High Speed Over Ocean Radio Link to Great Barrier Reef

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***Abstract*—This paper investigates the feasibility of using high speed microwave radio links to relay information from the Great Barrier Reef to the Australian mainland. The investigated solution is a low-elevation, microwave link operating at 10.5GHz. Radio signals in this band are known to often become trapped in the evaporation duct just above the ocean providing a suitable means to radiate signals well beyond the optical horizon. The paper describes experimental and prediction results for a 78km link between Davies Reef and the Australian Institute of Marine Science. The optimum frequency and antenna heights are determined and the expected variability in the received signal level is determined. It is predicted that using conventional radio equipment a received signal to noise ratio of 40dB should be achievable.**

I. INTRODUCTION

The Great Barrier Reef (GBR) is the largest protected marine area in the world. It stretches from Bundaberg to the Torres Straight Islands, over 2000km along the east coast of northern Australia. The Australian Institute of Marine Science (AIMS) has a number of autonomous weather stations located along the GBR which are used to collect data in order to understand complex marine processes [1]. In future, it will be desirable to complement the weather stations on the reef with ad-hoc sensor networks, in order to perform complex monitoring in real-time. The sensors in these networks will be close enough together that conventional high speed radio links can be used, but a problem exists when trying to relay information from the reef back to the mainland.

The Great Barrier Reef varies from being as little as 10km offshore in the North, to as far as 100km offshore in the Southern areas. In order to communicate over these distances, at present, HF radio systems are used [1]. However, since HF propagation relies on a ground wave diffraction to achieve beyond the horizon transmission, this communication scheme tends to be unreliable [2]. To overcome this in the current HF system, a store and forward protocol is used where the system can store data for up to 21 days [1], until a connection is established. A further problem with a HF link is the limited data rate that can be achieved.

There are a number of alternative methods of communication which can be used to provide a high speed link between the reef and the mainland. At these distances, conventional line-of-site radio techniques are generally not possible. The extremely high towers needed to avoid the earth bulge would not be practical on the reef or the mainland. Satellite systems may be used, but the cost involved would be quite significant, and uneconomical for this application.

Another long range propagation mechanism at microwave frequencies is due to a phenomenon called ducting. Above the ocean, there is often a region of rapidly changing humidity, which causes the refractivity to decrease with height [3], in a region known as an evaporation duct. This change in refractivity can cause microwaves traveling in the duct to be bent towards the earth as shown in Fig. 1.

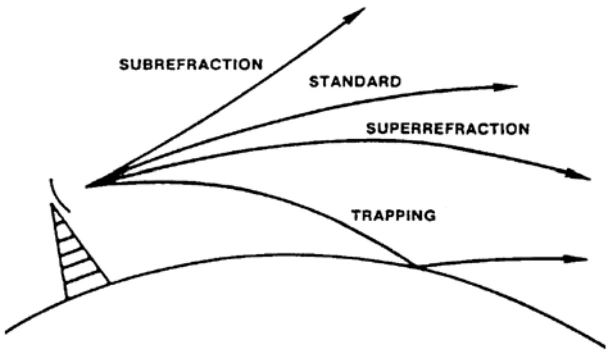

Figure 1. Ray paths for various refractivity profiles above the ocean surface.

The type of refraction of microwaves in an evaporation duct depends primarily on the frequency of the waves. As the frequency increases, the waves move from being subrefracted and hence divergent to being trapped. The strength of the received signal depends on the type of refraction, the condition of the duct and the height of the transmitting and receiving antennas.

This paper investigates the use of ducted microwave signals as part of a high speed communication link between the mainland and the reef. This paper studies the feasibility of a radio link between Davies Reef to AIMS research station near Townsville, a distance of approximately 78km. In looking at this link, this paper will determine the optimum frequency range and antenna height needed for high speed microwave communications in the over ocean environment.

II. Reef Link

A. Communication Link Options

The Great Barrier Reef comprises a vast number of smaller reef systems spanning most of the east coast of Queensland, Australia. The reefs in this system generally lie between 20 and 200km offshore and, apart from a few of the larger tourist islands, are almost totally devoid of any communication infrastructure. A complete reef monitoring system would require high-speed communication links from various reefs back to the mainland as well as between reefs where a direct link to the mainland was not feasible. However, for this particular study it was decided to investigate only a single reef to mainland link with the aim of then extrapolating the results to provide a better understanding of how the complete reef network would function. The radio link studied for this project was from Davies Reef (Latitude:18° 50’, Longitude:147° 38’) to the Australian Institute of Marine Science (AIMS) at Cape Cleveland (Latitude:19° 16’, Longitude:147° 04’). The range of this link was approximately 78km. A map of the link is shown in Fig. 2.

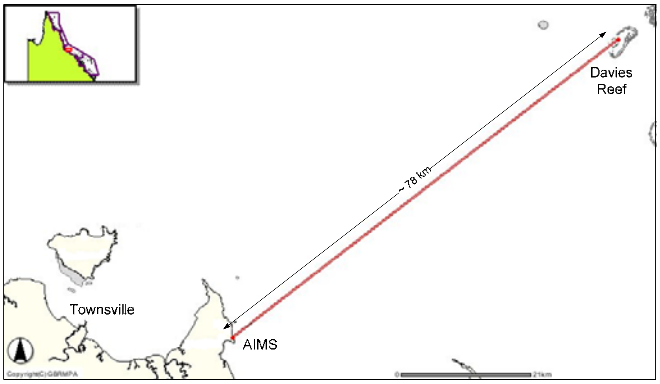

Figure 2. Investigated microwave path between Davies reef and AIMS.

This path was chosen for the study as the route was typical of a medium-long range link required for the reef-mainland leg of the reef monitoring system. This link was also beneficial as a tower (Fig. 3) had already been erected on Davies reef which provided an ideal location to install the radio equipment needed for the testing stage. Lastly, the mainland site provided access to a powered shed just above the beach and with unobstructed views of the ocean.

Figure 3. Radio tower on Davies reef.

Before investigating the microwave radio link, other options where considered. The AIMS had previously used a HF radio link from Davies reef to the mainland for low-speed environment monitoring. However, the low speed (600 baud) and low reliability of this link meant it would not be suitable for the new reef network application. The HF radio equipment was also quite bulky and expensive by modern standards. Another option was to use a satellite link. This option was supported by the availability of the Australian MobileSat service which provides radio coverage over the whole of the Australian mainland and to at least 200km offshore. Unfortunately, the access charges for this system are quite high and the equipment is also expensive. This option was not favored given the need for almost continuous, high speed access, as required in this application.

B. Microwave Radio Link

The concept of a microwave link was attractive from the point of view of offering high-speed access with minimal infrastructure and equipment cost. The most important question though was; “Would it be possible to send radio signals over the long distances involved”? Initially it was suggested that it might be possible to use conventional Wireless LAN (WLAN) equipment like that described in the IEEE802.11 b/g standards. This type of equipment was attractive because of its ready availability at low cost and since it could be easily interfaced with standard computer equipment. To test this approach, a computer simulation of the test link was implemented. The software used for this simulation was the Advanced Refractive Effects Prediction System (AREPS) program developed by Space and Naval Warfare Systems Centre, San Diego [3]. This program calculates the predicted path-loss for a radio link using the Parabolic Equation Method (PEM) [4]. An advantage of this software was that the effect of the evaporation duct could be included in the prediction based upon statistical Marsden square environmental data included within this program. Propagation loss predictions obtained from this software using environmental data for the local area, are shown in Fig. 4 and 5. The predictions shown are for a transmitter antenna height of 5m and for frequencies of 2.5GHz and 5GHz, respectively. These frequencies where chosen as they are commonly used in the IEEE802.11 WLAN standards.

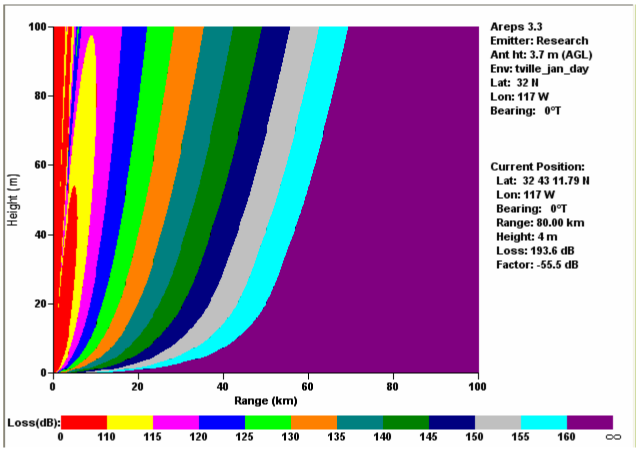

Figure 4. Pathloss diagram at 2.5GHz for Davies-AIMS link.

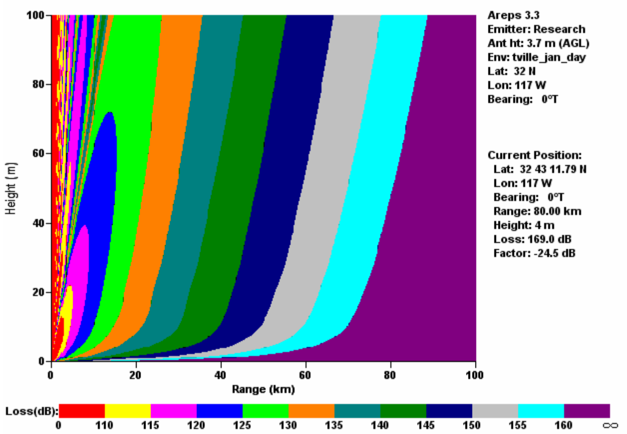

Figure 5. Pathloss diagram at 5GHz for Davies – AIMS link.

Close inspection of the pathloss diagrams in Fig. 4 and 5 shows that the ducting of the signals is not very strong at these frequencies. Note that the lobes tend to diverge away from the surface of the earth. At a range of about 80km, the path loss at 2.5GHz using a receiver at 4m above average sea level is measured to be about 195dB. At the higher frequency (5GHz) the signals are actually stronger due to the stronger ducting effect but even then the predicted loss is still 170dB. The high level of loss at these frequencies meant standard WLAN equipment was unsuitable for this application.

Given that current WLAN equipment and frequencies would not work in this application, it was decided to research other options. From examining the path loss diagrams it will be noted that as the frequency increases, the effect of the duct is more pronounced, and the pathloss decreases. It seemed sensible therefore to look at the possibility of using a higher frequency radio signal.

In Australia, the 10.5 GHz band is a license free band and was know to have been used in a number of commercial microwave link products. This band therefore appeared to be an attractive choice for this situation. The predicted pathloss at a 10.5GHz operating frequency is shown in Fig. 6.

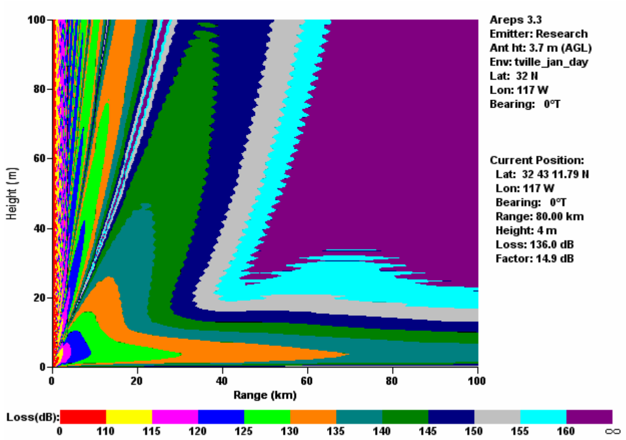

Figure 6. Predicted pathloss at 10.5GHz for Davies – AIMS link.

Examining Fig. 6 it is clearly seen that at this frequency the duct has a much larger effect on the propagating signal. In particular, it will be seen that the lobes are now directed along the surface of the earth meaning that signals will be stronger in this region. The effectiveness of the duct improves as the frequency increases up to around 10.5 GHz, at which point it starts to recede. This is shown in the pathloss height profiles for various frequencies shown in Fig. 7 produced using the AREPS software.

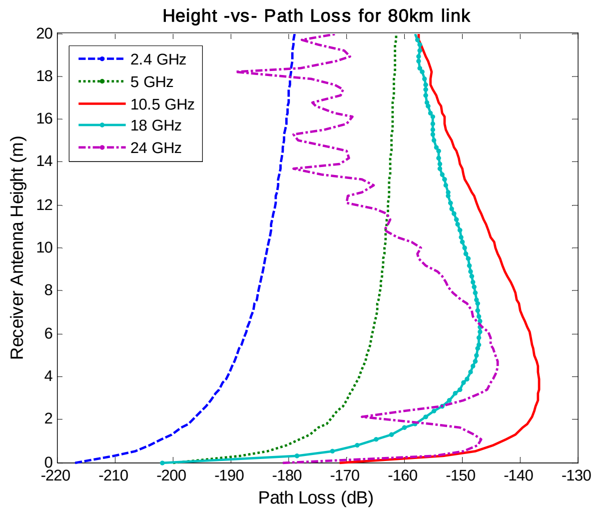

Figure 7. Height versus path loss for Davies/AIMS link.

By examining the height profile shown in Fig. 7 for a 10.5 GHz link, it can be seen that a receiver height of about 3-4 meters above sea level will provide the smallest path loss and hence the strongest received signal amplitude. Furthermore, at this frequency and height, the path loss does not appear to vary rapidly with small changes in height indicating that this would be an ideal position at which to mount a receiver antenna. Practically, a height of 3-4 meters is also convenient when mounting the antennas on the reef and the foreshore.

At a range of about 80km, the pathloss at 10.5GHz using a receiver at 4m above average sea level is predicted to be about 140dB. Thus, the 10.5 GHz signal is expected to be 35-60dB stronger than that obtained using the standard WLAN frequencies. The prediction software therefore shows that a 10.5GHz link will be a much better option than a standard WLAN link in this application. It should be remembered though that the strength of the duct will vary throughout the day and over the year. Thus it is predicted that the signal strength will also fluctuate depending on the prevailing conditions.

In order to obtain an estimate of the seasonal fluctuation in the duct and hence in the signal levels that could potentially be recorder at the receiver end of the Davies reef link, the AREPS software was also used to predict propagation losses at other months of the year. A plot of the minimum path losses during the day for the Davies reef link is shown in Fig. 8.

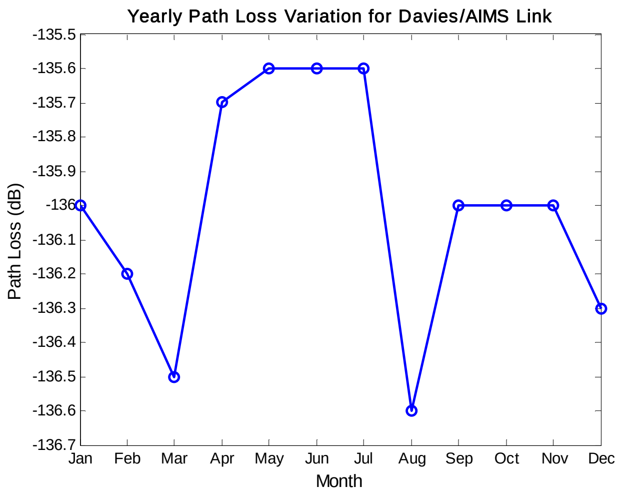

Figure 8. Monthly variation in path loss for Davies/AIMS link.

The maximum and minimum path losses were found to occur in August and May and were estimated to be 136.6 dB and 135.6 dB, respectively. Thus the path loss is predicted to vary by as little as 1 dB between seasons. The very small variation in pathloss shown in Fig. 8 means the link will have a high probability of holding up all year round. However this does not take into account the diurnal variation in the duct strength, which could make the pathloss vary by up to 15 dB [5].

C. *Microwave Link Budget*

Once the estimated path loss for the Davies reef link was known, it was then possible to perform a simple link budget calculation for this application. An example of this calculation is included below. A block diagram of the link is shown in Fig. 9.

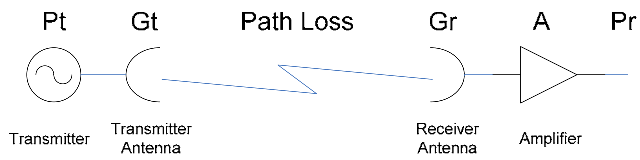

Figure 9. Microwave link block diagram.

Based on this model and Friis transmission formula [6], the amplitude of the signal power at the output from the receiver amplifier, Pr, is given by

$$Pr_{(dB)} = Pt_{(dB)} + Gt_{(dB)} - PathLoss_{(dB)} + Gr_{(dB)} + A_{(dB)} \quad (1)$$

where Pt is the transmitted power, Gt and Gr are the transmitter and receiver antenna gains, A is the amplifier gain and Path Loss is the estimated attenuation between the transmitter and receiver. All values are in decibels.

The noise power at the output of the receiver amplifier can also be calculated by

$$Noise = k \times (Ta + Te) \times A \times Bw \quad (2)$$

where k is Boltzmann's constant, Ta is the antenna noise temperature, Te is the effective noise temperature of the receiver amplifier and Bw is the system bandwidth.

Using (1) and (2) it is therefore possible to calculate the Signal to Noise Ratio (SNR) that would be obtained at the output of a certain link. An example calculation assuming the following typical values gave an estimated SNR of 41dB.

- Path Loss = 145dB
- Transmitted power = 15dBm (30mW)
- Receiver and Transmitter antenna gains = 35dB
- Amplifier gain = 50dB
- Amplifier noise figure = 1.32 (1.2dB)
- Antenna noise temperature = 200°K
- Bandwidth = 20MHz

The values chosen for this calculation were based on known specifications of commercially available equipment like satellite Low Noise Amplifiers, and conservative estimates of other parameters. The estimated gains of the antennas were based on parabolic dish antennas with a diameter of approximately 0.8 meter. The receiver bandwidth of 20MHz was estimated assuming that the data rate would be less than

10Mb/s and that the transmit signal would be modulated using NBFM.

The link budget calculations suggest that it would be possible to obtain a SNR of better than 40dB using transmitter and receiver equipment with moderate specifications. Since most of this equipment is commercially available at reasonable prices, these calculation indicate that it is technologically possible to build the microwave link described. It should be noted though that if the path loss increased by an additional 20dB or so, the signal to noise ratio would be marginal and the link might well fail. This therefore suggests that the link will not be 100% reliable. However, given the limited number of viable alternative systems, a certain level of unreliability may be an acceptable compromise for this application.

It should be noted that link parameters used for this example could be outside the regulatory limits for transmitted power in an unlicensed band. The transmitter Effective Isotropic Radiated Power (EIRP) for this calculation is

$$EIRP = Pt_{(dB)} + Gt_{(dB)} = 50dBm \quad (3)$$

The maximum allowed EIRP in the unlicensed 10.5GHz band in Australia is only 20dBm though. Since the value used for this calculation was outside the regulatory limit, means that special dispensation would need to be obtained from the spectrum management authority to use this power level. Given the remoteness of the sites, this might be a realistic option. Alternatively, a licensed band for which a higher EIRP is allowed might need to be considered.

D. Experimental Link Test

To further test the feasibility of operating a radio link between the reef and the mainland, an experimental link was established in December 2004. This link was operated between Davies reef and AIMS as shown in Fig. 10. The parameters of the equipment used in this experiment are listed below

- Transmitted power = 10dBm (10mW)
- Transmitter antenna (Horn) gain = 20dB
- Receiver antenna (0.6m dish) gain = 30dB
- Amplifier gain = 50dB
- Amplifier noise figure = 1.32 (1.2dB)
- Resolution Bandwidth = 3kHz
- Cable losses = 10dB
- Transmitter/ receiver height ≈ 5m AGL.

During this experiment the IF signal received at the AIMS site was measured on a spectrum analyzer and recorded on a PC every 10 seconds. Typical plots of amplitude and IF frequency recorded by this system during a 19 hour period on the 21/22 December 2004 are shown in Fig. 11 and 12, respectively.

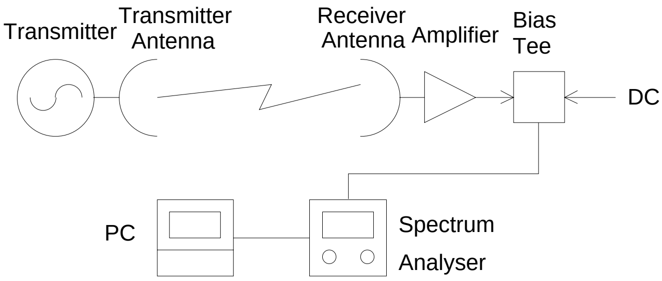

Figure 10. Experimental Radio Link

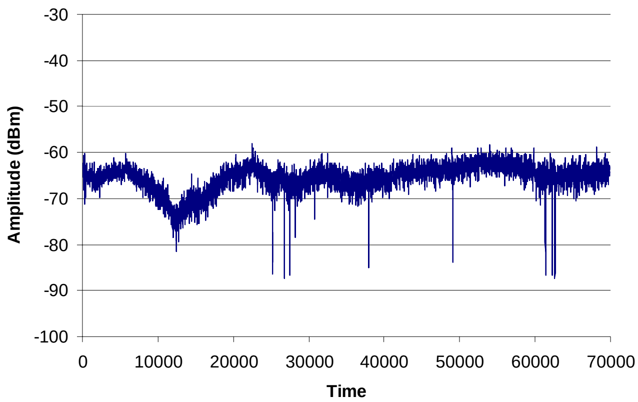

Figure 11. Amplitude of IF signal versus time.

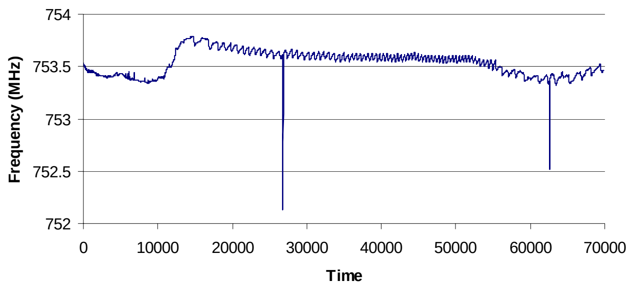

Figure 12. Frequency of IF signal versus time.

Considering firstly the frequency variation over this period, it can be seen that the system was quite stable. The transient at the beginning of the frequency plot is probably due to the temperature of the Gunn diode source having not settled to a constant level after the transmitter was installed on the morning of the 21st December 2004. The amplitude response is also quite pleasing considering that the signal is being sent over a 78km path from antennas just 5 meters above ground level! The average signal level received varies by about 15dB over the period which seems consistent with a diurnal variation in the average duct height [5]. These results also show a short term, 3-4dB variation in signal level. These fast fluctuations in the signal level are thought to be due to random variations in the duct structure over the length of the path [7].

Assuming the average received signal level was about -65dBm, the system parameters given above can also be used to estimate the pathloss during this test. The calculated value of 165dB appears to be about 20-30dB larger than expected from the predicted results. No complete explanation for this result is available though it is know that the staff that installed and aligned the antennas had no prior experience with this task. It is therefore suspected that the system may have been miss-aligned during this test. Unfortunately, due to receiver equipment failure shortly after the data given in Fig. 11 was recorded, the miss-alignment theory could not be confirmed. Certainly during other similar experiments, good agreement has been found between the measured and predicted values [5].

III. CONCLUSION

Predicted and experimental results were presented to show the possibility of using microwave radio links around 10.5GHz as high speed "pipes" to relay information from the Great Barrier Reef back to the Australian mainland. It was predicted that a Signal to Noise Ratio of about 40dB could be achieved using conventional radio technology.

While the results presented looked very promising, some further work needs to be done to fully verify this approach. In particular, the degree of variation in the duct height and hence the received signal levels, needs to be examined in more detail to determine the likely reliability of these types of links. This sort of information will impact on how the link is used and how a reef network might operate. Another aspect of these links which was not covered in this paper but that might be crucial to their success, is the amount of signal distortion that is introduced. Distortion may well determine what sorts of modulation techniques are best suited to this environment and what throughput is possible. The current authors are presently studying these topics.

ACKNOWLEDGMENT

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REFERENCES

[1] S. Kininmonth, S. Bainbridge, I. Atkinson, E. Gill, L. Barral, R. Vidaud, "Sensor Networking the Great Barrier Reef" *Spatial Sciences QLD.*, submitted for publication. Available: http://www.reeffutures.org/topics/publications/SNTGBR.pdf

[2] J. Payne. Space Weather and HF, VHF & GPS [Online]. Available: http://marineelectrics.org/spaceweather-hf-vhf-gps.html

[3] *Advanced Refractive Effects Prediction System (AREPS)* Available at : http://sunspot.spawar.navy.mil/

[4] M. Levy "Parabolic equation methods for electromagnetic wave propagation" IEEE Electromagnetic Wave Series, No. 45.

[5] A. Kerans and G.S. Woods "Observations of anomalous over the horizon microwave radio propagation inside the tropical maritime evaporation duct in North Queensland, Australia. Part One; normal ducting events" *URSI Commission F, Triennium Open Symposium*, Cairns, Queensland, Australia, 1-4 June 2004.

[6] K.F. Sanders and G.A.L. Reed "Transmission and propagation of electromagnetic waves" Cambridge University Press 1978.

[7] A.K. Kulessa, M.L. Heron and G.S. Woods "Temporal variations in evaporation duct heights", *Workshop on Applications of Radio Science (WARS'97)*, Adelaide.