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4RF White Paper

Advantages of sub 3 GHz transmission

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1 Overview

1.1 Introduction

4RF specializes in the design, development and manufacture of next generation wireless point-to-point linking systems. 4RF's systems operate in licensed spectrum bands that extend from 300 MHz to 3 GHz. The company's core business is to provide state of the art digital microwave radio solutions that address the sub 3 GHz low[1] to medium[2] capacity market. The Aprisa product was launched in 1999 and in October 2003 4RF launched the Aprisa XE to extend the product range. Today, in excess of 97% of the company's revenue is generated from export sales of the Aprisa products. 4RF systems are deployed in over 130 countries throughout the world.

1.2 Executive summary

This white paper outlines the advantages of sub 3 GHz transmission in comparison to commonly used linking technologies operating at higher frequencies. The use of sub 3 GHz frequencies combined with recent technological advances has resulted in the reach of digital terrestrial radio systems being greatly extended. Distances traditionally considered unachievable with digital microwave linking are now regularly being linked with carrier class performance over distances two to three times that of higher frequency microwave.

Key advantages of sub 3 GHz transmission include largely interference-free operation in licensed bands; an inherent long distance capability; and immunity to many atmospheric conditions. Modest infrastructure requirements also result in lower capital and operational costs, leading to a low total cost of ownership.

This paper details these and other advantages offered by the use of linking systems in this spectrum. The major advantages are summarized below:

- Greater linking distances, through reduced path loss, including operation with near non line-of-sight (NLOS) conditions, and greater system gain
- Reduced susceptibility to environmental effects: precipitation (rain) fades, Harmattan and Khamsin, ducting and storms and typhoons
- Reduced infrastructure and maintenance, through reduced tower loading and reduced operational costs

As a result of these advantages and the design of new products, linking systems can now address service requirements that were previously unreachable, even in the harshest environments. A true long haul terrestrial microwave solution now exists.

[1] Low capacity is defined in this document as 2 Mbit/s and below
[2] Medium capacity is defined in this document as 2 Mbit/s to 70 Mbit/s

Sub 3 GHz advantages

- Greater linking distances
- Reduced susceptibility to environmental effects
- Reduced infrastructure and maintenance

2 Greater linking distances

The ability to link greater distances with sub 3 GHz frequencies, particularly in the 1.4 GHz and 2 GHz spectrum, can be attributed to a number of characteristics. It is the combination of these factors, alongside recent technology advancements, that make linking distances in excess of 200 km possible.

This section outlines the following key advantages offered by sub 3 GHz linking that result in the ability to link greater distances than higher frequency systems:

- Reduced path loss
- Greater system gain
- Largely unaffected by precipitation fades – covered in detail in the environmental effects section

2.1 Reduced path loss

The path losses on a link are made up of the sum of the following:

- Free space loss (FSL)
- Obstruction and diffraction loss: operation with near non line-of-sight (NLOS) paths
- Gaseous atmospheric losses

The effects of all factors listed above increase significantly as frequency of transmission increases.

Free space loss

Free space loss is the loss that would occur on a path completely free from objects or obstructions that absorb or reflect radio energy, occurring as a result of the spreading, or de-focusing of the radio wave.

Free space loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the transmitted frequency. The formula for calculating FSL in dB is:

- FSL (dB) = 20 * Log_{10} (frequency in MHz) + 20 * Log_{10} (distance in miles) + 36.6 or,
- FSL (dB) = 20 * Log_{10} (frequency in MHz) + 20 * Log_{10} (distance in kilometers) + 32.44

Table 1 shows the FSL for a recently commissioned 50 km path at various frequencies.

Table 1: Free space loss for 50 km link at various frequencies

FREQUENCY (MHz)	FSL (dB)
1450	129
2100	133
6700	143
7500	144
18000	152

Obstruction and diffraction loss: operation with near non line-of-sight paths

Sub 3 GHz frequency systems that incorporate adaptive equalization allow operation on paths with high levels of obstruction and diffraction loss. 4RF has deployed many systems in these bands with over 20 dB of diffraction loss.

The wider channel spacing and higher obstruction loss encountered in higher frequency bands means design criteria are far more strict.

Diffraction loss refers to the attenuation that occurs as a result of a Fresnel or line-of-sight (LOS) obstruction. The level of attenuation depends on the type and extent of the obstruction and the frequency of operation.

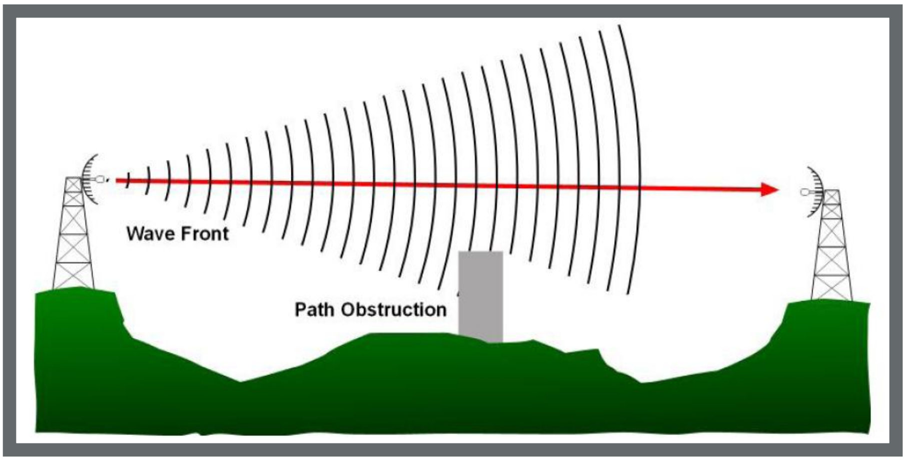


Figure 1: Example of diffraction due to Fresnel obstruction

Higher frequencies have shorter wavelengths and therefore smaller Fresnel zones. However, as the Fresnel zone is smaller, any Fresnel obstruction has a greater effect on the performance of the link.

As the frequency of operation increases the effects of Fresnel and LOS obstruction become more severe. With sub 3 GHz frequencies there is minimal loss due to Fresnel obstruction caused by buildings or trees [Ref 1].

In short, in contrast to higher frequency microwave systems, those operating at lower frequencies can accept partial and on occasion direct line of sight obstructions with various obstruction types having little or no effect on performance.

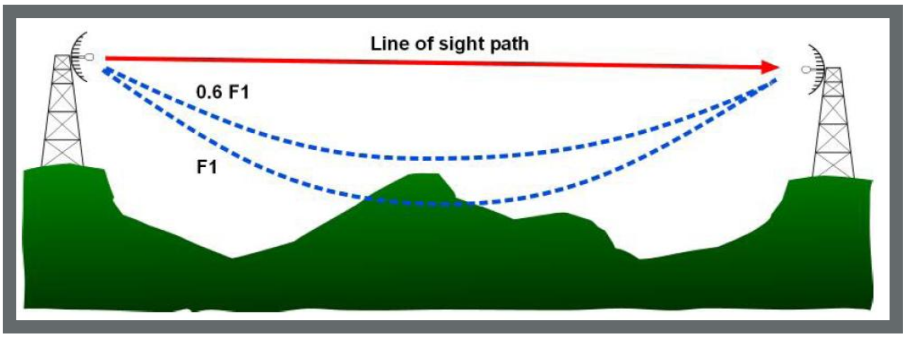


Figure 2: Fresnel obstruction outside 0.6 F1

As a rule of thumb, at higher frequencies there should be no obstruction inside 0.6 of F1 (refer to Figure 2). However with sub 3 GHz frequencies, paths providing carrier class linking are achievable with direct line-of-sight and in some cases near total Fresnel obstruction.

Experience counts in engineering successful long haul microwave links. This is especially critical where obstructed paths are being planned.

Gaseous atmospheric absorption losses

As transmissions pass through the troposphere they undergo interactions with gas molecules present in the atmosphere. These interactions cause loss of energy or strength of the transmission and hence cause attenuation.

While most gases can be ignored at typical microwave frequencies Oxygen becomes a factor at 57-60 GHz and 119 GHz. At sea level, this results in losses of 15 dB per km at between 57 GHz and 63 GHz [Ref 2].

2.2 Greater system gain

System gain for digital radio equipment is defined as the difference in dB between the output power and the receiver threshold. Receiver threshold is typically measured at the 10^{-6} or 10^{-3} BER sensitivity.

From a published specifications perspective there are different ways of expressing where the output power and receiver sensitivity are measured from. Some manufacturers measure from the transmitter output and at the receiver input, bypassing branching losses.

Lower frequency systems typically have more system gain (for the same size RF channel) because of:

- Higher output powers at the same modulation scheme
- Lower receive sensitivities at the same modulation scheme

Greater system gain allows for smaller antennas, higher availability and / or longer linking distances. The use of smaller antennas reduces installation costs, lowers mast rent and lowers costs for antennas.

Table 2 shows typical 10^{-6} BER system gain and capacity for radios using a 14 MHz channel at 16 QAM.

Table 2: system gain vs. frequency for a 14 MHz, 16 QAM system [REF 6]

Frequency (MHz)	System gain (dB)	Capacity (E1)
2000	111	22
7000	104	16

3 Reduced susceptibility to environmental effects

This section covers the major advantages offered by sub 3 GHz transmission under varying environmental effects. The key advantage of sub 3 GHz operation is the ability to significantly extend the linking distances or increase the availabilities under these conditions. In many cases where higher frequency links will fade to the point the linking system is completely lost, sub 3 GHz systems will be completely unaffected by the same condition. The main environmental challenges are:

- Precipitation (rain)
- Harmattan and Khamsin
- Ducting
- Storms and typhoons

3.1 Precipitation (rain)

Rain fade is a well known problem in microwave linking. The absorption or scattering of radio frequency energy by rain drops leads to attenuation of receive signal level on linking systems. Other types of precipitation, such as fog and snow, can also cause issues.

The effects of rain fade do not become significant until frequencies above 4 GHz are used. Figure 3 summarizes the attenuation in dB/km against frequency of transmission in ITU rain region N:

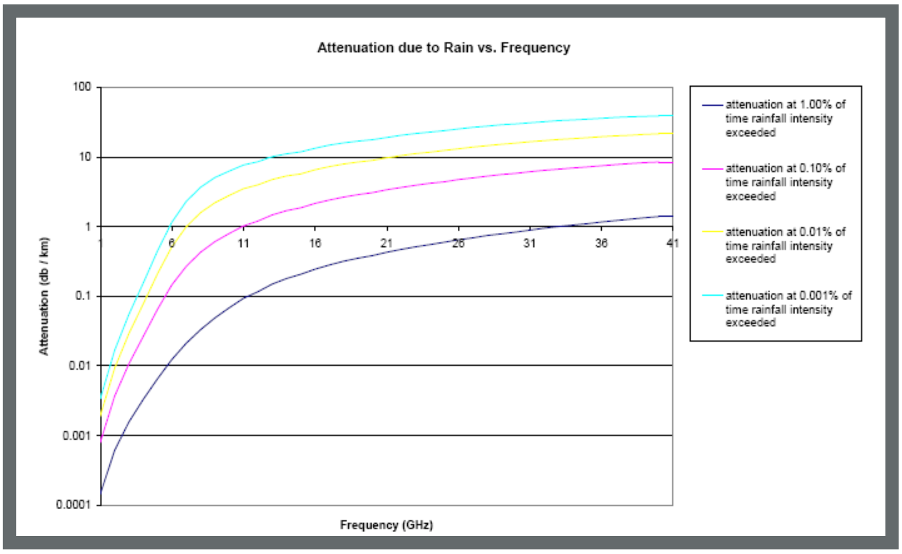


Figure 3: Attenuation vs. frequency for ITU rain climate zone N (35 to 180 mm per hour)
[Ref 3, 4, 5]

When considering a 50 km path with 60 mm/h rain rate affecting 100% of the path and using vertical polarization [Ref 5], Table 3 shows the rain attenuation.

The attenuation due to rain requires higher frequency systems to incorporate extra fade margin in areas where heavy rainfall is prevalent. In order to achieve this, larger antennas and associated expensive support structures are required, and achievable path lengths are often reduced considerably.

At sub 3 GHz frequencies rain fade can be ignored.

Table 3: Frequency vs. rain attenuation for a 50 km path

FREQUENCY (MHz)	Attenuation (dB)
2500	0.6
7000	27.2
10000	78

3.2 Harmattan and Khamsin

The terms Harmattan and Khamsin both refer to dust storms that result in a haze-like effect caused by fine dust particles (between 0.5 and 10 micrometers in size).

Harmattan refers to the West African trade winds originating in the Sahara moving south to the Gulf of Guinea and sometimes reaching as far as North America in severe cases. The Harmattan is sometimes known as 'the doctor', a nickname given in reference to its welcome cooling during oppressive heat. Harmattan occurs annually between the end of November and the middle of March.

Khamsin refers to the winds that blow from the Sahara across Egypt, or from the Arabic desert into surrounding areas. It is also commonly referred to as the 'fifty day wind', as it is believed to occur for fifty days annually. The Khamsin typically occurs in two seasons: between March and May, and between September and November. There are many other regions where similar phenomena occur, including:

- Australia
- China
- Mexico
- Mongolia
- Morocco
- Russia
- USA (the Great Plains)

There is no existing ITU recommendation for calculating the expected attenuation due to dust storms. There have been several studies conducted on working links to determine the effects of dust storms on linking systems [Ref 8].

The studies conducted confirm that linking systems experience the following symptoms during Harmattan conditions:

- Twice as many fading events occurring during Harmattan season
- Fade depth typically increasing by a factor of two to three times that experienced during normal conditions

The effects of dust storms on RF propagation are a combination of:

- Absorption and scatter of RF signal from dust particles
- Ducting due to temperature inversion

The attenuation by the dust content for a given optical visibility (dust mass density) increases with radio frequency and water content of the dust particles. Duct entrapment and fading under Harmattan conditions is a problem for microwave propagation which needs engineering attention in link planning.

Attenuation due to dust typically affects signals at, or above, 10 GHz. In the case of dust storms, visibility in terms of meters is used to calculate the resulting attenuation per kilometer. For particularly bad dust storms, visibility may be reduced to 10m. This would result in around 1.8 dB/km of attenuation assuming standard values for water content and particle size.

As with rain attenuation, transmissions at 3 GHz are less susceptible to attenuation from dust storms and the impact can largely be ignored.

3.3 Ducting

Ducting refers to the entrapment of RF energy in a ducted layer in the lower atmosphere (troposphere). Duct entrapment is caused primarily by temperature inversion (a warmer air layer sitting above a cooler air layer) and is often unpredictable and difficult to quantify during the design phase of a linking system. Ducts can generate both short term and long-term (>3 seconds in duration) refractive and reflective multipath fade outages.

The regular occurrence of strong duct entrapment layers is most prevalent in coastal areas and can make microwave transmission unreliable in certain geographic areas. The following locations are well known problem areas for ducting:

- The Gulf coast of Africa (especially Nigeria)
- The Gulf of Mexico
- India
- Arabian and Persian Gulf
- Mediterranean coastal areas
- Coastal areas in the tropics and sub-tropics

There are several problems caused by the ducting of RF signals in point to point linking [Ref 9]. The most common are:

- Variation of receive signal level
- Phase distortion due to multipath
- Interference between systems from overshoot

Variation of receive signal level

Receive signal variations occurs as a proportion of RF power is trapped within the duct. Increasing system gain, reducing link distance or increasing path inclination are typical methods used to combat the effects of ducting on high frequency linking systems.

Phase distortion due to multipath

Phase distortion occurs as a result of out of phase signals being received. The most common source of multipath is caused by reflections on the path. During ducting conditions the out of phase refracted signal can be at a higher level than the wanted in phase signal.

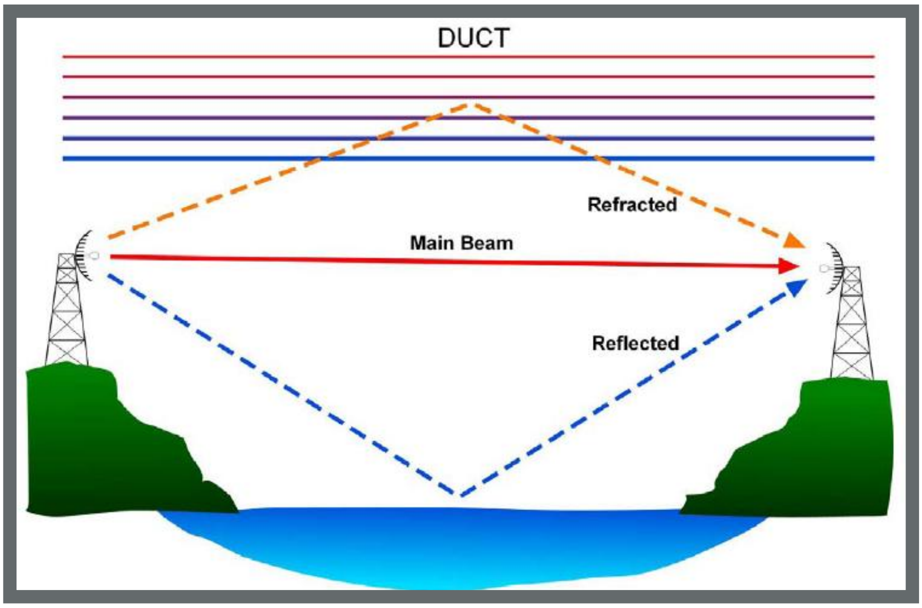


Figure 4: Reflected and refracted multipath

Interference between systems

Signals can travel much further in ducts than in normal conditions [Ref 9]. This can result in interference between co-channeled systems where interaction would normally be impossible.

Duct entrapment frequency

In order for ducting to occur, the frequency of the wave must be above a critical value, known as the minimum duct entrapment frequency. The value of the minimum entrapment frequency is determined by the physical depth of the duct and the refractivity profile (or rate of change of pressure in the atmospheric layers). Unfortunately, there is no reliable method to predict the depth of ducts before they occur.

All frequencies above 50 MHz are subject to the effects of ducting, with the effects of ducting increasing at higher frequencies [Ref 10].

3.4 Storm and typhoon activity

Table 4 outlines the seasons and average storm and cyclone events for each area:

BASIN	Season start	Season end	Tropical storms >34 knots	Tropical cyclones >63 knots	Cat 3+ tropical cyclones >95 knots
Northwest Pacific	April	January	26.7	16.9	8.5
South Indian	October	May	20.6	10.3	4.3
Northeast Pacific	May	November	16.3	9.0	4.1
North Atlantic	June	November	10.6	5.9	2.0
Southwest Pacific	October	May	10.6	4.8	1.9
North Indian	April	December	5.4	2.2	0.4

Table 4: Seasons and average storm events [Ref 7]

The challenges for RF linking in areas prone to storm conditions are a result of two main factors:

- High wind speeds
- Heavy rainfall

High wind speeds

High wind speeds cause stress to be placed on support structures. The greater the amount of surface area being presented to the wind, the greater the force exerted on the support structure. This can result in the need for large, free standing support structures in areas where storm conditions are common.

Wind gusts can also result in antennas becoming misaligned. This causes a reduction or loss of receive signal at both ends of the link.

Parabolic grid antennas used in Sub 3 GHz operation offer significantly reduced wind loading characteristics, typically in the order of one third the amount of loading for the same size solid high frequency antenna. This means that smaller support structures can be used to deploy new services or more services can be deployed using existing infrastructure without exceeding the load rating of the support structure.

Grid antennas weigh much less than solid antennas of the same size. This facilitates ease of installation and reduces haulage requirements. The reduced cost of grid type antennas results in a lower cost of deployment for services. This can result in significant reduction in the overall project costs when combined with the reduced cost of support structures.

Heavy rainfall

Rain attenuation is a well known problem in microwave linking as detailed above.

The practical outcome is that sub 3 GHz systems offer the following advantages over higher frequency systems in areas where typhoon, cyclone and storm activity is a consideration:

- Greater linking distances
- Reduced loading and infrastructure requirements
- Greater system availability during storm conditions

4 Reduced infrastructure and maintenance

Sub 3 GHz systems offer several infrastructure and operational cost advantages. The most significant of these advantages are reduced tower loading and operational costs as discussed in this section.

4.1 Reduced tower loading and requirements

The use of Yagi and small parabolic grid antennas greatly reduces the loading requirements of support infrastructure when compared with the solid parabolic antennas used by higher frequency systems

Inexpensive pole mounts or guyed masts can be used to support multiple antennas with sub 3 GHz. Solid parabolic antennas often require expensive self supporting structures.

Some points of comparison are outlined below:

- Solid parabolic antennas typically have three times the tower loading of grid antennas
- Solid parabolic antennas are often not suitable for use with guyed mast or pole mount support structures because of tower loading or excessive flex in guyed structures for narrow beam antennas
- Site acquisition can be expedited with the use of small, inexpensive support structures
- Visual impact for tourist or suburban deployment is greatly reduced with small, inexpensive support structures
- Busy or crowded support structures can continue to be used due to reduced tower loading and aperture

The overall cost of system deployment can be greatly reduced by the use of sub 3 GHz linking systems.

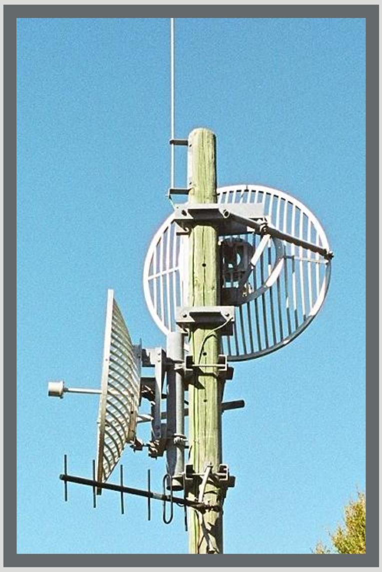
4.2 Reduced operational costs

Sub 3 GHz systems allow for significant reductions in operational and maintenance overheads. The most significant advantages are:

- No scheduled routine maintenance required - Install and forget
- No outdoor unit (ODU) maintenance
- Un-pressurized feeder systems remove compressor equipment and waveguide maintenance costs

Operational and routine maintenance costs can be measurably reduced by the use of sub 3 GHz systems.

Lightweight antennas for sub 3 GHz



5 Other linking options

Presented below is a brief summary of commonly used alternative transmission technologies.

5.1 Unlicensed point to point radio

- Distance limited by interference
- Many potential interference sources (microwave ovens, cordless phones, wireless LANs)
- Poor security and variable performance (availability affected by other users)
- Quick to deploy (no licence required)

5.2 High frequency (>6 GHz) digital microwave radio

- Subject to Harmattan, rain and other precipitation fades
- Extensive Infrastructure requirements (towers)
- High Antenna costs (solid parabolic antennas)
- Suitable short haul solution, high capacity solution
- OPEX costs (outdoor unit maintenance)

5.3 Satellite infrastructure

- Lowest bandwidth with high operational costs
- Susceptibility to climatic conditions
- Suffers from sun outages
- Capacity challenges – satellite asymmetry (medium downlink and low uplink speeds)
- High latency

While the technologies outlined above have specific applications to which they may be well suited to, the use of sub 3 GHz frequencies in combination with spectrally efficient modulation schemes makes 4RF linking systems flexible enough to address most applications. The interfacing options support voice, TDM and Ethernet requirements on a single platform, removing the requirement for external equipment.

6 Summary

The points above can be summarized in one sentence:

Sub 3 GHz linking systems allow users to connect greater distances whilst enjoying a lower cost of deployment.

The advantages offered in terms of availability, distance and near NLOS operations combined with the reduced infrastructure requirements result in more site options and lower costs to deploy services.

It is critical to get early advice in planning any long haul microwave radio system. Numerous economic and engineering trade-off considerations are possible when designing systems to address transmission in adverse linking environments. Sound advice from a reputable supplier with specialised path engineers is crucial to achieving the optimum long term solution with lower capital and operations costs.

7 References

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[10] ITU/INA Workshop: Spectrum Monitoring measurements and techniques – Space wave propagation

About 4RF

Operating in more than 130 countries, 4RF solutions are deployed by oil and gas companies, international aid organisations, public safety, military and security organisations, transport companies and utilities, broadcasters, enterprises and telecommunications operators. All 4RF products are optimised for performance in harsh climates and difficult terrain, and support legacy analogue, serial data, PDH and IP applications.

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