

Military antenna fundamentals

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*Pulpit Rock, a few km from Comrod headquarters,
A good area for communication testing*

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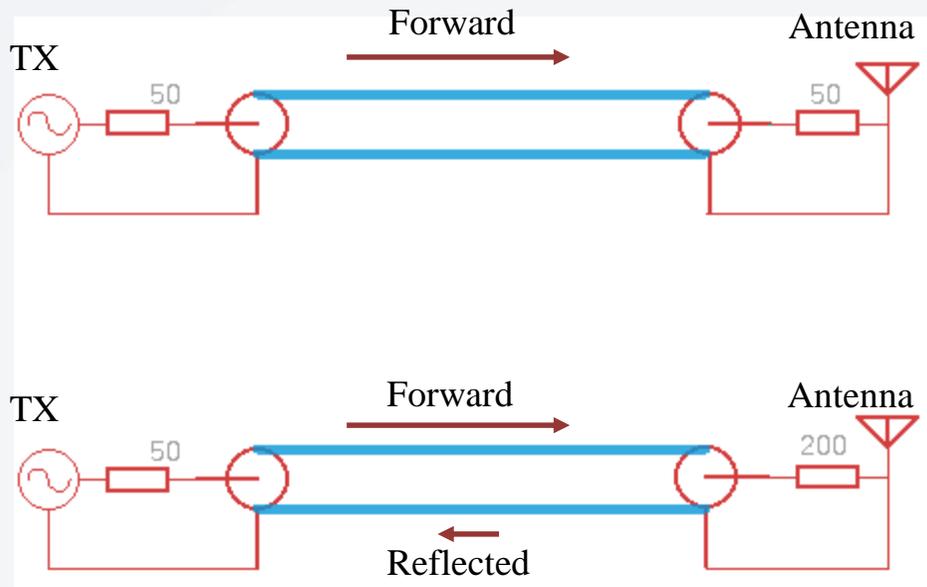
- Antenna characteristics
- Antennas
- Propagation
- Radio range and system calculations
- Co-location
- Antenna measurements

Antenna parameters

- Impedance & VSWR
- Polarization
- Efficiency
- Gain & directivity
- Radiation pattern
- Bandwidth

Impedance and VSWR

- Return loss describes the amount of reflected power from an antenna, this is due to impedance mismatch
- VSWR is short for **Voltage Standing Wave Ratio** and indirectly describes the amount of reflected power from a antenna



The forward and reflected waves interfere and make a standing wave pattern on the cable. VSWR is the ratio between max. and min. voltage in this pattern

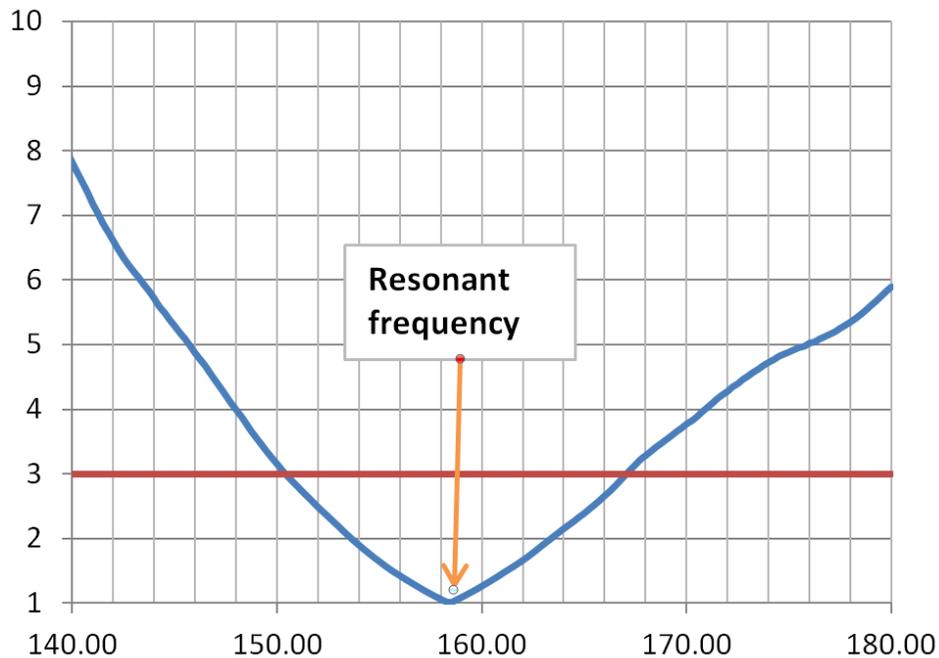
A perfect antenna has VSWR=1

When some of the power is reflected back to the transmitter the is VSWR larger than 1, in this example the VSWR is 4.

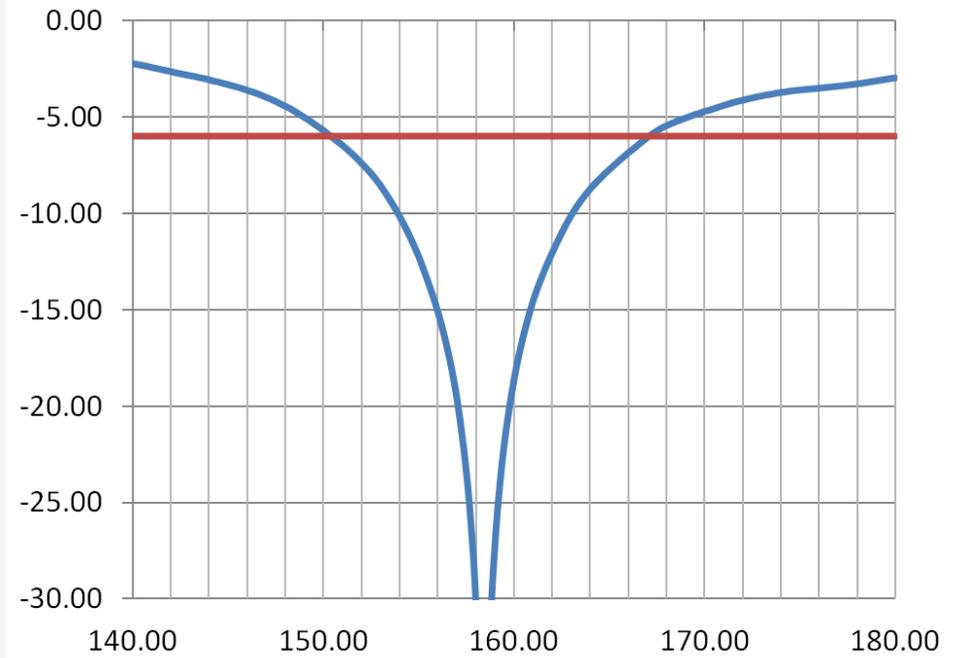
Impedance and VSWR (cont.)

VSWR	Return loss [dB]	Loss due to reflections [%]
1.0	-	0.0%
1.65	-12.21	6.0%
2	-9.54	11.1%
5	-3.6	44.4%
10	-1.34	66.9%

VSWR

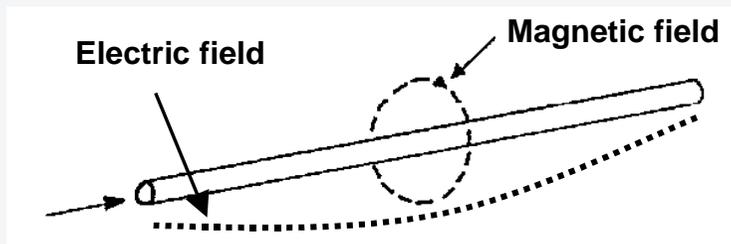


Return Loss

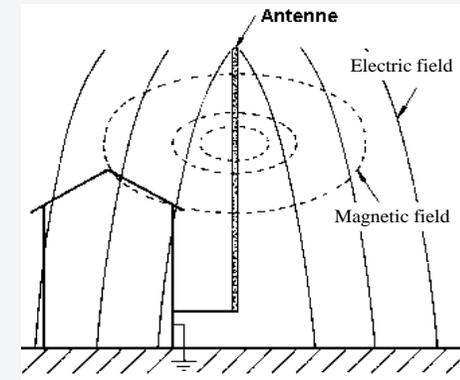


Polarization

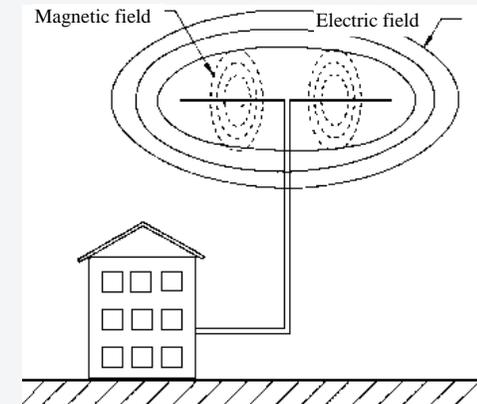
- The RF current flowing through the antenna produce electromagnetic waves which radiate into the atmosphere.
- The electromagnetic radiation from an antenna is made up of two orthogonal fields, one electric and one magnetic field called E and H-field.



Vertical polarization



Horizontal polarization



Efficiency

- All antennas have some resistive losses and an efficiency lower than 100%.
- Radiation resistance is the part of an antenna's feed-point resistance that is caused by the radiation of electromagnetic waves from the antenna, as opposed to loss resistance (also called ohmic resistance) which generally causes the antenna (or surroundings) to heat up
- Electrically short antennas have low radiation resistance

$$\eta = \frac{P_{\text{transmitted}}}{P_{\text{input}}}$$

$$\eta = \frac{R_{\text{radiation}}}{R_{\text{radiation}} + R_{\text{loss}}}$$

Improving efficiency

- Improving ground system
- Using low loss materials in antenna structure
- Use efficient matching network

Typical efficiencies

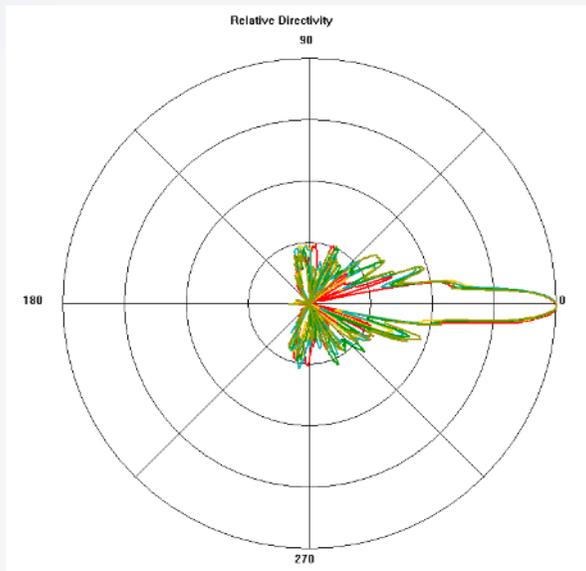
- | | |
|--------------------------|------------|
| • LF antennas | 0.1 - 10% |
| • HF antennas | 10 - ≈100% |
| • Broadband HF antennas | 1- 80% |
| • VHF antennas | ≈100% |
| • Broadband VHF antennas | 40 - ≈100% |
| • UHF antennas | ≈100% |
| • Broadband UHF antennas | 40 - ≈100% |

Gain and directivity

- Directivity is the ability of an antenna to focus energy in a particular direction.
- Gain is a measure of an antenna's directivity compared to a reference antenna.

$$\text{Gain} = \text{Directivity} * \text{Efficiency} = D \cdot \eta$$

- dBd is a gain referenced to a halfwave dipole
- dBi is a gain referenced to a isotropic antenna

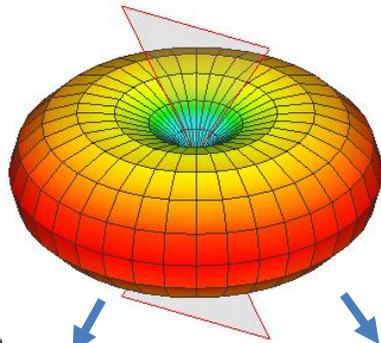


A 100 watt spotlight will provide more light in a particular direction than a 100 watt light bulb, and less light in other directions.

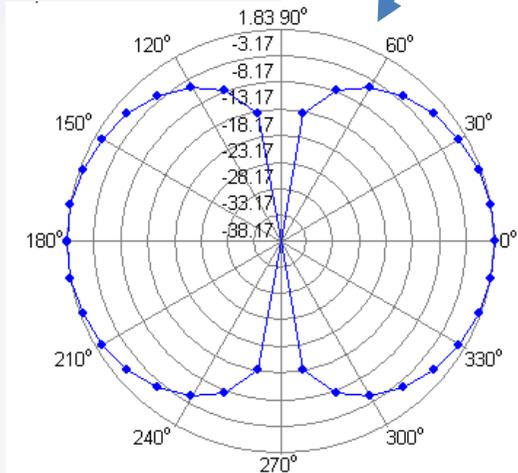
Radiation pattern

- The radiation pattern shows how the radiated signal varies for different directions from the antenna

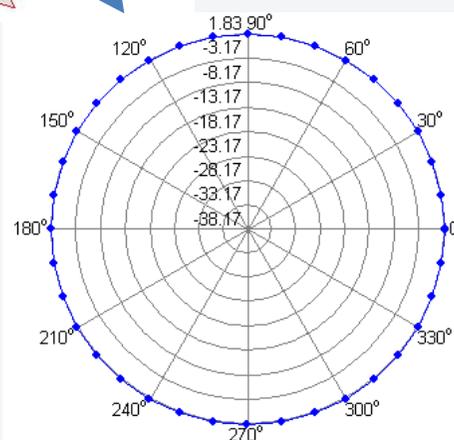
3D pattern omnidirectional antenna:



Directional antenna:



Vertical pattern

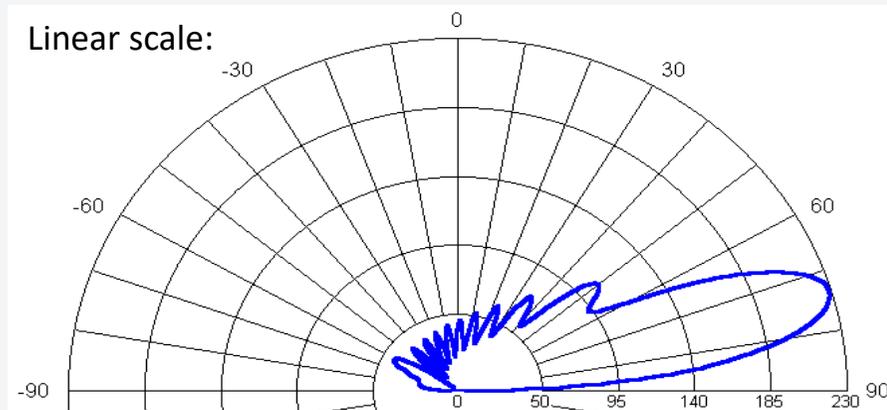
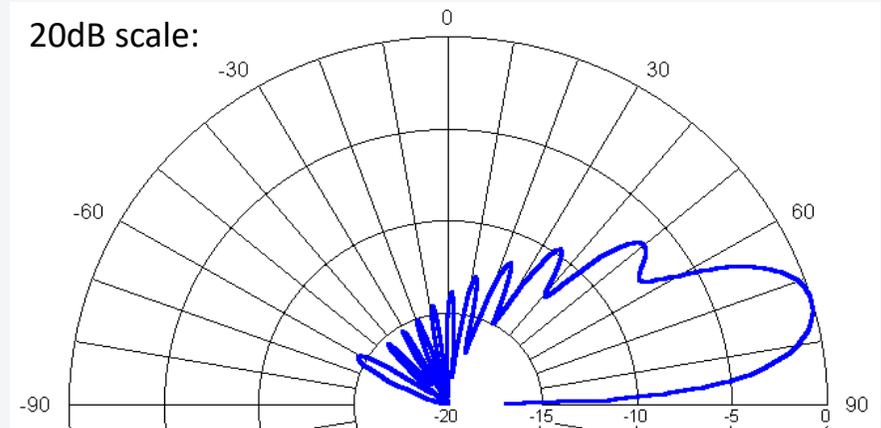
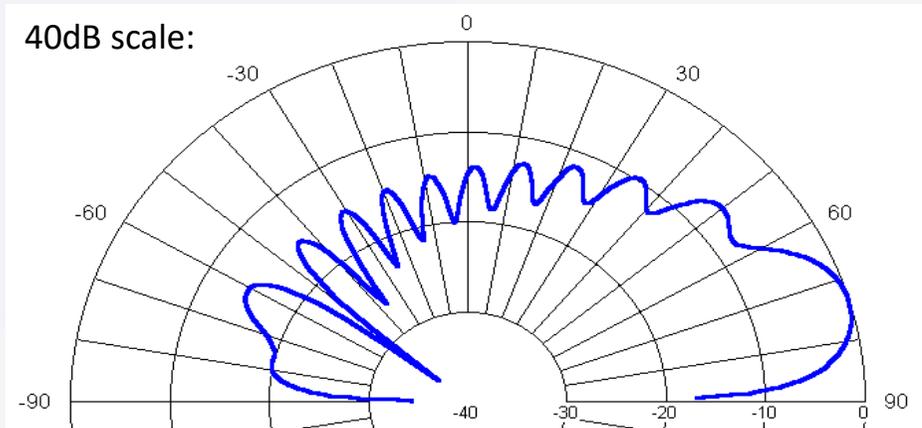


Horizontal pattern

Difference between Main and back lobe is called front/back ratio (F/B)

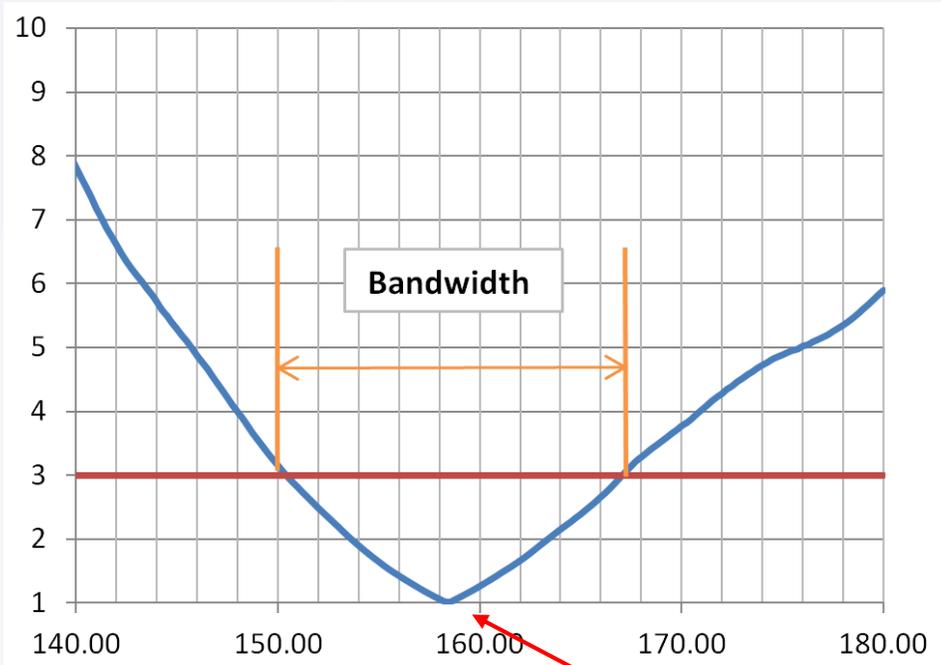
Radiation pattern, scale

- The scale can be used to manipulate results
- Vertical diagram same antenna



Bandwidth

- Bandwidth is the frequency range over which the antenna maintains a specified performance.
- For many antennas the SWR is the limiting factor for the bandwidth
- The Q-factor is directly related to bandwidth versus center frequency



VSWR curve

Resonant frequency

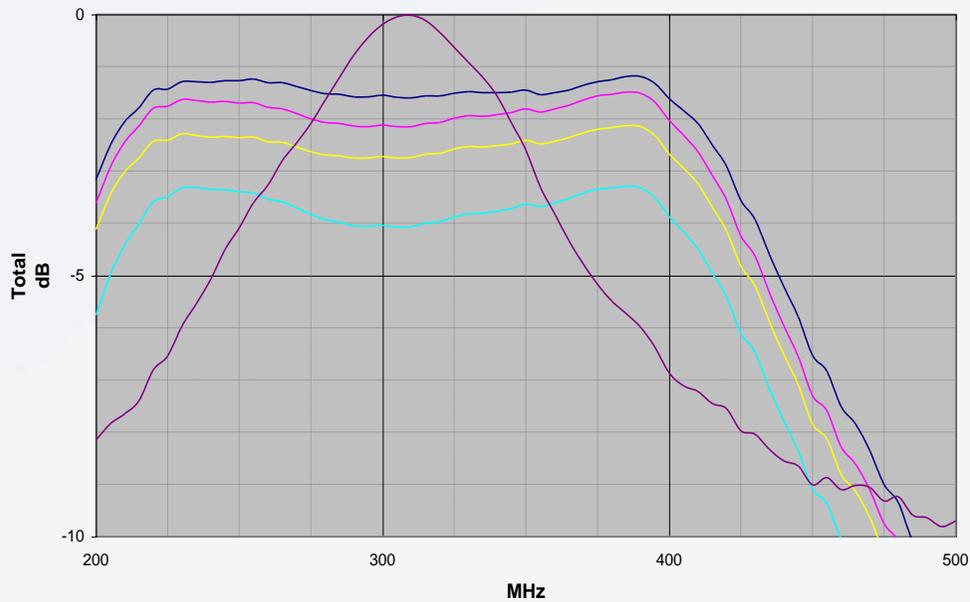
Increasing the bandwidth

- Broad band matching network.
- Broad band antenna design, log periodic, discone etc.
- Add loss

Example of matching network

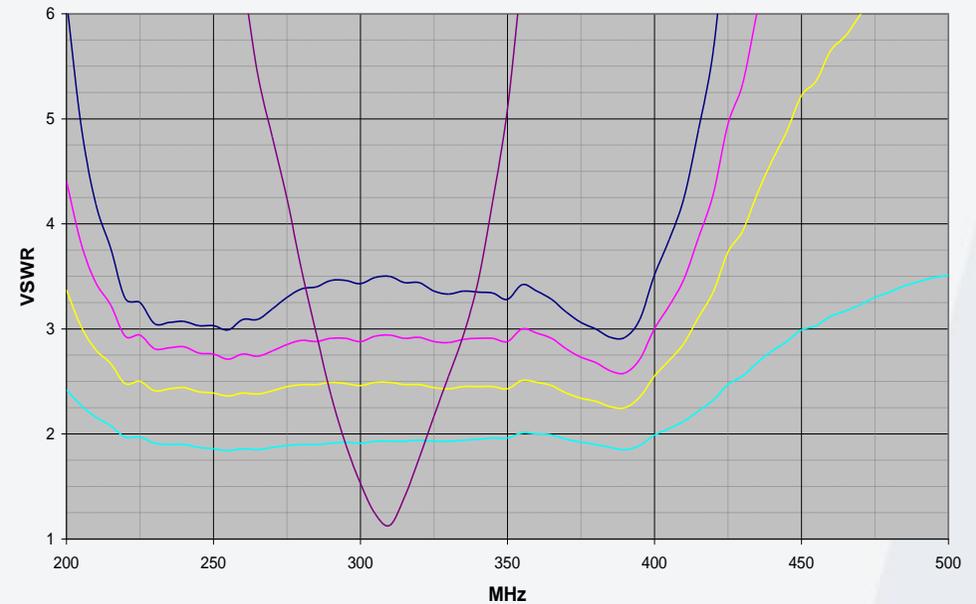
Gain

Mismatch loss + loss matching network, different networks
 140mm helix manpack at 10°6'4cm box,
 "radio" held in front of face



VSWR

VSWR, different matching networks
 140mm helix manpack at 10°6'4cm box,
 "radio" held in front of face



Reciprocity of antennas

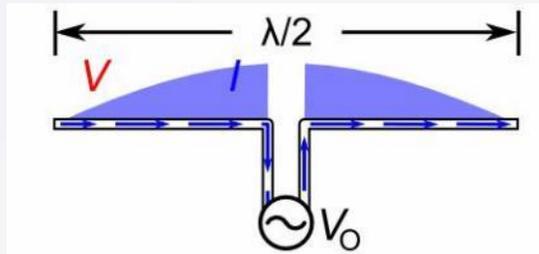
- Property of interchangeability of the same antenna for transmitting and receiving is known as antenna RECIPROCITY

Exceptions from reciprocity

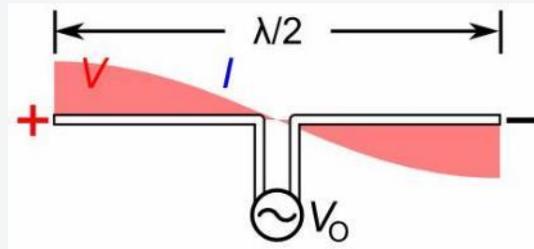
- Active receiving antennas (AR10)
- Receiving antennas for HF is not dimensioned for handling the high transmit power

Dipole antenna

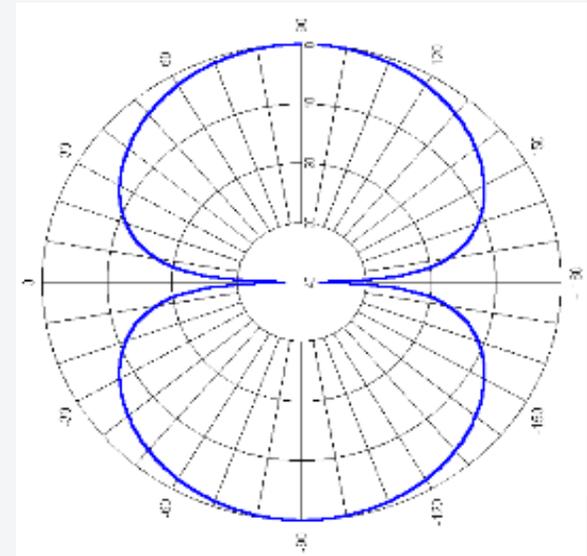
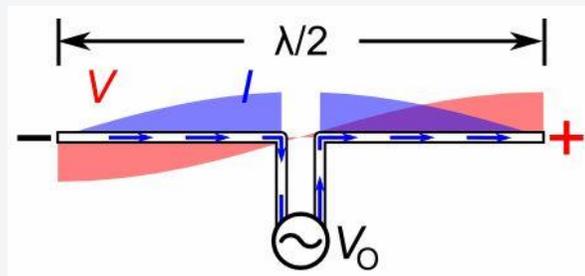
- The voltage will change back and forth between the antenna elements.
- Normally $\lambda/2$ long and fed in the middle
- Gain: 2.14 dBi
- Used alone or as a part of bigger antenna systems.



Current distribution

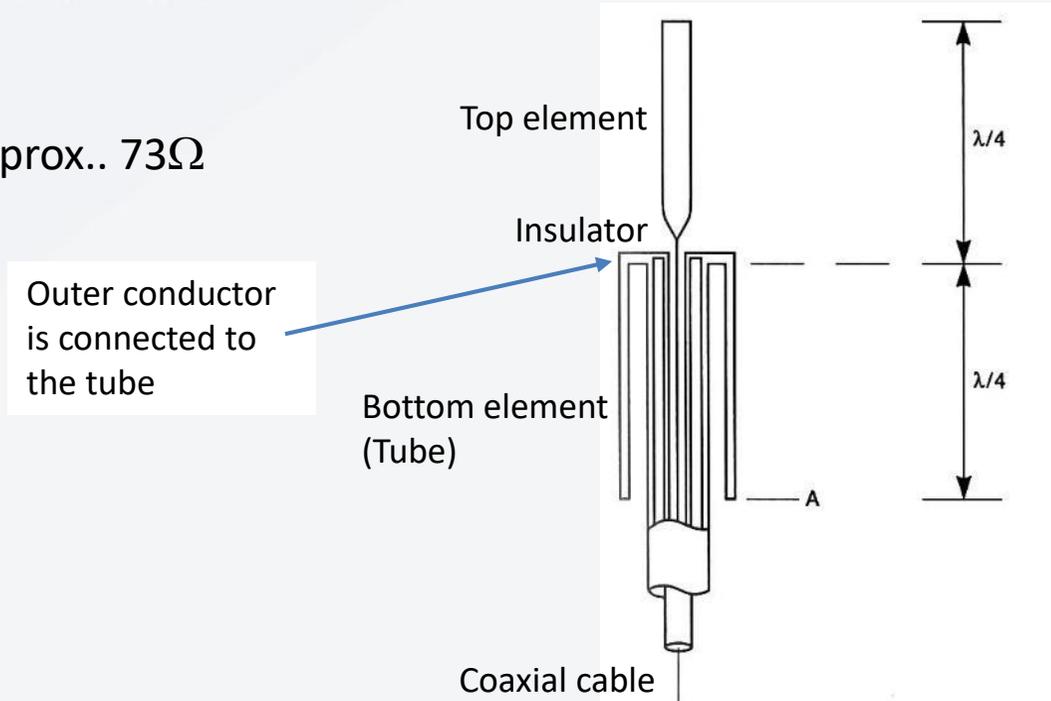


Voltage distribution

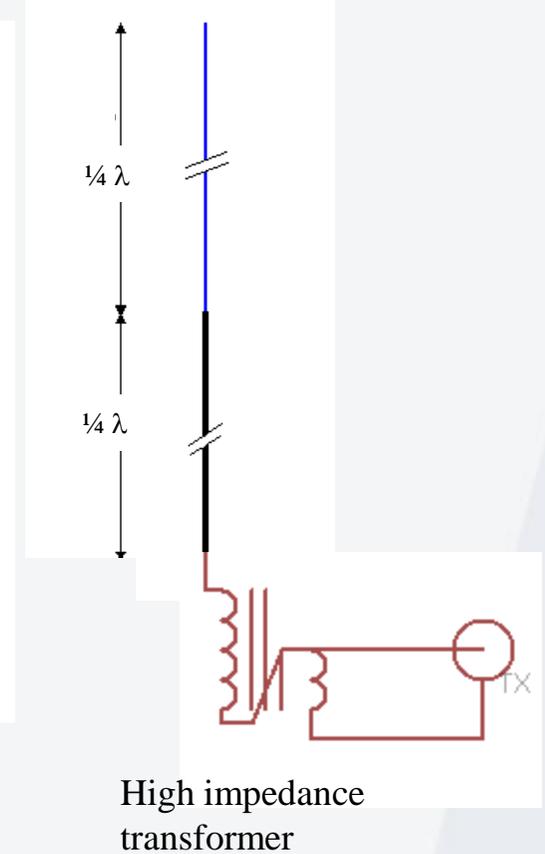


Coaxial dipole

- Gain: 2.14dBi
- Impedance approx.. 73Ω



End-fed half wave «dipole»

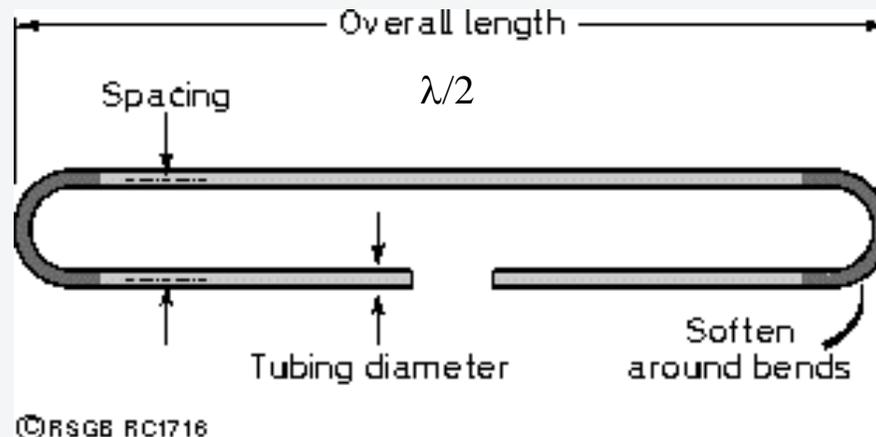


Comrod coaxial dipoles :

VHF3088VM, AV6K, AV7, AV15

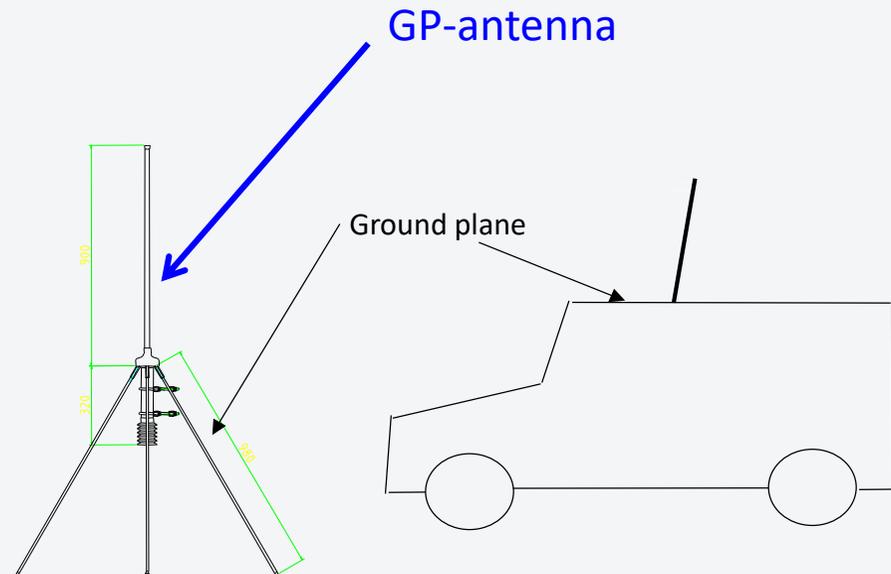
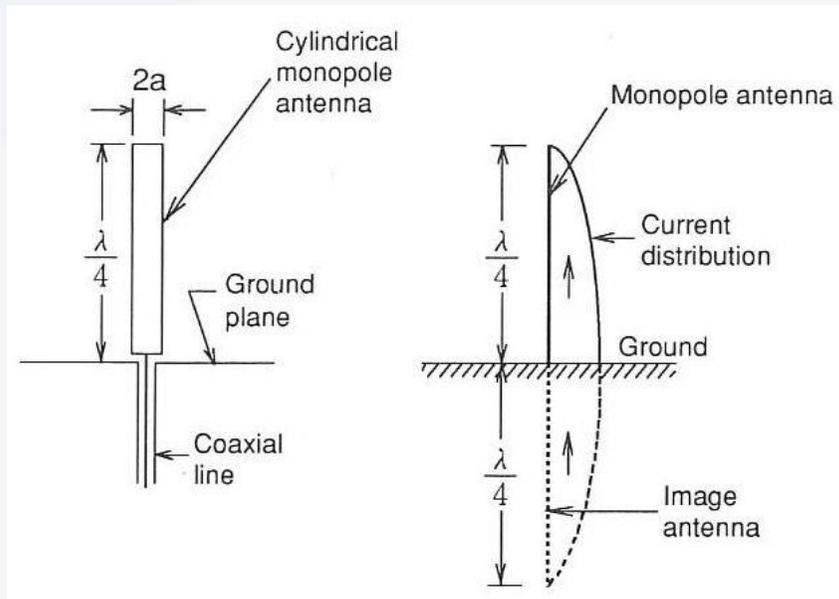
Folded dipole

- Same radiation pattern as a regular dipole
- Relatively good broad-band operation
- Large input impedance (288Ω), require matching network
- Often used as FM and TV broadcast antennas



Monopole antenna

- Normally $\lambda/4$ long , and also referred to as QUARTER-WAVE or Marconi antenna
- $\lambda/4$ long, => Gain 2.14dBi
- With an infinite ground plane it has the same radiation pattern as the upper half of a dipole in free space. Gain can then also be said to be 5.14dBi
- Monopole often combined with broad band matching
- On HF shorter monopoles are often used together with an antenna tuner that compensates for the missing length



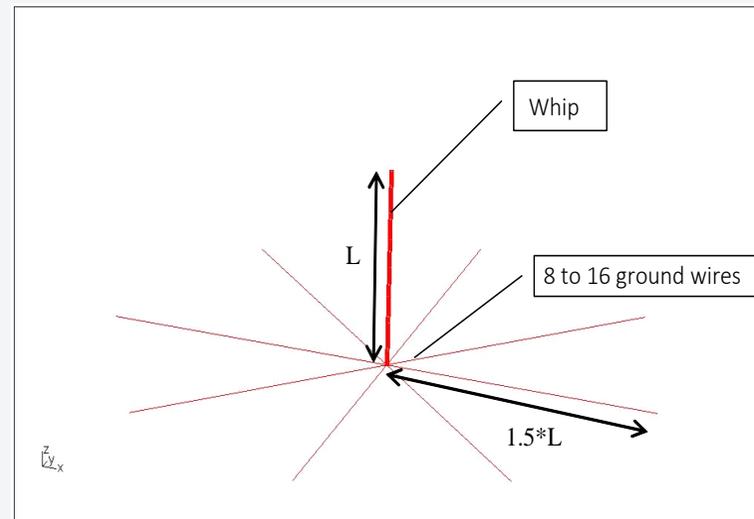
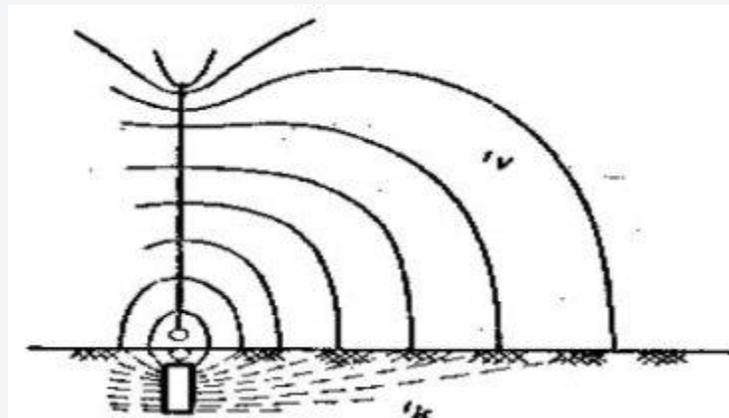
VHF3076, VHF3088PM, AV18, AC14,
HF whips, APX50, AT100 and other

Ground losses for HF antennas

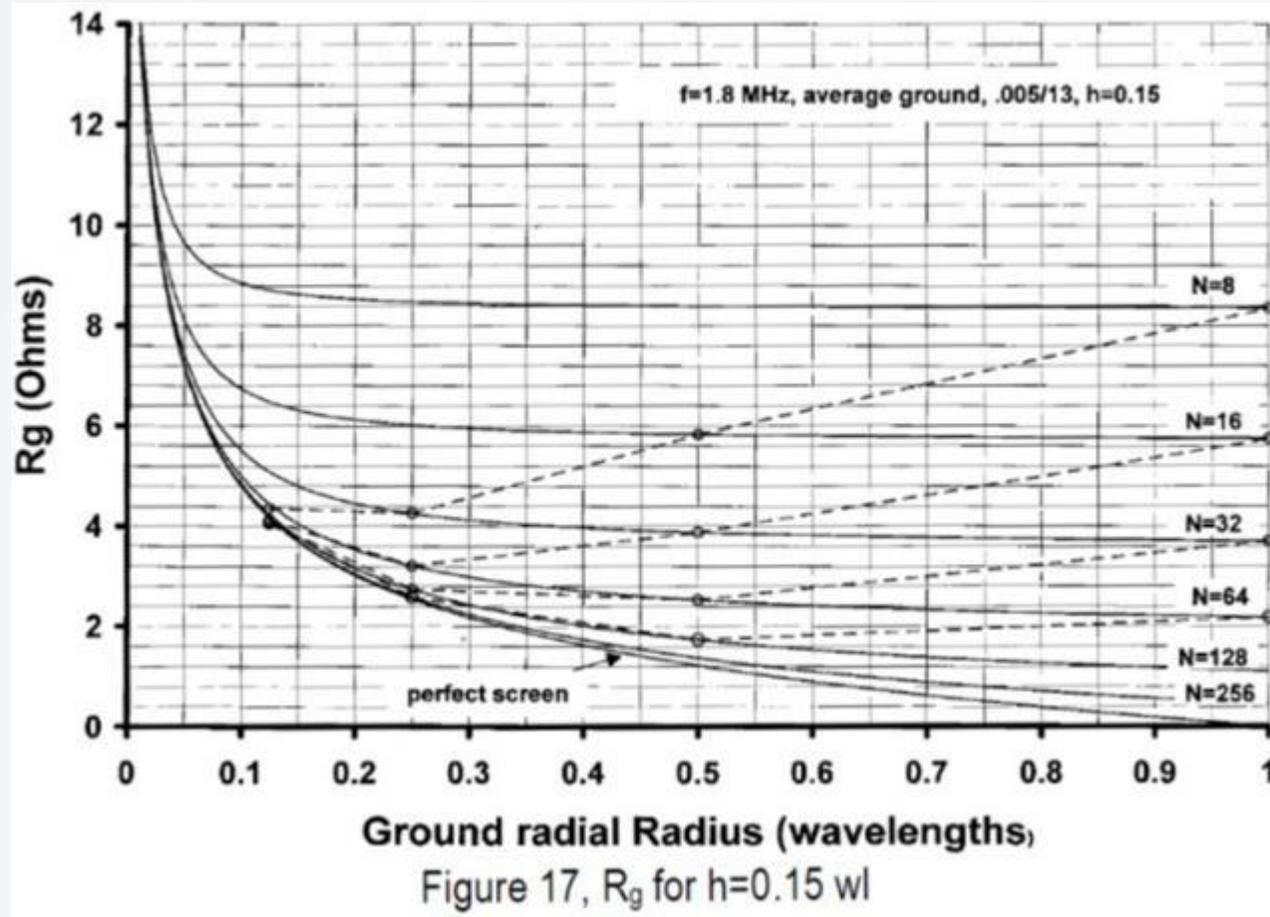
HF monopole whip antennas shorter than $1/4\lambda$

- A 4m long whip at 2MHz only has a radiation resistance of 0.3Ω . The ground resistance is in series with this and much higher
- A typical ground resistance can be around 10Ω , with the above whip the efficiency will be only 3%, other losses will often be insignificant
- When possible use many ground radials to reduce these losses

$$\eta = \frac{R_{\text{radiation}}}{R_{\text{radiation}} + R_{\text{loss}}}$$



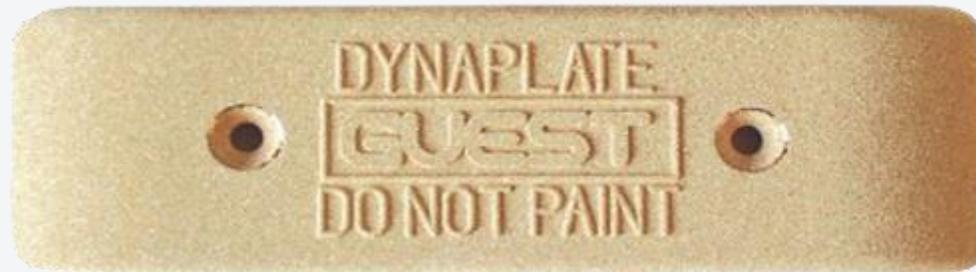
Grounding of HF antennas



Grounding of HF antennas

Grounding of HF antennas on composite vessels

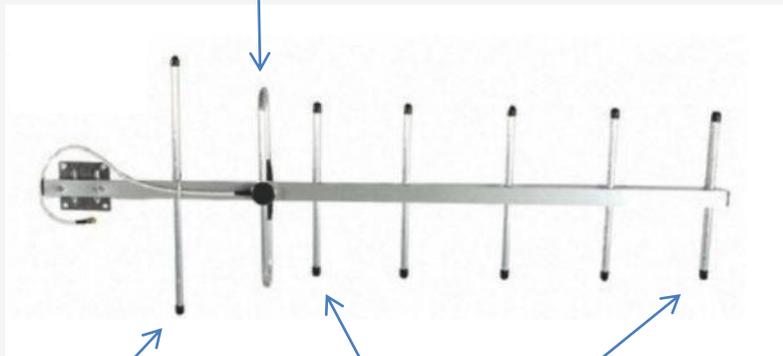
- Salt water
 - Direct contact with the salt water
 - Use in-water ground plate of porous bronze attached to the hull
- Metal surface at the antenna base
- 2dBi when $1/4\lambda$ long
- Metal strap between antenna base and ground



Yagi

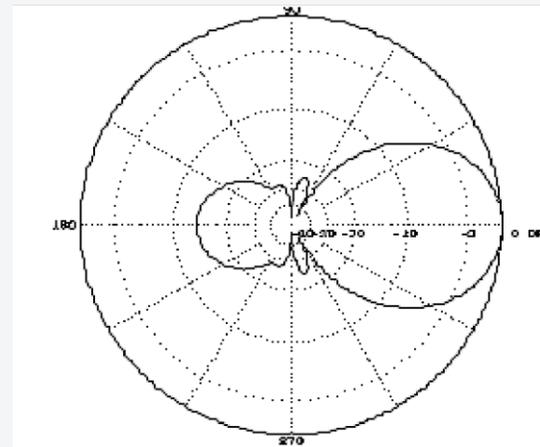
- Directive antenna (7-14dBi)
- Often combined with a folded dipole to obtain good broad-band properties
- Relatively cheap production cost
- More directors will increase the gain
- Often used for VHF/UHF antennas (TV receiving is a typical application)

Dipole (feed point)



Reflector

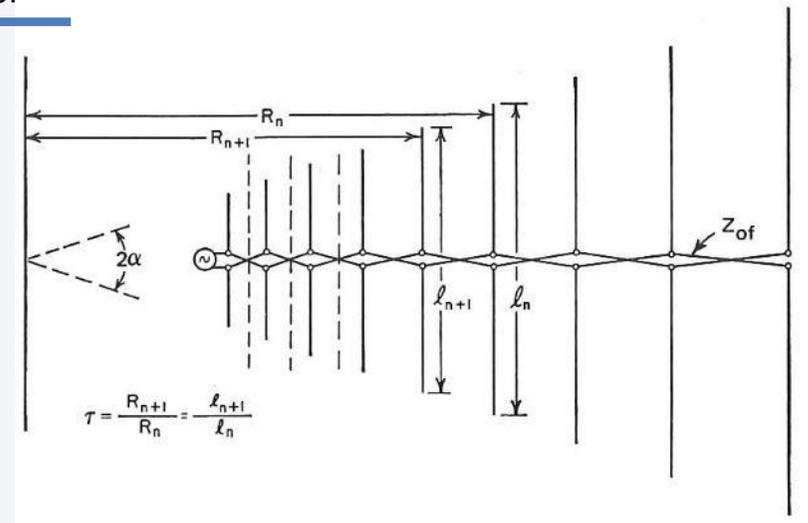
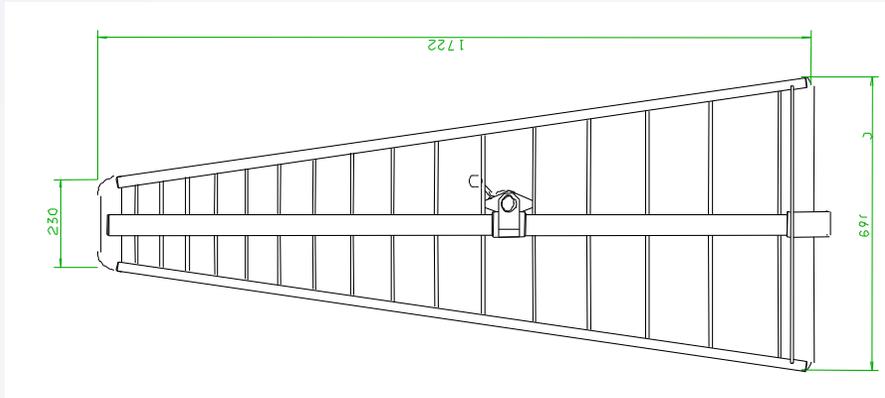
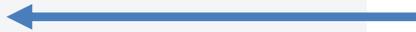
Directors



Log-periodic

- Wide frequency range
- Reasonable good gain (6 to 12 dBi)
- Useful for multi-band transceiver operation.

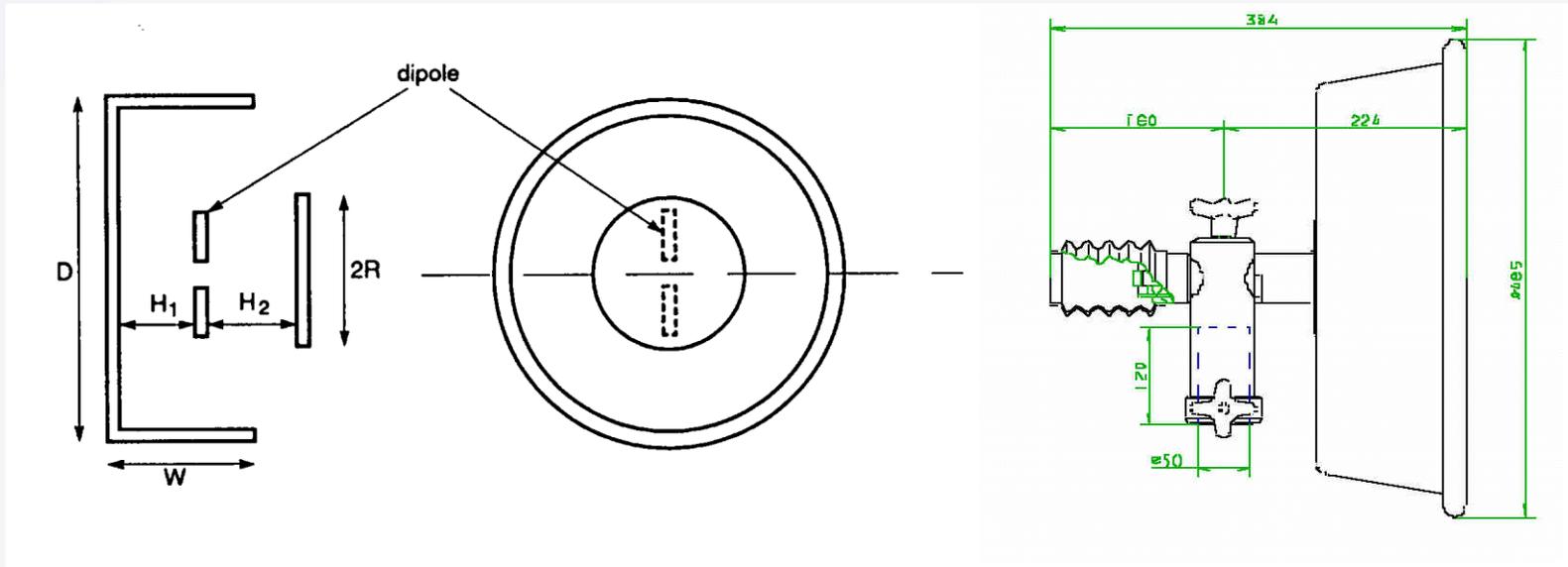
Radiation direction



Comrod antenna: **AV30**

Short backfire

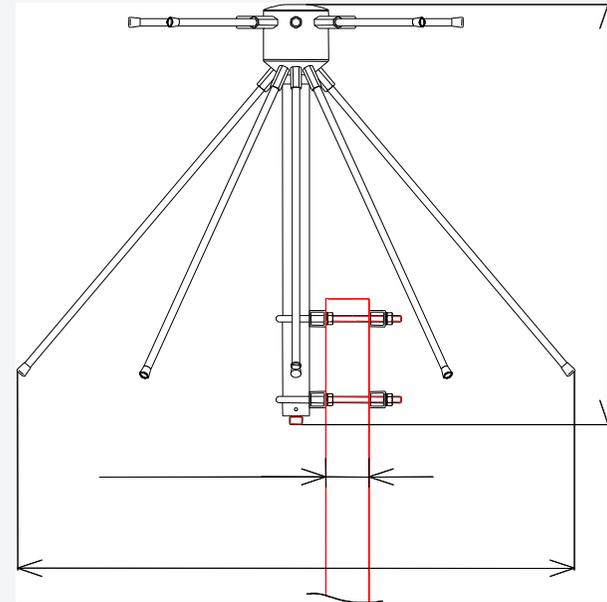
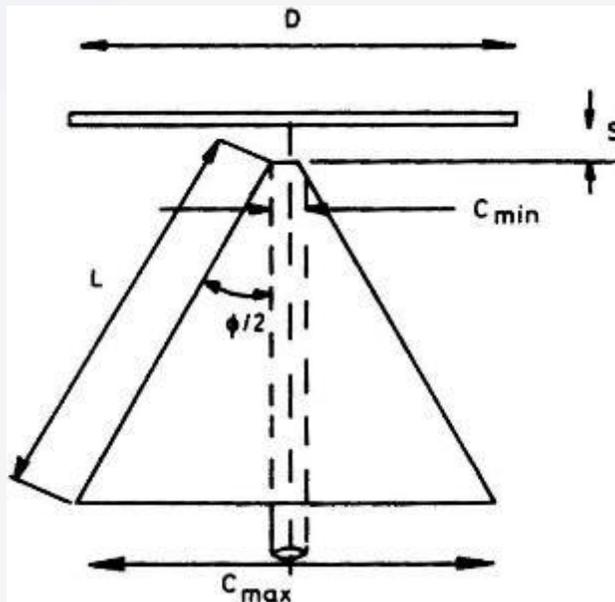
- Directive antenna (up to 18dBi)
- UHF frequency band (300MHz-3GHz)
- Gain is a function for the diameter of the reflector D
- Relatively broadband



Comrod antenna: [AMW60-1800](#)

Discone

- Relatively broadband (ex. 90-250MHz)
- Almost similar radiation pattern as a dipole with distortion as frequency gets higher

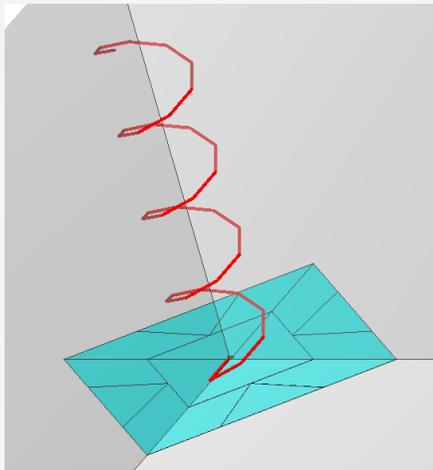


Comrod antenna: [AV21](#), [AV23](#)

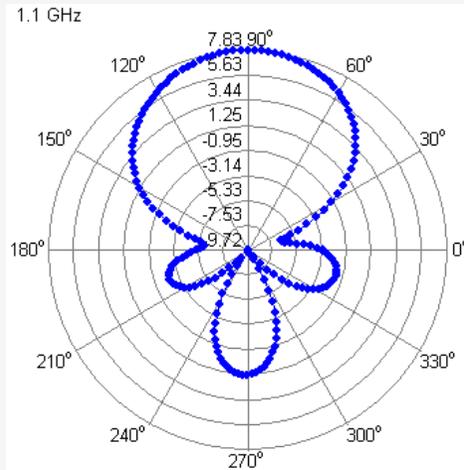
Helix

- Can radiate both in axial and omnidirectional (radial) mode
- Short compared with a dipole when used in omnidirectional mode
- Popular antenna for portable equipment
- Relatively directive when used in axial mode
- Circular polarization in axial mode

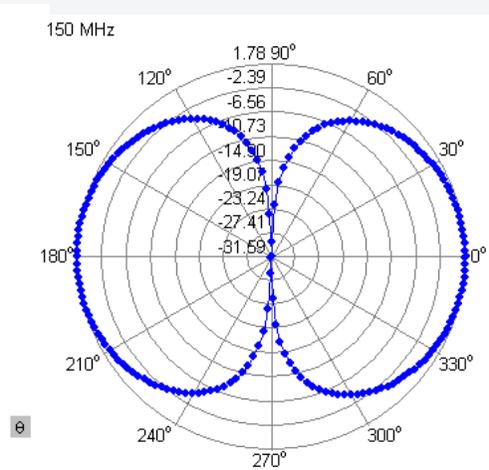
Helix antenna



1100MHz > Axial mode

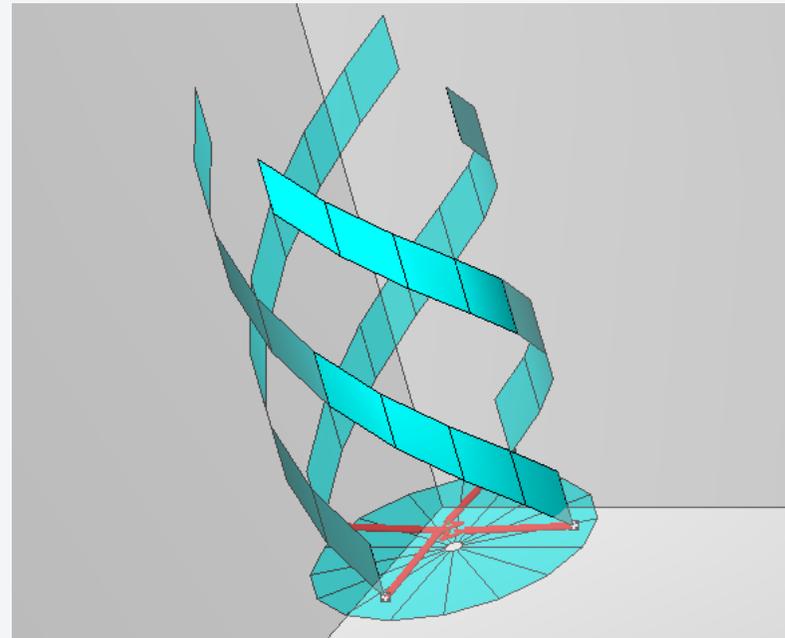
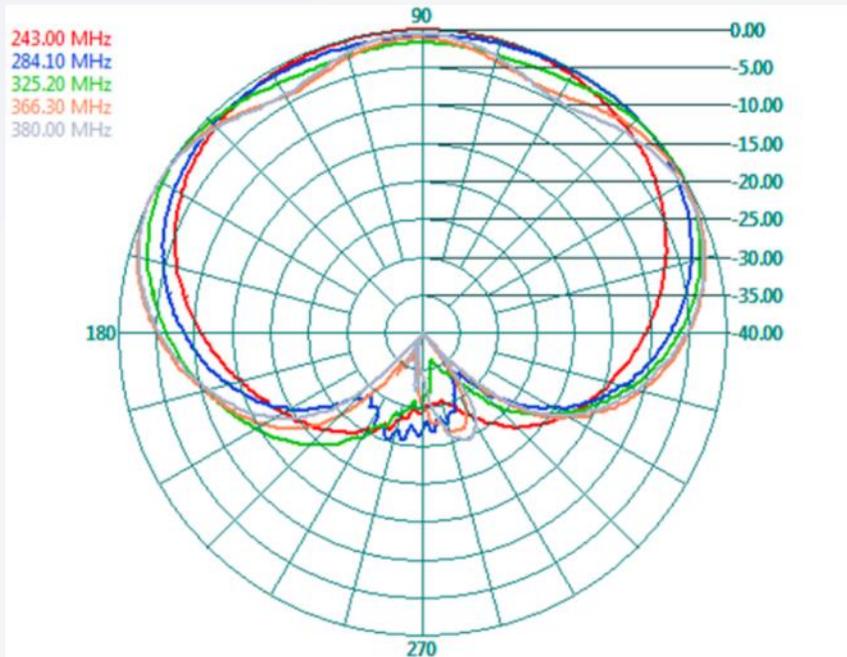


150MHz radial mode



Quad-Helix

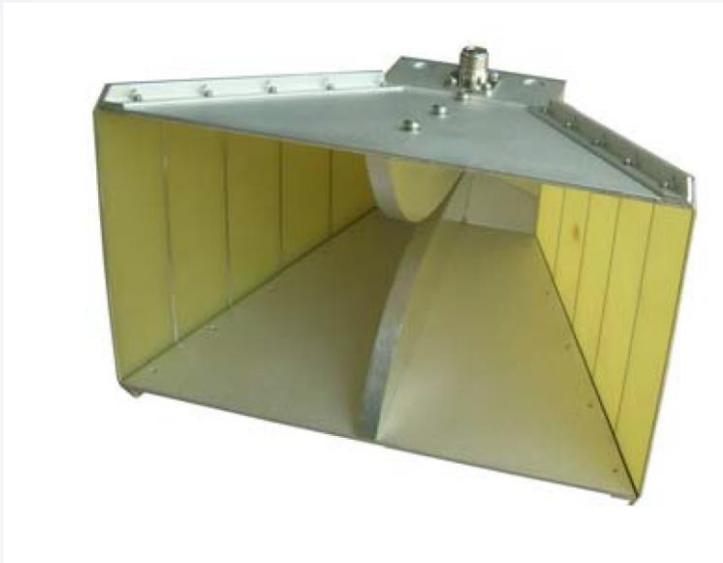
- Used mainly for satellite communication
- Radiation pattern covers upper hemisphere
- Circular polarization
- Spiral arms are fed with 90 degrees phase shift for each



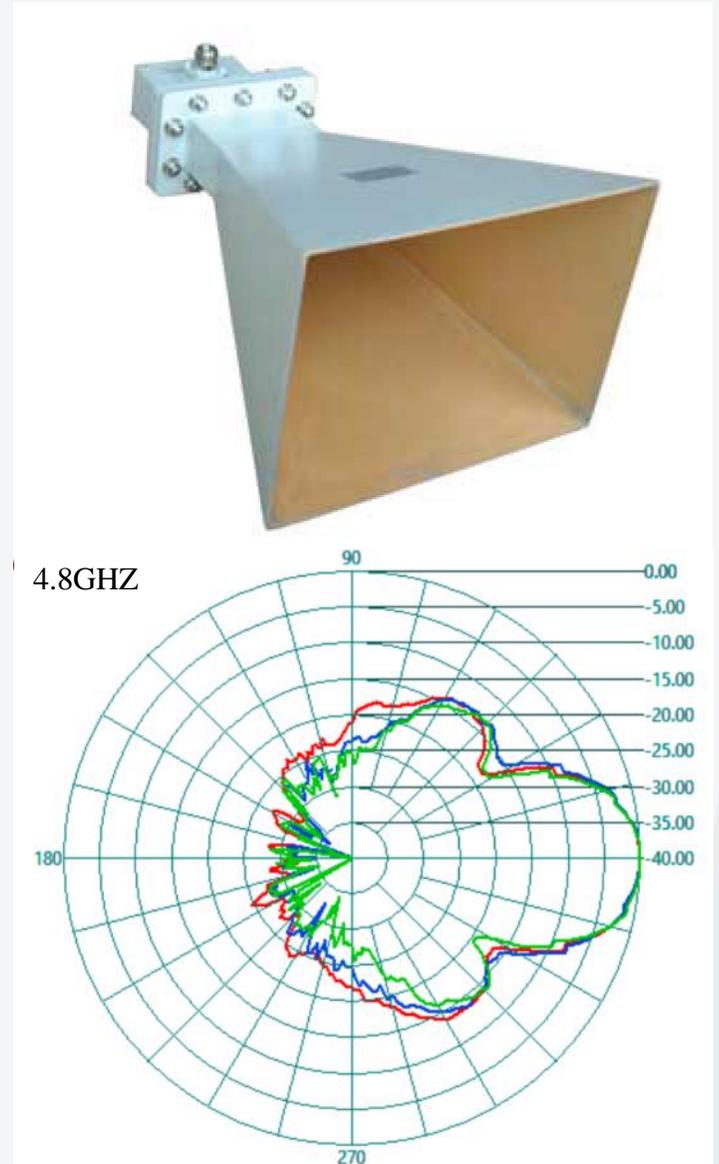
Horn antenna

- Often used as reference antennas for gain test
- Also commonly used feeding a parabolic dish
- Relatively high gain that depends on size versus wavelength

Typical broadband horn antenna
Bandwidth 20/1

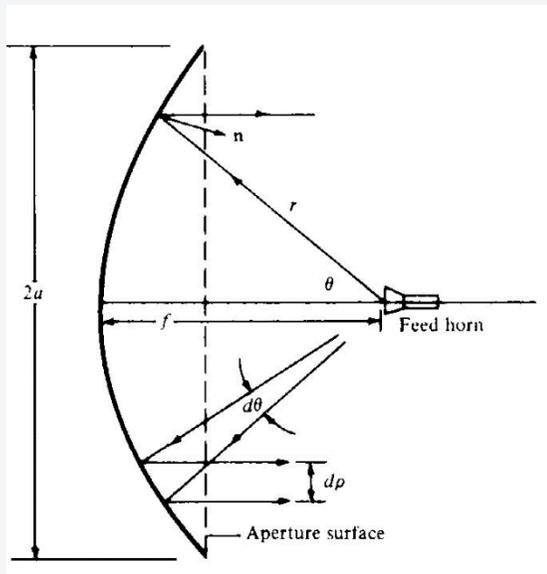


Typical standard gain horn antenna
Bandwidth around 40%



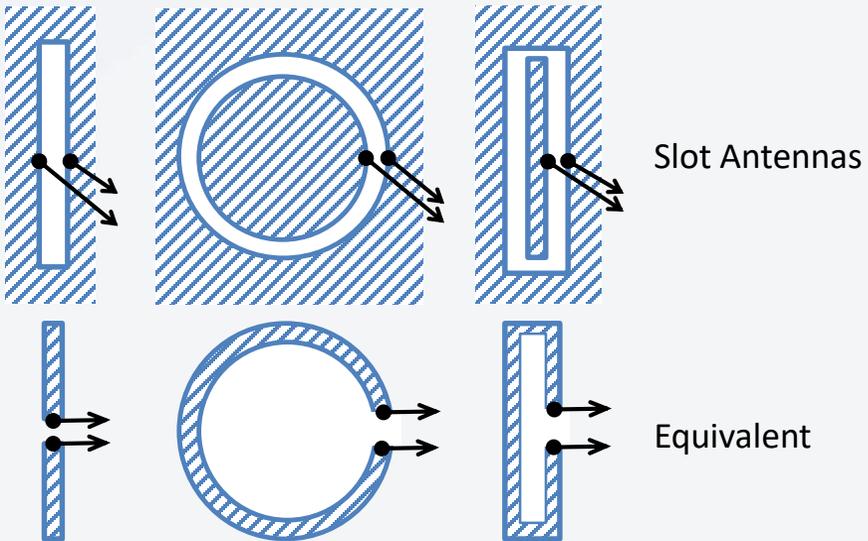
Parabolic reflector

- Very directive antennas (up to 50dBi)
- Normally frequencies above 2GHz
- Satellite and telecom communication



Slot antenna

- Coupling RF energy to a slot in a large metallic plane
- Works as a magnetic dipole
- Normal on aircraft

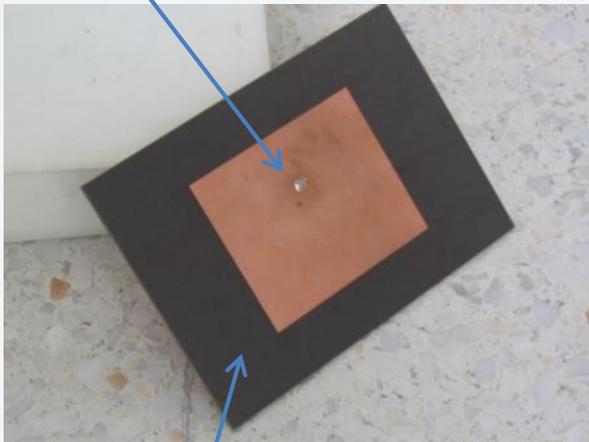


Comrod special wideband slot antenna going to Mars in 2020. Used for GPR (ground penetrating radar) on the rover

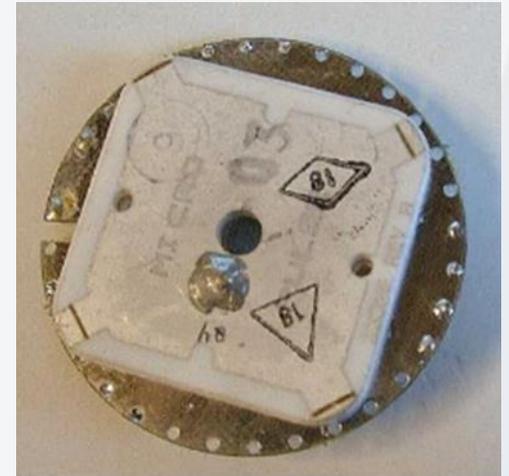
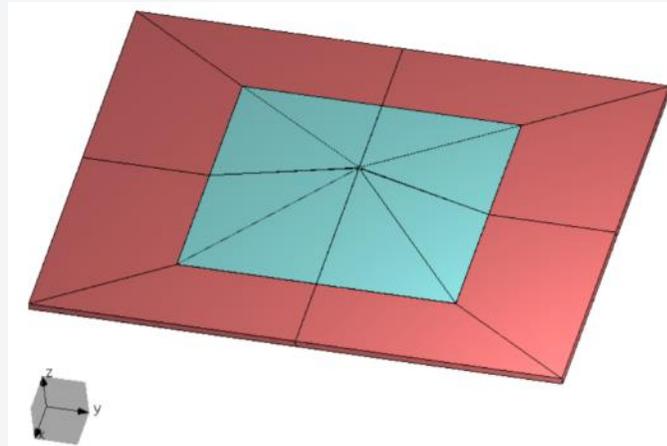
Microstrip antennas

- Radiates from a patch above a ground plane
- Cheap and popular antennas
- Mobile phones, GPS, radar systems...
- Very often used in an array to achieve high gain

Feed point

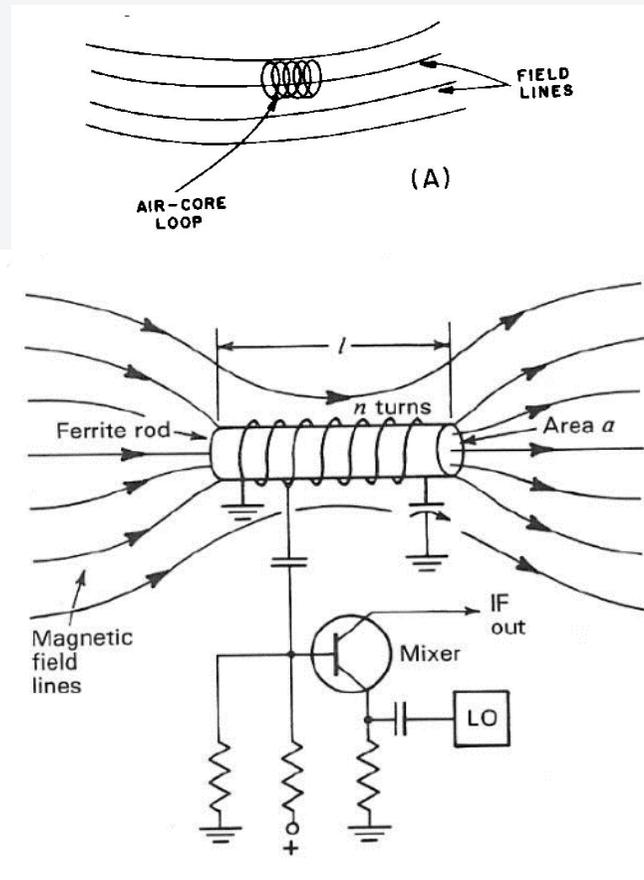
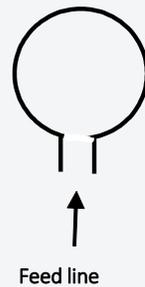


Copper backed dielectric



Loop receive antennas

- A loop antenna receives magnetic energy
- A ferrite increases the effective diameter of the loop
- Highly efficient receiving antennas
- AM broadcasting
- Less influenced by electrical noise
- Lower height



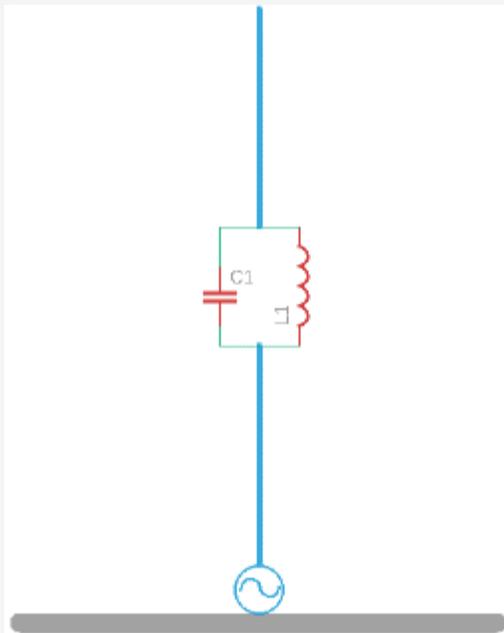
Loop transmit antennas

- Very small compared to wavelength
- Low radiation resistance means that very low resistive losses are necessary to avoid low gain
- Difficult to tune efficiently as impedance is very low
- Very high Q
- Good radiation pattern for NVIS communications
- Comrod provides the HF0230L/OTM loop antenna that overcomes the above problems



Multi band antennas

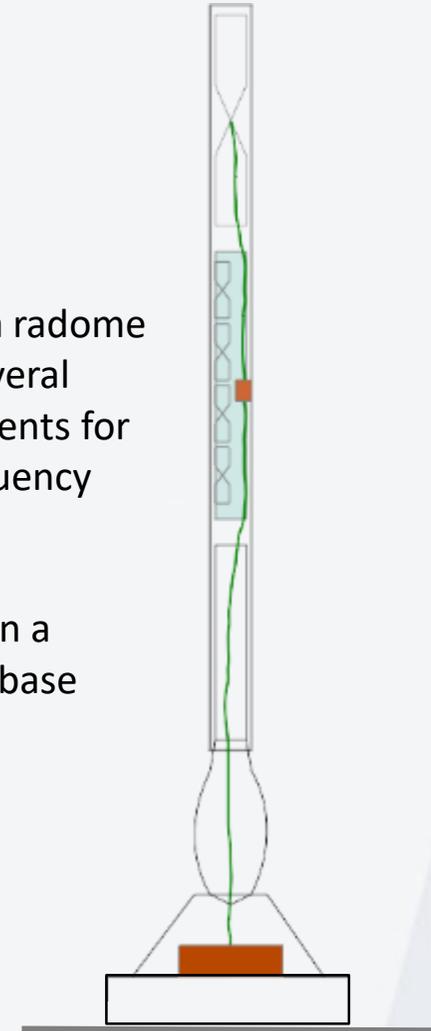
- As more and more systems are integrated on the same platform the demand for multi band antennas has increased
- Two main approaches to achieve this
 - Several single band antennas within the same structure/radome
 - Single antenna element with several resonances



Whip antenna element with resonant trap for extra frequency band

Whip antenna radome containing several antenna elements for different frequency ranges

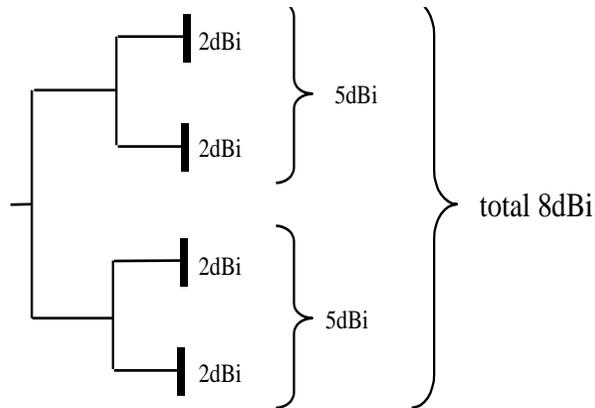
Here shown on a typical spring base



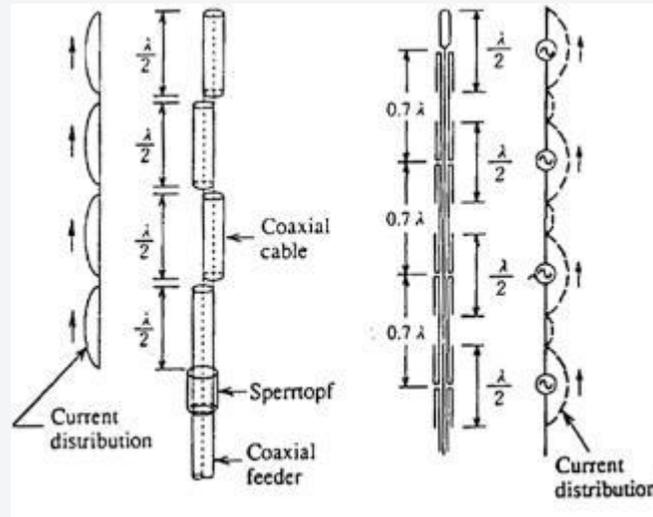
Array, multi element antennas

- Increase gain by connecting several antenna elements together via feed system
- Each element in phase -> maximum gain
- Double the number of elements will nearly double the gain (3dB)

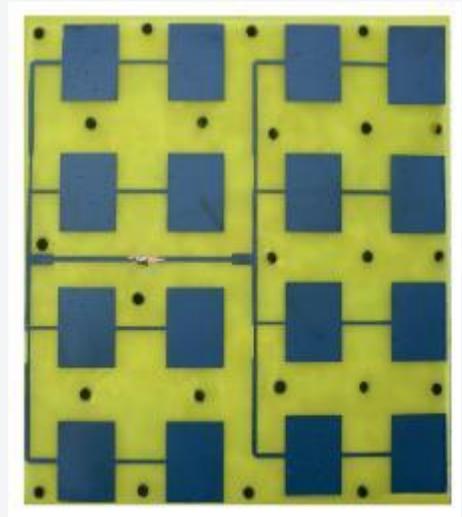
Principle



Collinear array



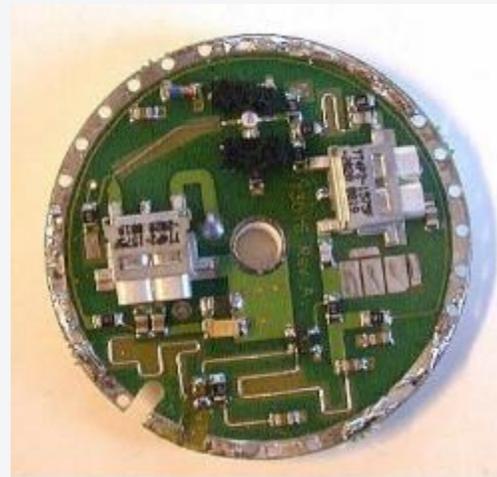
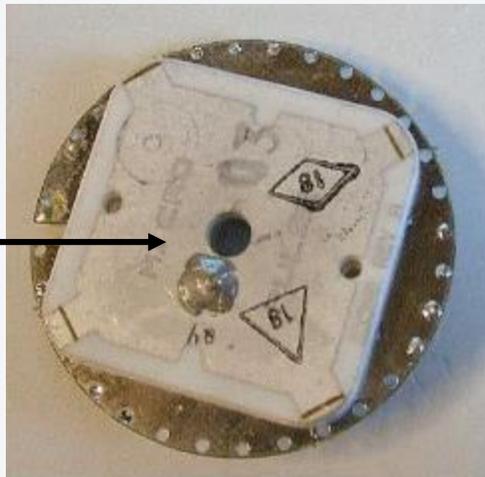
Patch array



Active antennas

- Active antennas consists of two parts:
 - Antenna element
 - Amplifier with/without filter
- Needs power supply
- Not reciprocal (receive and transmit with the same antenna)

Microstrip patch antenna (GPS)



HF antennas

HF antennas can be divided into three categories depending on application

Short Range:

Whip antennas, man-pack and on vehicles.

Medium Range:

Sky wave NVIS (Near Vertical Incidence Skywave) applications, loop antenna, bent whips, dipoles close to ground.

Long Range:

Large vertical whip antennas, dipoles higher above ground, yagi and log-periodic antennas.

Short range HF antennas

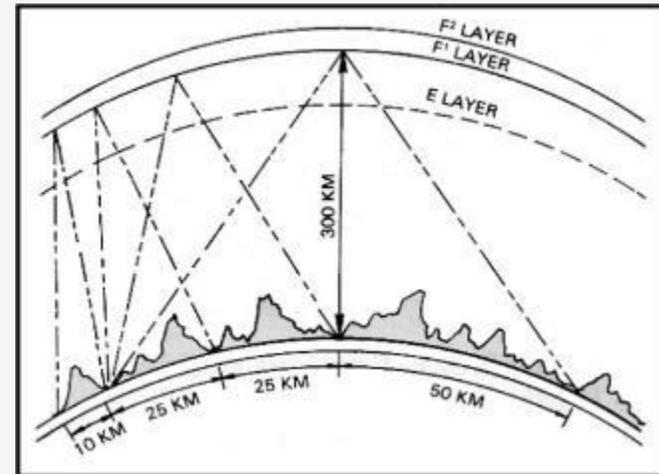
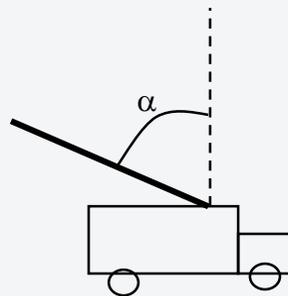
- Ground wave fades out quite fast. 0 - 50km
- To achieve maximum range a low angle of radiation is important.
=> Vertical whip antennas can provide that.
- When the range is not important, mechanical considerations may play a more important role than the actual performance.
 - Transmitter must be able to tune the antenna at relevant frequencies.
 - The length of the antenna will often be the limiting factor.

NVIS antennas

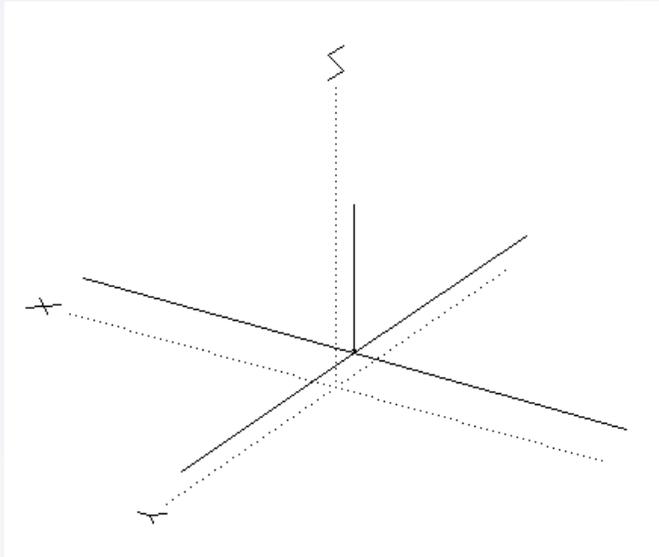
Near Vertical Incidence Sky wave

- Used for shorter distances on HF where the ground wave has died.
- Distance is normally 50 to 150km
- Frequencies: 2 and 8MHz
- Average path loss is 110dB
- Reflection at ~300km => high radiation angle.

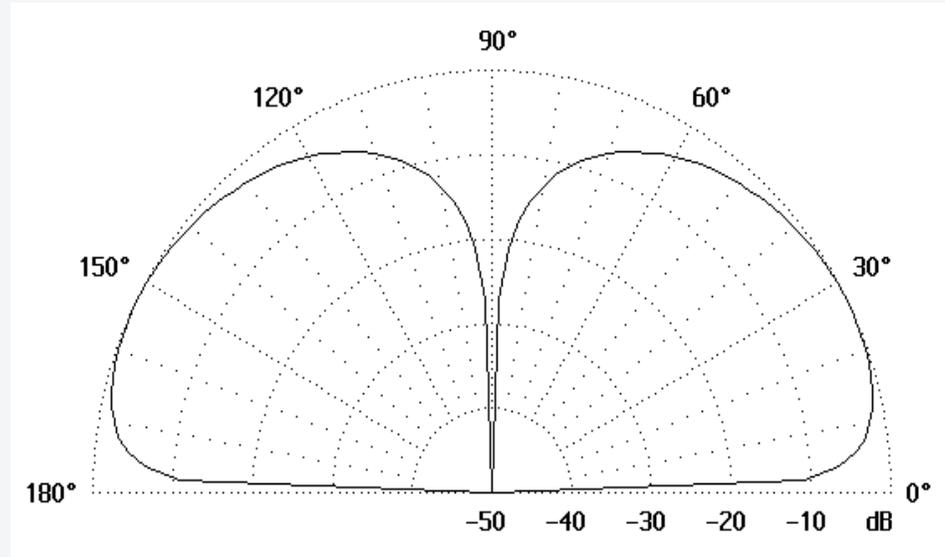
Distance [km]	Angle α
25	88°
50	85°
100	81°
200	72°



NVIS calculation, #1



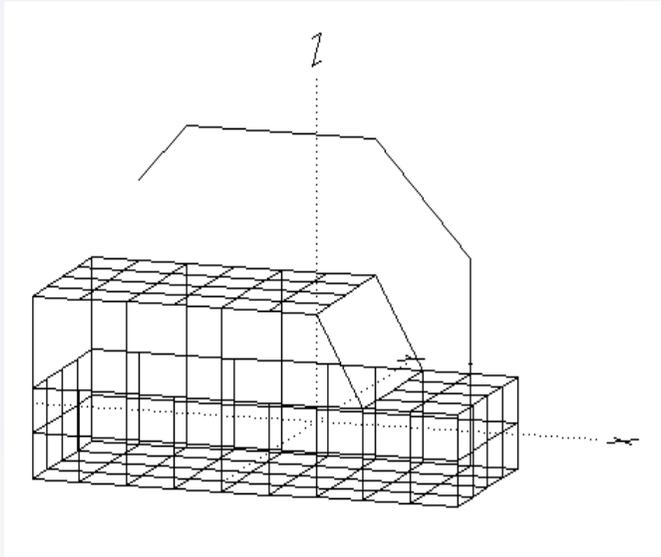
5m whip with 4 radials at ground level.



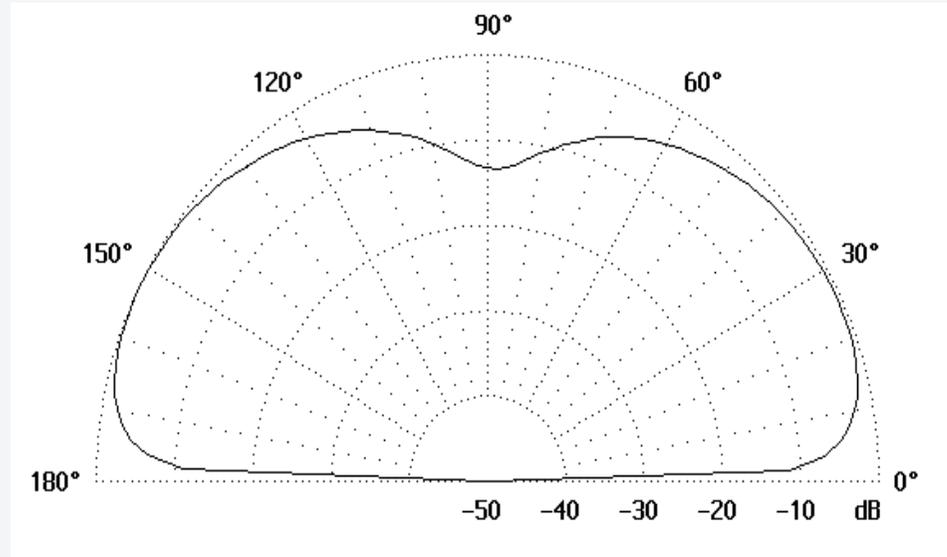
Elevation pattern at 2MHz: Max. = -12.5dBi

Elevation pattern has a null in zenith, and the antenna can therefore not be used for short range NVIS communications.

NVIS calculation, #2



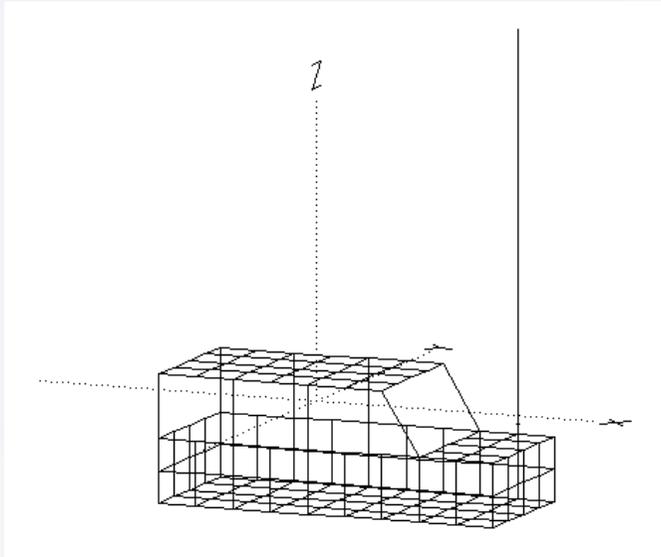
5m antenna bent over vehicle



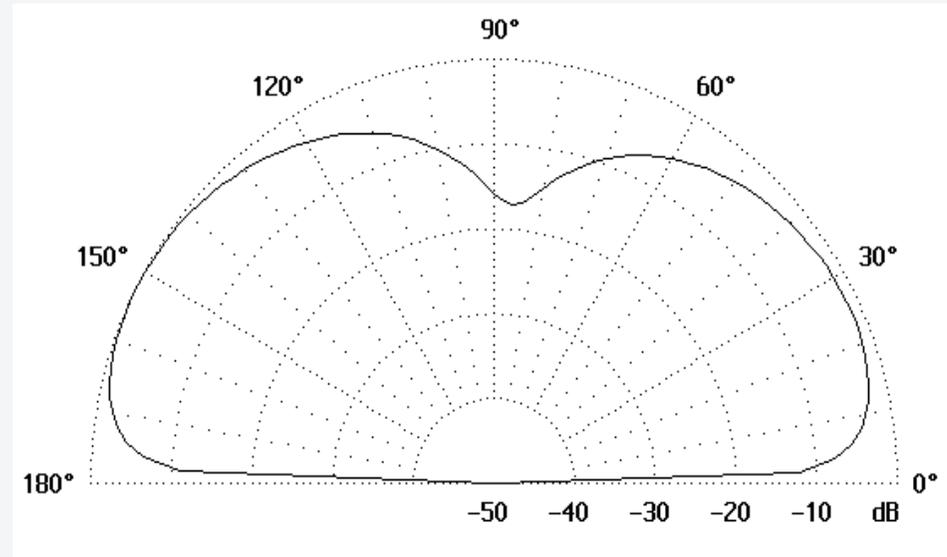
Elevation pattern at 2MHz: Max. = -10.7dBi

Azimuth pattern has slightly higher signal level backwards.

NVIS calculation, #3



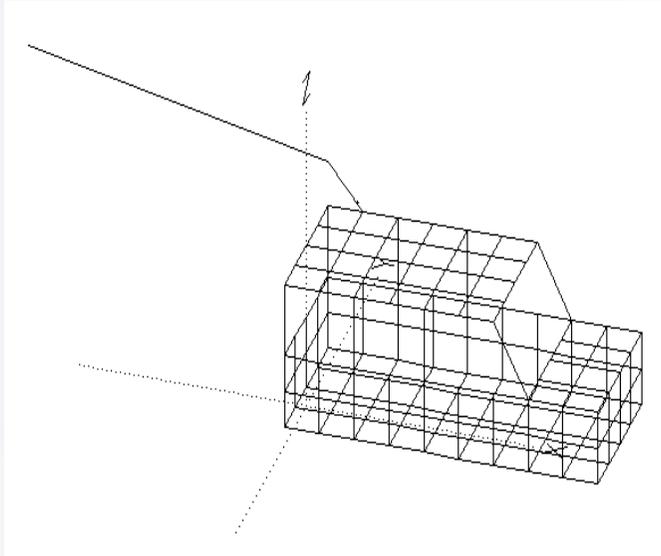
Vertical 5m whip on vehicle



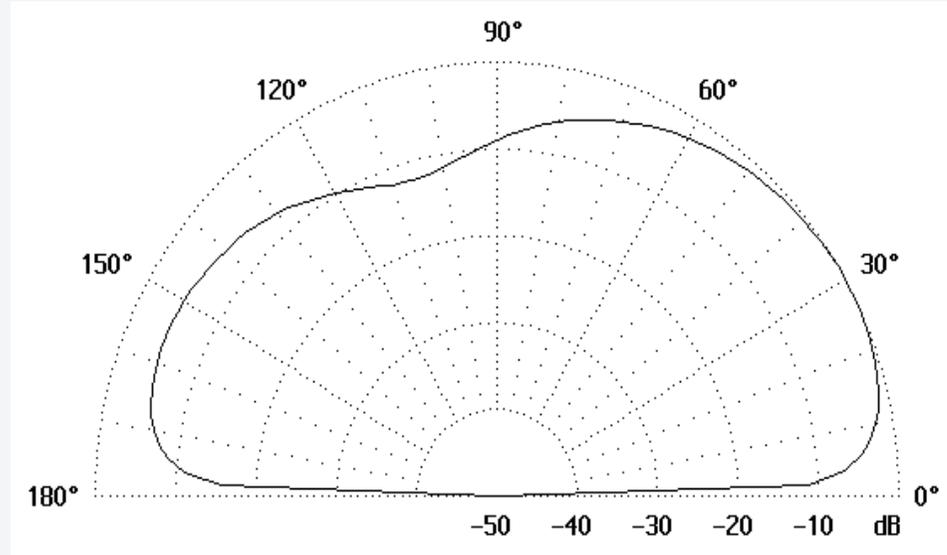
Elevation pattern at 2MHz: Max. = -8.4dBi

Azimuth pattern still has a maximum backwards as for the bent whip.

NVIS calculation, #4



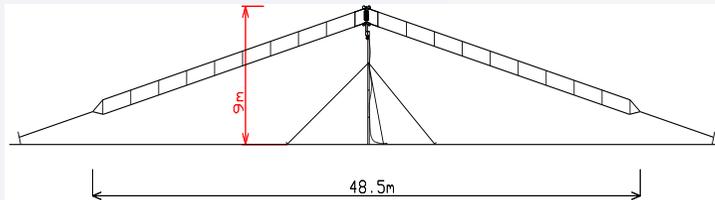
5m whip bent away from vehicle



Elevation pattern at 2MHz: Max. = -12.4dBi

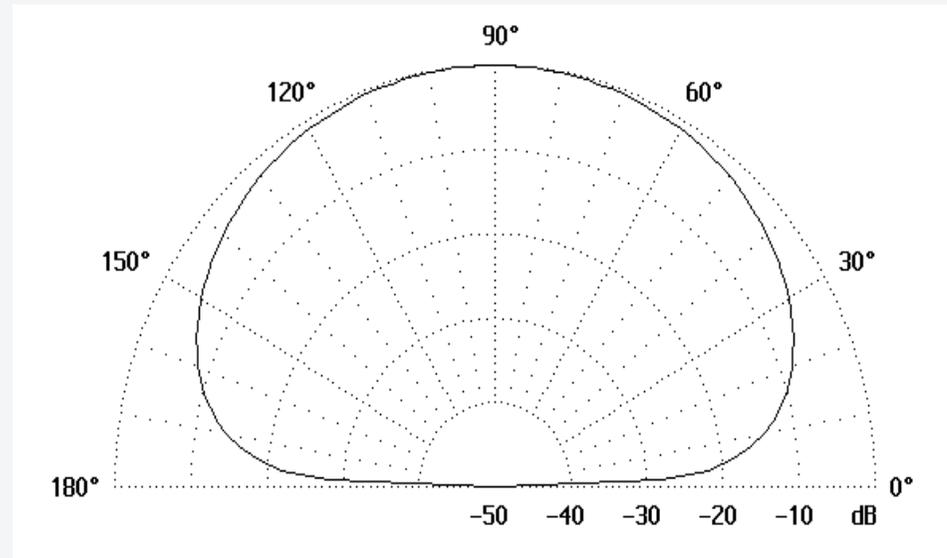
Azimuth pattern still has a maximum across the vehicle, but as the antenna is moved on the vehicle this is now forwards.

NVIS calculation, #5



50m broadband dipole antenna at 8m mast

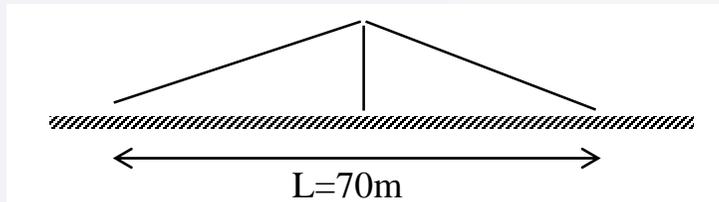
Comrod: AH51



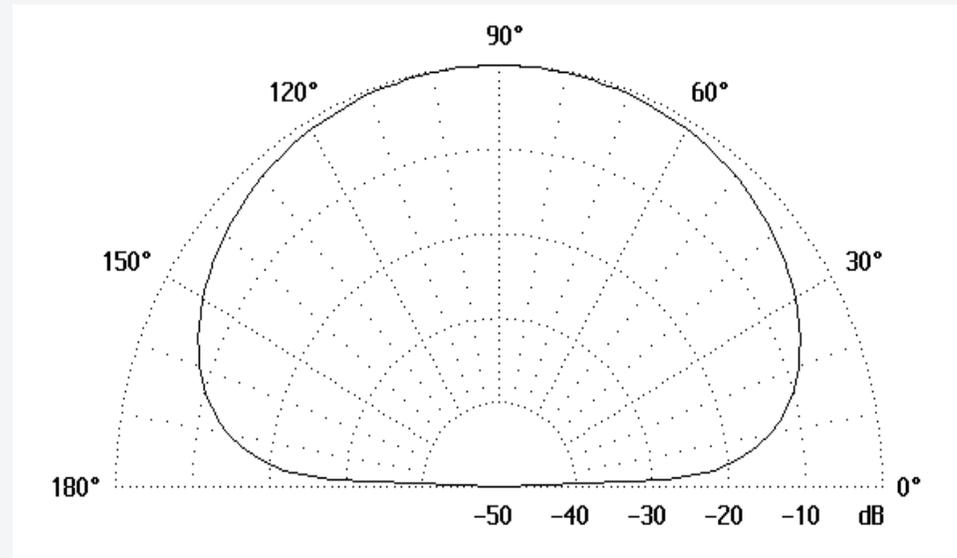
Elevation pattern at 2MHz: Max. = -15.9dBi

Azimuth pattern is omnidirectional on these low frequencies, but breaks up in the upper part of the HF band.

NVIS calculation, #6

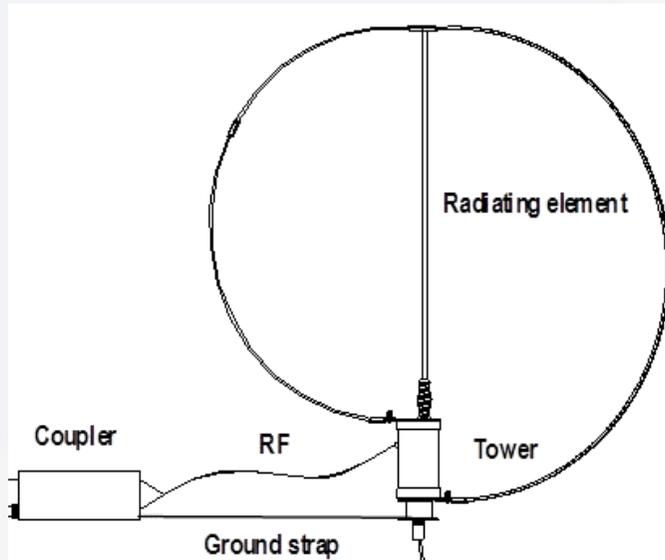


Resonant dipole antenna at 8m mast

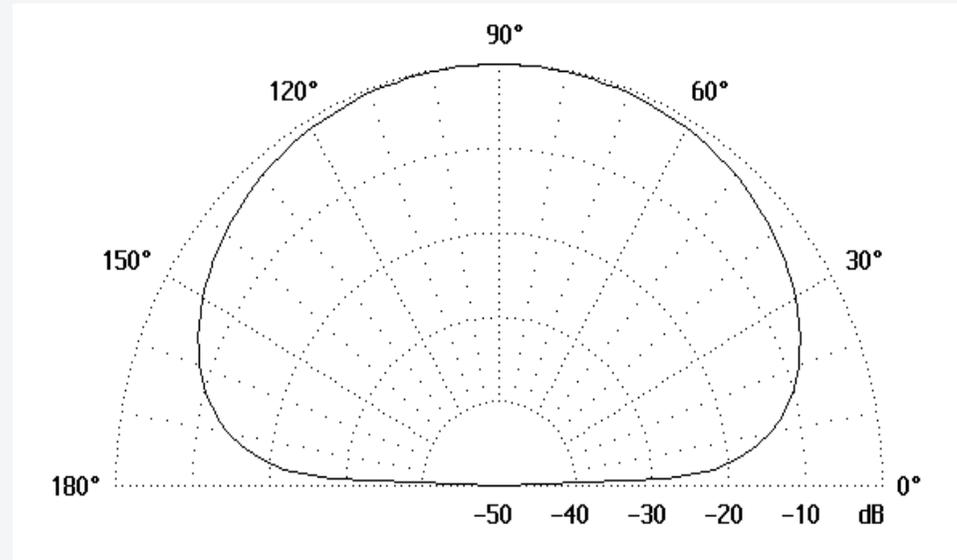


Azimuth pattern is omnidirectional at the resonant frequencies, but breaks up at higher frequencies.

NVIS calculation, #7



Loop, 2-30MHz



Elevation pattern at 2MHz: Max. = -15dBi

Azimuth pattern is omnidirectional for the elevation angles used for NVIS.

NVIS antenna test example (1)

- A bent whip is often used for HF NVIS communication on vehicles and Comrod wanted to compare the performance of this and a full loop antenna
- The whip is 4.6m long and installed on the corner of a 3x3m GP. The loop is 1.5m diameter
- The roof below the antennas are steel
- Antennas are connected to similar antenna tuners and transceivers (ICOM)

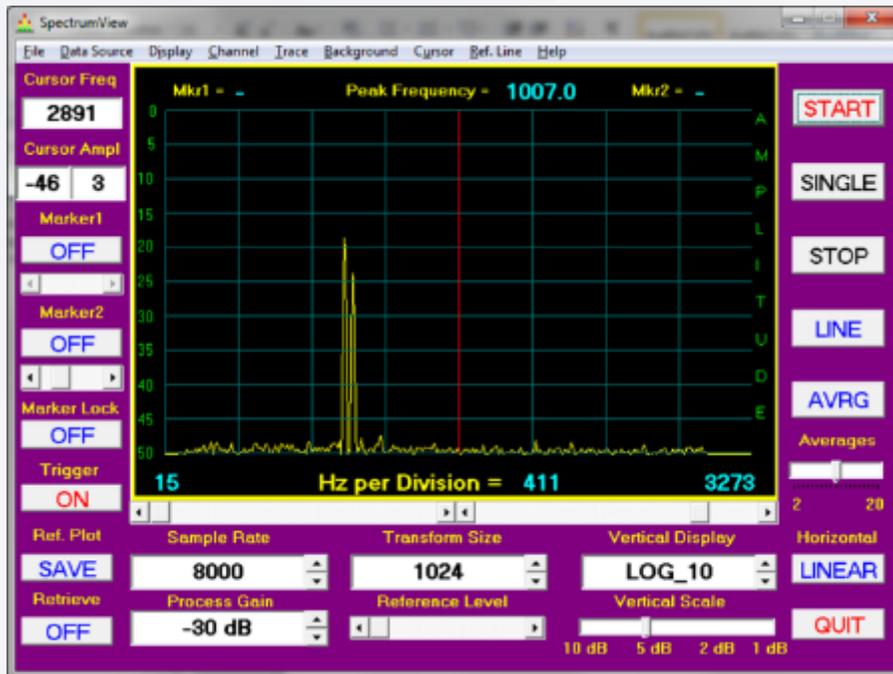


NVIS antenna test example (2)

- Both transmitters transmit at the same time and frequency ($\Delta f=70\text{Hz}$)
- Receiver located at 65km distance with mountain terrain between – ensures only NVIS propagation – remote controlled
- Audio spectrum analysis used to get exact reading of difference in signal strength



NVIS antenna test example (3)



Left signal is loop and 6dB stronger than whip



Whip bent away from ground plane

NVIS antenna test example (4)

Results

06.11.2017, around 10:00 CET:

Frequency	Loop	Vertical whip	Bent whip, over GP	Bent whip away from GP
5MHz	0	-5dB	-10dB	-13dB
4MHz	0	+2	-5	-3
6MHz	0	-7	-5	0
3.5MHz	0	-2	-7	-5dB (3350KHz, no tune at 3500)

07.11.2017, around 08:00 CET:

Frequency	Loop	Vertical whip	Bent whip, over GP	
3	0	-7	-10	
2.5	0	No tune	-10	

As can be seen from above the loop performs significantly better than the whip antenna for NVIS.

Comrod NVIS loop

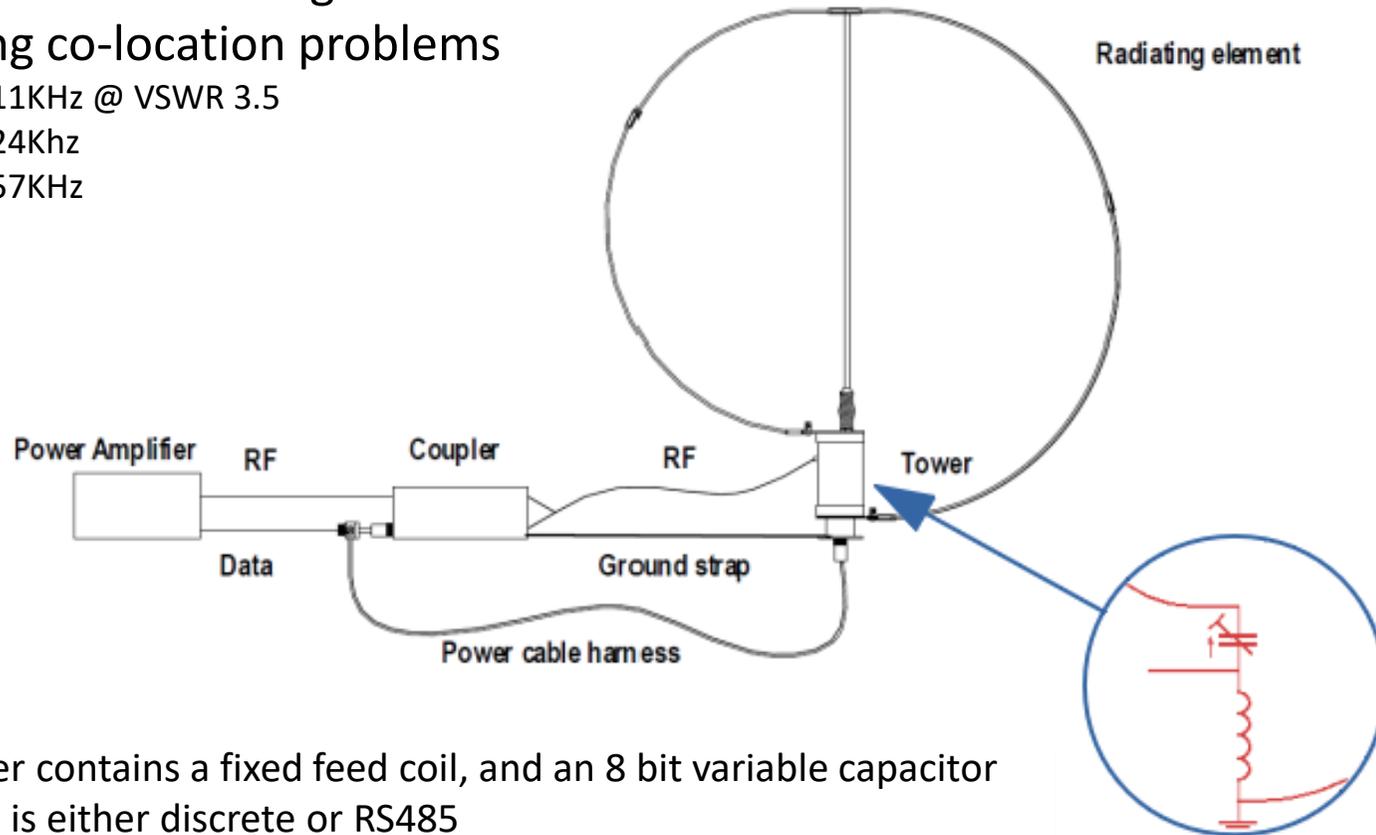
- The Comrod loop converts the low impedance of loop antenna into a higher impedance which can be tuned effectively with a standard antenna tuner

- Narrow bandwidth is good for reducing co-location problems

2MHz: 11KHz @ VSWR 3.5

4MHz: 24KHz

8MHz: 57KHz



The Tower contains a fixed feed coil, and an 8 bit variable capacitor

Interface is either discrete or RS485

Tuning time is down to ~1ms, suitable for 3G ALE

The Tower is self calibrating when switched on

Conclusions NVIS antennas

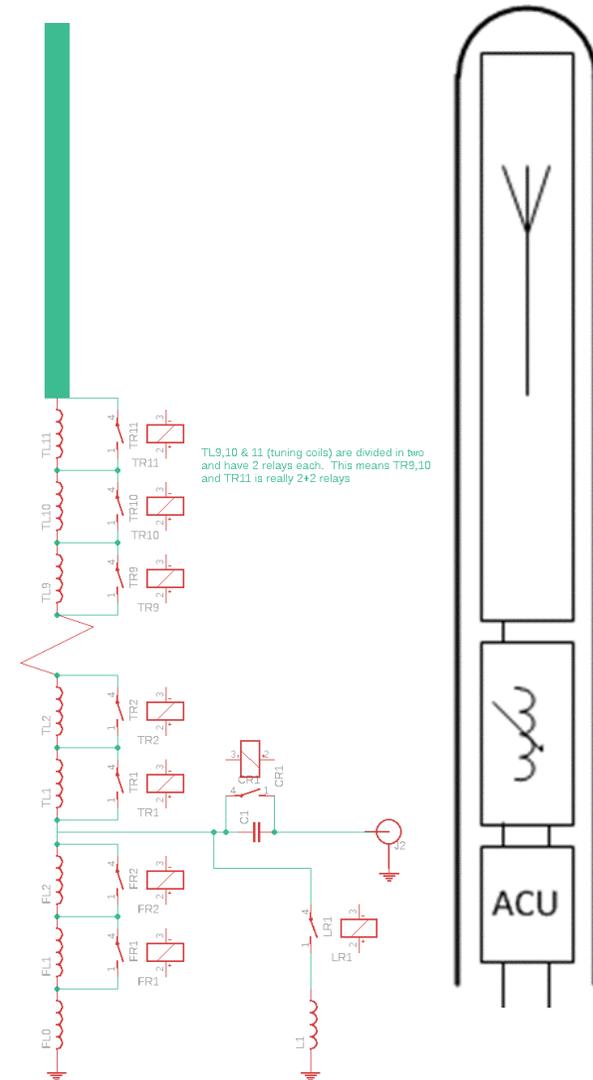
- Ground mounted whip - **not recommended**
- Vertical or bent whip at vehicle - **good**
- Whip is bent away from the vehicle – **good**
- Broad band dipole gives - **significantly better**
used for frequency hopping.
- Large tuned dipole/fan – **very good**
 - Used with OEM antenna tuner through high impedance feed line
- Resonant dipole – **best**
 - Has to be adjusted to the correct length, can not be used for frequency hopping
- Loop - **Significantly better**
On the Move

Long range HF antennas

- Approx. 5 to 30MHz
- For maximum range - gain should be as high as possible
- Low angle of radiation.
- Most commonly: Dipoles, Yagi, log-periodic and bigger whip antennas
- Smaller whip antennas like the 16' APX50 will normally give quite good performance
- NVIS antennas will often have a low radiation angle at these higher frequencies and can be used.
- Comrod
 - Maritime market: large range of whip antennas. (AT82, AT100 and AT101)
 - Military market : same whips as maritime + submarine antenna

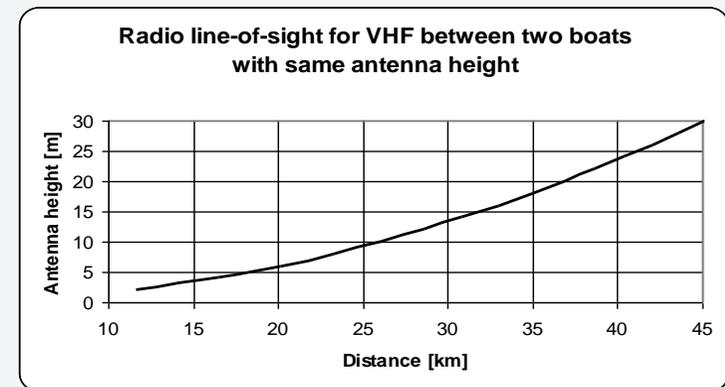
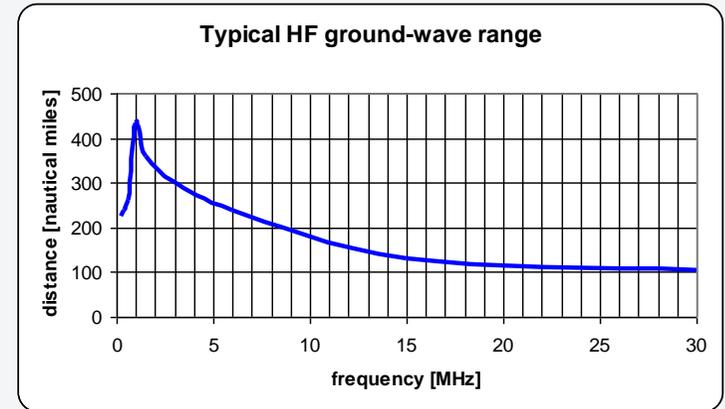
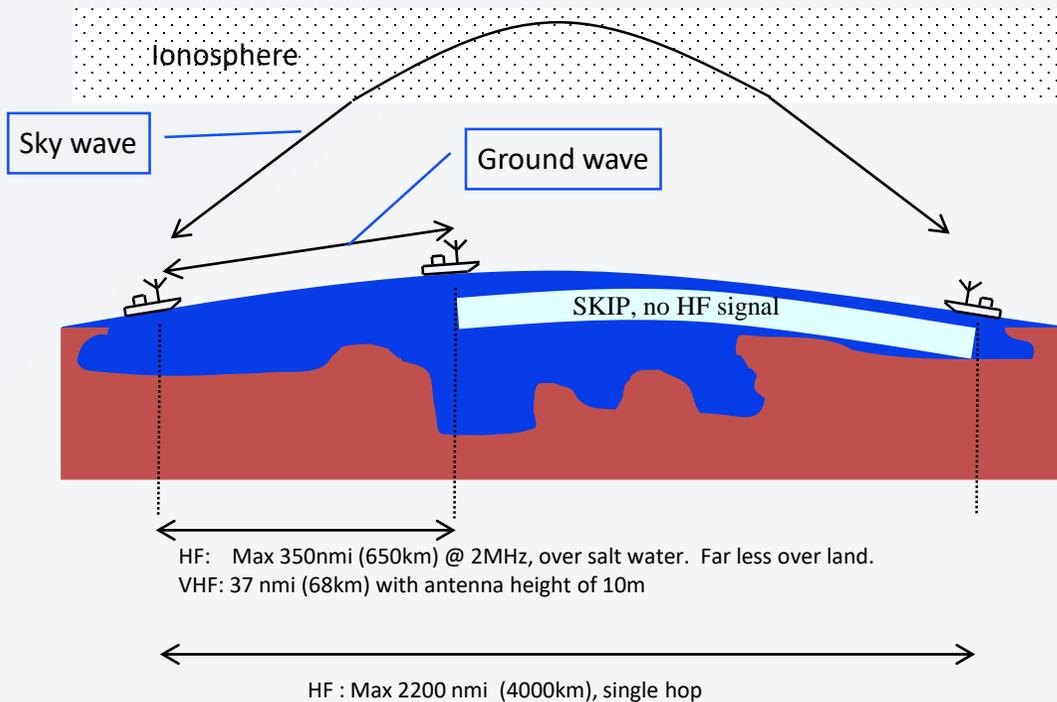
Comrod submarine HF antenna

- Relay tuned thick whip
- Fast switching time ~1ms
- Suitable for 3G ALE
- Controlled via RS-485
- Autonomous mode with frequency counting
- Self calibrating with built in VNA
- Uses vacuum relays for high power 1KW
- Available also for surface ships
- Narrow bandwidth is good for reducing co-location problems
 - 2MHz: 15KHz @ VSWR 3.5
 - 5MHz: 120KHz
 - 7MHz: 400KHz



Wave propagation

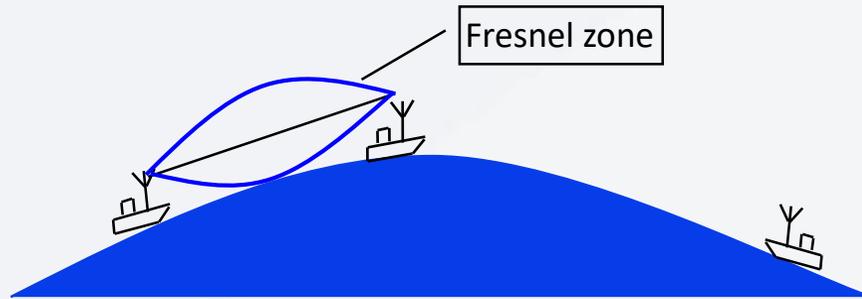
HF is reflected in different layers of the ionosphere depending on frequency, sunspot numbers etc.



$$D_{[nmi]} = 2.227 \cdot (\sqrt{h_t} + \sqrt{h_r}) \quad h \text{ in m}$$

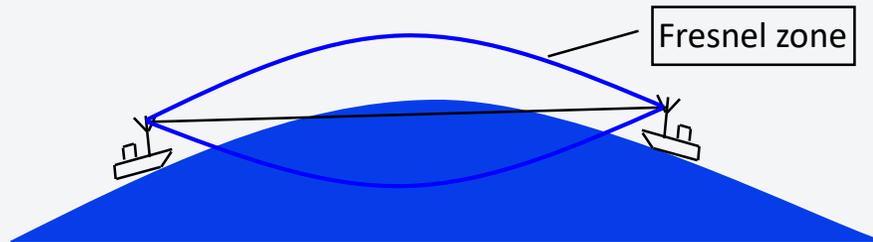
$$D_{[nmi]} = 4.454 \cdot \sqrt{h_{[m]}}$$

Free space attenuation



$$\text{Free space loss} = 20 \cdot \log\left(\frac{12.89}{f \cdot d}\right) \text{ [dB]}$$

where f [MHz] and d [nmi]



Line of sight

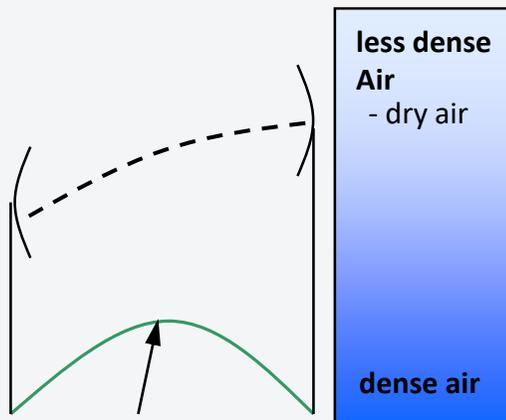
- Free space loss only
- Must clear the first Fresnel zone for maximum signal, otherwise ground reflections may arrive out of phase and reduce signal

Beyond line of sight

- Free space loss
- Diffraction loss
- Knife edge diffraction gives more signal than a smooth edge

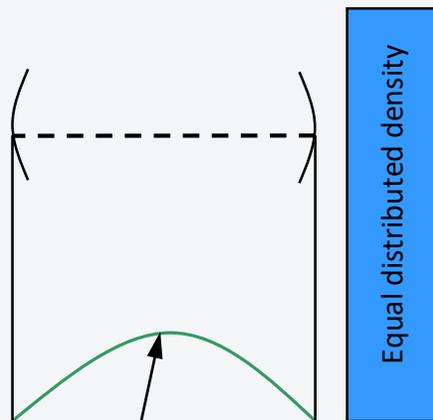
Radio waves in the atmosphere

- All frequencies reaches a bit further than line of sight
- Interaction with gases, water vapor and the ionosphere in the atmosphere bends the radio waves.
- The density of gases and water vapor will together with temperature and air pressure set the bending radius.
- The effect of the atmosphere is higher on higher frequencies



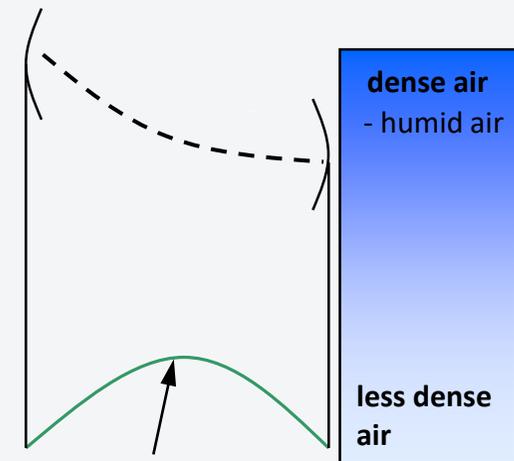
Earth curvature

Normal atmosphere



Earth curvature

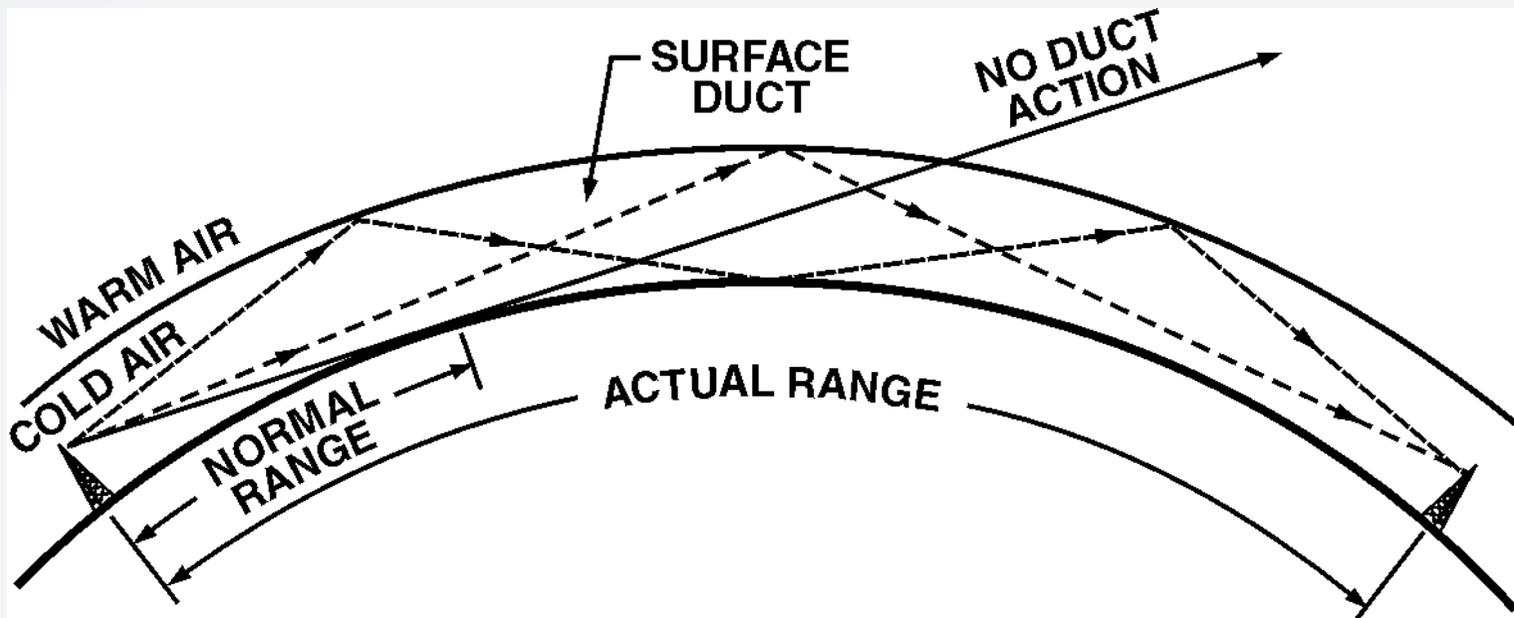
Same as no atmosphere



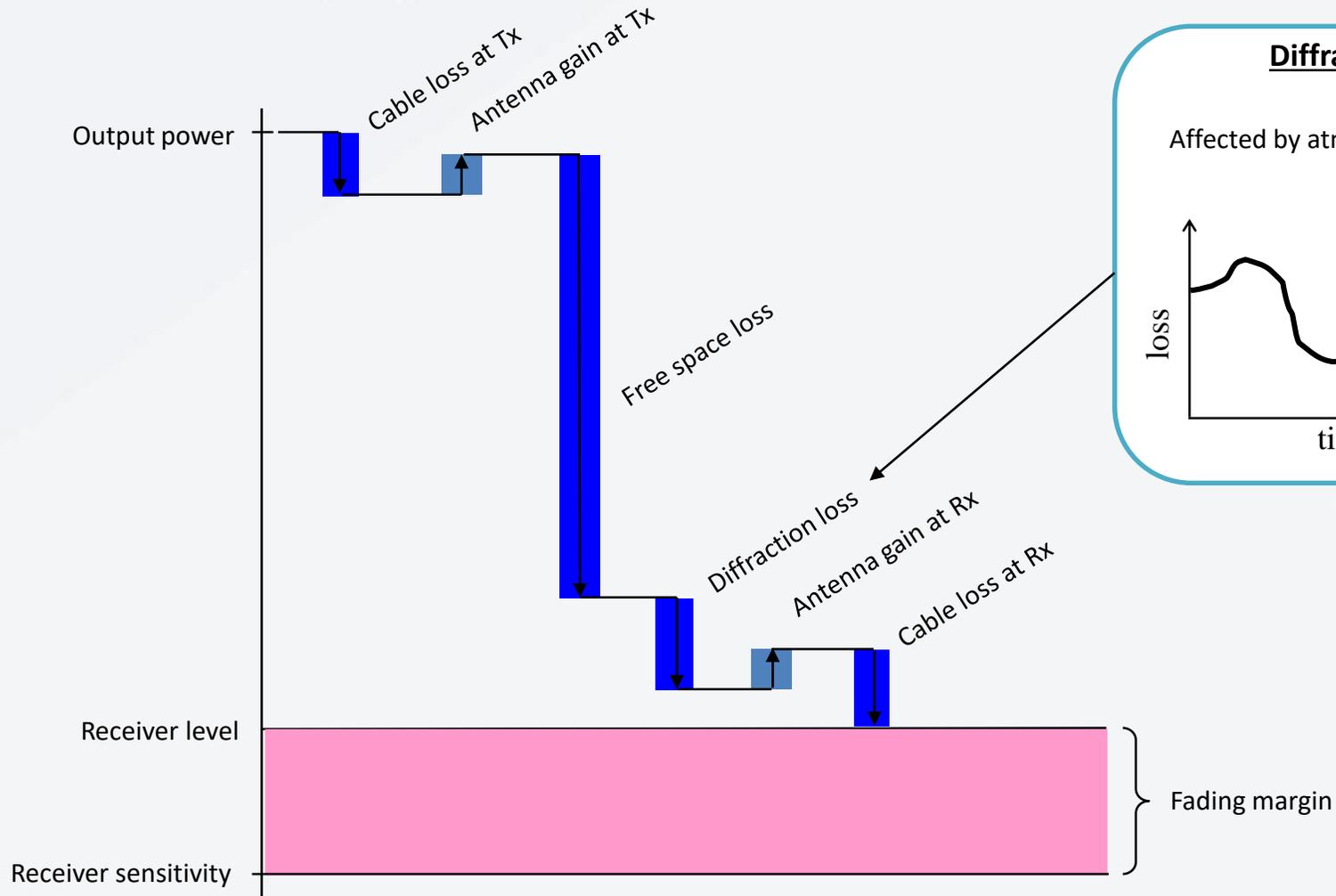
Earth curvature

Elevated duct

- With special weather conditions, an elevated duct can occur
- Radio signals trapped in a duct gives a radio range far beyond normal radio range
- Radio ducts occur most often in warm weather

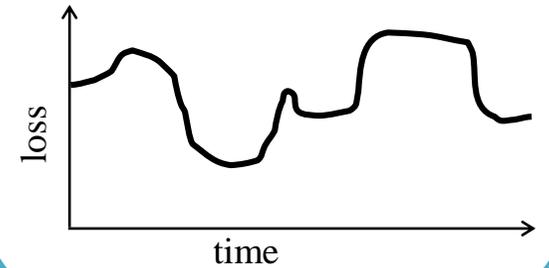


System calculation

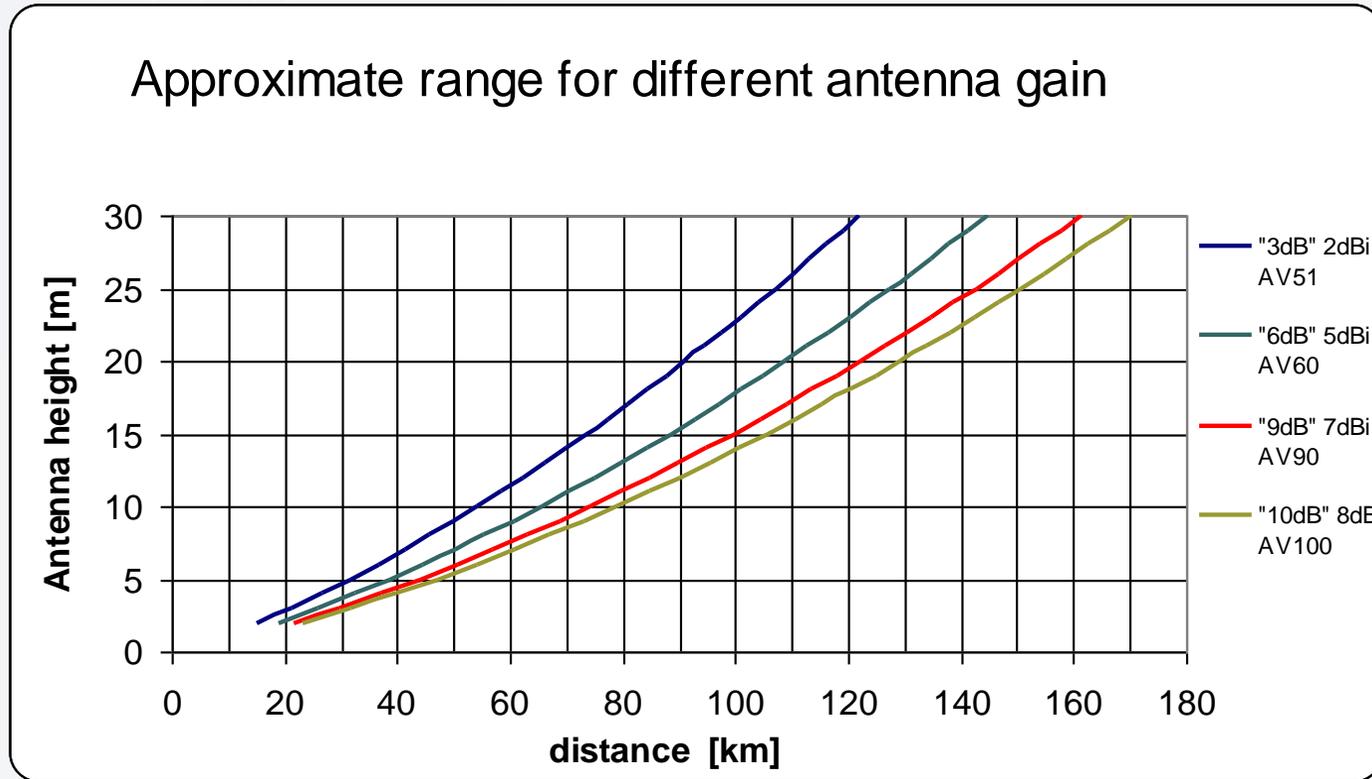


Diffraction loss

Affected by atmospheric conditions



Theoretical range for maritime VHF

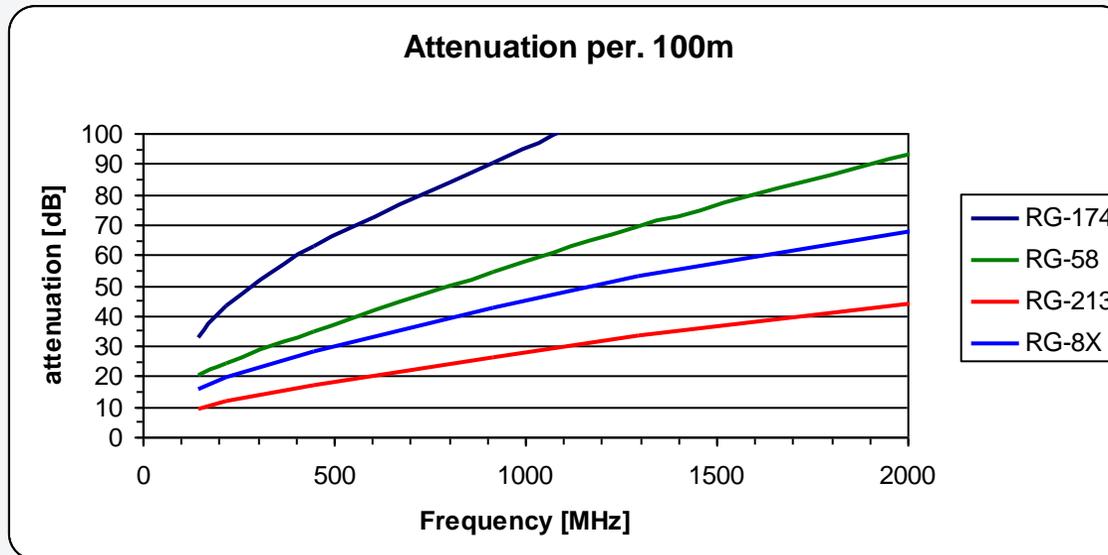


- Frequency =159MHz
- Transmitter power = 25W
- Both antennas at same height
- Cable loss, 2*11m(36ft RG58) = -4.0dB
- Receiver sensitivity = -121dBm (0.2μV)
- Open sea between the boats

Coaxial cables

- Energy is lost as heat due to resistance and dielectric loss
- Energy radiates from the cable
- The loss is strongly related to the frequency

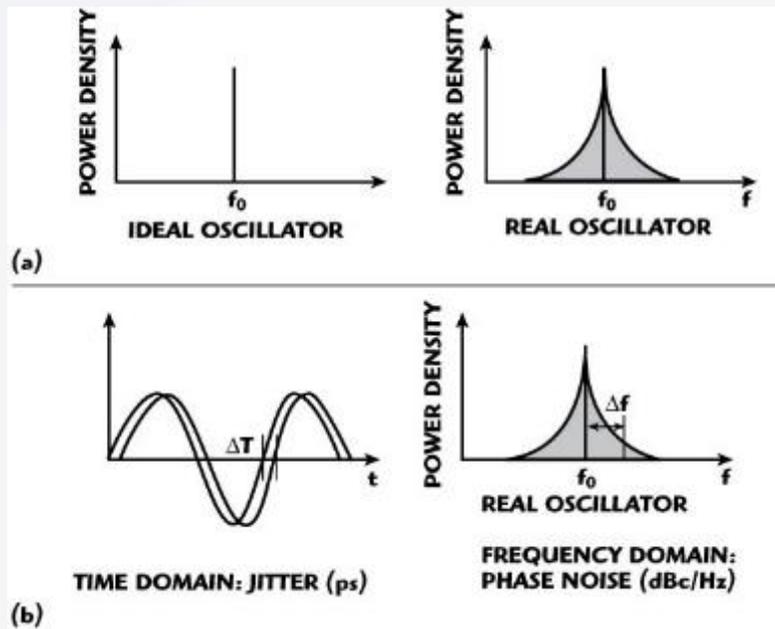
The higher frequency - the higher loss



Co-site interference

- Receiver overload/blocking
- Phase noise and wideband noise in TX/RX
- Harmonics
- Intermodulation

Phase noise:



Intermodulation occurs when two (or more) signals are mixed to produce spurious signals, 3rd order is strongest and is: $2 * F_1 - F_2$

All transmitters produce more or less harmonic distortion at $2, 3, 4, \dots * F$. On a good transmitter this signal is more than 60dB below the carrier

A good receiver may be able to withstand +10dBm before blocking

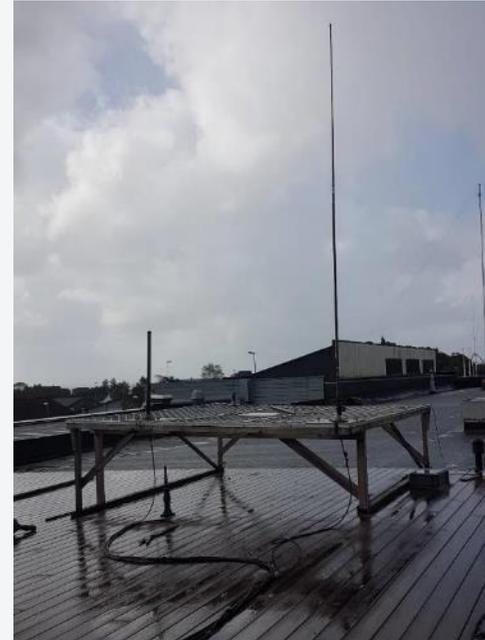
A good TRX may have phase noise -50dBm @ BW2.7KHz and Δf 20KHz @ 50MHz, Typical RX sensitivity is -123dBm (0.15 μ V)

Co-site interference

- Isolation between antennas on a vehicle is very low
- Within band interference is difficult to mitigate
- Cross band interference can be mitigated
- Most antennas have moderate suppression for out-off band signals



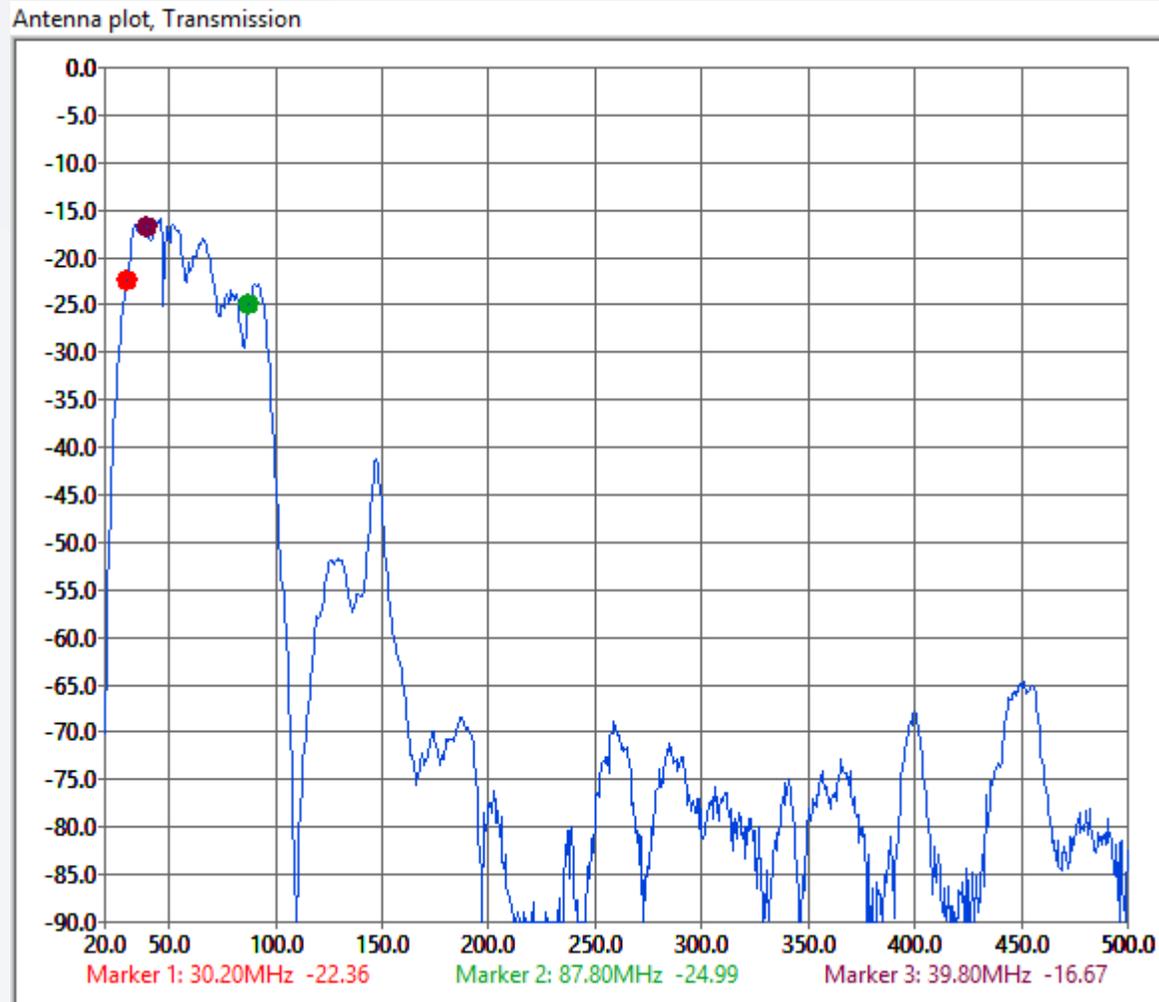
Vehicle with 2 x UHF + 1 x VHF whips



Ground plane used during tests at Comrod. Antennas spaced 2m, VHF & UHF whip shown.

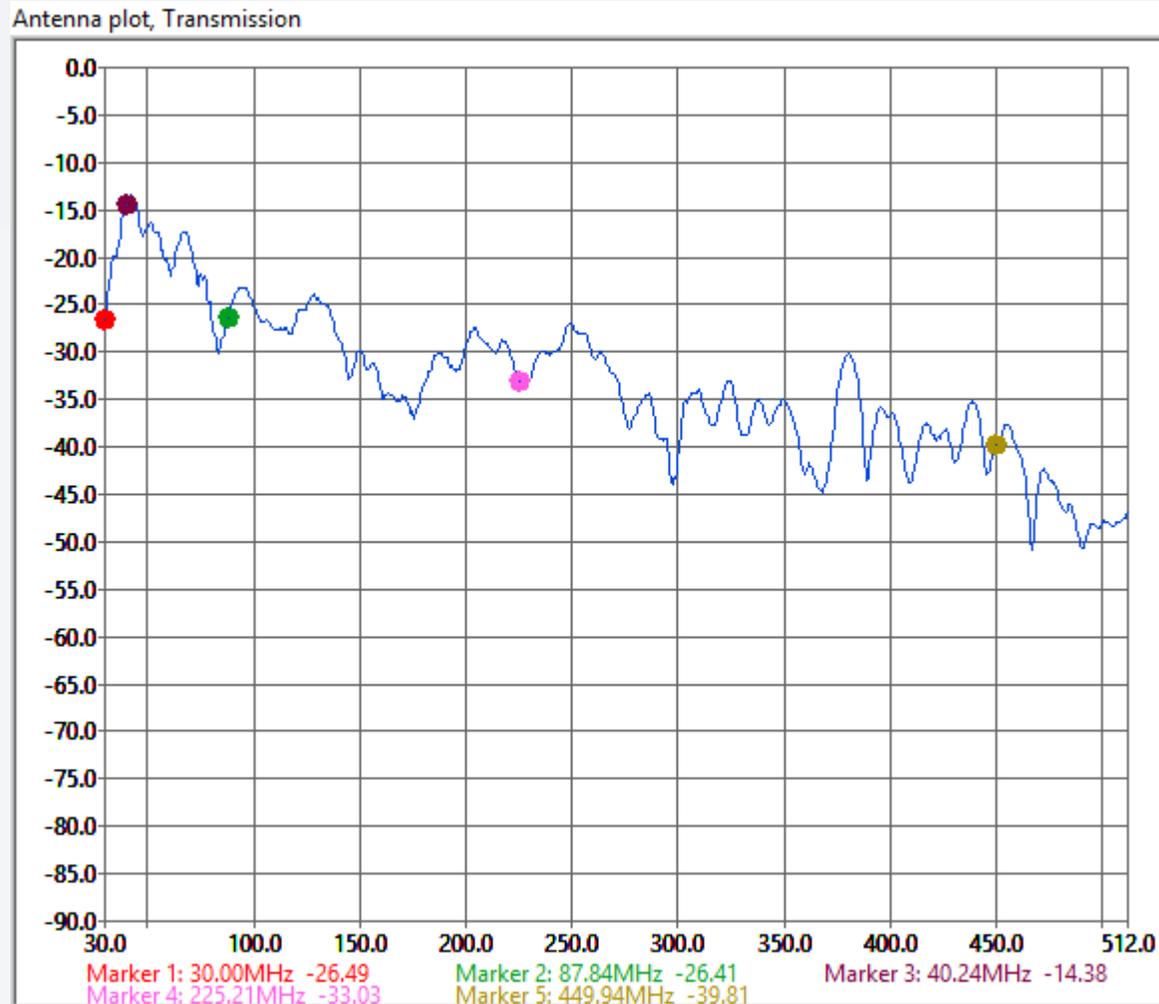
In band isolation

Isolation between 2 x Comrod VHF3088VM (30-88MHz dipoles) at 2m distance



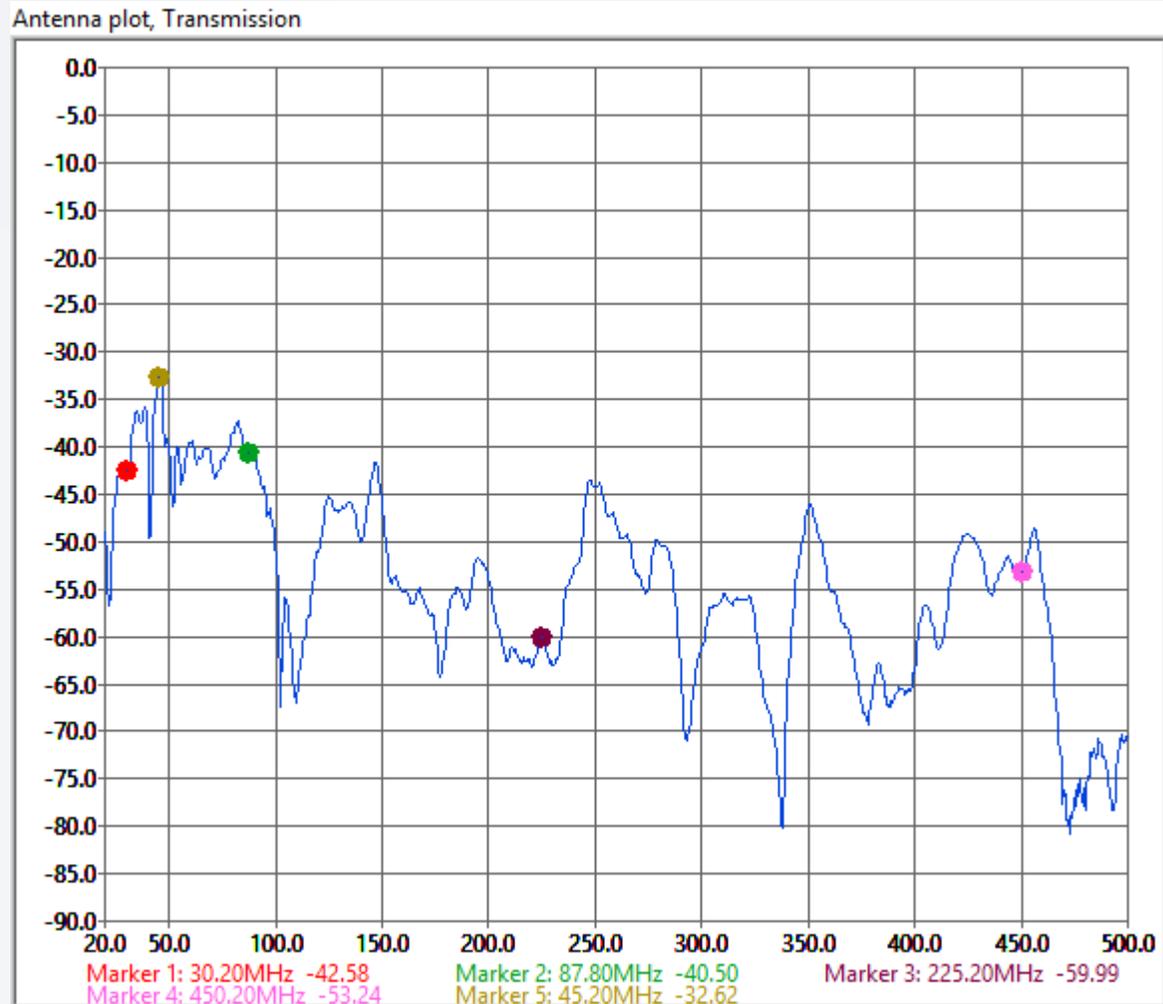
In band isolation

Isolation between 2 * Comrod VHF30315CEF (30-512MHz wideband antenna) at 2m distance



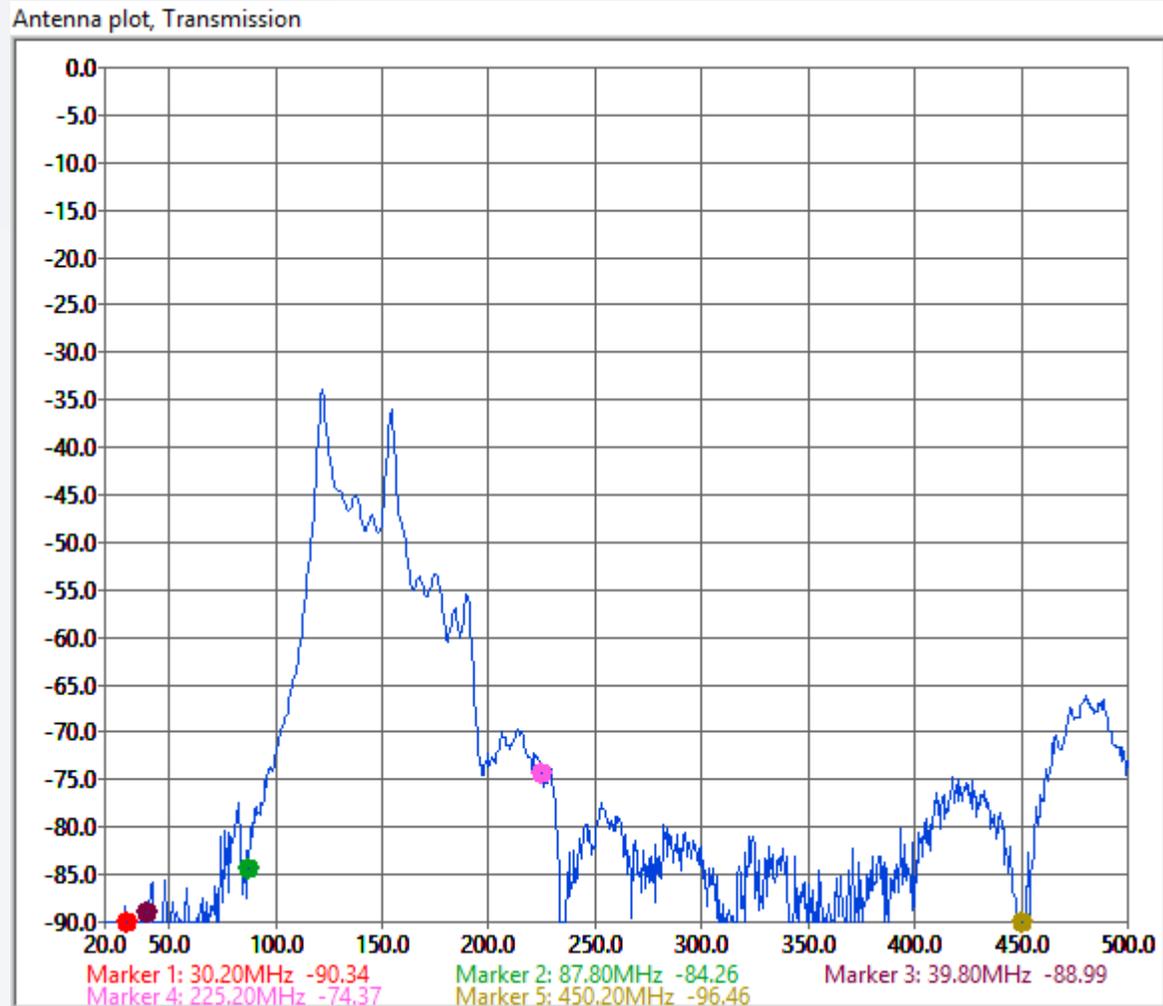
Cross band isolation

Isolation between Comrod VHF3088VM and UHF225450VM
(225-450MHz dipoles) at 2m distance



Cross band isolation

Isolation in a single Comrod VHF302000TB/F
(30-88MHz, 225-450MHz, 1200-2110MHz three port antenna)



Multi band antenna advantages

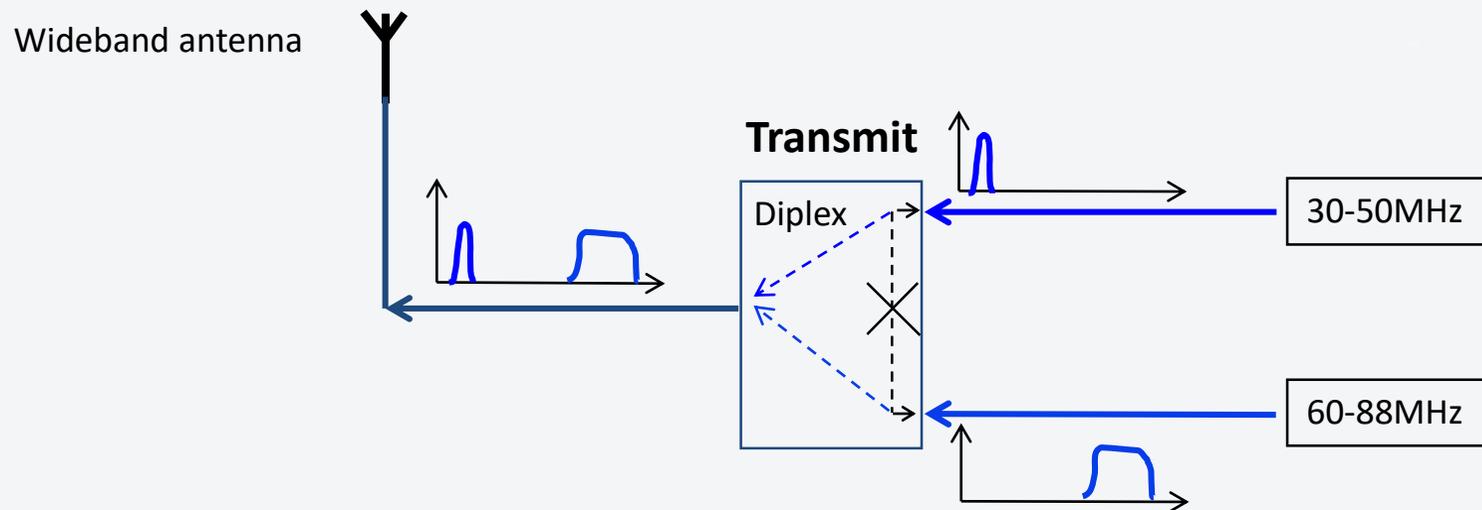
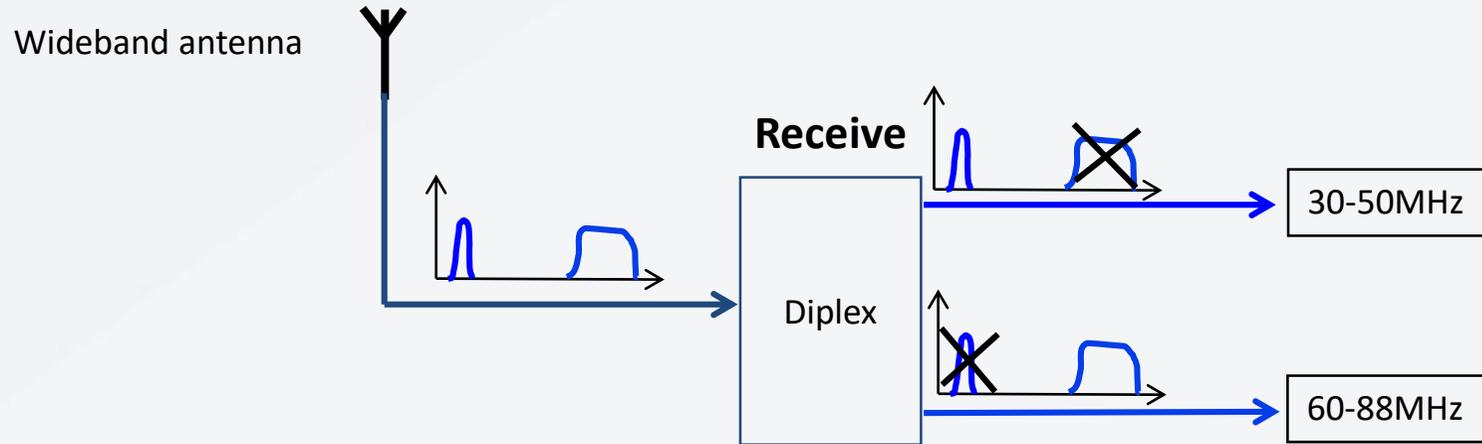
- Significantly better isolation than with banded antennas on the same platform
- Can be made with similar performance as single band antennas
- Reduces the total number of antennas on a platform – or often the only way to accommodate the required number of antennas
- Because of the reduced number it may be possible to find locations on the platform that give better performance

In band interference reduction

- Use duplexers/filters and split the band
 - Efficient, but needs frequency planning
- Increase distance between antennas
 - Not easy on small platforms, multiband antennas may free space
- HiQ/Selective adaptive antennas
 - More expensive than ordinary antennas
 - Needs frequency info from TRX – often not available
 - Often higher gain than similar size ordinary antennas
- Adaptive cancellation using directional couplers and vector modulators
 - Expensive, and may be a bit lossy
 - Will not reduce noise outside of the loop bandwidth of the control system
 - May be too slow for frequency hopping and some waveforms
- Adaptive notch filters
 - Expensive
 - Will not reduce wideband noise
 - Can be quick if frequency info is available
 - Relatively simple filter architecture
- Adaptive bandpass filter
 - Expensive
 - Will reduce wideband noise if used both in TX and RX path
 - Can be quick if frequency info is available

Diplexers

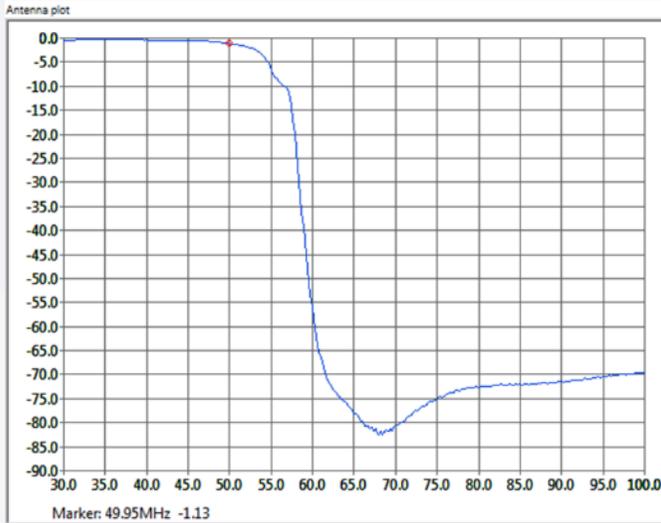
Diplexers can be used to reduce in band interference, and also the number of antennas on a platform. Supression of the other band can be in the region of 60dB (versus less than 20dB with separate antennas)



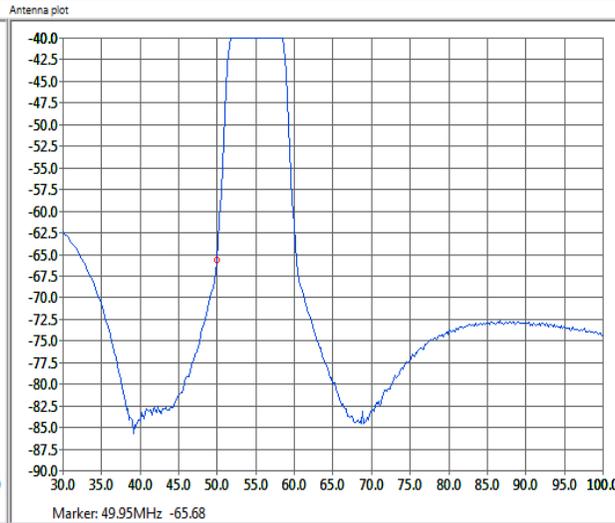
Diplexers

A diplexer with below performance is used successfully for a single antenna repeater station in the low-VHF (30-88MHz) frequency band

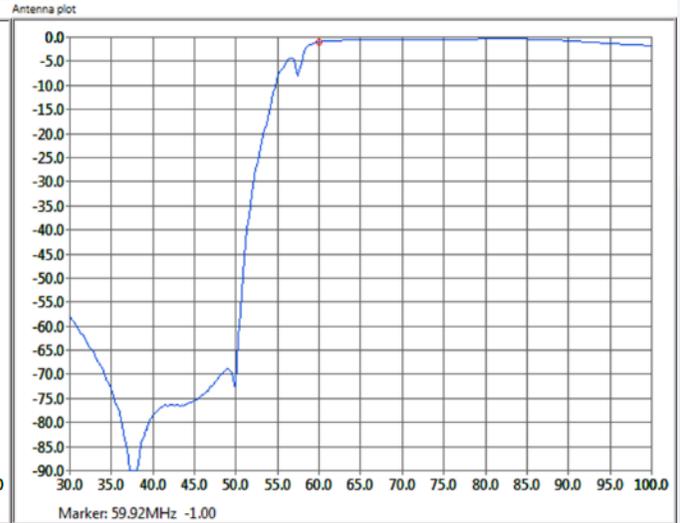
Low-pass



Port to port isolation



High-pass

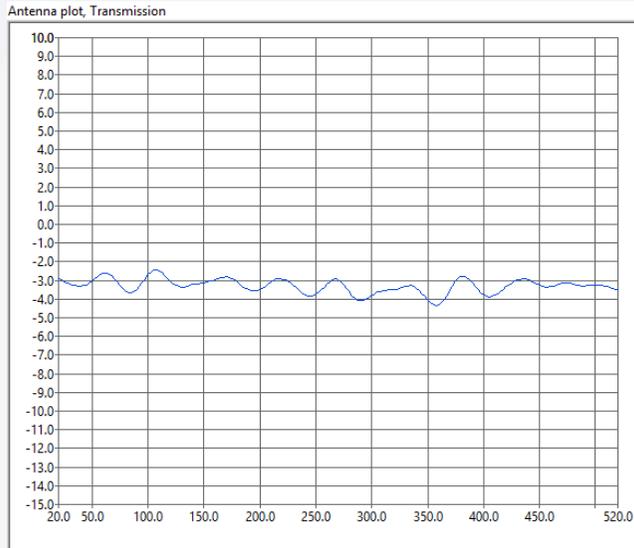


Passive combiners

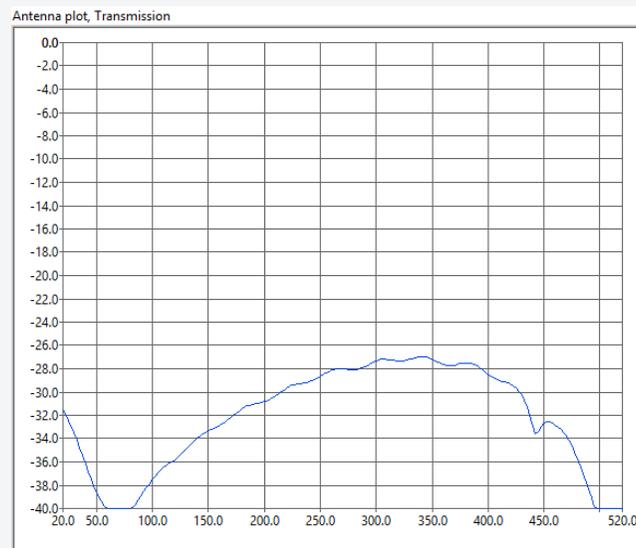
- Passive combiners are often used to reduce the number of antennas on a platform
- Available with different numbers of ports, 2 or 4 being the most common
- By nature a 2 port combiner will have 3dB loss, and a 4 port will have 6dB loss
- Isolation between ports highly dependent on impedance on the common port



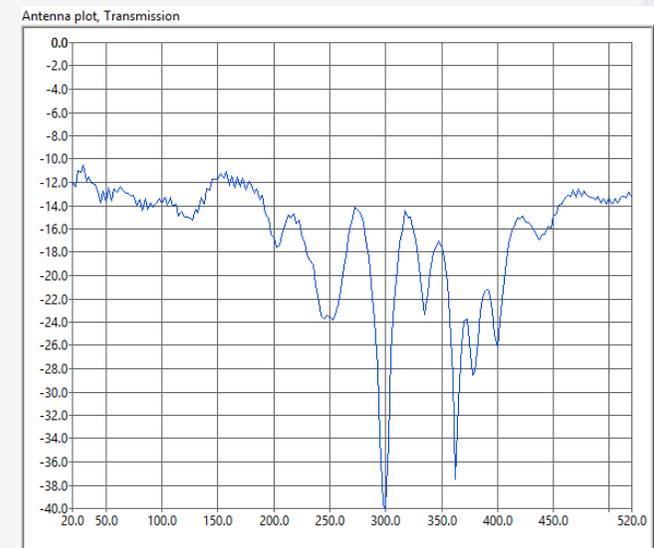
Loss from TX to antenna



Isolation with perfect antenna



Isolation with real antenna



Antenna measurements

- VSWR
- Gain
- Radiation pattern

VSWR

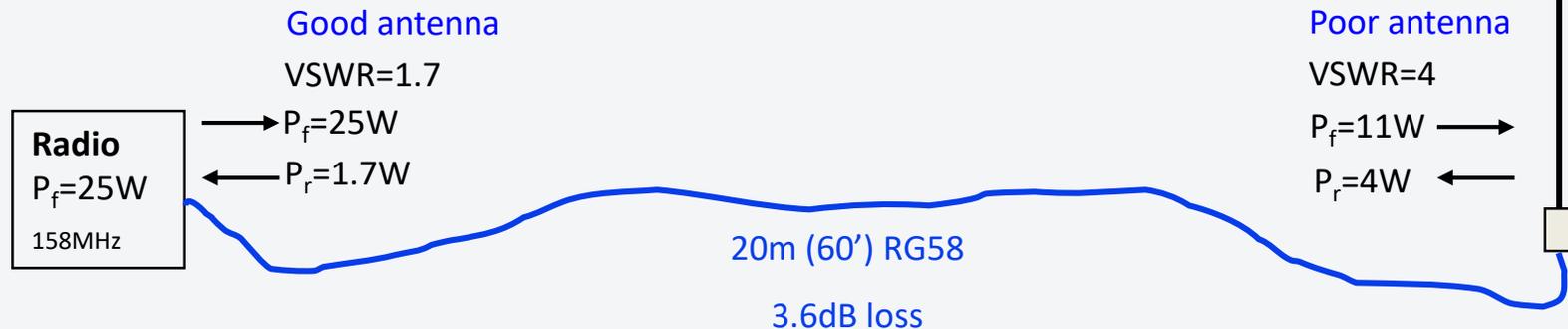
- Easy to measure with a directional RF power meter, often the only measurement possible
- Some meters can give the VSWR directly, but when measuring power the following formula can be used:

$$VSWR := \frac{1 + \sqrt{\frac{P_r}{P_f}}}{1 - \sqrt{\frac{P_r}{P_f}}}$$

P_r : Reflected power
 P_f : Forward power

- Ideally measured at antenna as cable loss will give too good results as both forward and reflected power is attenuated in the cable

Example:



Gain measurements

- Gain is measured by comparing signal levels between a known reference (often a dipole or horn) and the antenna to be tested
- The reference and test antennas must be in the same position
- There must be no difference in signal level & phase across the area of the test and reference antennas. This is often difficult to achieve, and normally means that a special site has to be used
- As a signal varies significantly with height above ground, horizontal polarization has to be used to minimize vertical area of the antennas
- To ensure that the phase difference across the antenna is small, the following formula must be used to calculate distance from transmitter to test antennas:

$$R > \frac{2d^2}{\lambda}$$

R : Distance

λ : Wavelength

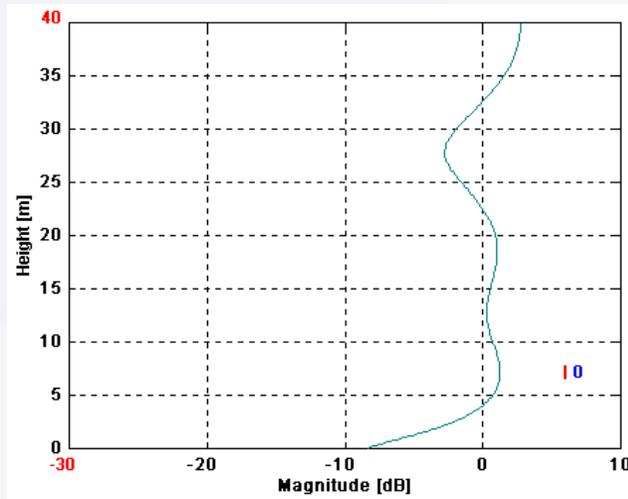
d : Maximum size of test antenna

- This formula does not ensure that the field strength is uniform across the antennas

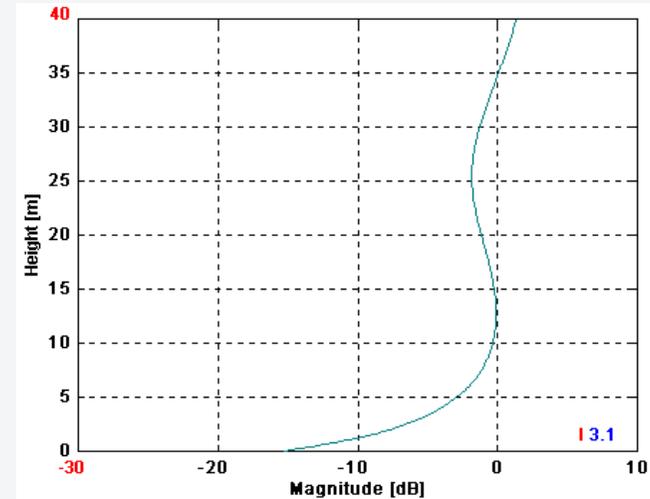
Gain measurements (cont.)

Signal level versus height for a typical test range:

$H_{TX}=3.8m$



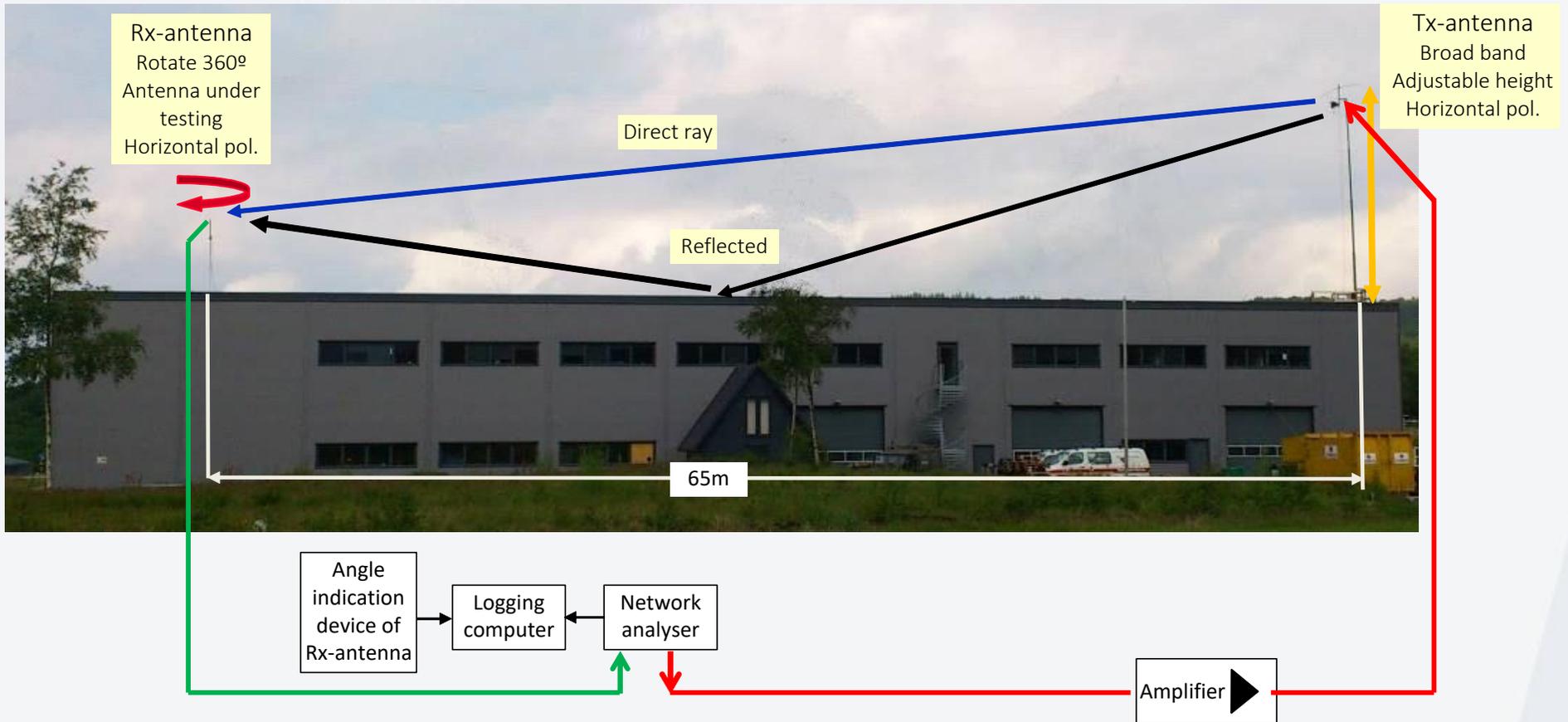
$H_{TX}=1.5m$



Ground is "rich soil" with $\epsilon_r=17$, $\sigma=0.02$. Distance TX/RX=68m and frequency is 156MHz.

- To ensure that gain measurements are correct the test antennas should be placed so that there is no variation of signal along its length. With horizontal polarization this is easier to achieve
- With vertical polarization, if a short antenna (reference dipole) at $H=1.5m$ is compared to a longer antenna with the base at the same height, the longer antenna will receive a significantly stronger field at the top - consequently the gain readings will be too high
- RS329-1, part II method for gain measurements, requires both antennas at approx. 1.5m. This method therefore favors long antennas even if they are not good

Gain measurement – far-field



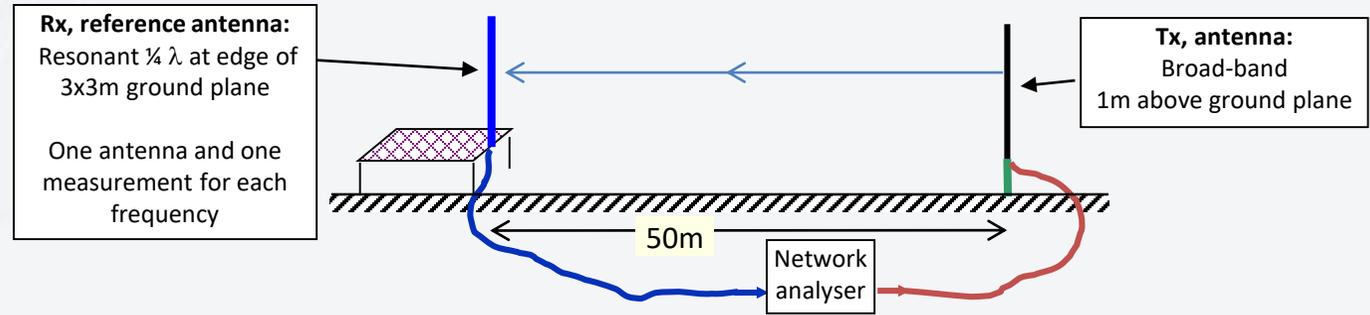
$$R > \frac{2d^2}{\lambda}$$

R : Distance
 λ : Wavelength
 d : Maximum size of test antenna

Gain - large vehicle mounted antennas

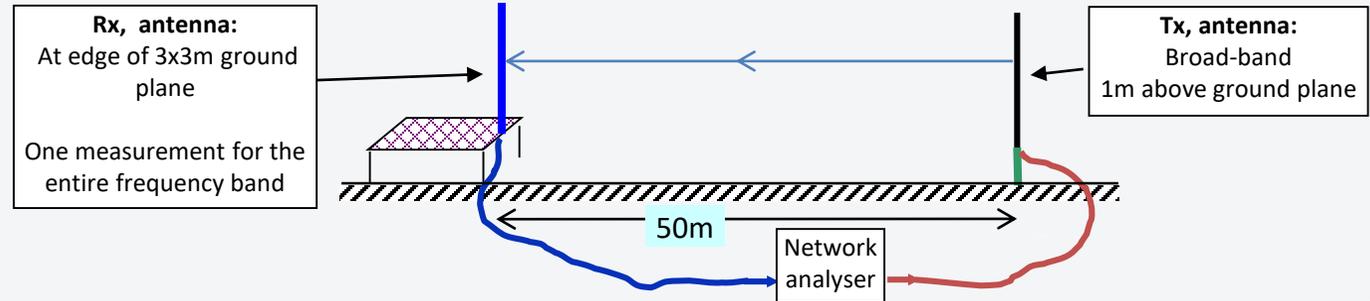
1. Reference antenna

Ex. Tested frequencies:
30 50 70 88 MHz



2. Antenna under test

Ex. Tested frequency band:
30 - 88 MHz



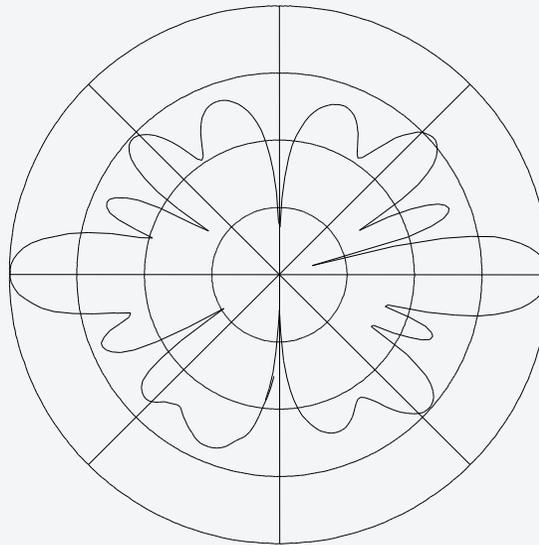
3. Calculate gain

Compare the receiver levels of the reference antenna and the “antenna under test” - find the gain with reference to a resonant $\frac{1}{4} \lambda$

Freq.: [MHz]	30	50	70	88
Ref. ant. [dB]	-70	-72	-73	-79
Test ant. [dB]	-65	-72	-78	-77
Gain [dB relative $\frac{1}{4} \lambda$ whip]	+5	0	-5	+2

Radiation pattern

- Tested by installing the 'antenna under test' at a rotator
- The position and received signal strength is recorded as the antenna is rotated through 360°
- The test range must fulfill the same qualities as for "gain measurements"
- As the optimum height changes with the frequency, several sweeps may be necessary



AV100, Maritime VHF
"10dB" antenna

10dB/div

F=156.8MHz
Ch. 16

Thank you, questions?



References

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- Short backfire, coaxial dipole, monopole: Figures from VHF and UHF antennas, R.A. Burberry
- Log periodic: Figure from Antenna Engineering Handbook, Henry Jasik - Second Edition
- Loop receive: Figure from Antennas, John D. Kraus – Second Edition
- Dipole: Figure from Wikipedia, Creative Commons – no copyright
- Phase noise: Figure from Synergy Microwave Corporation web article
- NVIS propagation: Figure from QRZNOW and also found on other web sites
- Horn antennas: Pictures from A-info sales brochure