves



# Dipole element

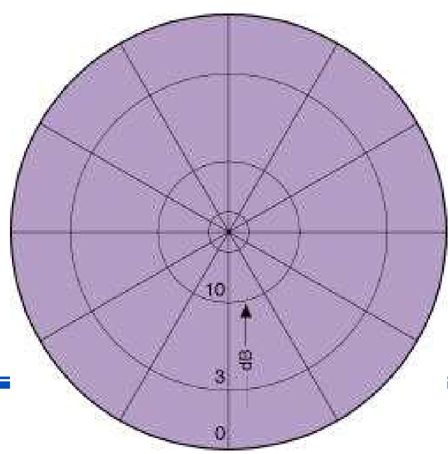
- Basic radiating element is usually a $\lambda/2$ dipole.
- The resonance frequency of the dipole is determined by its mechanical length, which is half of the corresponding wave length
- Relation between frequency and wave length is given by

  $\lambda = 300/f$, where $\lambda$ [m] and f [MHz]

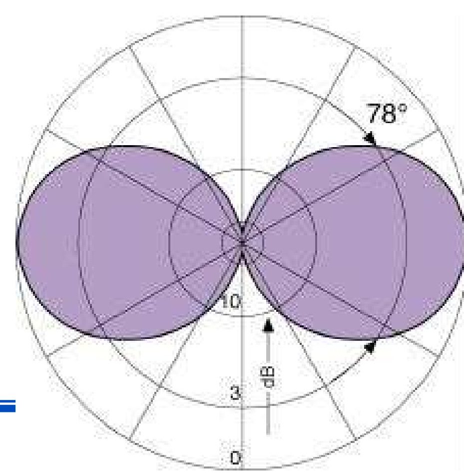
- Example : f = 900 MHz => $\lambda$=0.33m and dipole length is 165 mm

# Radiation pattern

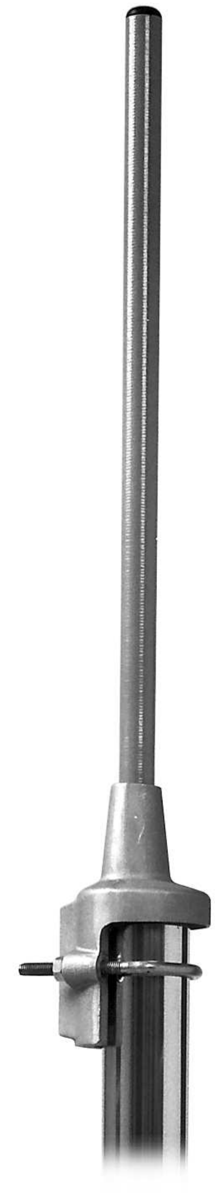
- The 3-dimensional antenna gain pattern is usually described by a vertical and horizontal cut
  - Vertical polarization: Horizontal pattern = H-plane (magnetic field)
  - Vertical pattern = E-plane (electric field)
- The half power beam width (power reduced by 3dB) is depicted in the figure as well as the opening angle of the beam determined by the half power points




Horizontal pattern



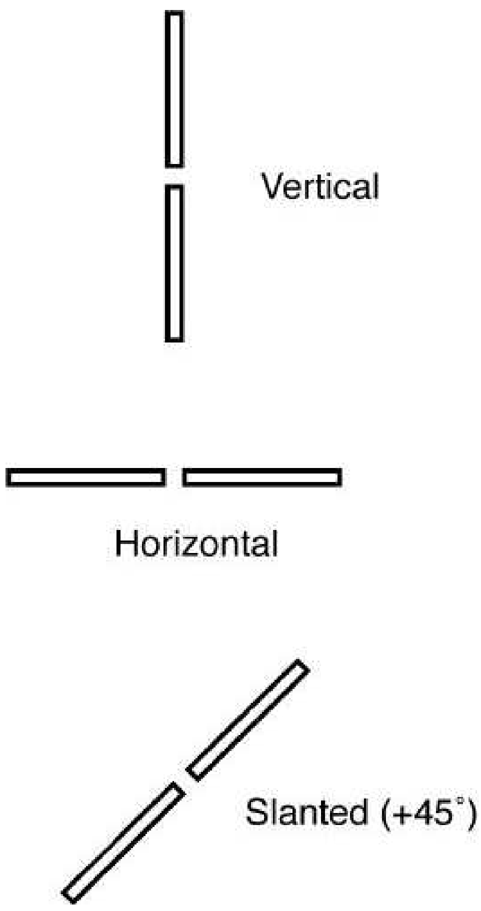

Vertical pattern



Omnidirectional antenna

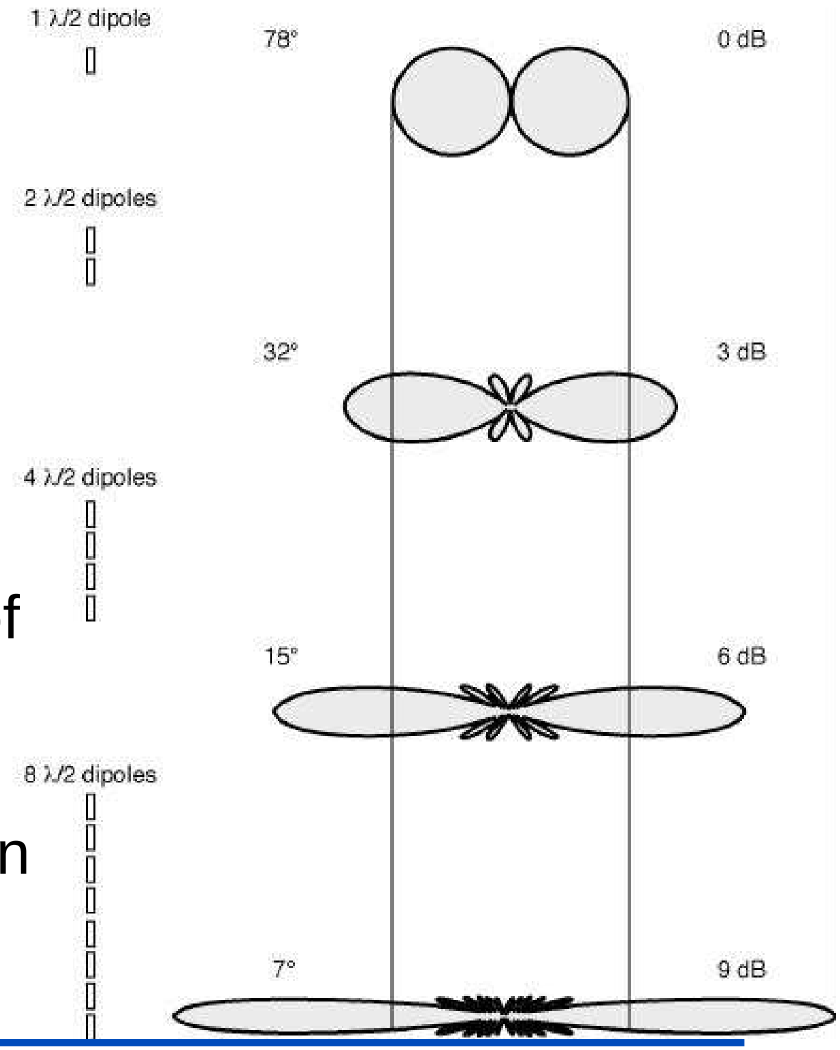
# Polarization

- The polarization is defined as the direction of oscillation of the electrical field vector
  - Dipole orientation vertical: Vertical polarization is mainly used for mobile communication
  - Dipole orientation +/-45° slanted : cross polarization used for polarization diversity



# Antenna gain

- In order to direct the radiated power into a specific area half wave dipoles are arranged vertically and combined in phase
  - While doubling the number of dipoles the half power beam width approximately halves
  - The gain increases by 3 dB in the main direction



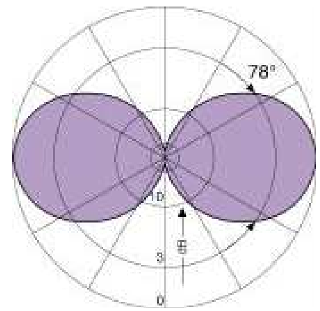

Note: Here antenna gain is measured in dBd's

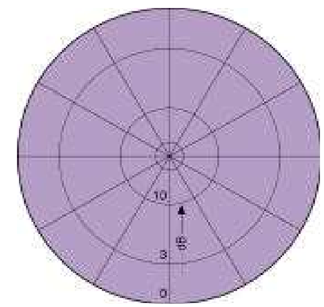
# Antenna gain

- Gain references are

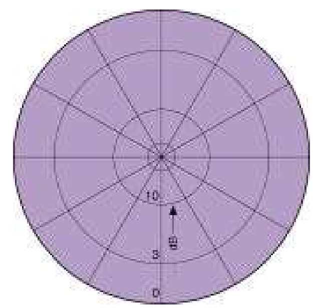
Vertical pattern Horizontal pattern

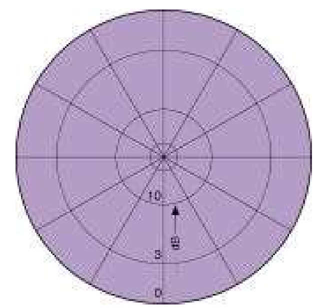
Half wave dipole (dBd)



Isotropic radiator (dBi)



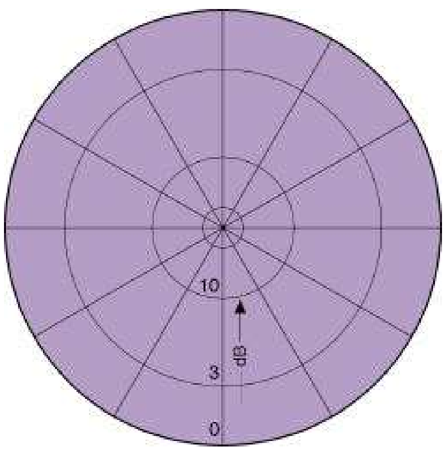


- Relation between dBi and dBd:

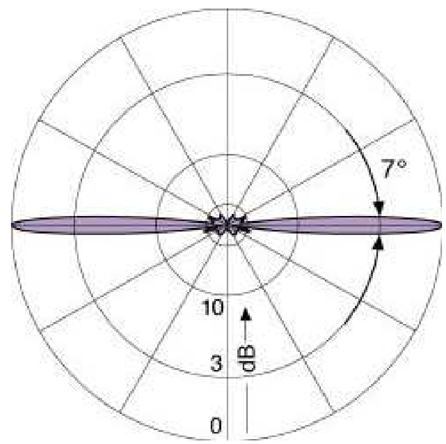
$$dBi = dBd + 2.15dB$$

# Omnidirectional antenna

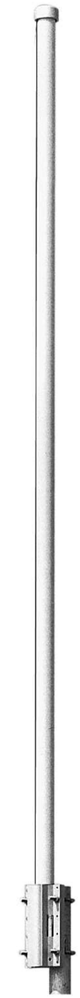
- Standard omni gain antenna for cellular application. Antenna gain is 11dBi.




Horizontal pattern

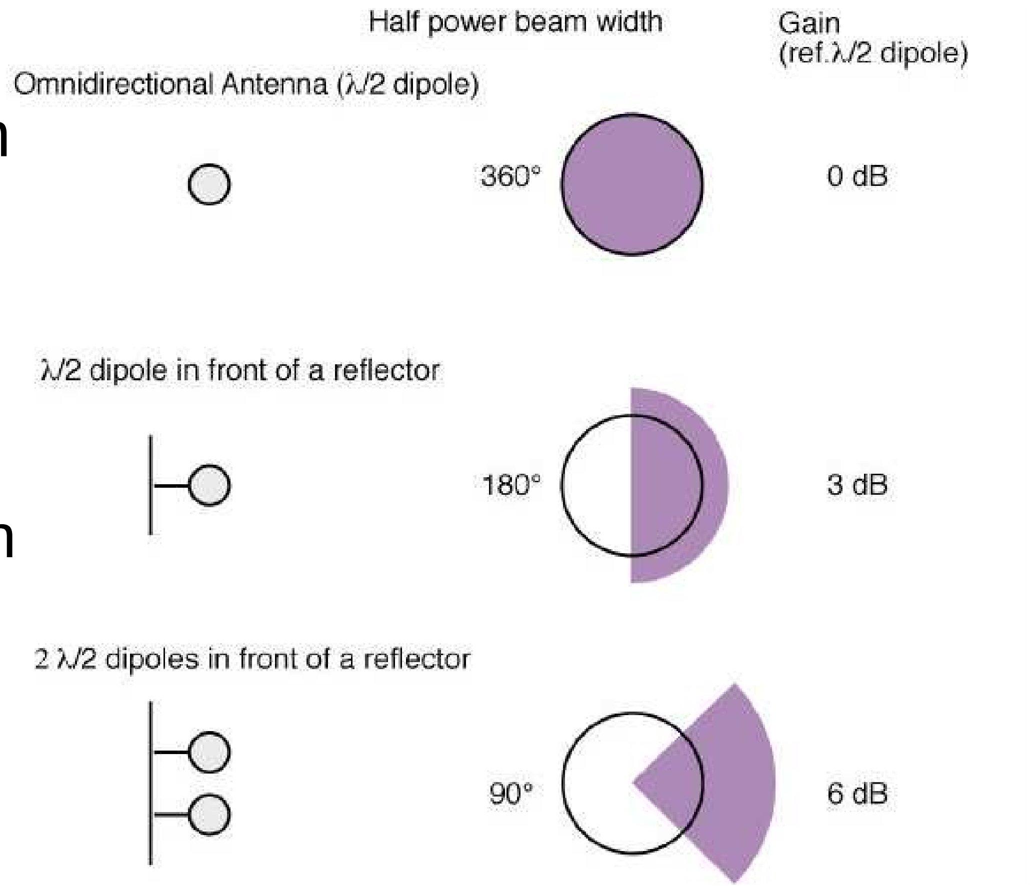



Vertical pattern



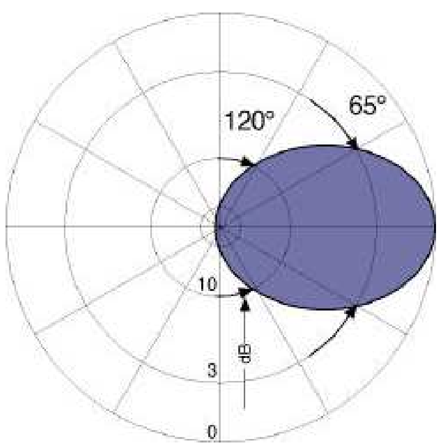
# Antenna gain

- Like in vertical plane, also in horizontal plane a beam can be created
  - While halving of the beam width the gain is increased by 3 dB
  - The resulting gain of an antenna is the sum of the vertical and horizontal gain

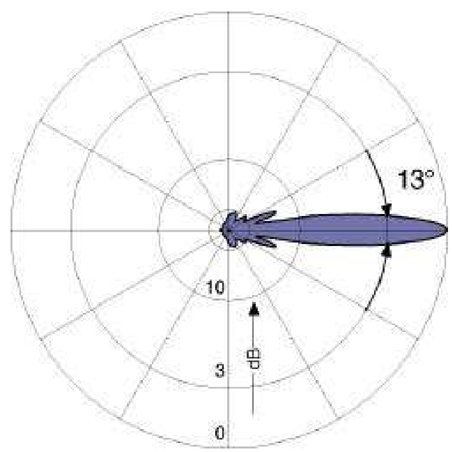


# Panel antenna

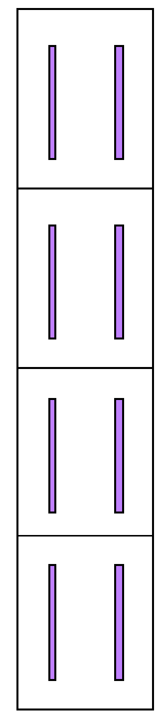
- Standard directional panel antenna for cellular networks: Antenna gain 15.5 dBi, 3dB beam width 65 degrees.
  - Gain from both planes




Horizontal pattern

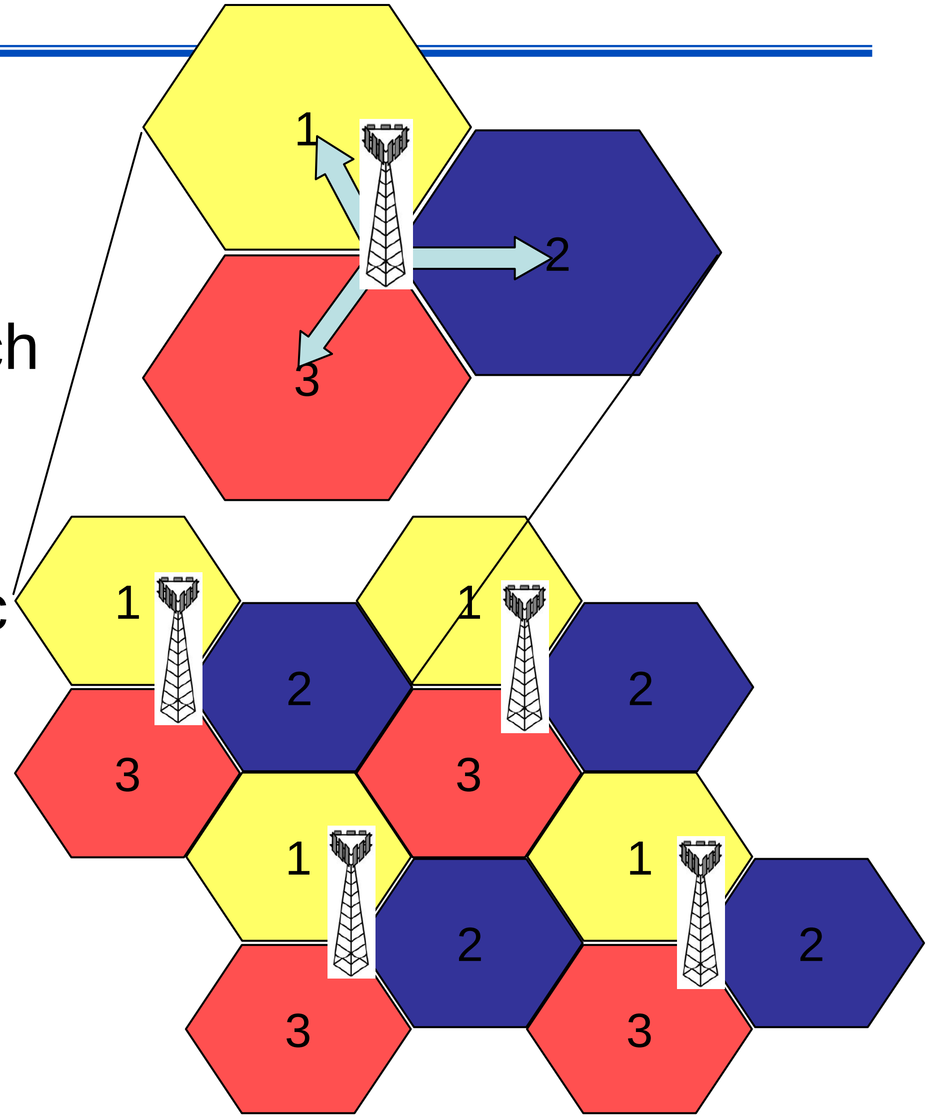



Vertical pattern

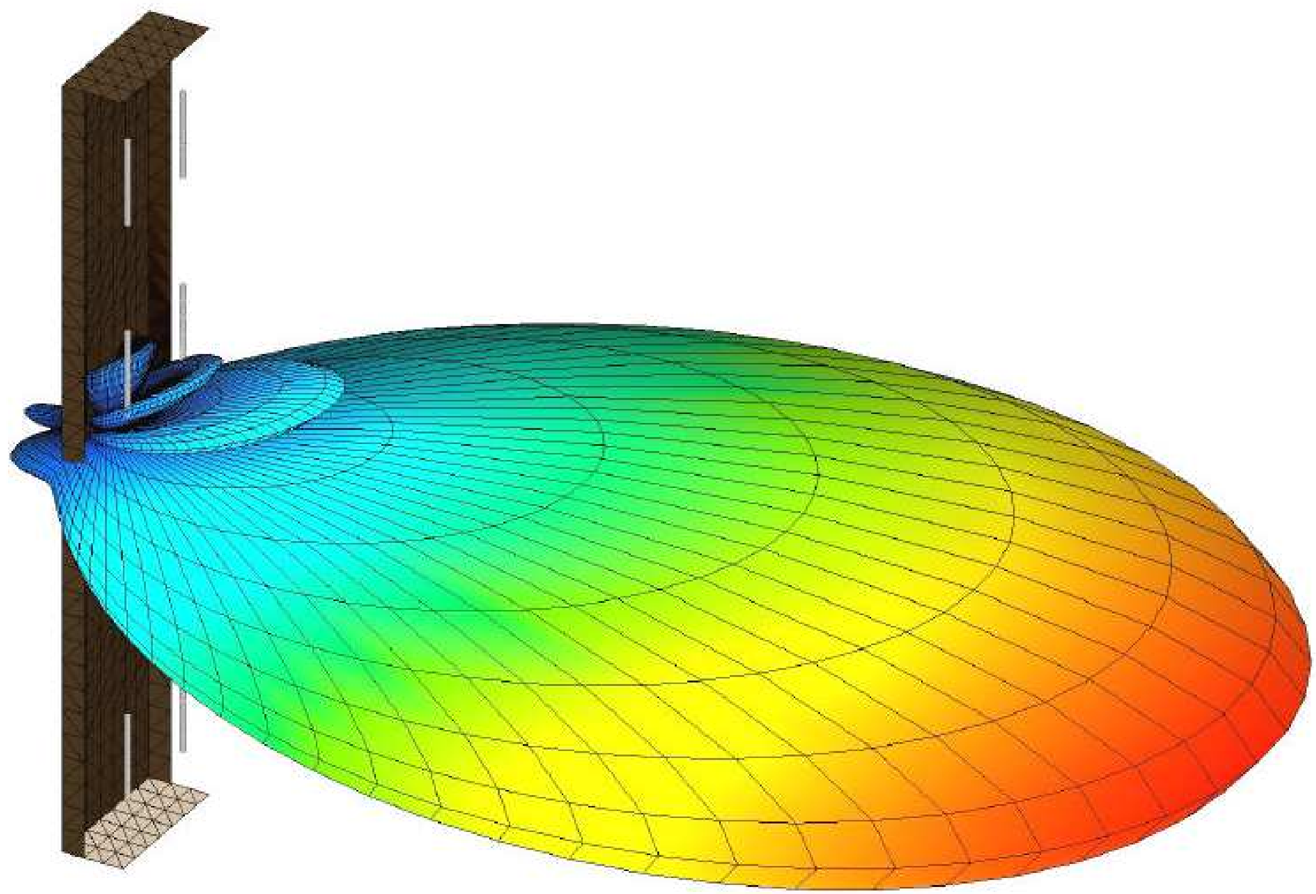


# 3-Sector sites

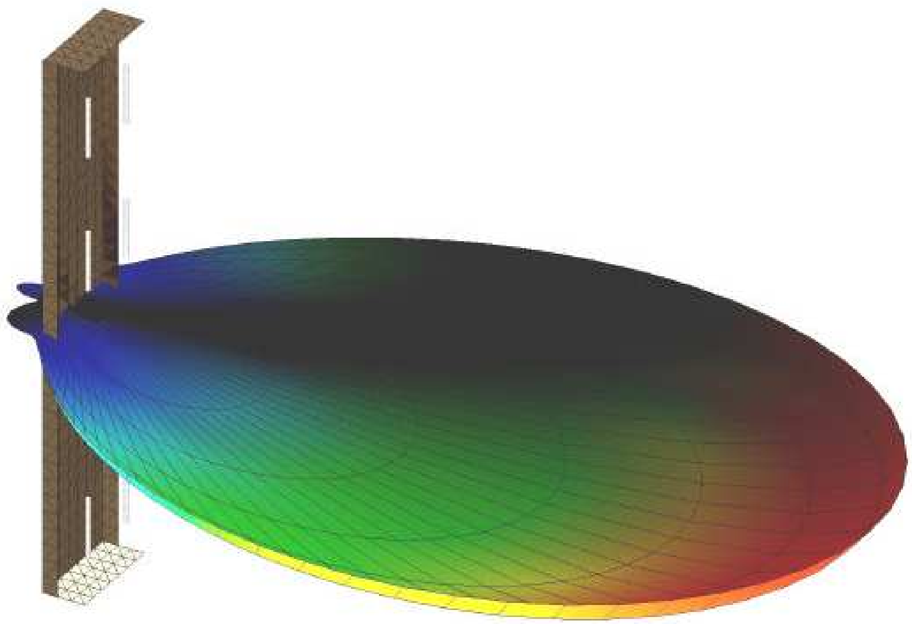
- Site = location (premises) for base station, antennas, cables, etc.
- The use of 3 sectors in each site is the most common approach.
- Omnidirectional antennas used in cells with low traffic load
- Here color code refers to coverage areas of different antennas (frequencies can be same or different in different sectors)

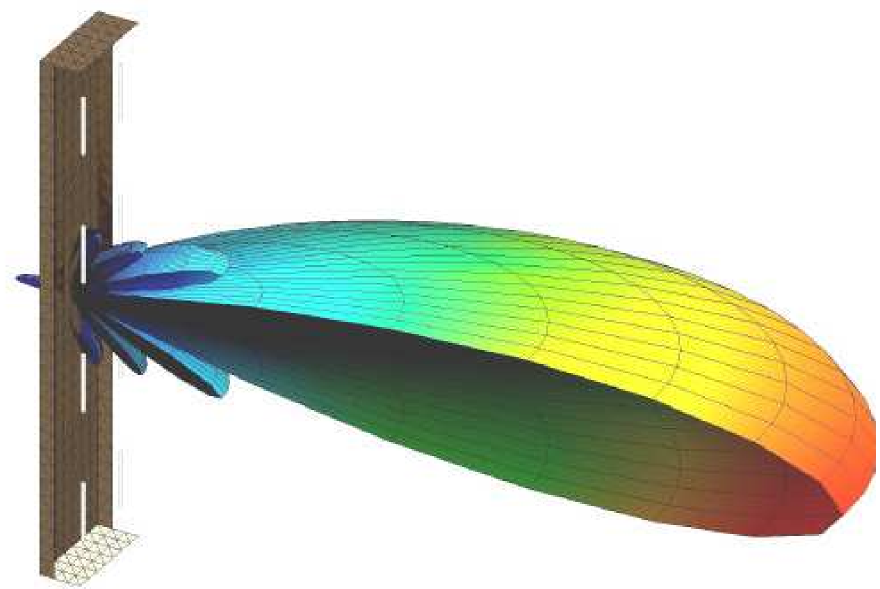


# 3D Radiation pattern/panel antenna



# 3D Radiation pattern/panel antenna





Horizontal pattern

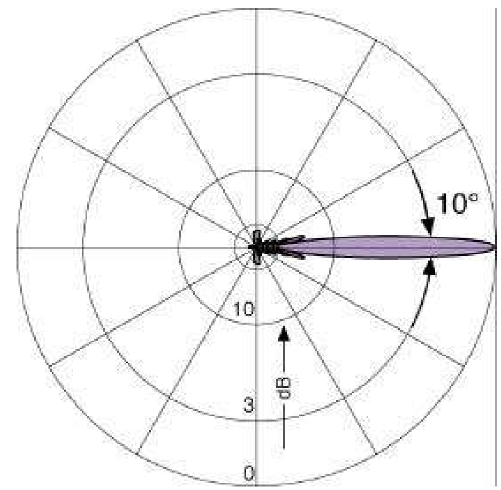
Vertical pattern

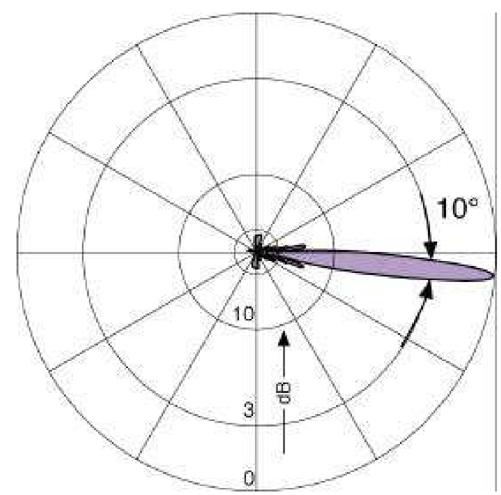
# Example

- Assume an antenna in which there are 6 $\lambda/2$ dipoles on top of each other so that narrow vertical beam can be formed.
  - What is antenna gain (in dBi's) of an ideal panel antenna when horizontal 3dB beam width is 65 degrees (3-sector site)?
- Solution.
  - Gain of vertical pattern is 10*log(6)dBd = 7.78dBd
  - In dBi's the gain of vertical pattern = 9.93dBi
  - Gain from horisontal pattern is 10*log(360/65) = 7.43dB
  - Total antenna gain = 17.36dBi

# Antenna tilting

- Compared to case where vertical beam is pointing to the horizon the down tilting of the pattern provides the following benefits:
  - The majority of the radiated power is concentrated within the sector
  - The reduction of the power towards the horizon avoids interference problems with the adjacent cells
  - Selected down tilt angle depends on the vertical half power beam width as well as the radio access system.

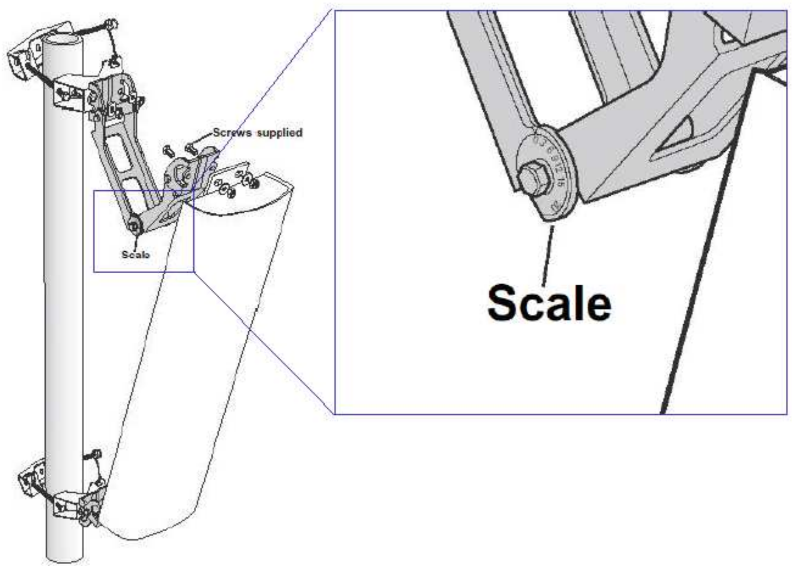


# Mechanical down tilt

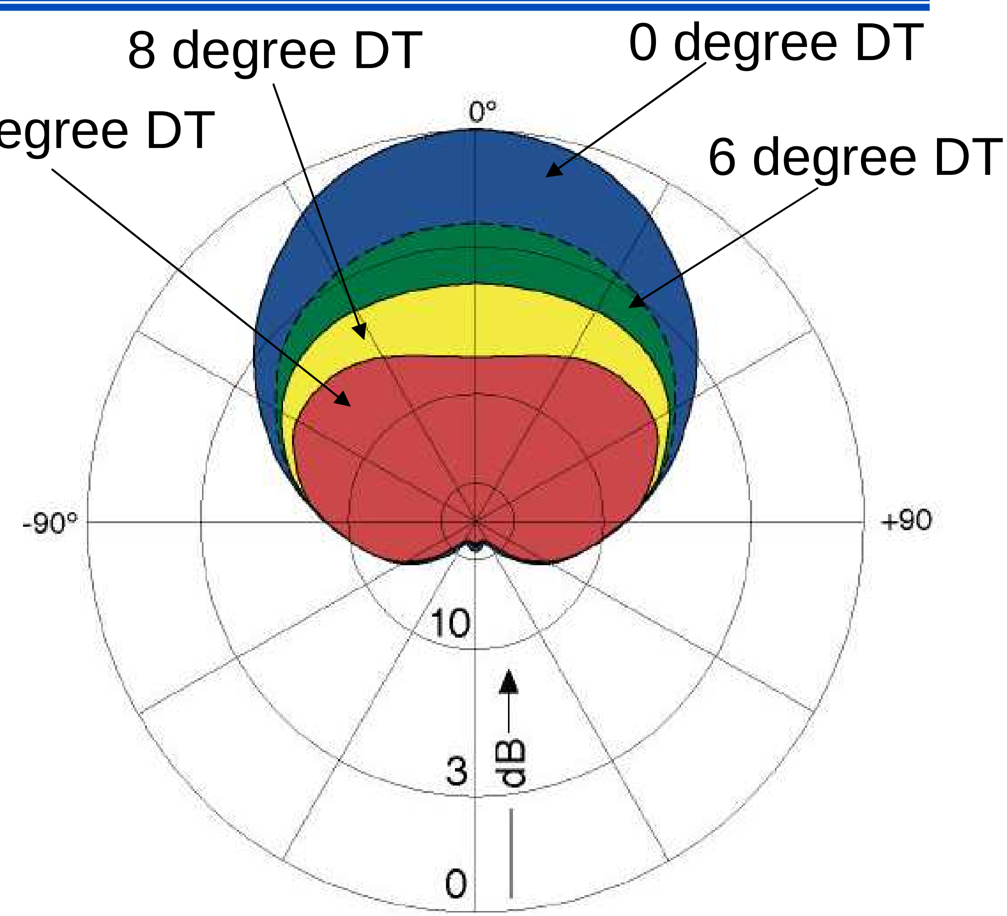
- Mechanical down tilt is used to point the vertical pattern towards desired direction
  - The main impact of down tilt is achieved in main direction
  - Effective down tilt varies across the azimuth.
  - Change is smallest in sideslopes

Mechanical Tilt



# Mechanical down tilt

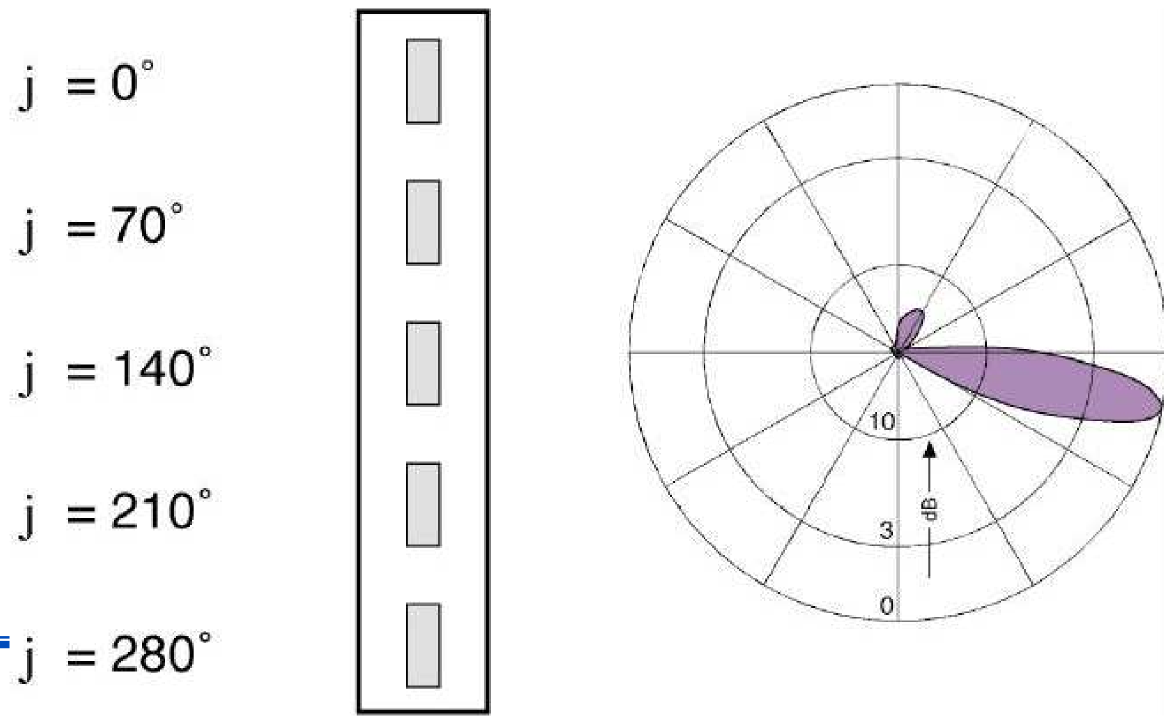
- The effect to the horizontal pattern
  - Largest gain reduction in main direction
  - The form of the horizontal pattern changes
  - It is difficult to consider pattern deformation in network planning.




Horizontal pattern 105°/ mechanical DT

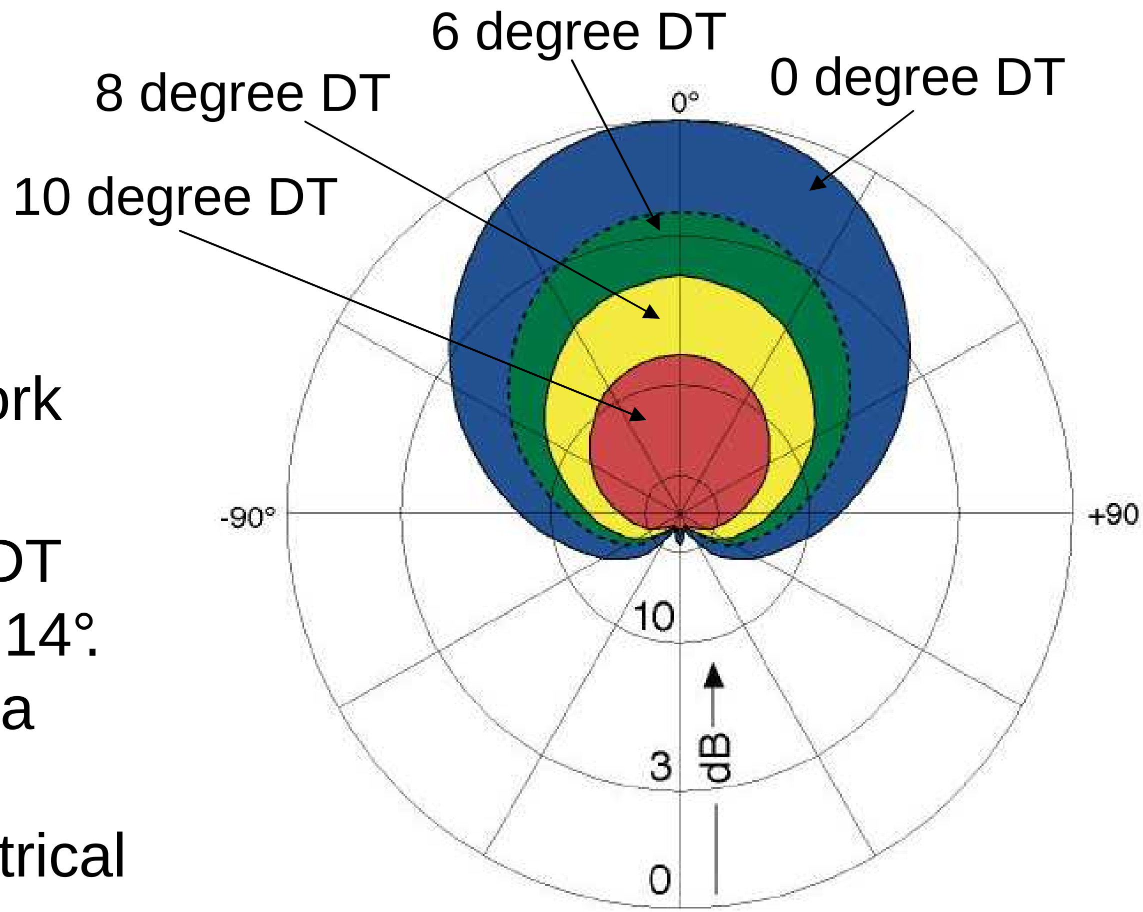
# Electrical down tilt

- In electrical down tilt the antenna remains upright position
  - Instead of equal phases on the dipoles, different phase combinations are selected by varying the cable lengths to the dipoles. As a result different vertical patterns is formed.



# Electrical down tilt

- Electrical Downtilt :
  - The shape of the horizontal pattern remains constant
  - More accurate network planning is enabled
  - Maximum electrical DT angle approximately 14°. For higher DT angle a combination of mechanical and electrical DT is recommended



# Diversity antennas

# Diversity antennas

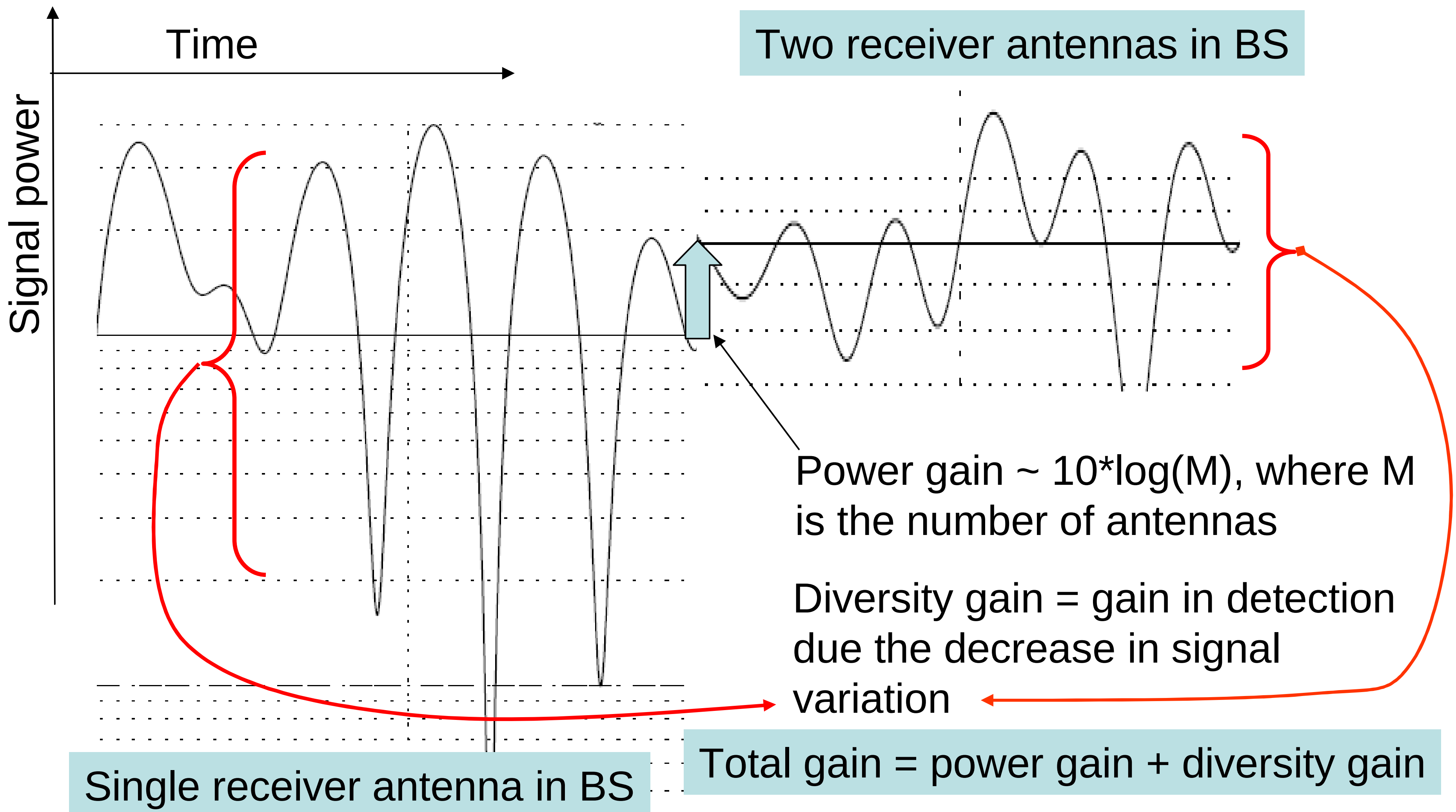
- Diversity antennas are used in BS to catch two or more uncorrelated signals simultaneously
- Here 'uncorrelated' means that fast fading in diversity antennas is different => by combining signals from such antennas we obtain diversity.

Diversity antennas for one sector (cell)

# Recall: Fast fading

- Conventionally diversity methods have been used to increase the signal level from MS to BS. This is due to asymmetry between downlink and uplink:
  - Uplink (MS): Small antenna, very limited power resources and practically no antenna gain
  - Downlink (BS): High power transmission and high antenna gain
- Especially in build areas signals between BS and MS doesn't usually contain direct wave component but instead, signals are merely combinations of reflected, scattered and heavily attenuated wave components.

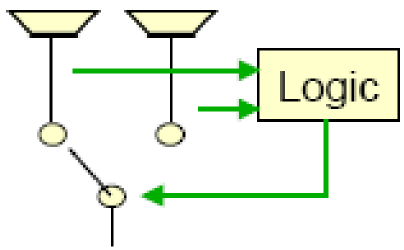
# Illustration of diversity reception

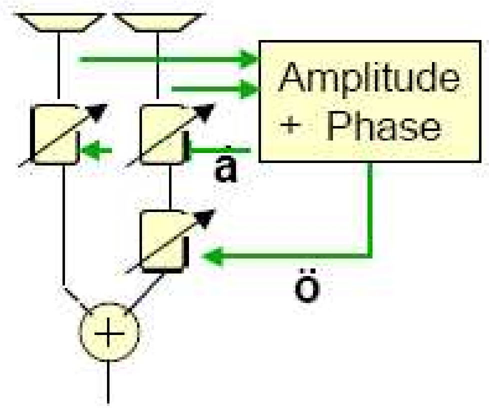



Total gain = power gain + diversity gain

# Diversity methods/2 antennas

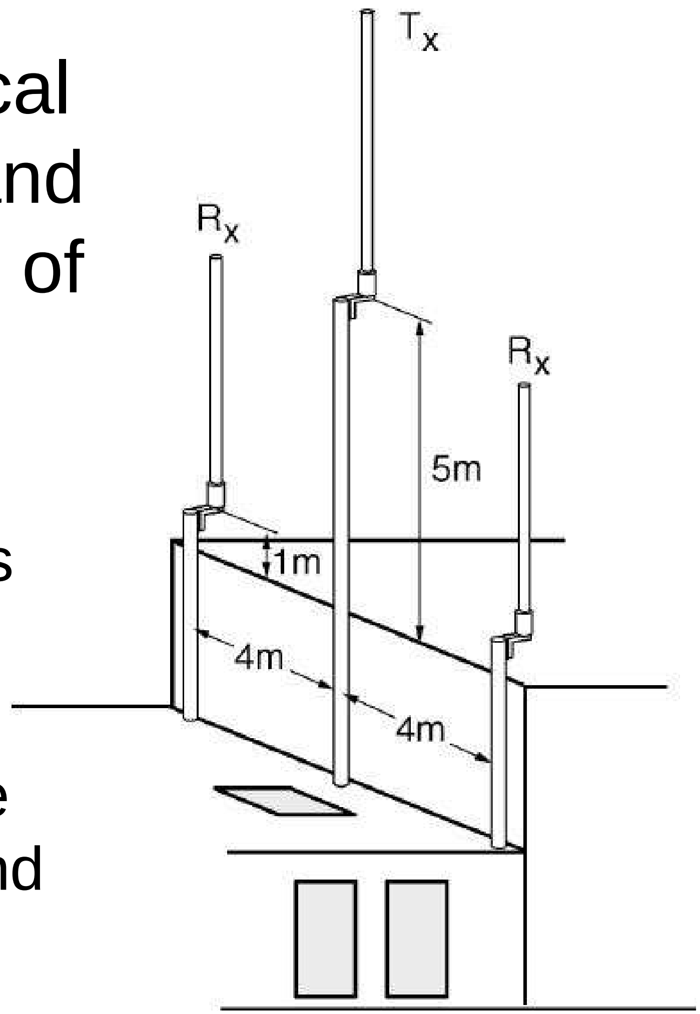
- In selection combining (SC) there is switching between the two antennas and aim is to select the stronger signal
- In maximum ratio combining (MRC) signals are equalized and summed up
- MRC is more effective method but SC is more simple from implementation perspective
- Gain from 2 BS antennas is usually 3-7dB depending on the environment, diversity method, antenna system and applied service.



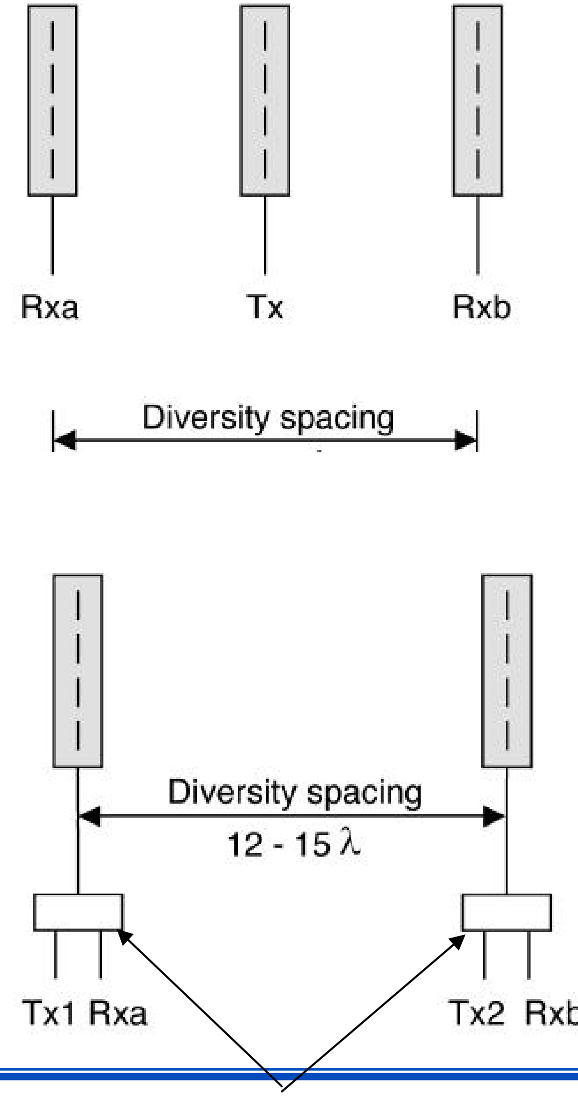
# Space diversity/omnidirectional

- Space diversity uses two vertical polarized RX antennas (RXa and RXb) with a horizontal spacing of 12-15 λ
- Example
  - Omnidirectional diversit antennas
  - TX antenna on a higher level to achieve an ideal omnidirectional radiation pattern and to reach the required isolation between RX and TX (>30 dB)



# Space diversity/panel antennas

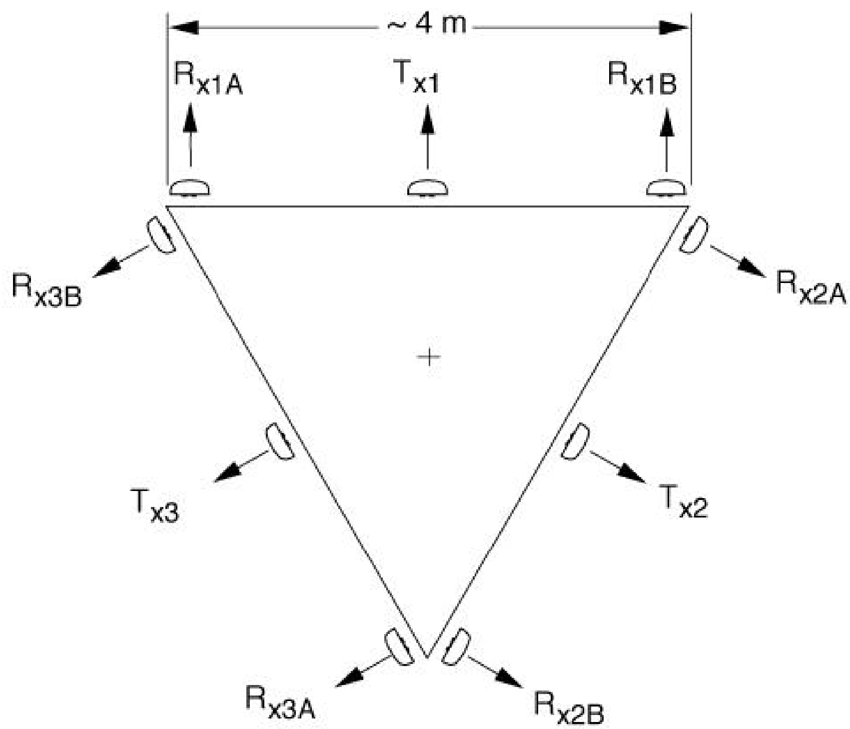
- Space diversity admit good performance, but big spacing between antennas is required
  - Towers/masts are relatively expensive
  - By using duplexers the number of antennas can be reduced
  - In some countries it can be difficult to receive permission for large antenna systems.
  - Site prices can be huge.




Duplexer is needed to separate RX and TX branches

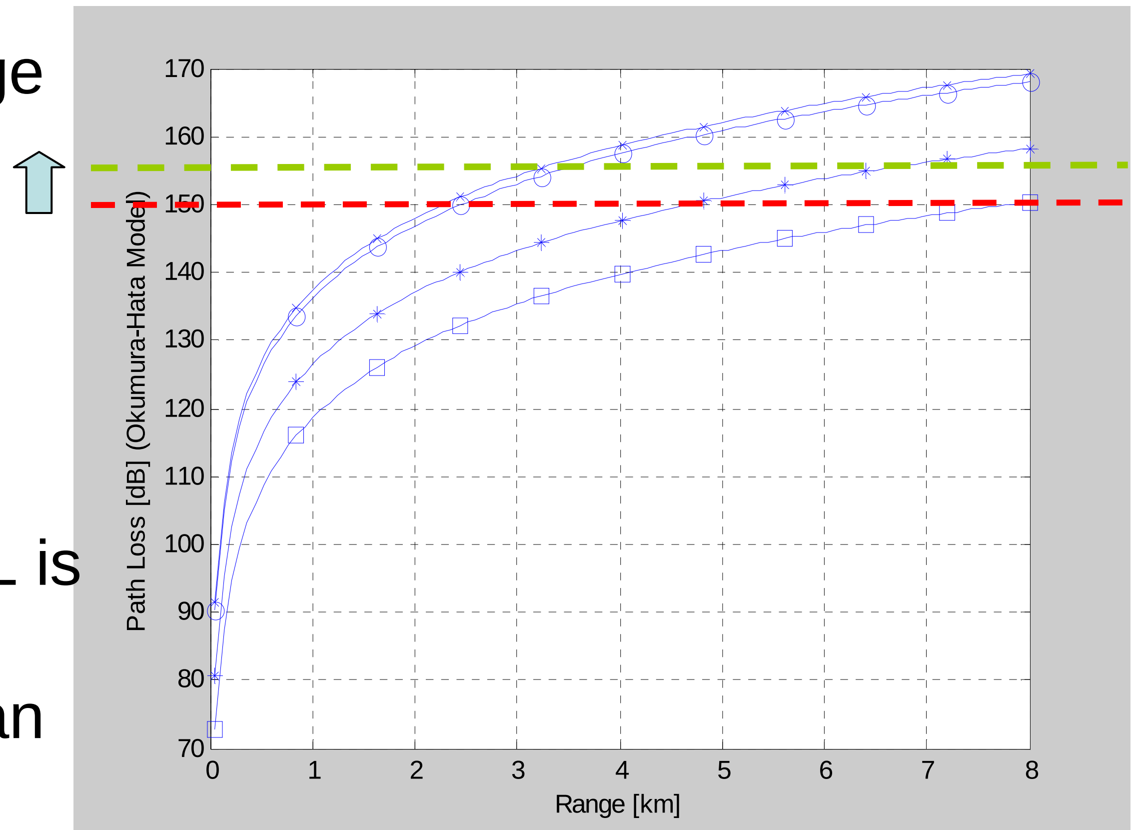
# Space diversity/sectorization

- 3-sector site
  - 3 directional antennas per sector
  - All antennas at the same level due to better isolation compared to omnidirectional antennas
  - TX antenna in the middle so that RX (diversity) antenna separation is maximized



# Space diversity/range

- Recall Okumura-Hata example. Path loss in large city when
  - $f$ = 450 MHz (□)
  - $f$ = 900 MHz (*)
  - $f$ = 1800 MHz (o)
  - $f$ = 1950 MHz (x)
- Assume that allowed PL is 150dB. Then by antenna diversity (6dB gain) we can increase the cell range




f = 1800MHz: 2.5 km -> 3.3 km; 74% coverage increase
f = 900MHz: 4.7km -> 6.7km; 103% coverage increase



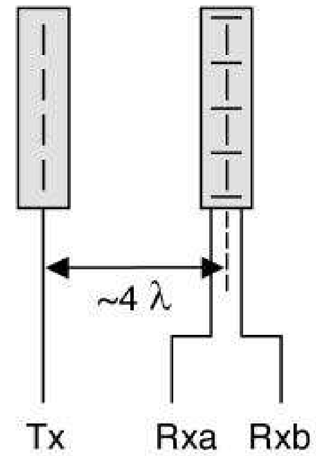
BS height = 30m, MS height = 1.5m

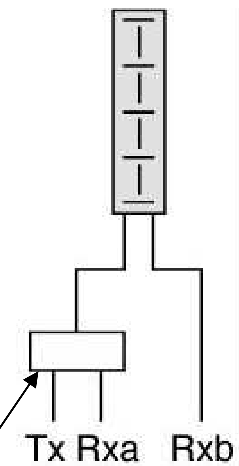
# Space diversity/comments

- Dimension of the diversity antenna system depends on the carrier frequency. In space diversity we usually need antenna separation larger than 12λ
  - λ = 300/f, where λ [m] and f [MHz] =>
  - F = 900MHz: separation > 12*0.33m = 4m (GSM)
  - F = 1800MHz: separation > 2m (GSM)
  - F = 2600MHz: separation > 1.38m (mobile WiMAX)
  - F = 3500MHz: separation > 1.02m (fixed WiMAX)
- Diversity reception is commonly used in uplink. Recently diversity reception has been introduced also to mobile terminals.
- If diversity is used only in uplink then it doesn’t necessarily lead to range extensions if downlink becomes a bottleneck

# V/H Polarization diversity

- Signal contains vertical (V) and horizontal (H) polarization component.
- V and H polarizations are orthogonal i.e. component signals are not correlating. Yet they may have different mean power
- In polarization diversity V and H polarized antennas are used. Great advantage is that <u>space separation between diversity branches is not needed.</u>
- Disadvantage
  - In rural areas power difference between V and H polarization can be large




Duplexer is needed to separate RX and TX branches

# Some theory behind

- Let us take a simple complex signal model
  - Received signal is denoted by $S = X + jY$
- Assume V/H polarized signals
  - $S_V$, $S_H$ are signals in vertically and horizontally polarized antennas respectively
  - Problem is that in some environments powers of differently polarized signals can be very different, i.e.

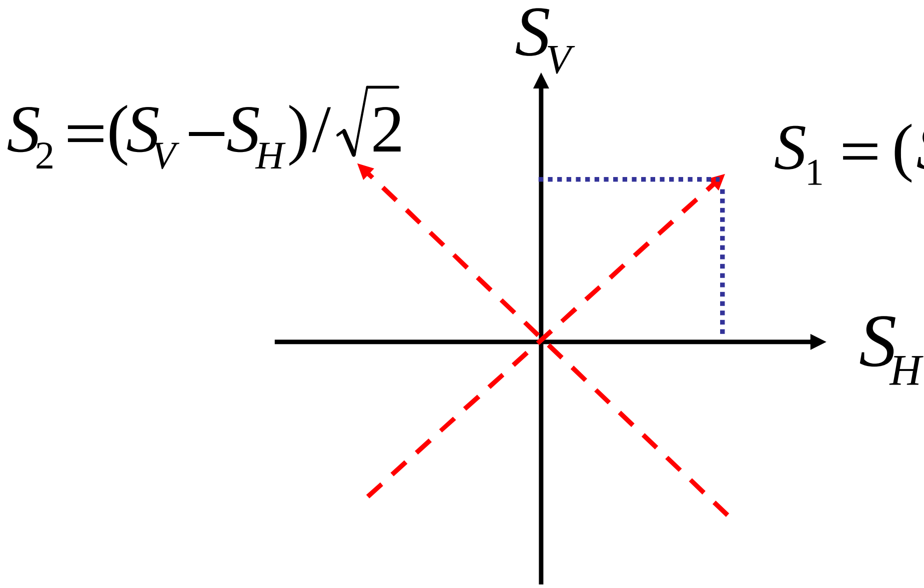
$$P_V = E\left\{\left|S_V\right|^2\right\} >> P_H = E\left\{\left|S_H\right|^2\right\}$$

    where E{.} refers to expectation (mean power of the signal is expectation over the square of absolute value)
  - Good news is that $S_V, S_H$ are uncorrelated, i.e.

$$E\left\{S_V^* S_H\right\} = 0$$

# Some theory behind

- The power difference between diversity branches can seriously reduce the detection efficiency. In order to get rid of the power difference we rotate the system 45 degrees



# Some theory behind

- Now powers of signals from rotated system are equal:

$$P_1 = E\{|S_1|^2\} = \frac{1}{2}\left(E\{|S_V|^2\} + E\{|S_H|^2\} + E\{S_V^* S_H\} - E\{S_H^* S_V\}\right)$$

$$= \frac{1}{2}\left(E\{|S_V|^2\} + E\{|S_H|^2\}\right) = \frac{1}{2}(P_V + P_H)$$

$$P_2 = E\{|S_H|^2\} = \frac{1}{2}\left(E\{|S_V|^2\} + E\{|S_H|^2\}\right) = P_1$$

- But on the other hand we will have some correlation between signals

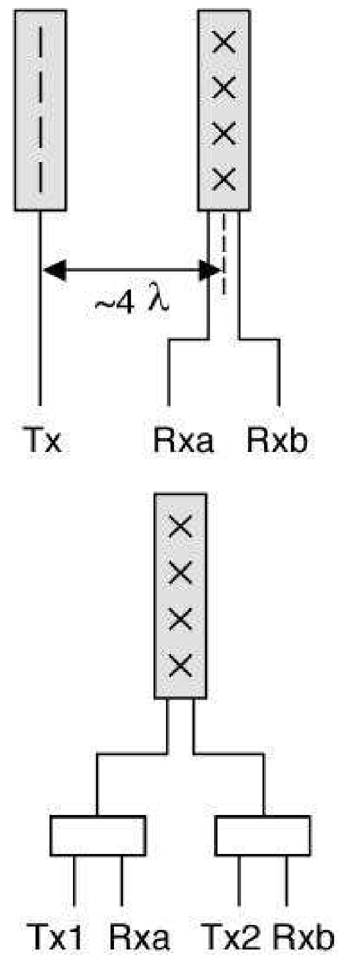
$$E\{S_1^* S_2\} = \frac{1}{2}\left(E\{|S_V|^2\} - E\{|S_H|^2\}\right) = \frac{1}{2}(P_V - P_H)$$

# Some theory behind

- We started from V/H polarized system
  - V and H polarized signals are uncorrelated but power difference between V and H branches might become a problem
- We rotated system 45 degrees and obtained a system where
  - Signal power from branches 1 and 2 are equal
  - Yet, there is now correlation between signals.
  - The amount of correlation depends on the power difference between V and H polarizations. This is related to physical environment. In rural areas correlation (power difference between V/H polarizations) is larger than in urban environments
- Now it is time to consider the so-called X-polarized antennas

# X Polarization diversity

- By rotating V and H polarizations we obtained +/- 45 degrees slanted polarizations
  - Antenna branches admit equal power => ‘easier’ signal from receiver perspective.
  - X-polarized antennas fit well for both rural and urban environments
- Both RX and TX can be embedded to the same physical antenna box




Duplexer needed

# Space vs X-polarization diversity

- Instead of 9 antennas (or 6 when duplexer is used) per site/base station, only 3 X-polarized antennas are required
- Size is reduced => better opportunities to find good antenna locations
- Site costs may be reduced (depending on the site contracts and regulations)

Space diversity, 2RX, 1 TX per sector, no duplexer

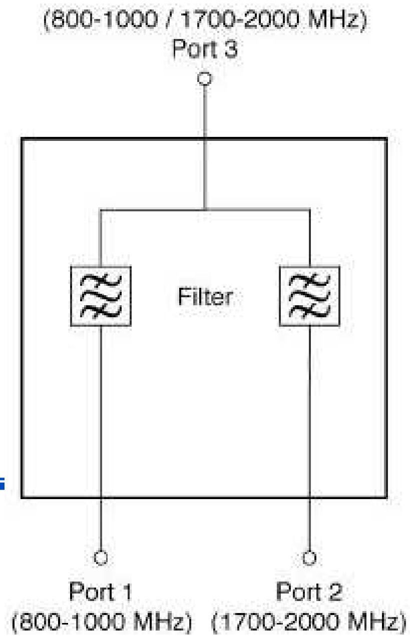
X-polarization diversity, 2RX, 1 TX per sector, duplexer

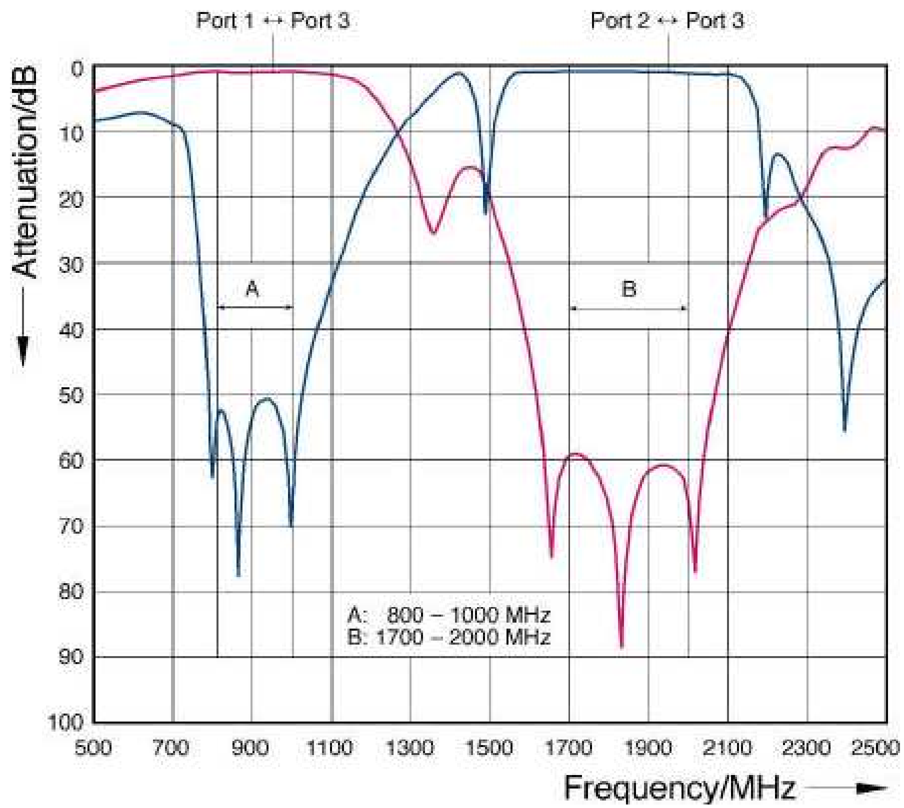
# Dualband antennas

- Dualband antennas are used when two systems operate on different frequency bands but on same sites.
- Operators always try to use old sites for new systems (sites can be very expensive)
- Dualband antennas with diversity
  - Space diversity (left; visual catastrophe)
  - XX-polarization diversity (right)

# Diplexer

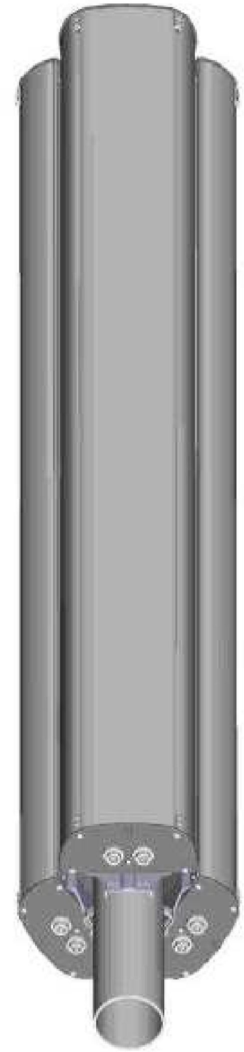
- Problem is solved by using diplexer. It consists of two band pass filters
  - Low insertion loss (approx. 0.2 dB)
  - High port isolation (> 50 dB)



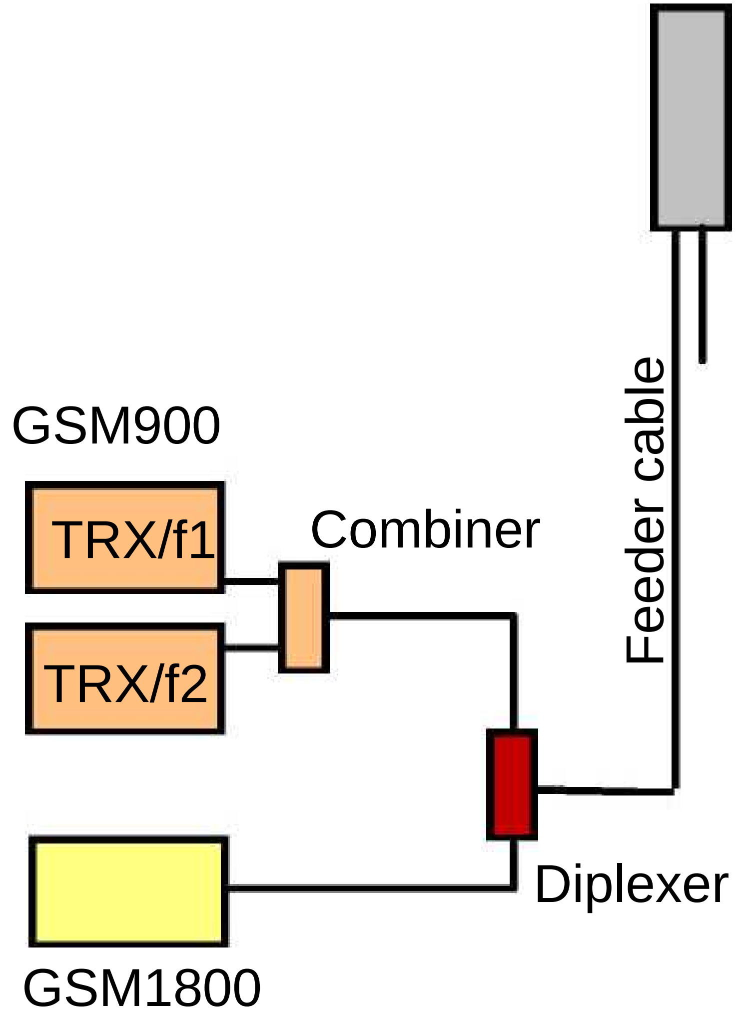
# Dualband X-polarization

- Using X-polarized antenna branches, diplexer and duplexer it is possible to design a compact antenna design for 3 sectors
  - 900/1800 MHz (e.g. GSM) ,
  - Two-branch diversity in uplink (X-polarization)
  - Design contains only 3 antennas (still 6 feeder cables)



# Example

- GSM 900 with 20 W output
  - Losses and gains
  - Combiner: -3 dB
  - Diplexer -0.5 dB
  - Feeder cable -2.5 dB
  - Antenna gain +17 dBi
  - <u>Total +11 dB</u>
- Effective Isotropic Radiated Power (EIRP)
  - EIRP = 43dBm + 11 dB = 54dB (=251W)



# Terminology

- Combiner (3dB coupler) = device that combines feeds from several TRXs so that they could be sent out through a single antenna. To be taken into account in GSM DL link budget.
- Duplexer = Used for separating sending and receiving signals to/from antenna. Can be used to decrease the number of antennas.
- Diplexer = a device that implements frequency domain multiplexing. Two ports (e.g., L and H) are multiplexed onto a third port (e.g., S). The signals on ports L and H occupy disjoint frequency bands. Consequently, the signals on L and H can coexist on port S without interfering with each other.

# Terminology

- dBi = dB(isotropic). It is the forward gain of a certain antenna compared to the ideal isotropic antenna which uniformly distributes energy to all directions.
- dBd = dB(dipole). It is the forward gain of an antenna compared to a half-wave dipole antenna.
- dBm = dB(1 mW) is a power measurement relative to 1 mW (e.g. 20W is 10*log(20/0.001)= 43 dBm
- Effective isotropic radiated power is the amount of power that would have to be emitted by an isotropic antenna (that evenly distributes power in all directions and is a theoretical construct) to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna.