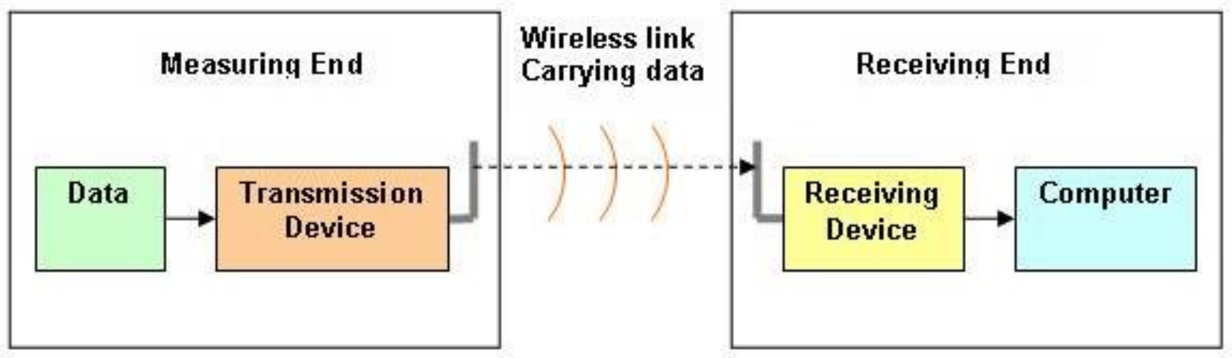
20IS709
Communication Systems For Industrial Networking


Wireless Communication

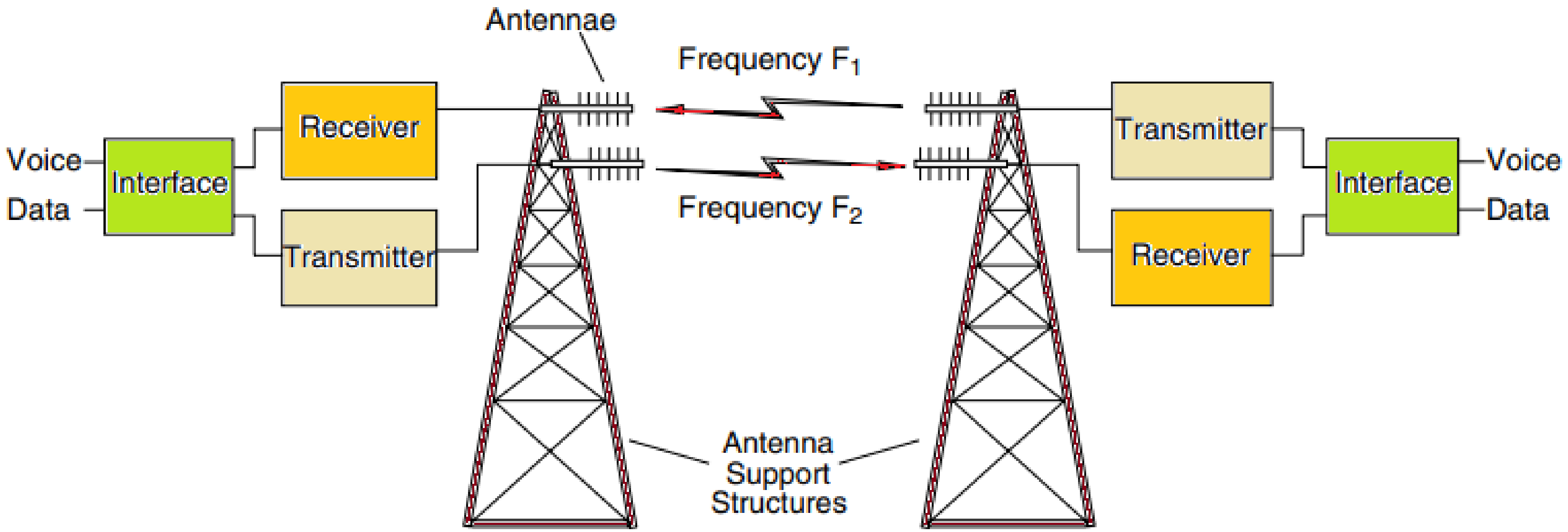
Radio Telemetry Systems

- Many industrial protocols are transferred using radio telemetry systems.
- Radio is often chosen in preference to using landlines.
  - Costs of cable can far exceed that of radio telemetry systems
  - Radio systems can be installed faster than landline systems
  - Radio equipment is very portable and can be easily moved
  - Radio can be used to transmit the data in any format required by the user
  - Reasonably high data rates can be achieved compared to some landline applications



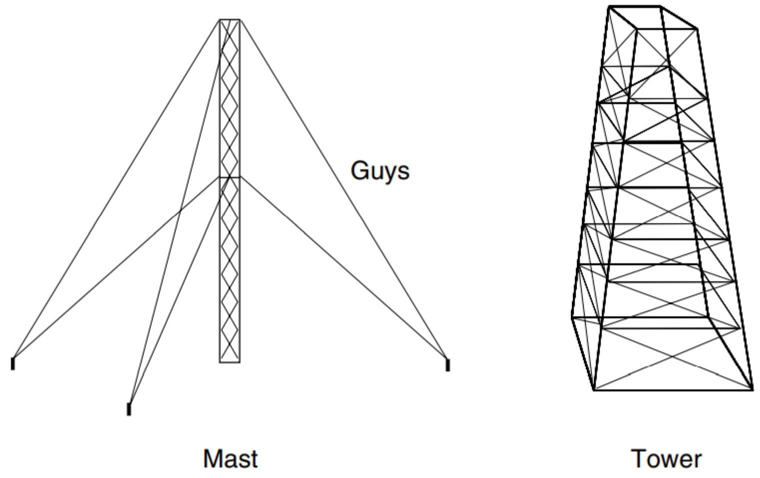
Components of a radio link

- Antenna - used to radiate or detect the electromagnetic waves.
- Transmitter - converts the voice or data signal into a modulated higher frequency signal.
- Receiver - converts the radio frequency signals back into voice or data signals.



Components of a radio link

- Antenna support structure - used to mount antennas, in order to provide a height advantage, which generally provides increased transmission distance and coverage - may vary in construction from a three-meter wooden pole to 1000 m steel structure.



- Cabling - three main types of cabling used in connecting radio systems:
  - Coaxial cable for all radio frequency connections
  - Twisted pair cables for voice, data and supervisory connections
  - Power cables.
- Interface equipment - allows connection of voice and data into the transmitters and receivers from external sources - controls the flow of information, timing of operation on the system and control and monitoring of the transmitter and receiver.

Radio spectrum and Frequency allocation

- Very strict regulations govern the use of various parts of the radio frequency spectrum.
- Specific sections of the radio frequency spectrum have been allocated for public use.
- All frequencies are allocated to users by a government regulatory body.
- No transmission is allowed on any frequency unless a license is obtained

Table *The radio spectrum for public use*

Ultra High Frequency (UHF)	Mid Band UHF	960 Mhz	800 Mhz
	Low Band UHF	520 Mhz	335 Mhz
Very High Frequency (VHF)	High Band VHF	225 Mhz	101 Mhz
	Mid Band VHF	100 Mhz	60 Mhz
	Low Band VHF	59 Mhz	31 Mhz
High Frequency (HF)		30 Mhz	2 Mhz

Radio characteristics of VHF

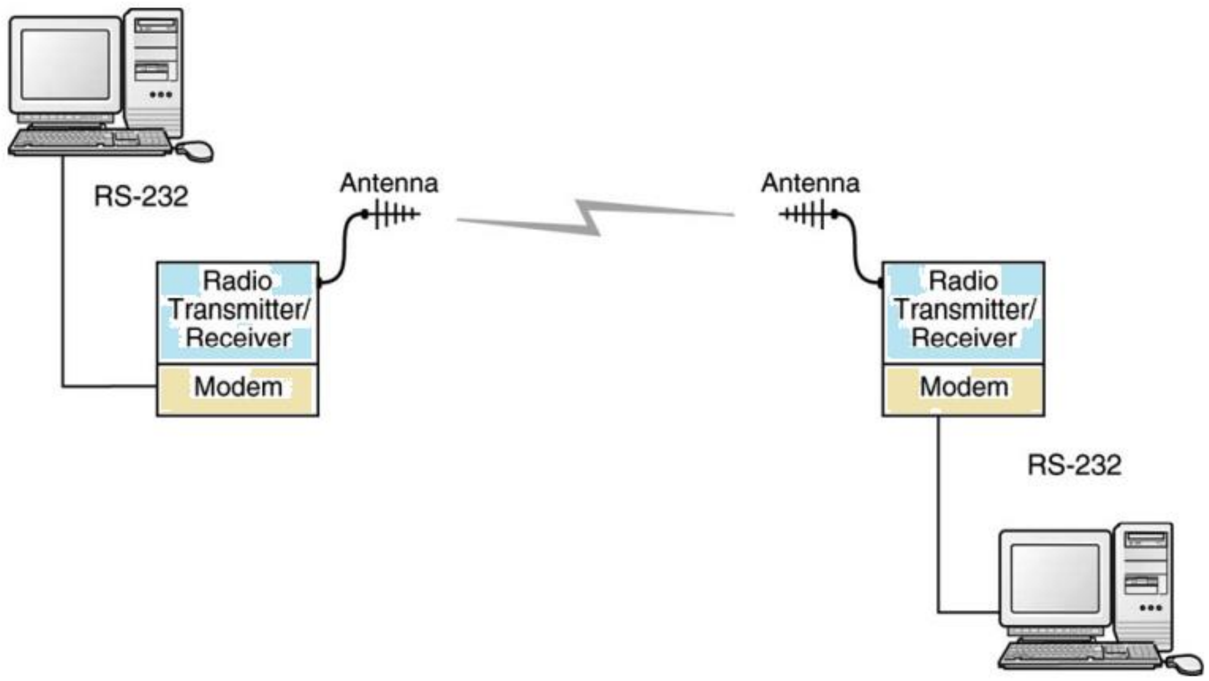
	Low band VHF	Mid band VHF	High band VHF
Propagation mode	Mostly L.O.S. some surface wave	L.O.S. Minimal surface wave	L.O.S.
Data rates	600 Baud	1200 Baud	2400 Baud
Diffraction properties	Excellent	Very good	Good
Natural noise environment	High	Medium	Low
Affected by man-made noise	Severe	Bad	Some
Penetration of solids	Excellent	Very good	Good
Fading by ducting	Long term	Medium term	Short term
Absorption by wet vegetation	Negligible	Low	Some
Equipment availability	Minimal	Reasonable	Excellent
Relative equipment cost	High	Medium	Low
Uses	- In Forested areas - Mostly mobile - Very hilly	- Very hilly & Forested areas - Mostly mobile - Over water	- Long Distance / L.O.S. / hilly areas - L.O.S. links - Mobile - Borefields - Over water

Radio characteristics of UHF

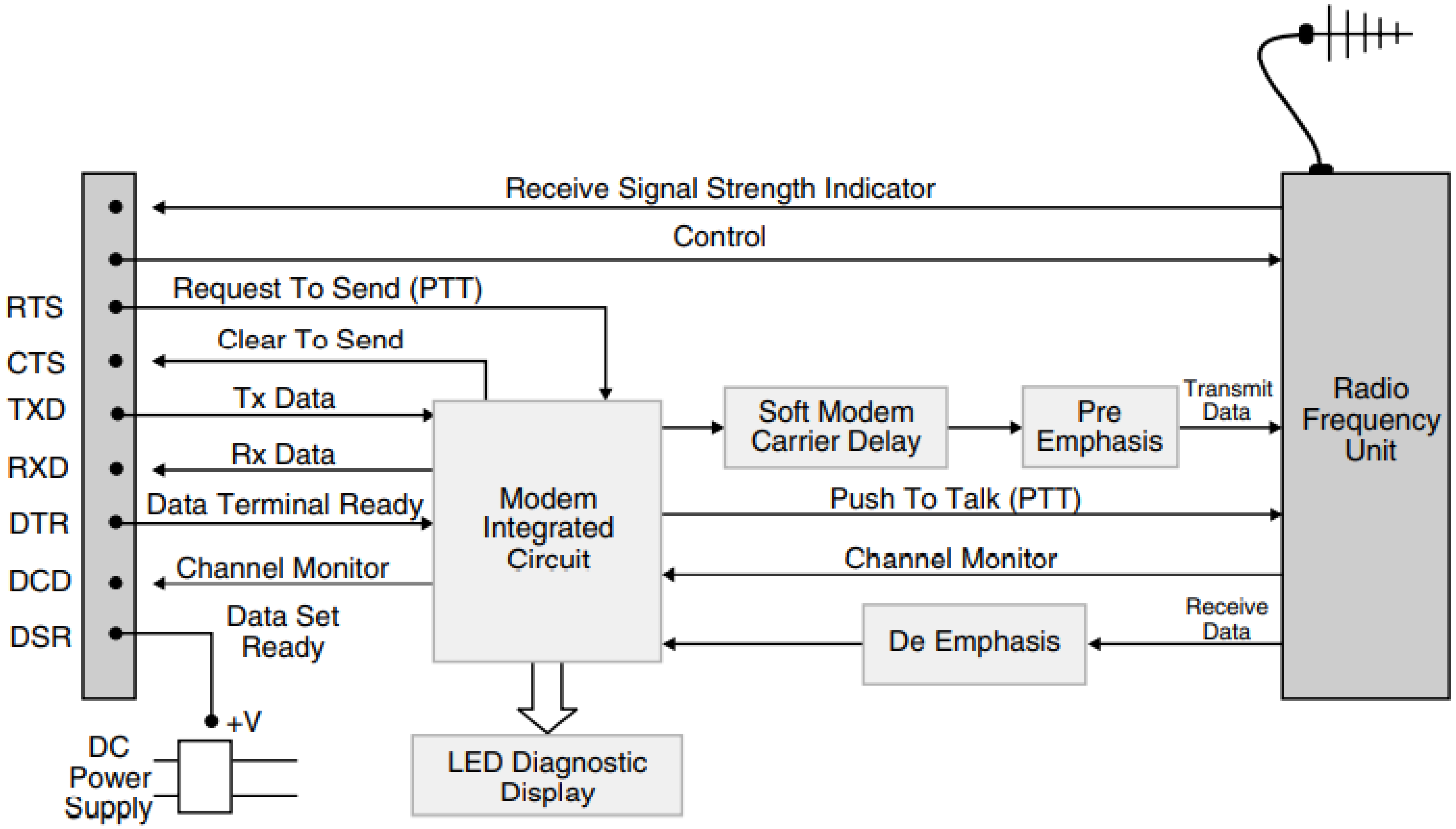
	Low band UHF	Mid band UHF
Propagation mode	L.O.S.	L.O.S.
Data rates	4800 Baud	9600 Baud
Diffraction properties	Some	Minimal
Natural noise environment	Low	Negligible
Affected by man-made noise	Low	Very low
Penetration of solids	Low	Negligible
Reflection & absorption by solids	Good (enhanced multipathing)	Excellent (excellent multipathing)
Absorption by wet vegetation	High	Very high
Interference by ducting	Some	Some
Equipment availability	Excellent	Reasonable
Relative equipment costs	Low	Medium
Uses	- Telemetry - Mobile	- Telemetry - Mobile - Links

Radio Modems

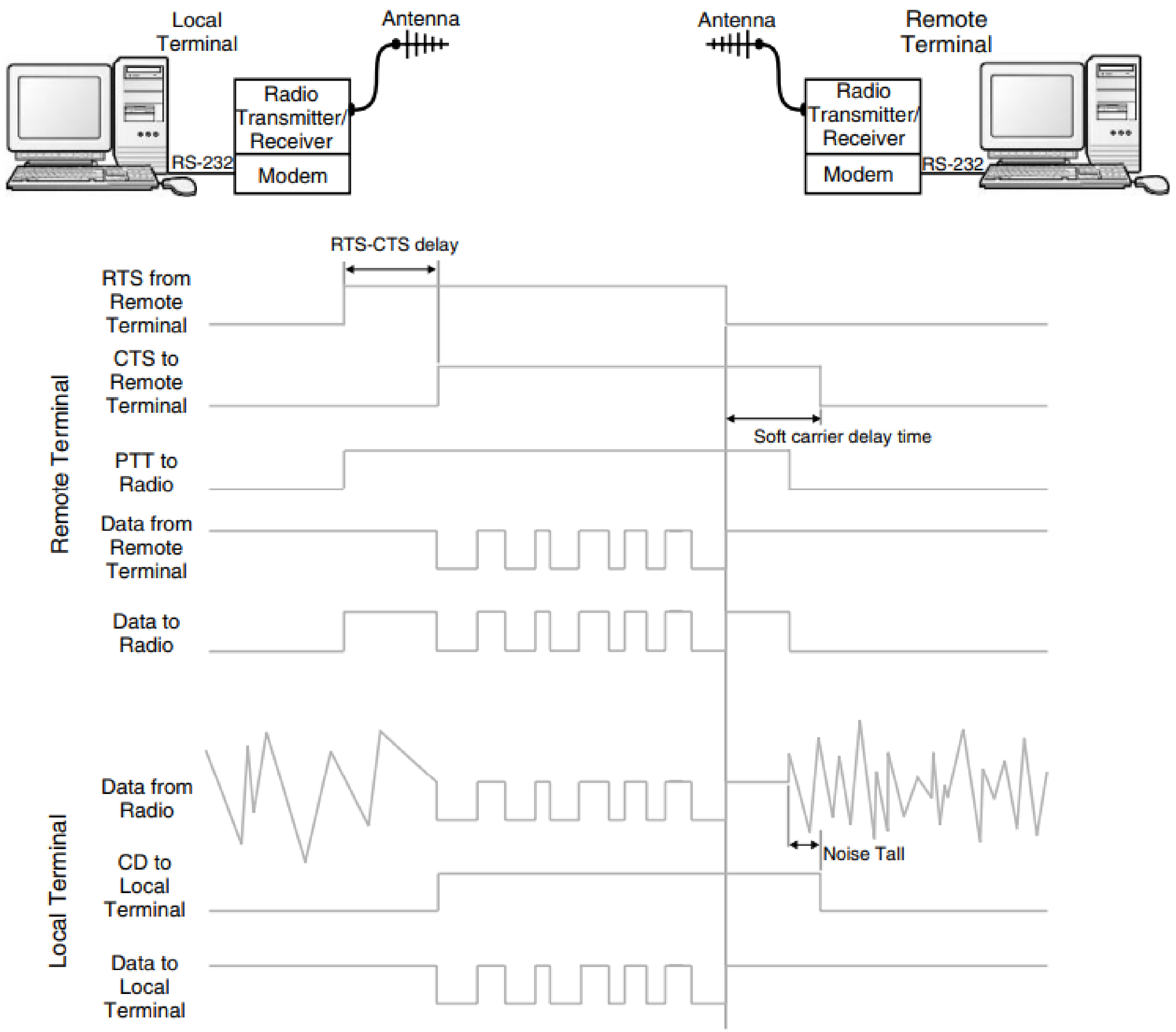
- Suitable for replacing wire lines to remote sites or as a backup to wire or fiber optic circuits, and are designed to ensure that computers can communicate transparently over a radio link without any specific modifications required.
- Modern radio modems operate in the 400 to 900 MHz band.
- Propagation in this band requires a free line of sight between transmitting and receiving antennae for reliable communications.
- A master station communicates with multiple radio field stations and use a simple poll/response technique.
- Use one as a network watchdog to periodically poll all the radio modems on the network and to check their integrity
- Interface to the radio modem is typically EIA-232 but EIA-422, EIA-485 and fiber optics are also options.



Block diagram of Radio modem



Timing diagram of Radio modem



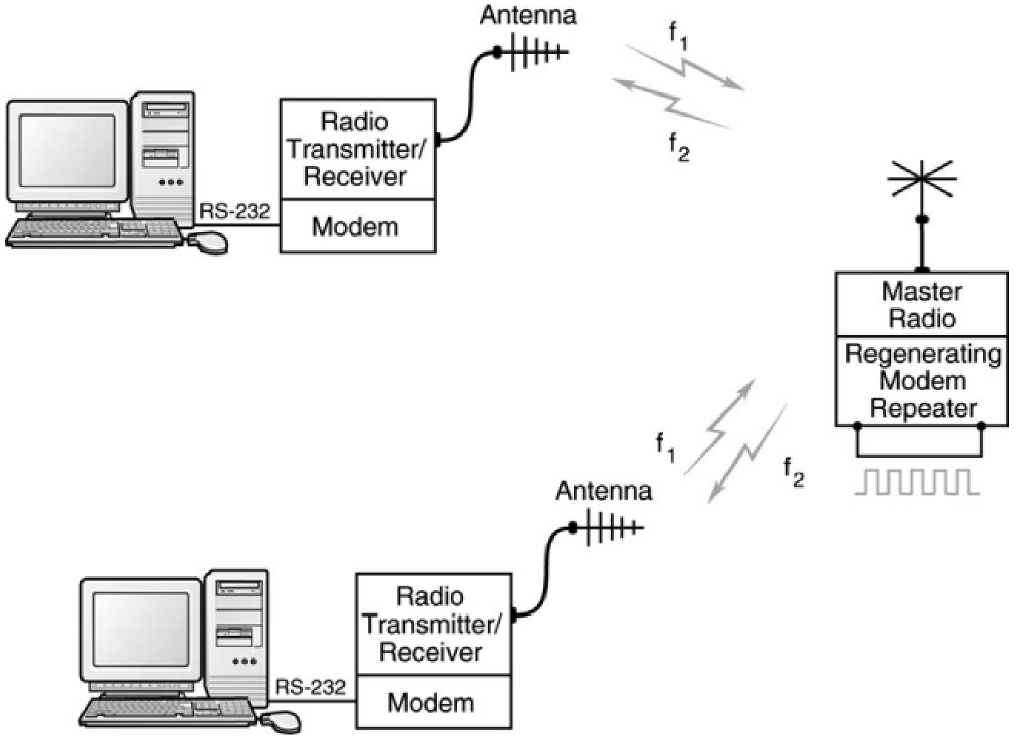
Modes of radio modems

Point-to-point system

- Can operate in continuous RF mode - has a minimal turn on delay in transmission of data
- Can operate in non-continuous mode - there is a considerable energy saving
- The RTS to CTS delay for continuous and switched carriers is of the order of 10 ms and 20 ms respectively

Point-to-multi-point System

- Operates with only the master and one radio modem at a time.
- When the data link includes a repeater, data regeneration must be performed to eliminate signal distortion and jitter.
- Regeneration is performed by passing the radio signal through the modem which converts the RF analog signal back to a digital signal and then applies this output binary data stream to the other transmitting modem, which repeats the RF analog signal to the next location.



Features of radio modems

- Transmit/receive radio channel frequency
  - Running in a dual frequency/split channel assignment
- Host data rate and format
  - Data rate/character size/parity type and number of stop bits for EIA-232 communications
- Radio channel data rate
  - Data rate across the radio channel defined by the radio and bandwidth capabilities - set at the time of manufacture.
- Minimum radio frequency signal level
  - Should not be set too low on the receiver otherwise noise data will also be read
- Supervisory data channel rate
  - Used for flow control and therefore should not be set too low otherwise the buffer on the receiver will overflow.
- Transmitter key up delay
  - Time for the transmitter to energize and stabilize before useful data is sent over the radio link - should be kept as low as possible to minimize overheads

RF Interference

- Another radio user operating close by on the same frequency as the system suffering from interference.

- Noisy transmitters that emit spurious frequencies outside their allocated bandwidth - tend to fall on other users' channel bandwidths and cause interference problems – caused by aging transmitters and those that are not well maintained.

- Intermodulation - common source of interference and generally the most difficult to locate and the most costly to eliminate.

Intermodulation

- When two or more frequencies interact in a non-linear device such as a transmitter, receiver or their environs, or on a rusty bolted joint acting as an RF diode to produce one or more additional frequencies that can potentially cause interference to other users.
- When two electromagnetic waves meet and intermodulate in a non-linear device, they produce a minimum of two new frequencies – one being the sum of the frequencies and the other being the difference of the frequencies.
- A nearby receiver may be close to one of the intermodulation frequency products, receive it as noise and interference and then could also retransmit it as further noise and interference.
- Example, if two frequencies a and b interact, then they will produce two new frequencies c and d referred to as intermodulation products.

$$a + b = c \text{ and } a - b = d$$

- c and d will be of significantly less magnitude than a and b and their exact magnitude depends on the magnitude of a and b.
- This problem is only really significant when the two transmitters for a and b are within close proximity

Intermodulation

- Intermodulation products produced at a distant location cause noticeable background noise.
- If there are more than two frequencies at one location then the number of intermodulation products possible increases dramatically.
- For example, if there are transmitters on frequencies *a*, *b* and *c* at one location then the intermodulation products become:

$$a + b = f1$$
$$a – b = f2$$
$$b + c = f3$$
$$b – c = f4$$
$$a + c = f5$$
$$a – c = f6$$

$$a + b + c = f7$$
$$a + b – c = f8$$
$$a – b + c = f9$$
$$a – b – c = f10$$

- Each frequency from a transmitter will produce a significant harmonic at twice, three times, four times, etc., its carrier frequency - lesser magnitude than the previous one.
- If the transmitter is operating on frequency a, then harmonics will be produced at 2a, 3a, 4a, etc. The 2a and 3a harmonics can be quite large.
- These harmonics are produced because of resonant properties of antennas, cables, buildings and tuned circuits in the receivers and transmitters themselves and due to harmonic side bands produced in FM

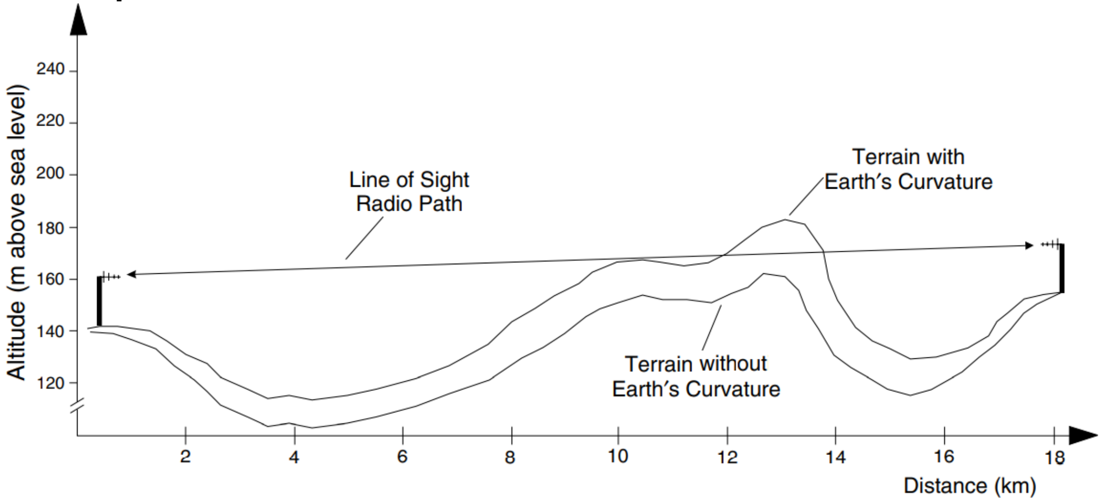
Implementing a radio link

Design methodology

- Carry out a radio path profile
- Calculate RF losses for the radio path
- Calculate affects of transmitter power
- Decide on required fade margin
- Choose cable and antenna
- Purchase equipment
- Install equipment

Radio Path Profile

- The first requirement in establishing a successful radio link is to draw up a radio path profile.
- Path profile is a cross-sectional drawing of the earth for the radio propagation path showing all terrain variations, obstructions, terrain type (water, land, trees, buildings, etc) and the masts on which the antenna are mounted.
- The first step in this process is to obtain a contour map of the location - survey maps readily available from government departments that oversee land administration and private companies that carry out surveys and publish their material.



- Locate the RTU and master site locations on the map and draw a ruled line between the two locations with a pencil.
- Then assuming that the master site is at distance 0 km, follow the line along noting the kilometer marks and where a contour line occurs and at that point, also note the contour height.

Radio Path Profile

- The surface of the earth is not flat but curved - therefore to plot the points obtained from the map directly would not be a true indication of the path.
- The height correction factor that can be applied to each point obtained from the map to mark a true earth profile plot is given by:

$$h = \frac{d_1 \times d_2}{12.75K}$$

where:

h = height correction factor that is added to the contour height (in meters)

d_1 = the distance from a contour point to one end of the path (in kilometers)

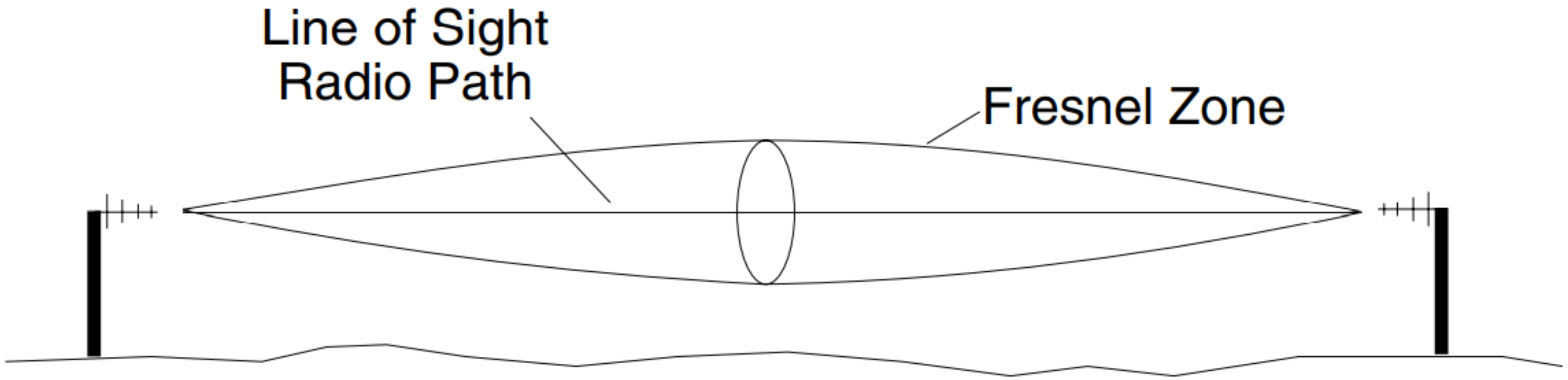
d_2 = the distance from the same contour point to the other end of the path (in kilometers)

K = the equivalent earth radius factor.

- The equivalent earth radius factor K is required to account for the fact that the radio wave is bent towards the earth because of atmospheric refraction - amount of bending varies with changing atmospheric conditions.
- For the purposes of radio below 1 GHz it is sufficient to assume that for greater than 90% of the time K will be equal to 4/3 - to allow for periods where a changing K will increase signal attenuation, a good fade margin should be allowed for.

Radio Path Profile

- The K factor allows the radio path to always be drawn in a straight line and adjusts the earth's contour height to account for the bending radio wave.
- Once the height has been calculated and added to the contour height, the path profile can be plotted – can see if there are any direct obstructions in the path.
- As a general rule, the path should have good clearance over all obstructions.
- There is an area around the radio path that appears as a cone that should be kept as clearance for the radio path - referred to as the 'Fresnel zone.'



- Fresnel zone clearance is of more relevance to microwave path prediction than to radio path prediction.

Radio Path Profile

- If from the plot it appears that the radio path is going dangerously close to an obstruction, then it is worth doing a Fresnel zone calculation to check for sufficient clearance.

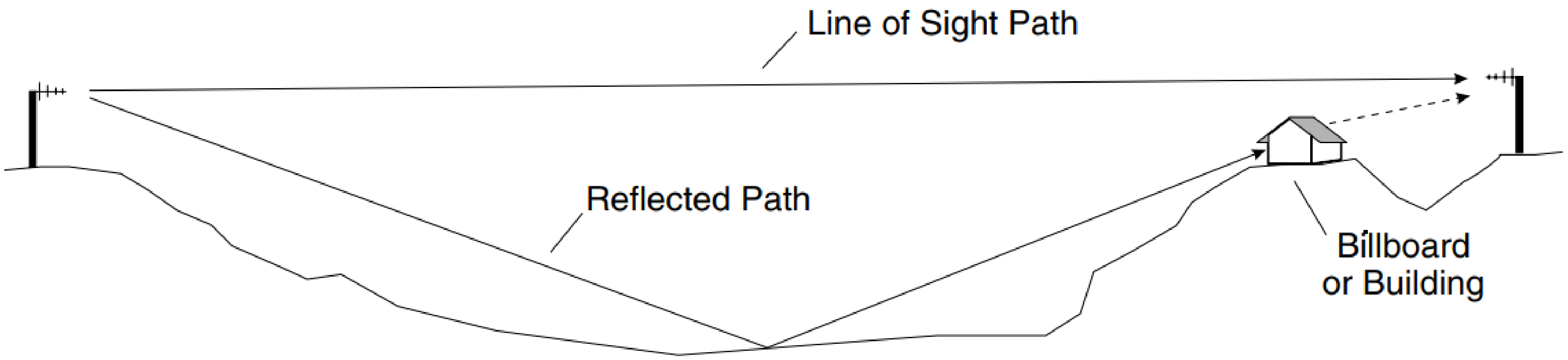
Fresnel zone clearance $F = 0.55\sqrt{\frac{d_1 \times d_2}{F(\text{MHz}) \times D}}$

Where: F = Fresnel zone clearance in meters (i.e. radius of cone)
d_1 = distance from contour point to one end of path (in km)
d_2 = distance from contour point to other end of path (in km)
D = total length of path (in km)
F = frequency in MHz

- Normally, the mast heights are chosen to provide a clearance of 0.6 × the Fresnel zone radius.
- This figure of 0.6 is chosen because it firstly gives sufficient radio path clearance and secondly assists in preventing cancellation from reflections.
- At less than 0.6 F, attenuation of the line of sight signal occurs.
- At 0.6 F, there is no attenuation of the line of sight signal and therefore there is no gain achieved by the extra cost of providing higher masts.

RF path loss calculations

- To calculate the total attenuation of RF signal from the transmitter antenna to the receiver antenna which includes: Free space attenuation, Diffraction losses, Rain attenuation, Reflection losses.
- Rain attenuation is negligible at frequencies below 1 GHz
- The strength of the reflected signal depends on the surface it is reflected off (for example, water, rock, sand).
- The reflected signal may arrive in phase, out of phase or at a phase angle in between - so reflected waves can be anything from totally catastrophic to enhancing the signal.
- Good engineering practice should always assume the worst case, which would be catastrophic failure - when designing a link, a check is made for reflections and if they exist, measures should be taken to remove the problem.
- This is done by moving antennas or masts to different locations and heights or by placing a barrier in the path of the reflection to absorb it.



RF path loss calculations

- The free space path loss can be expressed in terms of either the wavelength or the frequency.

In terms of wavelength $$\text{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2$$

In terms of frequency $$\text{FSPL} = \left(\frac{4\pi d f}{c}\right)^2$$

Where: FSPL = Free space path loss

d = distance from the transmitter to the receiver (metres)

λ = signal wavelength (metres)

f = signal frequency (Hz)

c = speed of light (metres per second)

- Path loss is expressed in terms of a direct loss in decibels.

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right)$$

d = distance of the receiver from the transmitter (km)

f = signal frequency (MHz)

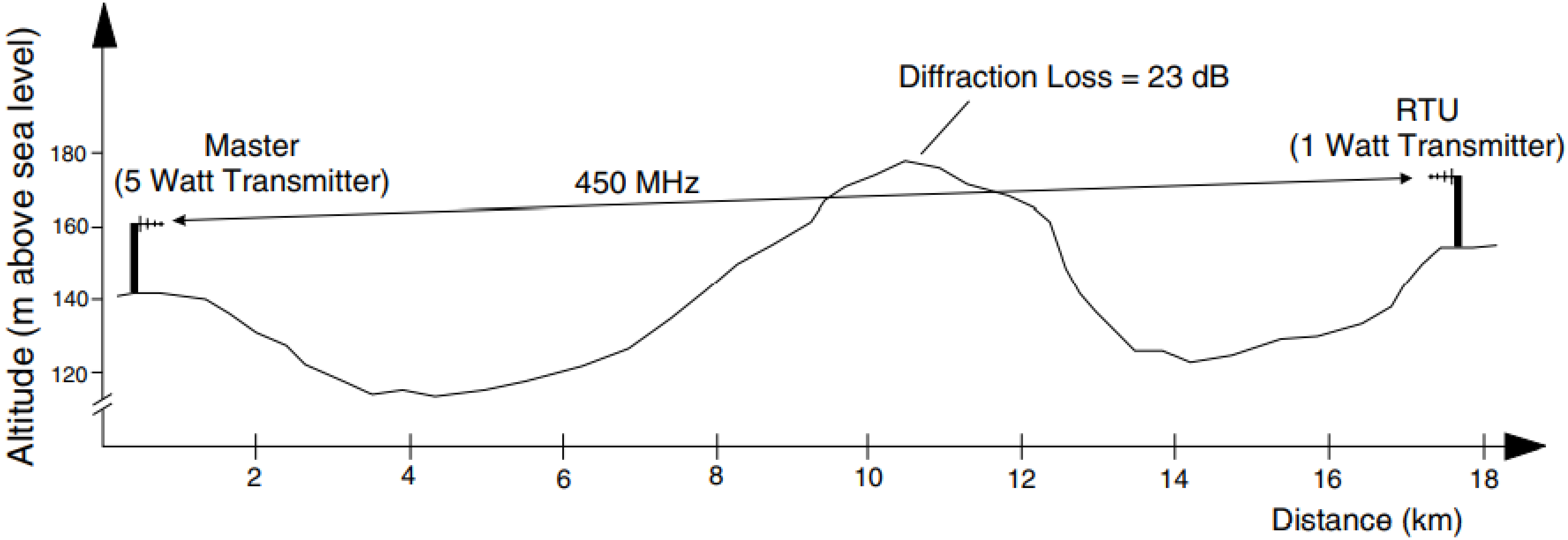
$$\text{FSPL(dB)} = 20\log(d) + 20\log(f) + 32.44$$

$$F = 20\log(d) + 20\log(f) + 32.44 - Gtx - Grx$$

Gtx = overall transmitter antenna gain including feeder losses

Grx = overall receiver antenna gain including feeder losses

RF path loss calculations



total RF loss is free space loss + *Diffraction loss*

$$\text{free space loss} = 32.5 + 20\log_{10} F + 20\log_{10} D$$

$$= 32.5 + 53.1 + 24.6$$

$$+ 110.2 \text{ dB}$$

Diffraction loss = 23 dB

the total loss = 133.2 dB

Transmitter power

- First step is to determine the gain provided by the transmitters.
- If in a link configuration one transmitter operates with less power than the other, the direction with the least power transmitter should be considered.
- As per Australian Communication Agency (ACA) regulation, requires that RTUs be allowed to transmit a maximum of 1 watt into the antenna, while master stations can transmit 5 watts into the antenna (sometimes higher), then the path direction from the RTU to the master should be considered.

$$\text{Power, } x = 10\, log_{10} \frac{P}{1\, mW}$$

For an RTU, Power = +30 dBm

Receiver sensitivity

- The next step is to determine the minimum RF level at the receiver input that will open the front end of the receiver (i.e. turn it on) - referred to as the 'receiver threshold sensitivity level' or 'squelch level' - obtained from the manufacturer's specification sheets.
- The smaller the sensitivity the better the receiver – ability of the receiver to detect radio frequency signals.
- A de facto standard is used where the RF signal is at its lowest but still intelligible - referred to as the 12 dB SINAD (signal to noise and distortion) level.
- For a typical 450 MHz radio, this level is approximately –117 dBm (from manufacturer's data sheets).
- Link's performance calculation:

Tx Pwr = Transmit power at RTU = + 30 dBm
Loss = RF path attenuation = 133.2 dB

Rx Sen = Receiver sensitivity for 12 dB SINAD = –117 dB

Available power at receiver = Tx Pwr – Loss
= + 30 – 133.2 = –103.2 dBm

- Since the receiver can accept an RF signal down to –117 dBm, then the RF signal will be accepted by the receiver - in this case, 13.8 dBm of spare RF power is available.

Signal to Noise ratio and SINAD

- A measure of the signal power level compared to the noise power level at a chosen point in a circuit - signal plus noise compared to noise.

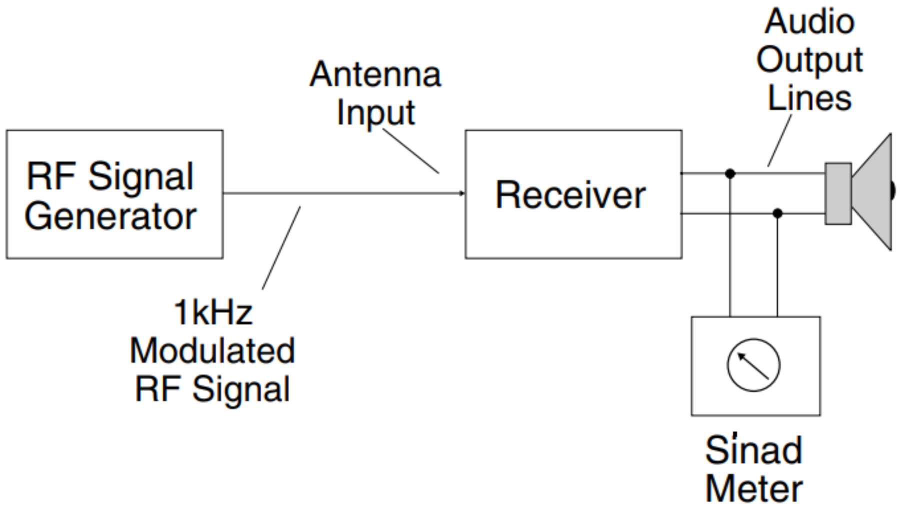
$$SNR = \frac{Psignal + Pnoise}{Pnoise}$$

$$SNR = 10\log_{10}\left(\frac{Psignal + Pnoise}{Pnoise}\right)$$

- At the radio receiver, as the receive signal at the antenna increases, the noise level at the audio output of the receiver effectively decreases.
- The highest level of noise at the audio output will be when the RF input signal is at its lowest level.
- The receiver input signal level is measured for an SNR of 12 dB at the audio output - referred to as the 12 dB SINAD level (signal to noise and distortion) - measurement is made with a device called a SINAD meter.

Signal to Noise ratio and SINAD

- The SINAD measurement is carried out by feeding the input of the receiver with an RF signal that is modulated by a 1 kHz input audio signal.
- The 1 kHz signal will produce harmonics and unwanted distortion in the audio output.
- A SINAD meter is placed at the receiver audio output which measures the power level of the 1 kHz plus the noise and distortion.
- It then filters the 1 kHz signal and measures the broadband level of noise power without the 1 kHz signal.
- It then divides the two measurements and provides a reading of SNR in dBs.
- The level at the receiver RF input is slowly increased until the SNR at the audio output is 12 dB, the RF input level is then noted – referred as the 12 dB SINAD level.
- Typical 12 dB SINAD sensitivity figures for modern radios in the VHF and UHF bands are 0.25 μV to 0.35 μV



Fade margin

- Due to degrading effects of reflections, multipathing, ducting and RF interference, a link may lose or gain signal by up to 15 dB over short or long periods of time.
- Because of this unpredictability, it is important to have a safety margin to allow for intermittent link degradation (or spare RF power) - referred to as the fade margin.
- It should be the intention to design most links to have a fade margin of approximately 30 dB - if there was a 30 dB drop in RF signal level then the RF signal at the receiver input would drop below the 12 dB SINAD sensitivity.

Fade margin = – (free space attenuation) – (diffraction losses) + (transmitter power)
+ (receiver sensitivity) + (antenna gain at master site) + (antenna gain at RTU)
– (cable and connector loss at master) – (cable and connector loss at RTU)
– (multicoupler filter or duplexer loss) + (receiver pre-amplifier gain)

Fade margin

- Example: A radio link use a 13 dB gain Yagi antenna at the RTU and a 6 dB gain omni-directional antenna at the master site with an extra 19 dB gain of the signal. The system have 20 m of 3 dB/100 m loss at each end, total connector losses of 0.5 dB at each end and a multicoupler loss of 3 dB at the master site. Find the fade margin for the link.

Total gain in the system = 13 + 19 = 32 dB

Other losses introduced by cables, connectors and multicouplers

Cables: 2 x (0.2 x 3 dB) = 1.2 dB

Connectors: 2 x 0.5 dB = 1 dB

Multicoupler = 3 dB

Total extra losses = 3 + 1 + 1.2 = 5.2 dB

Therefore the fade margin for the link is = 32 - 5.2 = 26.8 dB

Reference

1. Steve Mackay, Edwin Wright, Deon Reynders and John Park, —Practical Industrial Data Networks: Design, Installation and Troubleshooting, Newnes (Elsevier), 2004.