Report to Estimate the performance of a RF Link down a tunnel at 2400 MHz

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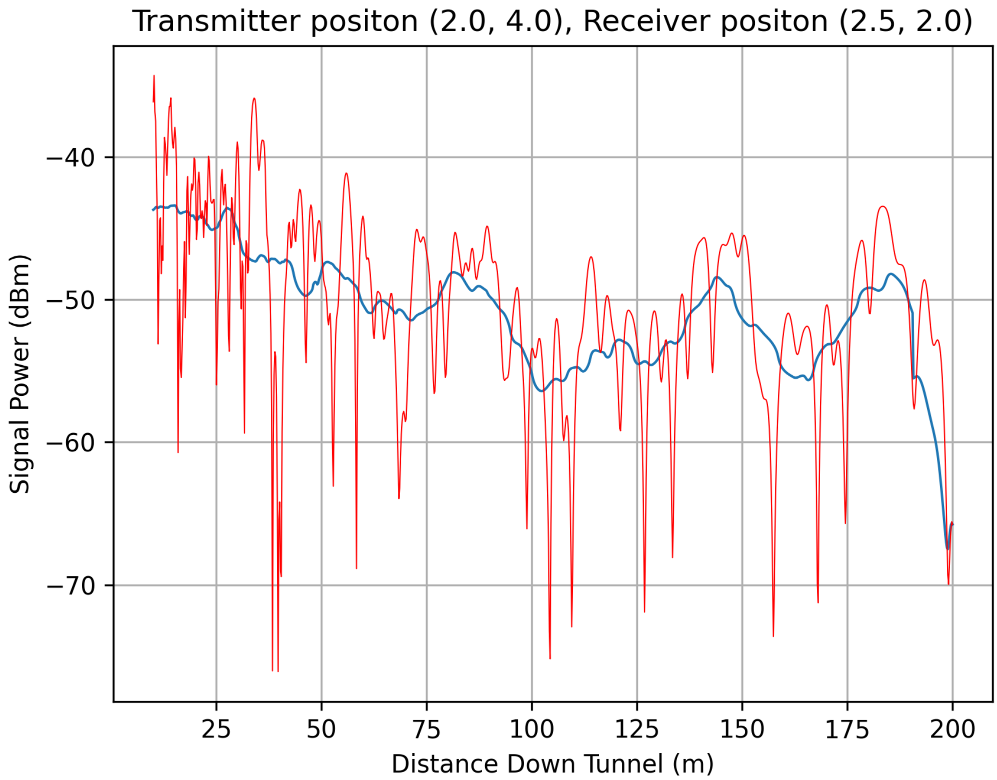
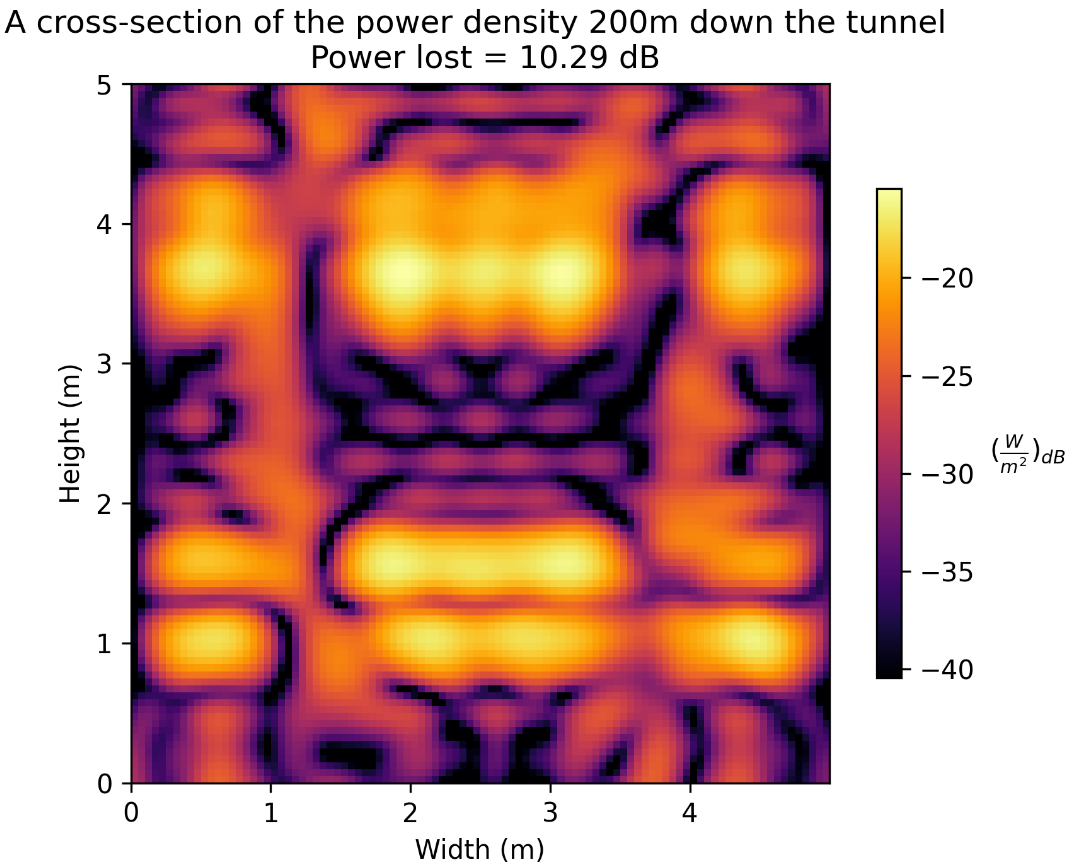
1. Your Results

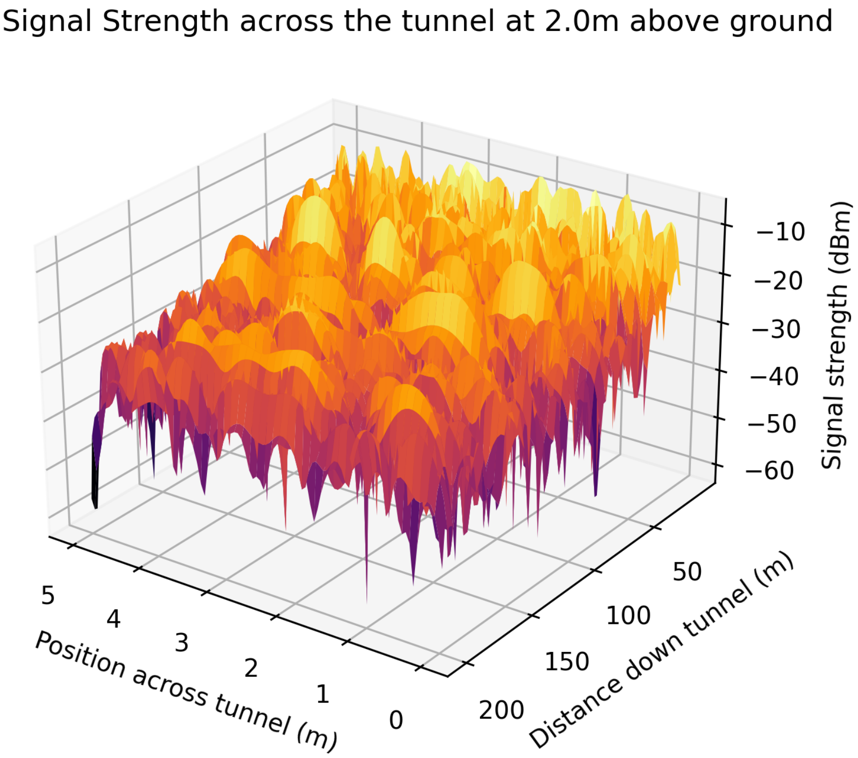
The link and environmental considerations for your simulation were as follows:

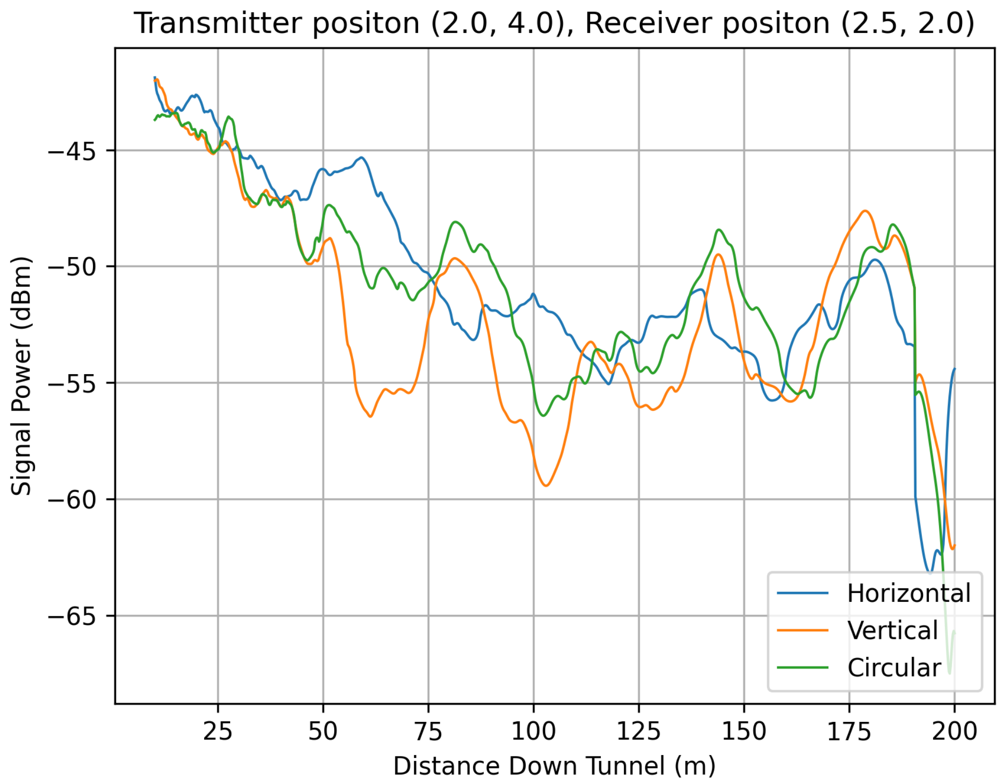
Tunnel Dimensions	Value
Height	5.0 m
Width	5.0 m
Length	200.0 m
Electrical parameters of the walls	**Value**
Conductivity	0.02 S/m
Relative permittivity	12.0
Roughness	4.0 mm RMS
Tilt	0.0 degrees
Frequency Channel	**Value**
Frequency	2400.0 MHz
Transmitter parameters	**Value**
Antennna Gain	9.0 dBi
Transmit Power	20.0 dBm
Height above ground	4.0 m
Distance from wall	2.0 m
Receiver parameters	**Value**
Antennna Gain	4.0 dBi
Sensitivity	-60.0 dBm
Height above ground	2.0 m
Distance from wall	2.5 m
Distance along tunnel	200 m

The performance graphs generated by the application follow. Use the explanation in section 2 to interpret the results


Transmitter positon (2.0, 4.0), Receiver positon (2.5, 2.0)
Signal Power (dBm)
−40
−50
−60
−70
25
50
75
100
125
150
175
200
Distance Down Tunnel (m)


A cross-section of the power density 200m down the tunnel
Power lost = 10.29 dB
Height (m)
Width (m)
0
1
2
3
4
5
−20
−25
−30
−35
−40
$(\frac{W}{m^2})_{dB}$


Signal Strength across the tunnel at 2.0m above ground
−10
−20
−30
−40
−50
−60
Signal strength (dBm)
5
4
3
2
1
0
Position across tunnel (m)
50
100
150
200
Distance down tunnel (m)


Transmitter positon (2.0, 4.0), Receiver positon (2.5, 2.0)
−45
−50
−55
−60
−65
Signal Power (dBm)
25
50
75
100
125
150
175
200
Distance Down Tunnel (m)
Horizontal
Vertical
Circular

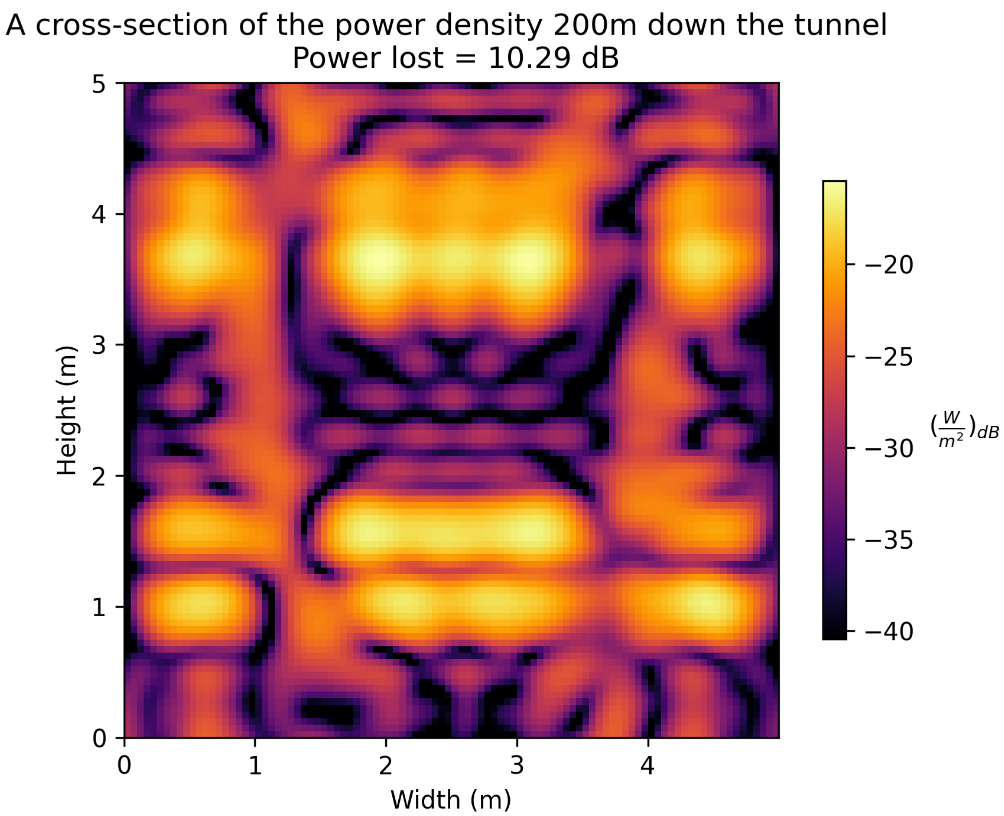
2. Interpreting the plots

Estimating the performance of a link in a tunnel is an extremely complex undertaking as there are many factors that influence the link. These factors include:

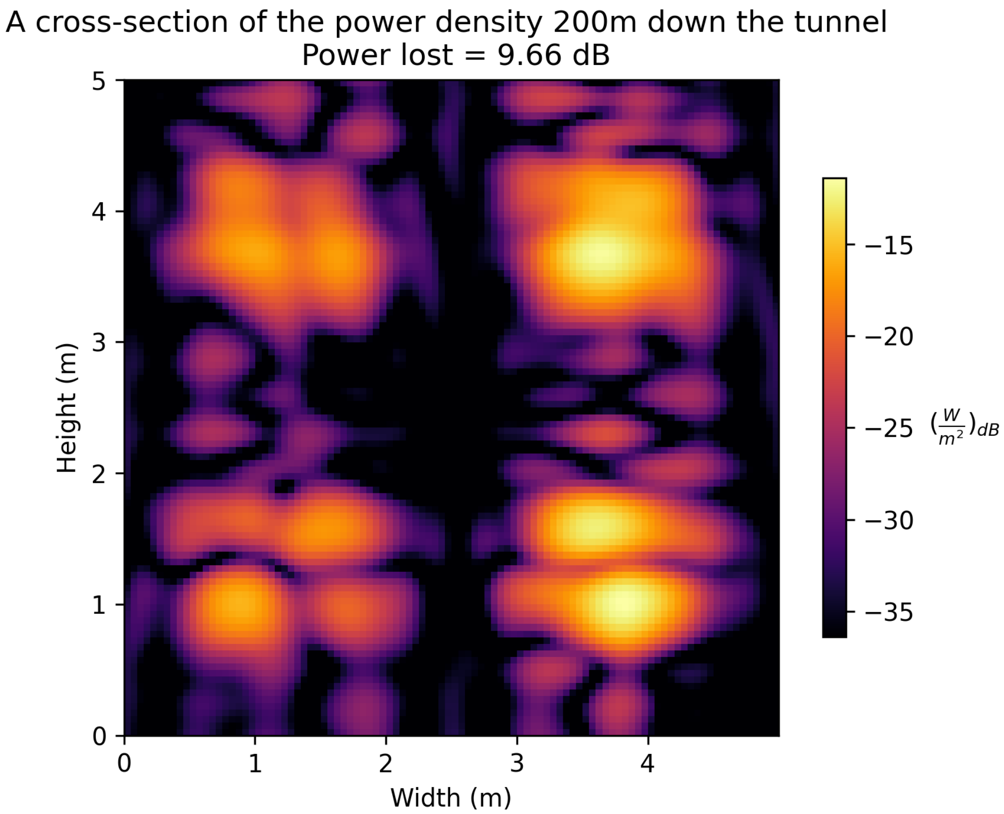
- Frequency of operation
- Polarisation of the antennas
- Electrical properties of the walls(conductivity and permittivity)
- Wall roughness
- Wall tilt
- Tunnel dimensions
- Transmitter and receiver position within the tunnel
- Plus many others

This application produces 4 plots that illustrate the signal strength in a tunnel under various conditions. The interpretation of each of these plots will be discussed.

2.1. Tunnel cross-section power density



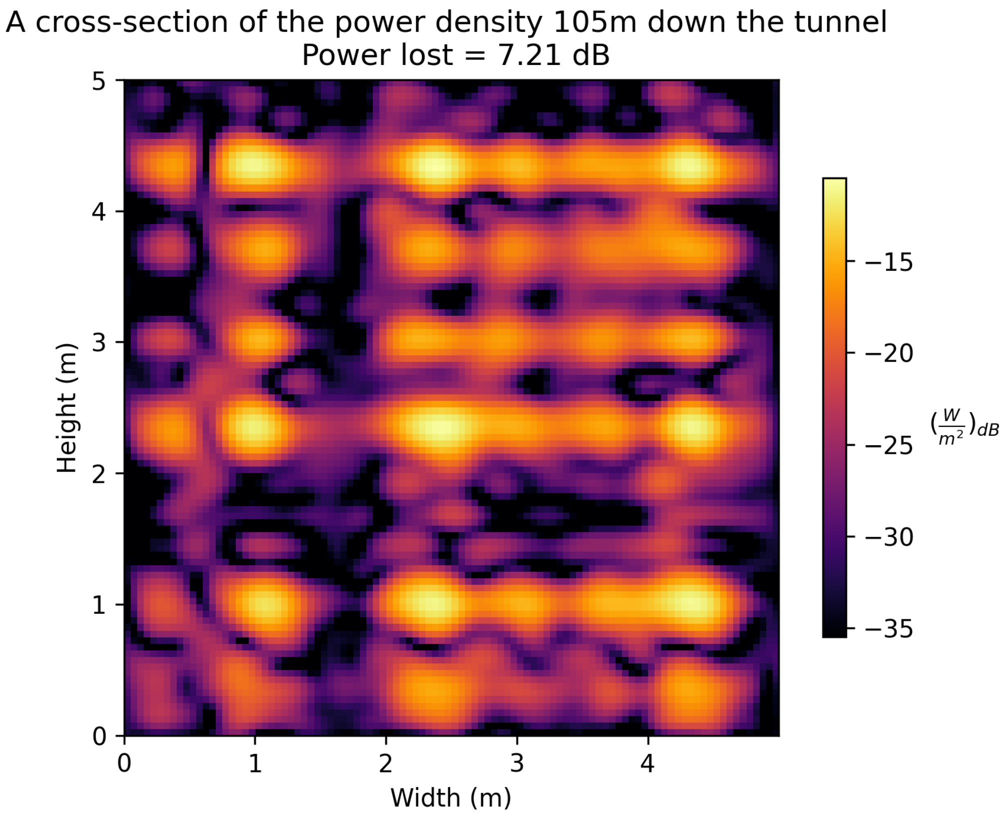
This plot shows the distribution of power across the tunnel at a given distance from the transmitter. One can see that power is concentrated in certain parts of the tunnel cross-section and is weak at others. There are many factors that influence the power distribution, such as tunnel dimension, frequency of operation, properties of the tunnel walls, position of the transmitter etc.). For example, moving the transmitting antenna towards a wall results in the following power density distribution.



The power lost in the signal as it propagates down the tunnel is reported in the title of the plot. In the first example, 13 dB of the transmitted power is lost (due to absorption in the walls, roughness and so on.). In the second example where the position of the transmitter was moved, the power lost was only 1dB.

So, what can be learnt from such a plot?

We can see that the received signal will vary depending on where the receiving antenna is placed. There is little point in using a plot at 50m (say) down the tunnel to position the receiver because a little further down the tunnel the power distribution could change markedly. By way of example, the following plot shows the power density distribution due to the off-centre transmitter at 105m down the tunnel.



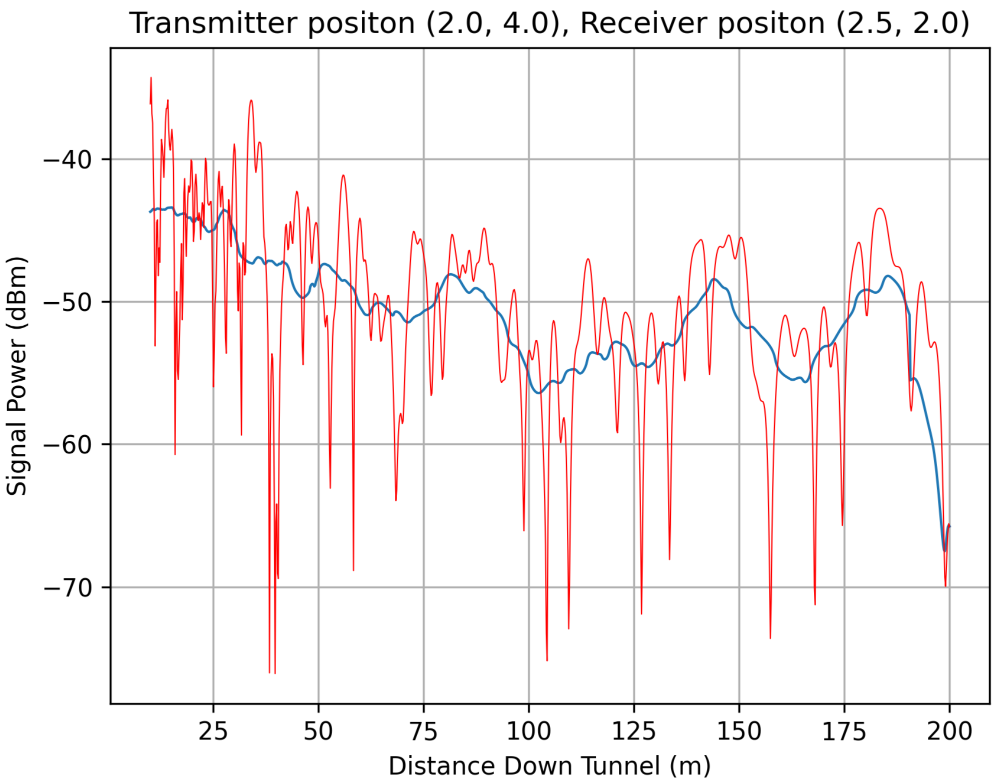
One thing is clear though, you do not want to position the receiving antenna too close to a side wall.

When interpreting the performance of a link using the above plots one must remember that these plots are of power density (W/m^2). An antenna has a property called its effective aperture which is given in m^2. When an antenna is positioned at a point in the cross -section of a tunnel, the signal it receives is not just the signal at that point. Rather it is the sum of all the 'power density values' * that lie within the effective aperture of the antenna. So, positioning an antenna where the power density is very low does not necessarily imply that the received signal will be too weak to use. It may well be that the power density close to the antenna is high and within the effective aperture of the antenna in which case the received signal may be satisfactory. In the unfortunate situation where the signal is low within the entire effective aperture you can expect a severe dip in the received signal (an example of a slow fade)
The effective aperture of an antenna is directly proportional to its gain, the higher the gain, the larger the effective aperture. So, using high-gain antennas in tunnels has an advantage.

* The sum of the power density multiplied by the effective aperture

2.2. Signal strength versus distance down the tunnel

As one moves a receiver down a tunnel, the signal power that it receives changes. This fact should be obvious from the discussion on the cross-section power density plots and experience.



This plot is produced under very specific conditions in the application. The transmitter is kept at a fixed position. The receiver is kept at a fixed position within the cross-section of the tunnel and is moved only down the tunnel. If the receiver could move about within a cross-section as one moved down the tunnel another result would be expected.

The plot shows the signal strength in red (in fine position increments) and the average signal strength in blue. You can see that the magnitude of the signal varies very quickly near the tranmitter and less so as one moves down the tunnel. The reason for this is that close to the transmitter signals are being reflected all over the place and they are strong enough to cause havoc. As one moves down the tunnel, so these signals decay and interact more weakly with the dominant propagating signal[**]. So the signal becomes more stable.

From the graph one can see that measuring the signal at one place and then moving down the tunnela bit can cause a drastic change in received signal strength.

This is one reason that it is extremely difficult to assess the quality of an antenna in a mining environment. One antenna may just be unlucky be positioned in a deep fade and end up with a bad rating.

The signal behaviour reported is the signal one would get if everything in the tunnel remained absolutely still. If anything moves in the tunnel, the field distribution changes and you can get a different reading. This is the reason that when doing real life measurements the reading always fluctuates a bit. It can fluctuate drastically if something close to the receiver or transmitter moves.

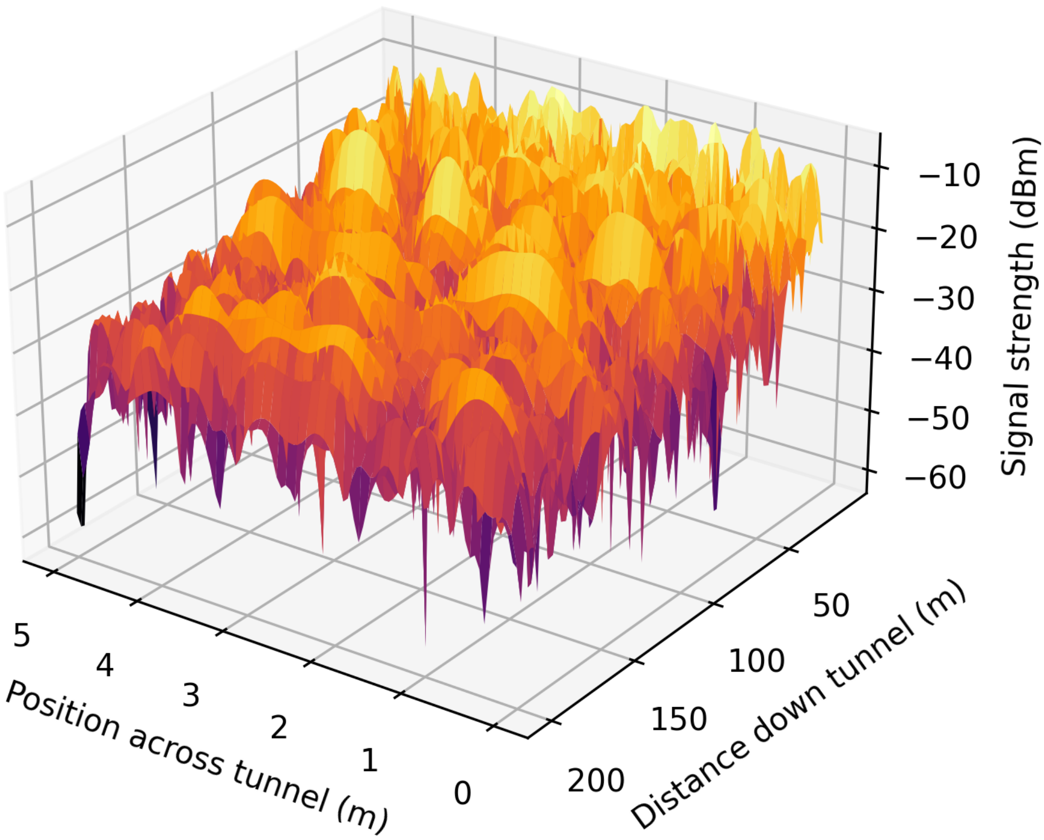
[**]The higher order modes decay relatively quickly leaving only a few dominant modes.

2.3. 3D power density at the receiver height

In this plot, the position of the transmitter is fixed. The height of the receiver is fixed but its position across the tunnel is varied as is its distance down the tunnel.

This figure gives an appreciation of the variation of the signal strength within the tunnel. There are peaks and troughs all over the place showing that communicating down a mine can be a bit unpredictable at times. One clear observation from this plot is that it is best to keep antennas as far away from the walls as possible, but we saw this in the first plot so nothing new.

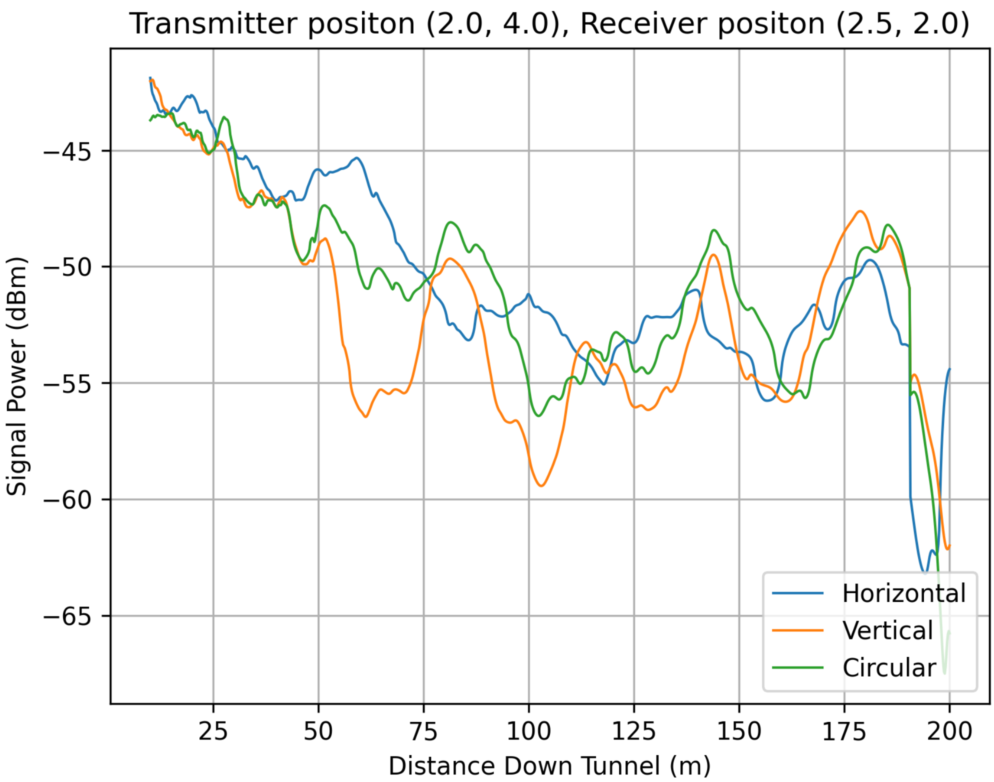
Signal Strength across the tunnel at 2.0m above ground



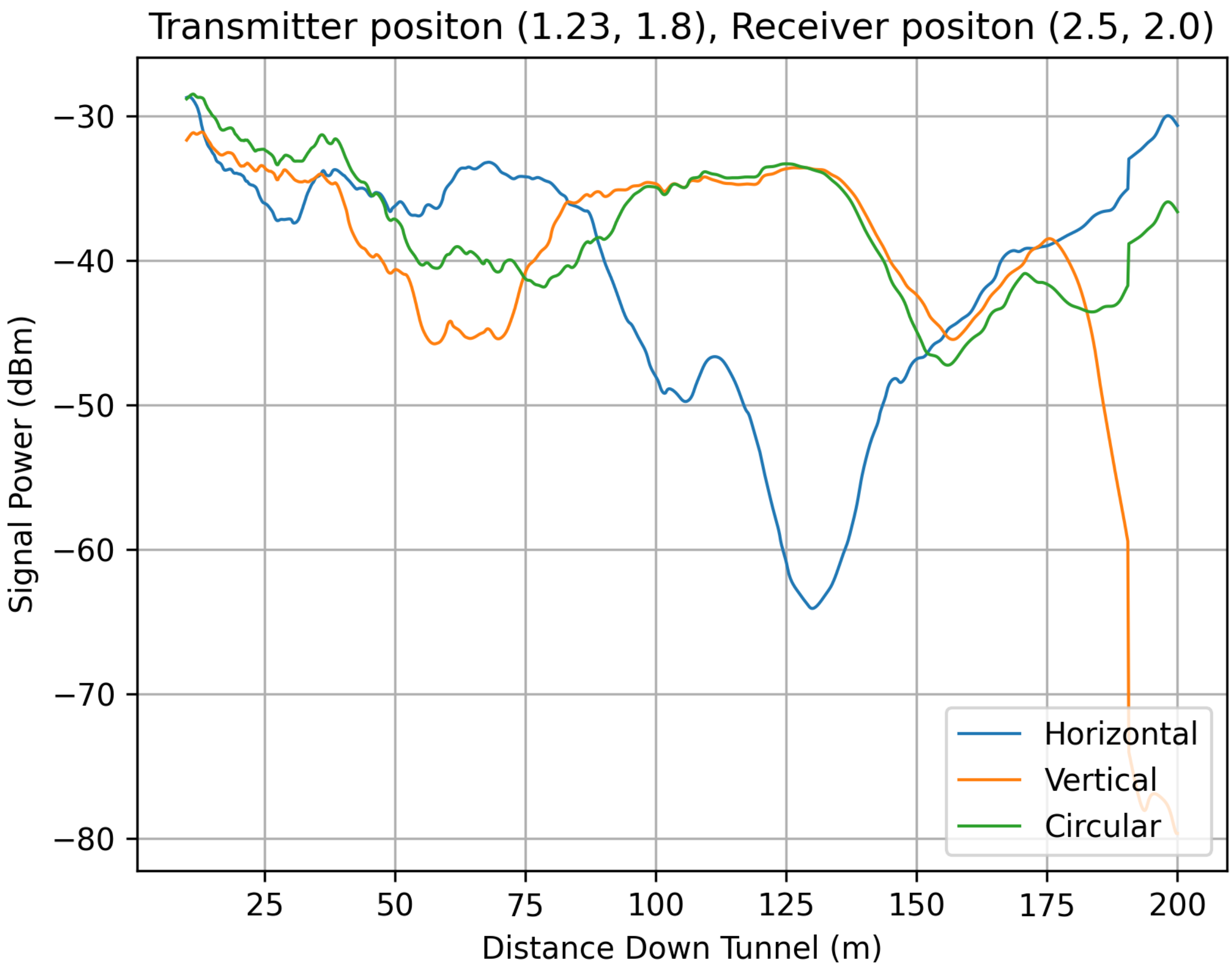
2.4. Comparing the performance of antennas with different polarisations in a mining environment

We have seen that the mining environment has a severe effect on the propagation of a radio signal. This is due to physics and there is nothing that can be done about that. So, what can we do to improve matters?

The following plot shows the signal variation over distance down the tunnel using linearly and circularly polarised antennas. The graph in green represents the performance of a vertically polarised antenna, cyan is for horizontal polarisation and red is for a circularly polarised antenna. The circularly polarised antenna's performance is generally better then either of the linearly polarised options.



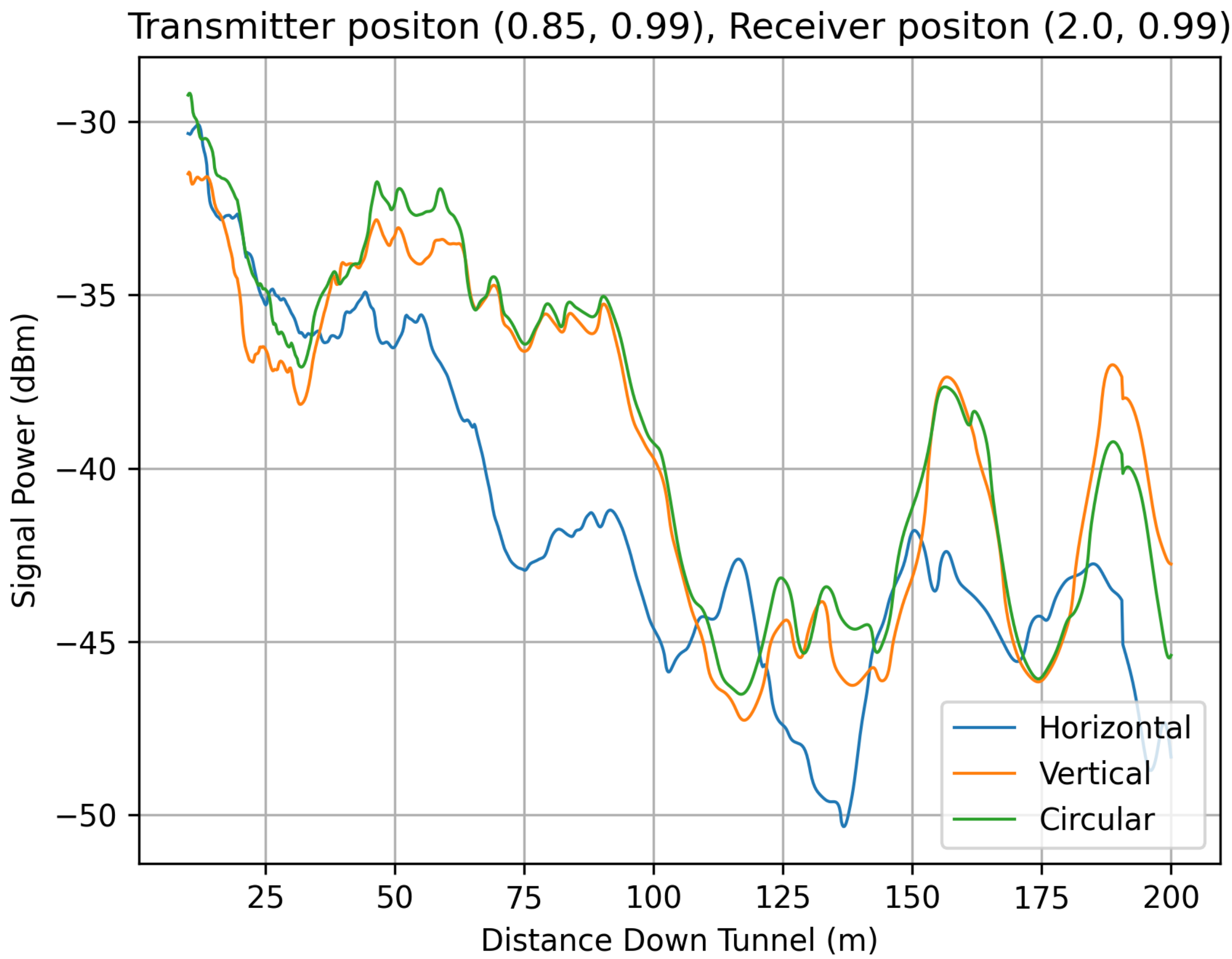
The explanation as to why circular polarisation in the above case is better is difficult to explain. There is a more obvious explanation when considering the graph below.



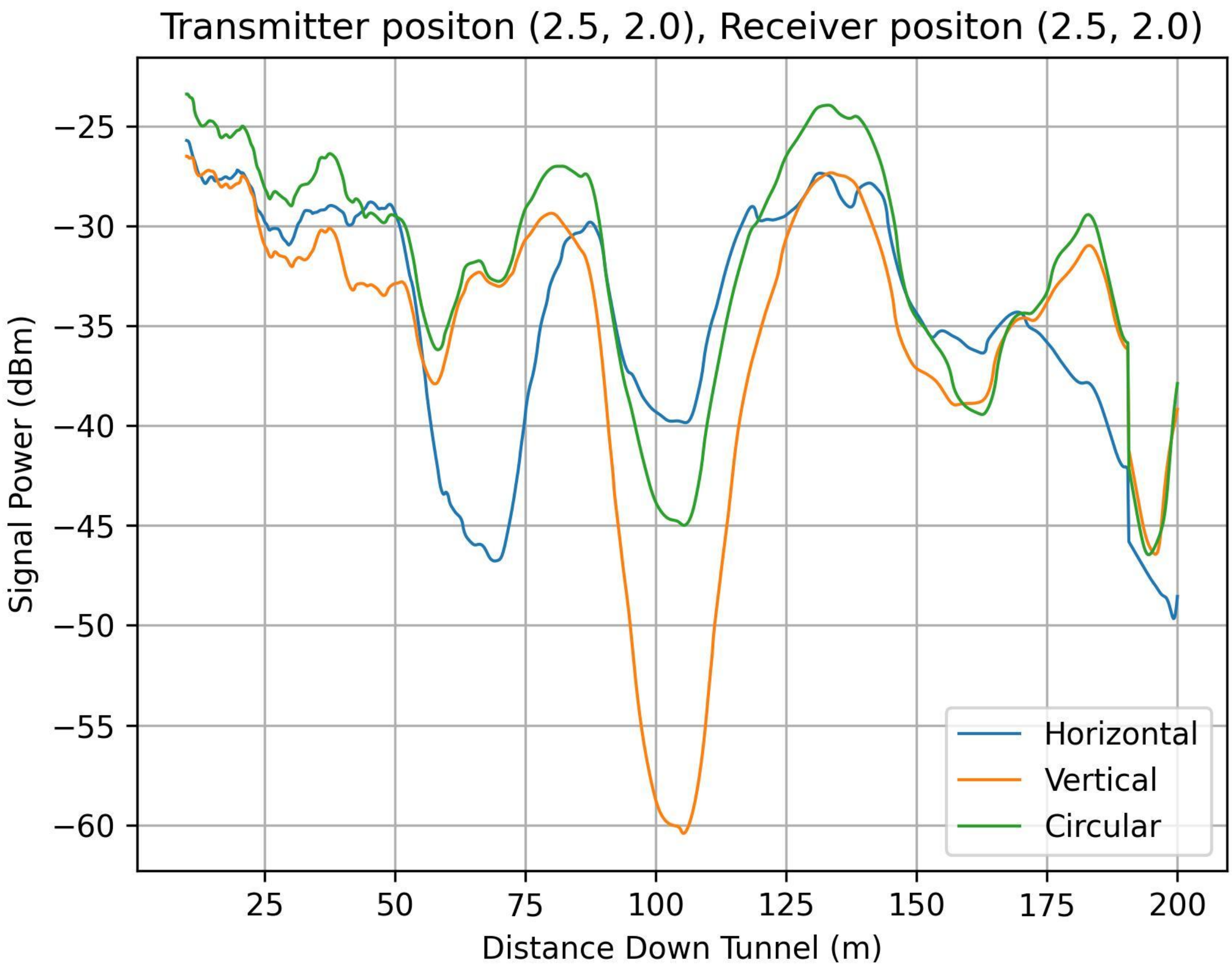
This is a tunnel in which horizontally polarised waves do not propagate well. A circularly polarised antenna can detect all linearly polarised waves (irrespective of their orientation with respect to the ground) with only a slight degradation in received signal strength. So, it has no problem with either vertically or horizontally polarised waves.

Had we chosen to use a horizontally polarised antenna in this tunnel, communications would be very poor. Choosing a vertically polarised antenna would be much better and very much the same as choosing a circularly polarised antenna.

It is not always the case that circularly polarised antennas are as good as a linearly polarised antenna. For example, consider the following graph,



Here it would be advantageous to choose a horizontally polarised antenna, a disaster to choose a vertically polarised one, and fair performance would be achieved using a circularly polarised antenna; however, the choice is not always this clear cut. Consider the following:



From 110 to 150m, a horizontally polarised antenna would be best. From 150 to 190m it would be better to choose a vertically polarised antenna. Choosing a circularly polarised antenna does not outperform the linear antennas at all points along the tunnel, but its behaviour is certainly the more consistent of the 3 options.