A theoretical path design for long range over ocean microwave

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Abstract- This paper presents the culmination of ten years of research into propagation inside the tropical maritime evaporation duct. The results of this research are used to develop a theoretical path design for an over ocean microwave radio system and this design is compared with results from an actual deployed system.

I. INTRODUCTION

Measurement and simulation of the evaporation duct over warm tropical waters in the Australian littoral zone have shown that an oceanic duct is present for a significant part of each day over the full year. This duct is capable of maintaining signals over paths of up to 100 km with a predicted reliability exceeding 50%. Such systems could be used for store and forward transmission of non-time critical data. In order to maximise the availability of such systems careful link planning is necessary. Such a link could be used to transmit store and forward non time critical data between platforms at sea or from sea to land and vice versa. This paper draws from ten years of research in order to provide what the authors believe is the first published comprehensive theoretical methodology for planning a link using the duct as a communications channel and compares this to a link established on the Great Barrier Reef by James Cook University.

II. METEOROLOGY

In order to use the duct to support a communications channel we first need to have an idea of its height and its persistence. In [1] the authors report on a campaign of measurements that resulted in the diagram shown in Fig. 1. From this diagram we can gain an understanding of duct heights and the percentage of time they are prevalent.

In Fig. 1 the solid curve is for the equatorial West Pacific in February, the purple, dashes and dots, curve is for the Coral Sea in May and the pale blue, dashed, curve is for the coastal region around Lucinda, Queensland in October. From this data the authors established that the upper extent of ducts was 40 metres and a duct height of 20 metres was exceeded for approximately 50% of the time. Using this data and given the variability of duct heights we will use a height of 20 metres as our design height.

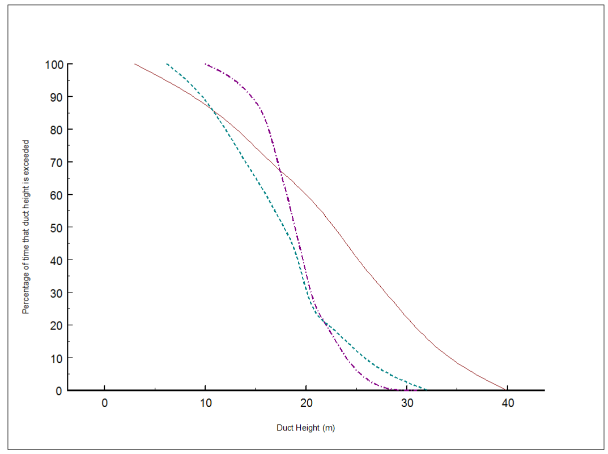

Figure 1. Duct height statistics for the North Eastern Australian littoral

One final piece of information not clear in Fig. 1 is that the reliability of the measuring equipment decreased with duct height. Ducts of around 10 metres and below are difficult to measure and are unstable, thus from this data we can establish that a reliable duct is only available for 90% of the time.

Other factors affecting the reliability of the path are duct strength, which is a function of atmospheric bulk parameters [2], wind and rain as a duct collapses in light winds or in heavy rain.

III. FREQUENCY SELECTION

Propagation in the duct is frequency dependant. Measurements have confirmed that available PEM based models, AREPS and TERPEM are sufficiently accurate to determine bulk effects of ducts. These can therefore be used to determine the best available bands in which to deploy the link.

The first task will be to select a frequency band that is most resilient to varying duct height. From Fig. 2 we can see that the lowest path losses are available from 3 GHz to about 6 GHz, however these ideal path losses are only available in a duct range of between 25 and 40 metres, or from Fig. 1 a theoretical maximum availability of only 10 – 15%.

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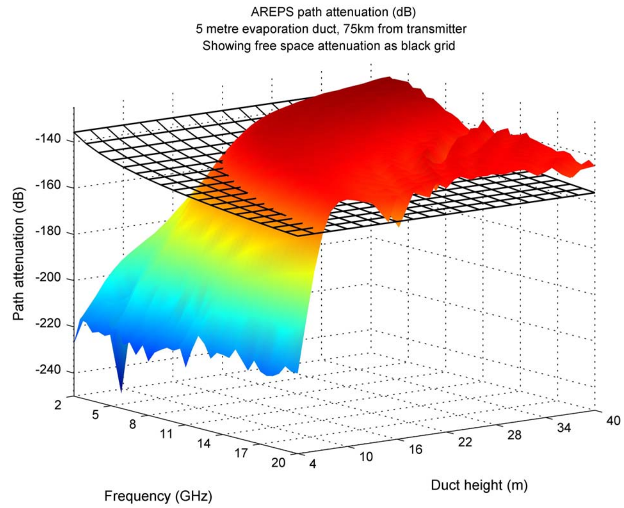

Figure 2. A collated AREPS simulation of path loss against frequency and duct height

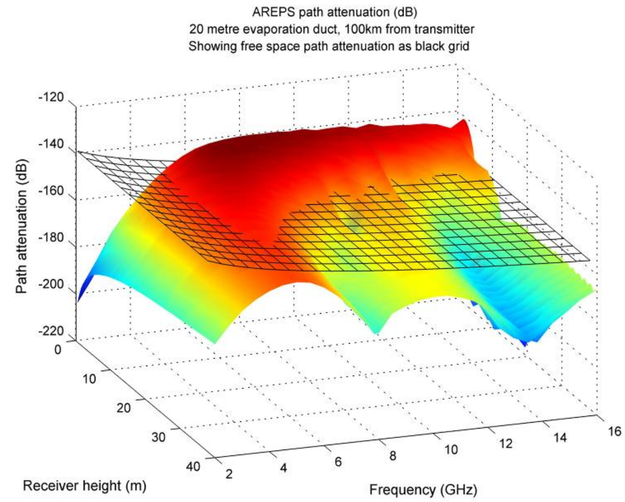

Figure 3. Collated AREPS simulation showing ideal antenna heights vs. frequency

Looking again at Fig. 2 we must sacrifice some signal strength to maximise availability and using the -140 dB contour we can see that a band at around 8 GHz will sustain a path loss of -140 dB or better over a duct height range of 15 to 40 metres for a theoretical availability of 80%. Gain however can be derived from antennas and controlled via power, so a range of between 5 GHz and 11 GHz would seem to be viable. This would allow the use of two 'Class Licensed' [3] point to point bands in Australia.

IV. System Design

To operate using the lower path losses inside the duct both transmitter and receiver must be inside the duct. The ideal height of each (which will be the same) can also be derived using another interpretation of collated AREPS plots for a given range.

We can see in Fig. 3 that at 100 km a band around 6 GHz gives the best available antenna height range. This is important because for systems deployed at sea tidal ranges can vary up to seven metres and systems must generally be deployed above maximum wave height. At 10 GHz a height of 5 metres is important while at 5.8 GHz a range of between 5 and 20 metres is available.

Fig. 4 shows an actual measurement compared to a TERPEM simulation for a 76 km path in a measured 15 m duct. We can see that the strongest signal was received at about 6 metres AMSL which strongly supports the receiver height suggested by the simulation in Fig. 3.

So our ideal design would be at 5.8 GHz (a 'free' class licensed band) with both transmit and receive antennas at around 7 metres AMSL. However to use 10.7 GHz we could design the system with both antennas at 5 – 6 metres AMSL with the maximum gain permitted by the class licence. Alternatively a licensed system in 6 GHz could use additional power to overcome fade.

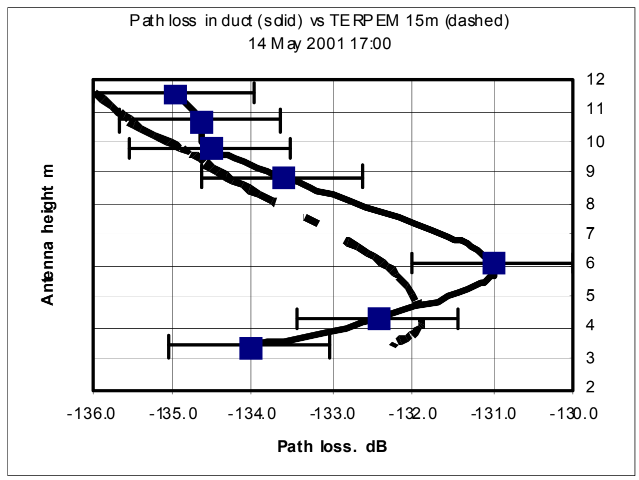

Figure 4. An actual measurement over a 76 km path at 10.7 GHz

V. Critique of an Actual System

In a separate but related project to our research James Cook University constructed an actual high capacity microwave link from Davies Reef on the Great Barrier Reef to the Australian Institute of Marine Science (AIMS) on Cape Cleveland near Townsville, this system is reported in [4].

The system operated over a 78 km path at a frequency of 10.6 GHz, very similar to our long range experiment reported above. The paper reports that similar findings to ours with a theoretical ideal height for the antennas of 5 metres although we disagree with the paper in that it suggests 10.7 GHz is 'ideal' where we find the lowest loss band for this situation to be 8 GHz. Due to mounting constraints both the transmit and receive antennae were installed at an average of 7 metres AMSL.

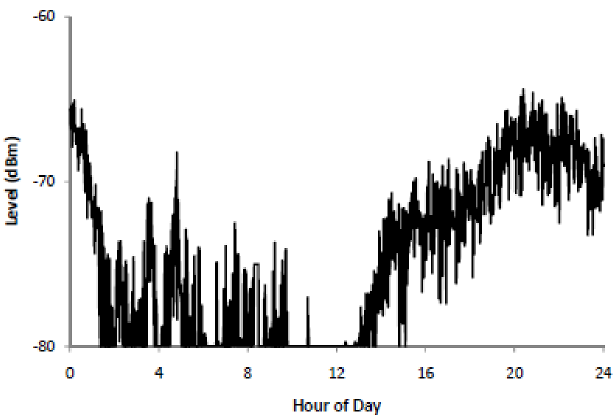

Figure 5. Received signal level for 6 August 2007 for the Davies link

Fig. 5 shows the received signal level for this system on one day of the trial. As expected from our research the signal level, corresponding to a collapsed or weak duct, is very low in the early morning. However counter-intuitively the signal remains low until about 13:00 hours when we would expect the duct to have become established at between 5 and 25 metres depending on wind conditions. Supporting this, our long path experiment showed the lowest receive powers shortly after sunrise (as expected) with a peak at around 15:30 at a 4.5 metre antenna height. A 24 hour period of our experiment is shown in Fig. 6. Of note that while our transmit arrangement was similar, our receive antennae were only 16 dBi slotted guide systems compared with high gain parabola in the Davies link. A significant difference.

Of interest a low tide of 1.0 metres occurred at about 09:45 on 6 August 2007. This would mean the antennae at both end would have been a minimum of 8 metres AMSL at that time. With the tide rising to a high of 2.5 metres at 5 pm the effective height of the antennae would have dropped to 6.5 metres, approaching ideal. It would be possible to suggest that this is indicated as a causal factor in the signal strengths, but this is inconclusive.

In addition Fig. 2 indicates that signal strength over a long path drops significantly in any duct at or below about 15 metres. From Fig. 1 this represents about 30% of the time for this region.

Overall our research suggests that an additional path loss of between 5 and 10 dB per antenna will be encountered at an effective antenna height of eight metres. This can be seen in Fig. 6 or simulated using AREPS.

We would also suggest that at our calculated optimal frequency of about 8 GHz an additional 5 dB of 'duct gain' would be available bringing the overall path loss down by 20 dB except where no duct existed.

While it is not possible to derive the actual received powers from Fig. 5 for the morning of 6 August 2007 it is obvious that an additional 20 dB of signal would have made a significant difference for most if not all of that day in terms of availability.

VI. Conclusions

Our research has shown that the tropical evaporation duct is capable of sustaining a high data rate microwave link over ranges of up to 80 km with an availability of up to 80%. This would be useful for data which is not time critical that can be transmitted at varying speeds on a store and forward basis.

We have concluded though that the design of such systems is critical given the physical factors at play and have discussed this in terms of another trial experiment that, while not in our view a perfect design, proved highly successful.

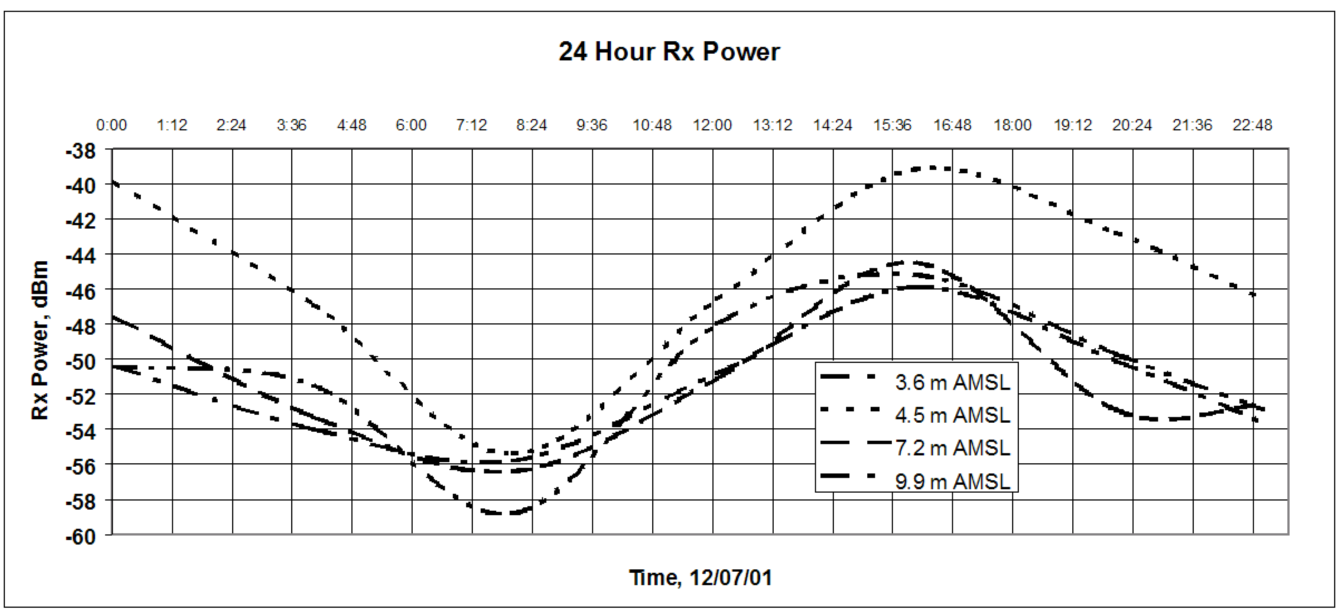

Figure 6. A 24 hours snapshot of the authors' long range experiment

VII. References

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[4] High Capacity, Long Range, Over Ocean Microwave Link using the Evaporation Duct. Graham S. Woods *Member, IEEE*, Adam Ruxton, *Member, IEEE*, Cameron Huddlestone-Holmes and Gilles Giga.