Radio Frequency and Antenna Fundamentals – Part 2

COMP3049 Intermediate Wireless Technology

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Objectives

- Basic RF Math
- Other RF Parameters
- RF and Antenna Terminology
- Antennas and Antenna Systems

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Basic RF Math

- Watt
- Milliwatt
- Decibel (dB)
  - dBm
  - dBi
  - dBd

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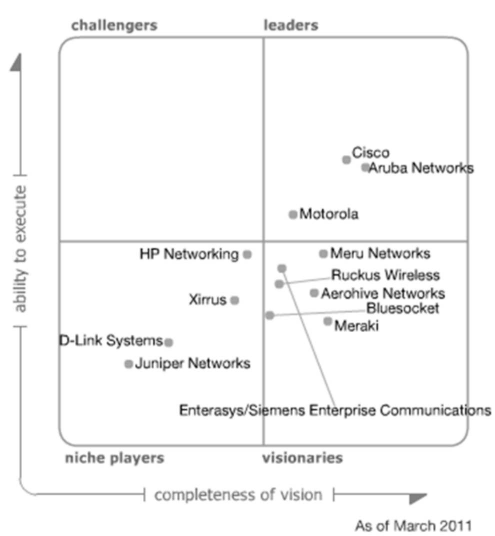
Wireless Industry



Magic Quadrant
Source: Gartner Inc.

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Watts and Milliwatts

- Watt is basic unit of power
  - 1 Watt = 1 joule per second
  - 1 joule = the work required to produce one watt of power for one second
  - Named after James Watt; Scottish inventor who also improved the steam engine
  - 1 Watt = 1 Amp flowing at 1 Volt
  - Increased voltage, increased amperage, or both, results in increased wattage

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Watts and Milliwatts

- 1 Milliwatt = 1/1000 of a Watt
- WLANs need minimal power to transmit a signal over an acceptable distance
- You can see a 7 Watt light bulb more than 80 km away on a clear night
- Enterprise devices – up to 100 mW
- SOHO/Residential – usually 30 mW

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Do you know this already?

- How much is 1μ Watt?
  - 1/1,000,000 Watts or 0.000001 (10^{-6})Watts
- Which unit is used to measure the magnitude of an electrical signal?
  - Volt
- How would you express 1 Milliwat in dB?
  - 1 milliWatt = 0 dBm

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Watts and Milliwatts

- Indoor use – no more than 100 mW
- Using a 2 dBi antenna = 160 mW
- Provides sufficient coverage indoors
- Outdoor applications may use more power, especially with point-to-point links
- Maximum EIRP for 2.4 GHz band is 4 W

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Decibel (dB)

- Comparative measure between two power levels
- 1/10 of a Bel
  - The Bel was named after Alexander Graham Bell
- Decibel is a logarithmic value; mW is a linear value
- Decibel calculations use smaller numbers and simpler calculations to refer to power levels
- Decibels are relative whereas mW are absolute measurements

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Decibel (dB) "Rule of Thumb"

- A gain of 3 dB magnifies the output power by two
- A loss of 3 dB equals one half of the output power
- A gain of 10 dB magnifies the output power by 10
- A loss of 10 dB equals one-tenth of the output power
- dB gains and losses are cumulative
  - You add and subtract numbers, instead of dividing and multiplying

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Pop Decibel (dB) Quiz

- Examples:
  - 100 mW +3 dB = ?
    - 200 mW
  - 30 mW +3 dB = ?
    - 60 mW
  - 6 dB gain = 3dB +3 dB
  - 100 mW = +6 dB = ?
    - 400 mW
  - 40 mW = +20 dB = ?
    - 4000 mW or 4 W
  - Same rules apply to losses
  - 100 mW – 6 dB = ?
    - 25 mW
  - 1 W – 20 dB = ?
    - 10 mW

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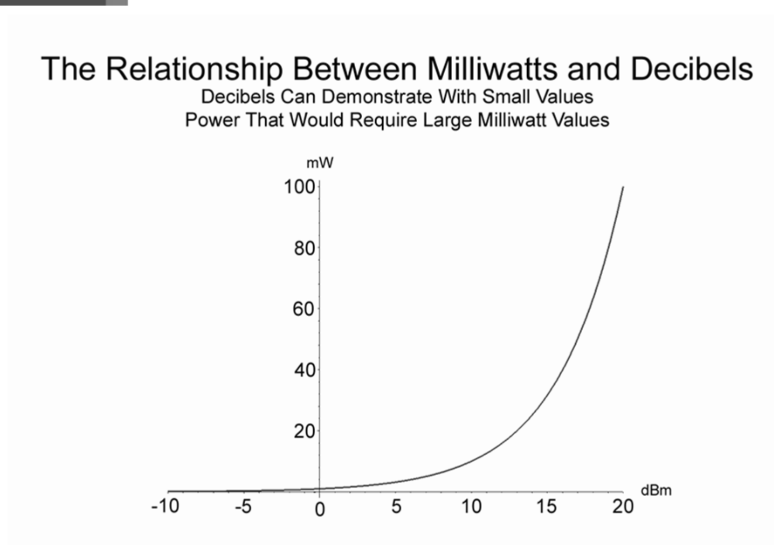

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Using the 3 dB and 10 dB Rule-of-Thumb

- 30 mW + 8 dB
  - +10 +10 -3 -3 -3 -3 = 8
  - 30 mW x 10 = 300 mW
  - 300 mW x 10 = 3000 mW
  - 3000 mW/2 = 1500 mW
  - 1500 mW/2 = 750 mW
  - 750 mW/2 = 375 mW
  - 375 mW/2 = 187.5 mW

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Expressions of 10s and 3s

Gain	Expressed in 10s and 3s
1	+10 -3 -3 -3
2	+3 +3 +3 +3 -10
3	+3
4	+10 -3 -3
5	+3 +3 +3 +3 +3 -10
6	+3 +3
7	+10 -3
8	+10 +10 -3 -3 -3 -3
9	+3 +3 +3
10	+10

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dBm

- Absolute measurement of power
- 0 dBm = 1 mW

mW	dBm
1	0.00
10	10.00
20	13.01
30	14.77
40	16.02
50	16.99
100	20.00
1000	30.00
4000	36.02

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dBi and dBd

- dB isotropic
  - Measurement of power gain used for antennas
  - Gain as compared to an isotropic radiator
  - Isotropic radiator, the ideal antenna; not practical or impossible to create with current technology
- dBd
  - Directional gain, as compared to a dipole antenna
  - Equal to value in dBi +2.14
  - 0 dBd = 2.14 dBi

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Other RF Parameters

- SNR – Signal to Noise Ratio
- RSSI – Received Signal Strength Indicator
- Link Budget
- SOM – System Operating Margin
- Fade Margin

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SNR – Signal to Noise Ratio

- Background RF noise caused by various RF systems and natural phenomena is known as the *Noise Floor*
- SNR is the power level of the RF signal relative to the noise floor (ratio)
- WLAN signal ≥ 20 dB higher than the *noise floor* or any source of interference
  - Otherwise the signal may not be detected correctly

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RSSI – Received Signal Strength Indicator

- Arbitrary measurement of received signal strength defined in the IEEE 802.11 standard
- One byte long – range = 0-255
- Implemented differently by each manufacturer
- Most manufacturers applications display percentage values

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RSSI (cont'd.)

- Different transmission speed (data rates) use different modulation techniques
  - Lower speeds = simpler modulation/encoding methods; less susceptible to interference
  - Higher speeds = more complex modulation/encoding; more susceptible to interference
- Different speeds have different receive sensitivity threshold

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RSSI (cont'd.)

Data Rate	Received signal, minimum amplitude
54 Mbps	-50 dBm
48 Mbps	-55 dBm
36 Mbps	-61 dBm
24 Mbps	-74 dBm
…	…

The table above is an example only; keep in mind that different receivers may have different thresholds

Link Budget and System Operating Margin

- Budget is a plan for controlling a resource
- For WLANs RF energy is the resource
- Results in SOM – System Operating Margin
- Accounting of all components, i.e. their gain or loss
- Also includes *free space loss*

Link Budget and System Operating Margin

- First determine the minimum signal strength required by the receiving device
- Then use this value to determine requirements at the transmission point(s)
- Check manufacturer specs for signal strength vs. data rate for reliable reception
- As per the IEEE 802.11 Std., the farther away you need to communicate, the slower the data rate
- Check receiver's sensitivity (expressed in dBm)

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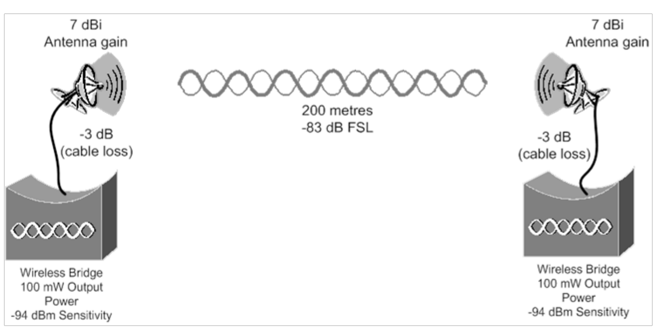
Link Budget and System Operating Margin

- SOM = Receiver sensitivity - Signal Strength
- Link Budget is rarely used for indoor applications
- Link Budget = (-94 dBm) – (-59 dBm) = SOM 35 dBm



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Fade Margin

- Link Budget is commonly *padded*
- Changes in weather, trees that grow in summer, etc
- Example: using -80 dBm receiver sensitivity instead of the manuf. spec. of -94 dBm
- SOM in prev. diagram drops to 21 dBm (14 dB diff.)

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RF and Antenna Terminology

- Intentional Radiator
- EIRP – Equivalent Isotropically Radiated Power
- FCC Rules for Output Power

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Intentional Radiator

- The point at which the antenna is connected
- Regulatory organizations set rules based on:
  - The max. amount of power delivered to the antenna
  - The max. gain of the antenna
  - For most 2.4 GHz 802.11 WLANs this is:
    - 1 Watt at the intentional radiator
    - 4 Watts max. output power from the antenna (EIRP)

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EIRP – Equivalent Isotropically Radiated Power

- Output power from the intentional radiator added to the antenna gain
- Measured at a specific distance from the antenna
  - Done by engineers during product development
- 1 W output from the intentional radiator plus 6 dBi of antenna gain = 4 W of total output power in a PTMP link

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Regulatory Rules for Output Power

- FCC/CRTC
- PTMP and PTP are the same for ISM 2.4 GHz
- Reality is that you can have more than 4 W in PTP links if your antennas are *very* directional
- For U-NII there are different rules for PTMP and PTP

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PTMP Output Power (ISM 2.4 GHz)

Intentional Radiator Power (dBm)	Antenna Gain	EIRP (dBm)	EIRP (Watts)
30	6	36	4
27	9	36	4
24	12	36	4
21	15	36	4
18	18	36	4
15	21	36	4
12	24	36	4

Note: North America (FCC/CRTC)

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PTP Output Power (ISM 2.4 GHz)

Intentional Radiator Power (dBm)	Antenna Gain	EIRP (dBm)	EIRP (Watts)
30	6	36	4
29	9	38	6.4
28	12	40	10
27	15	42	16
26	18	44	25
25	21	46	39.8
24	24	48	63
23	27	50	100
22	30	52	158

Note: North America (FCC/CRTC)

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Output Power for U-NII Bands

U-NII Band	Int. Radiator Power (dBm)	Antenna Gain (dBi)	EIRP (dBm)	EIRP (mW)
5.150 – 5.250 GHz	16 (40 mW)	6	22	160
5.250 – 5.350 GHz 5.470 – 5.725 GHz	23 (200 mW)	6	29	800
5.725 – 5.825 GHz	29 (800 mW)	6	35	3200

Note: North America (FCC/CRTC)

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Regulations for Sector and Phased-Array Antennas

- Transmit only in the direction of the receiver
- May use the same regulations as for PtP antennas except:
  - Limit the total power for each individual beam to 0.125 W or 1 W depending on modulation
  - Limit the aggregate power transmitted simult. on all beams to 8 dB above the limit for one individual beam
  - Transmitter output power reduced by 1 dB for each 3 dB tghat the directional antenna gain of the complete system exceeds 6 dBi

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RF Signal and Antenna Concepts

- Visual LOS (Line of Sight)
  - Actual path of the light waves from one object to another
- RF LOS
  - More sensitive to interference than visible light
  - RF waves take more space than visible light
  - Extra space is called *Fresnel Zone*

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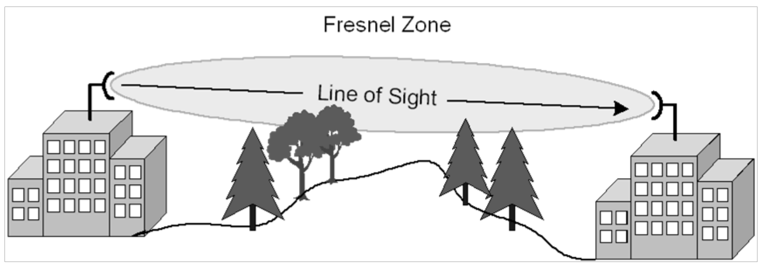
RF Signal and Antenna Concepts

- Fresnel Zone
  - Theoretically infinite number of ellipsoidal areas around the LOS in an RF link
  - Fresnel zone has greatest impact on WLAN links



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More on Fresnel Zone

- If blocked 40% or more, signal is lost
- Max. recommended blockage is 20%
- See calculations in course book (not required for exams)
- If link points are 11.263 Km or more apart, curvature of planet interferes
- Antennas need to be raised
- Related to frequency, not antenna types

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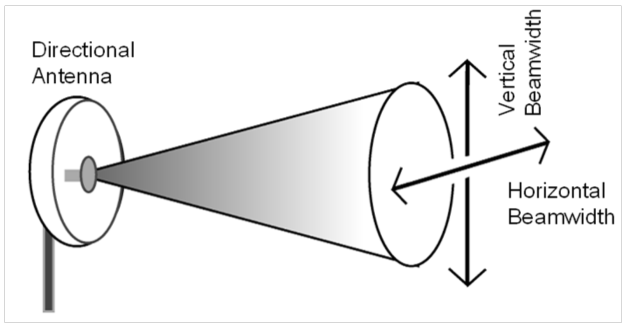
RF Signal and Antenna Concepts

- Consider beamwidth of antenna
- Provided by manufacturers in *degrees*; measured at the point where the loss = 3 dB (-3 dB)



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Typical Antenna Beamwidths

Antenna Type	Horizontal Beamwidth	Vertical Beamwidth
Omnidirectional	360	7 – 80
Patch/Panel	30 – 180	6 – 90
Yagi	30 – 78	14 – 64
Sector	60 – 180	7 – 17
Parabolic Dish	4 – 25	4 - 21

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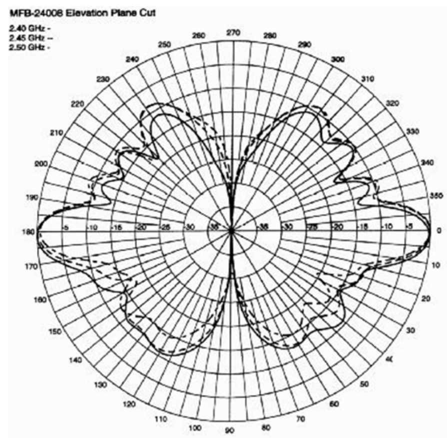
Azimuth & Elevation

- Covered in greater detail in the EM course
- Shows antenna radiation pattern
- Helps position the antenna



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Isotropic Radiator

- Closest match is the Sun
- Sphere that radiates equal energy in all directions
- Cannot be created with current technology

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Antenna Polarization

- Physical orientation of an antenna
- Can *make or break* a WLAN
- Example:
  - AP with vertical antenna; USB or PCMCIA WLAN adapter with antenna mounted horizontally
- Affects quality of reception
- Due to multipath, not so important indoors

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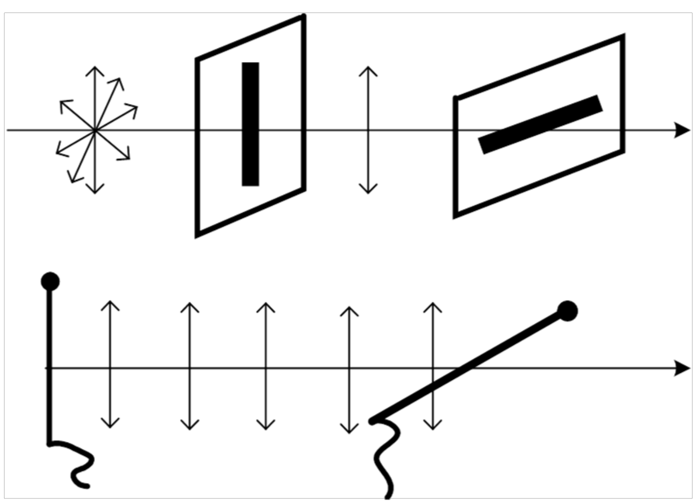
Comparative Effect of Polarization



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Antenna Diversity

- Feature offered by many devices with two or more antennas
- Device looks at quality of signal received by each antenna during frame preamble
- Some devices even transmit back to each client via the antenna that received the best signal

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Antennas and Antenna Systems

- Three major types:
  - Omnidirectional
  - Semi-directional
  - Highly directional

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Omnidirectional Antennas

- Most commonly used for WLANs indoors
- Also used for hot-spots or central antennas in PtMP applications
- Consider impact of beamwidth, azimuth and elevation charts when installing
  - Whether you want to reach receivers farther away or closer and lower than the antenna

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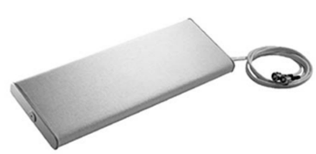
Omnidirectional Antennas

Omni Ceiling Mount Antenna

Omni Ground Plane Antenna



Omni Pillar Mount Antenna

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Semi-directional Antennas

- Focus most of the energy in a particular direction
- Patch, panel and yagi
- Yagi azimuth and elevation charts look similar
- Patch and panel antennas usually emit a narrow horizontal and wide vertical beam
- Patch and panel antennas radiate signal backwards as well
- May be used in place of multiple omni antennas

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Semi-directional Antennas

Panel Antenna

Patch Antenna

Yagi Antenna

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Highly Directional Antennas

- Parabolic dish (or grid)
- Emit a very narrow beam
- Great for distances of 25+ kilometres
- Difficult to align
- Must use non-visual tools due to great distances and installation height

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Highly Directional Antennas

Parabolic Dish

Parabolic Grid

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Sector and Phased-Array Antennas

- Sector usually used to divide a circular or semi-circular area
  - Concept is also used in *smart* antenna systems
- Phased array consists of multiple antennas connected to a signal processor
  - Each transmits signals in different phases
  - Result is a beam that can be aimed at the client device(s)
  - Very specialized and expensive

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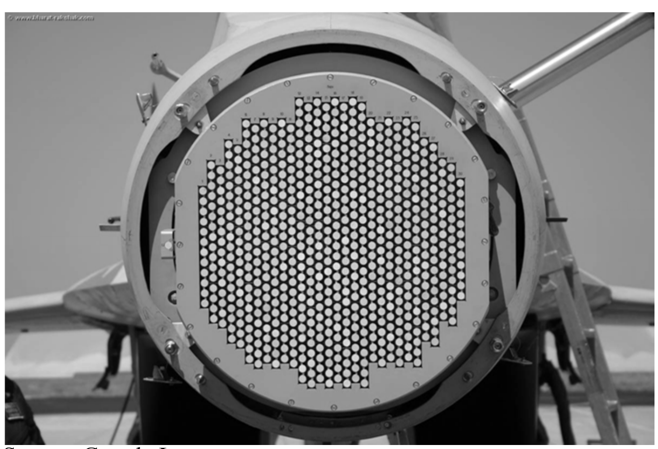
MIG-35 Nose Radar (PA)



Source: Google Images

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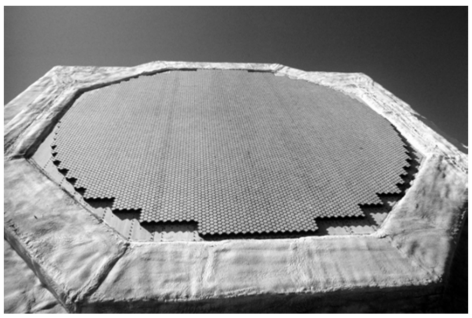
Large Phased-Array Radar Antenna



Source: Google Images
Cobra Judy

Source: Google Images
Pave Paws, Beale AFB

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MIMO – Multiple Input, Multiple Output

- Not just an antenna but a system of antennas
- Multiple radio transmitters
- Multiple antennas used to receive multipath reflections
- Used in combination with a signal processing system

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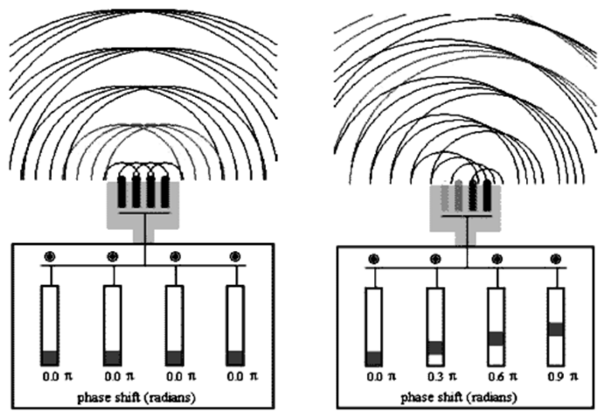
MIMO Beam Forming



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Beam Forming

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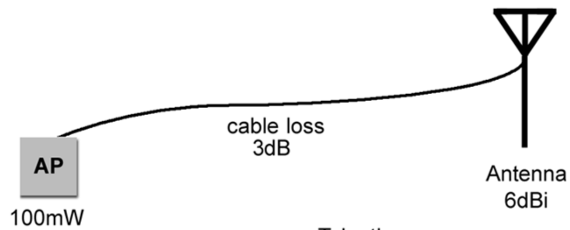
RF Math Problem 1

Calculating the Equivalent Isotropic Radiated Power (EIRP)



Covert mW to dBm:

$P_{dBm} = 10 \text{Log } P_{mW}$

$= 10 * 2$

$= 20 \text{ dBm}$

Take the sum of all dB values

$EIRP = P_x + A_c + A_{ant}$

$= 20dBm - 3dB + 6dBi$

$= 23dBm$

LOSS is a NEGATIVE GAIN

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