10 and 24 GHz Terrestrial DX

by Rex Moncur, VK7MO

The use of portable stations designed for EME (20 to 50 watts feeding 70 cm to 1 metre dishes) using digital modes and GPSDO locking opens up opportunities to increase terrestrial distances at 10 and 24 GHz, explore various modes of propagation and the effects of spreading and absorption. This has led to World Record distances of 2732 and 2793 km for terrestrial propagation on 10 GHz in southern Australia(1)(2).

Techniques for setting accurate bearings such as differential GPS (3) that have been refined for EME are also of considerable value for terrestrial operations. Single tone techniques developed for EME are useful for looking for terrestrial openings. Atmospheric absorption is a critical factor for not only 24 GHz but also for long distance terrestrial contacts at 10 GHz. For example, analysis of the 10 GHz 2732 km contact shows absorption losses of around 40 dB and explains why 10 GHz signals were so much weaker than UHF at the same time.

Modes of Propagation and Reported DX

Propagation	10 GHz	24 GHz
Tropo-scatter*	650 km Estimated*	250 km Estimated*
Aircraft-scatter	905 km VK7MO to VK3HZ	566 km VK7MO to VK3HZ
Rain-scatter	1129 km DK3SE to IK7UXW	710 km LX1DB to F2CT
Tropo-ducting	2793 km VK7MO to VK6DZ	581 km DL7QY to F6DKW

Fig 1: DX Records as reported on the OK2KKW web site. (* Tropo-scatter is not generally reported separately from tropo-ducting so estimates are included based on tests between VK7MO and VK3HZ)

Meteorological Data for understanding DX situations

Excel Spreadsheets have been developed by the author to show the intensity and height of ducts and also the absorption loss based on radiosonde data. Radiosonde data is widely available for sites throughout the World and is made available by the University of Wyoming as below:

University of Wyoming Upper Air Soundings web site:
http://weather.uwyo.edu/upperair/sounding.html

Spreadsheet 1: Ducting
Spreadsheet 2: Atmospheric absorption

Please use the link below to download the spreadsheets from a Google Drive directory; then open to use on your computer. The method of opening may depend on your operating system and browser. On Windows with Firefox you right click on the spreadsheet picture and then go to download. The graphs work correctly on Microsoft Excel but may not on other programs. For example on Google Sheets the graphs are changed from lines to dots and are not useful for finding ducts.

https://drive.google.com/open?id=1ctR-ptUrW_6ZBmOlSkxy2NpUrM1Su_Gz

If you wish to try out these spreadsheets an interesting example is to try the Hawaii to California path. Set the date to 29 July 1991 at 00z and click on PHTO at the Hawaii end to find the data. Copy this data into Spreadsheet 1 and you will see an intense duct at around 2500 metres that goes off the scale. This relates to the time of the still current 5.7 GHz terrestrial World Record between N6CA and KH6HME. You can use data at the California end at San Diego (NKX) to see an interesting change in the level of the duct. You can use Spreadsheet 2 at the height of these ducts to gain estimates of the absorption that these stations had to cope with at 5.7 GHz and how much worse it would have been at 10 GHz.

Analysis of 2372 km 10 GHz QSO based on the above Spreadsheets

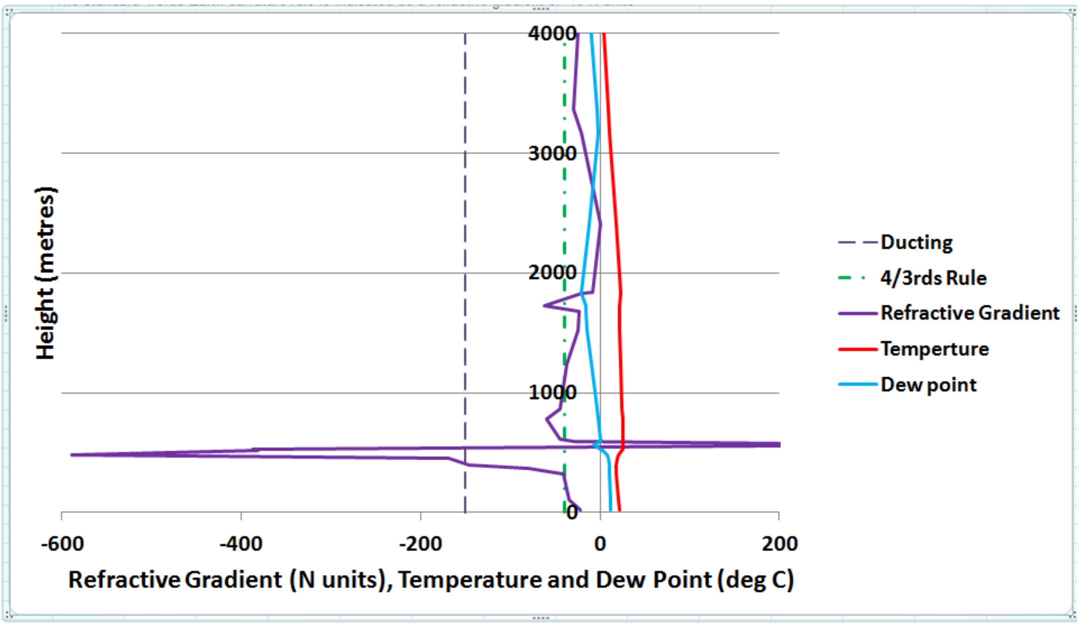

Fig 2: Shows radio refractive gradient at the time of the 2732 km 10 GHz terrestrial QSO on 5 January 2015.

Fig 2 shows an intense duct at about 500 metres with a refractive gradient of -588 N units. Note that ducting can promulgate around the curvature of the Earth with a refractive gradient of just -157 N units indicating that this was indeed a very intense duct. While absorption losses are much higher at 24 GHz they cannot be ignored on long terrestrial paths at 10 GHz. Applying Spreadsheet 2 at the time of this QSO gave 40 dB absorption loss at 10 GHz at 500 metres and at least in part explains why 432 MHz was S9 compared to 10 GHz at S1 (if one takes account of relative propagation loss, antenna gains, and power, 10 GHz should have been in front by around 10 dB).

Fig 3 is an International Telecommunications map of the global incidence of ducting. Surprisingly the current world record across Southern Australia is not in an area of high incidence nor is the Hawaii to California path. There are a few possible explanations. Firstly, records are more driven by availability of operators and locations, and secondly, while ducting tends to be more frequent in the tropics, absorption which affects 10 GHz is much higher in the tropics. There are some interesting possibilties from the East Coast of Australia out to the Central Pacific but absorption is likely to be a limitation.

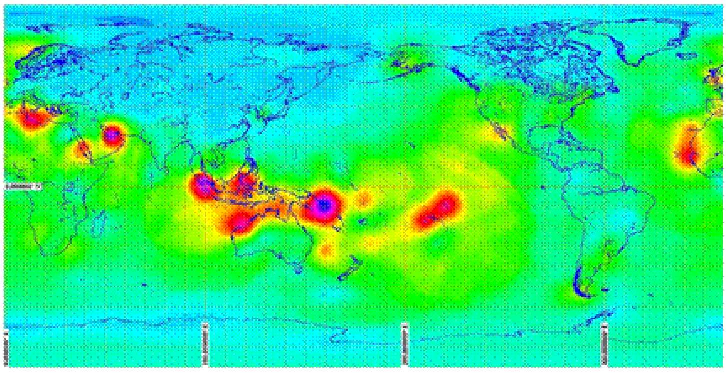

Fig 3: Global incidence of ducting

Atmospheric Absorption

Atmospheric absorption is the key reason that 24 GHz is so much more difficult than 10 GHz (Fig 4).

Temperature and Relative Humidity	1.296 GHz (dB)	10.368 GHz (dB)	24.048 GHz (dB)
0 Deg C, 20%	3.4	5.1	18.9
0 Deg C, 50%	3.4	5.9	34.9
0 Deg C, 80%	3.5	6.6	50.8
15 Deg C, 20%	3.0	5.2	35.0
15 Deg C, 50%	3.0	7.1	76.4
15 Deg C, 80%	3.1	9.0	117.1
30 Deg C, 20%	2.7	6.2	71.0
30 Deg C, 50%	2.7	10.4	164.0
30 Deg C, 80%	2.8	14.8	254.6

Fig 4: Absorption at sea level, over a 500 km path based on International Telecommunications method which has been applied with a Spreadsheet 2.

Atmospheric absorption at 24 GHz is primarily related to water vapor, which is in turn directly related to "Absolute Humidity". A common misunderstanding is to use "Relative Humidity" as an indicator of absorption rather than " Absolute Humidity". As shown in Fig 3 the simple use of "Relative Humidity (RH) " without referring to temperature can lead one to think that it is better to operate at 20% RH and 30 degree C whereas in fact the loss would be 20 dB less by operating at 80% RH and 0 degrees C .

Unfortunately it is not easy find a forecast of "Absolute Humidity" to plan a DX attempt. However, forecasts of Precipitable Water are readily available up to 4 days in advance. Most of the Water Vapor is concentrated in the lower layers of the atmosphere and while Precipitable Water is the sum of all layers it is a good relative approximation of what one can expect and relates directly to the absorption caused by water vapour. URLs to find forecasts of Precipitable Water, are as follows:

North America: http://wxmaps.org/pix/nam.pw

Australia: http://wxmaps.org/pix/aus.pw

Europe: http://wxmaps.org/pix/euro.pw

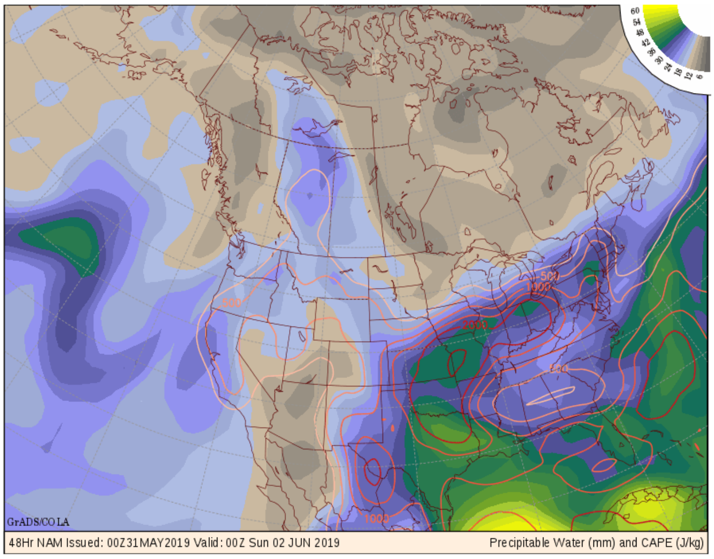

Fig 5: An example of a Precipitable Water forecast for North America.

From the example at Fig 5 it is seen that the water vapor can vary from around 5 mm in Canada to 50 mm in Dallas which means the absorption loss due to water vapor is around 10 times worse in Dallas at the time of this forecast.

Absorption Loss on Aircraft Scatter

One means of reducing absorption is to use aircraft scatter so that much of the path is at high levels where the water vapor is low. This essentially eliminates absorption at 10 GHz. On 24 GHz we have been able to complete an aircraft scatter QSO out to 566 km but despite repeated attempts at 700 km we received nothing at all while 10 GHz was giving strong signals. We have concluded that at the low elevations necessary to work to 700 km so much of the path goes through the lower atmosphere that the absorption losses prevent a QSO.

Absorption Loss on Rain Scatter

Rain-scatter can occur at potentially higher levels than the flight levels of civil aircraft and thus reduce the absorption losses and potentially allow longer distances. In addition the scattering volume is typically much larger which should at least partly offset absorption losses. Our experience on 10 GHz is that on a 580 km path rain-scatter can be significantly stronger than aircraft-scatter. A potential issue with rain-scatter at 10 and 24 GHz is the loss of signal due to scattering from rain at low levels along the path but we have not seen this as significant on 10 GHz. My preliminary view is that loss due to rain along the path is not all that significant as the intercepting rain drops still scatter useful energy in the forward direction. This is a fertile field for further work on 24 GHz with EME capable stations.

Spreading

Spreading affects rain-scatter and tropo-scatter as in both cases the scattering is from a large common volume and the path length varies from the side of the beam to the centre. Spreading can be significantly reduced by using forward scatter rather than seeking out strong rain cells to the side. Forward rain-scatter works well with low spreading if both stations beam accurately at each other and just wait for the rain to pass between. Even light rain that is not visible on a 4 GHz rain radar is sufficient to complete a digital QSO on 10 GHz over 600 km. QRA64 D works well for both rain and tropo-scatter at 10 GHz with dishes in the range 60 cm to 1 metre.

Forward scatter spreading increases in proportion to antenna beam-width and also in proportion to frequency.   However, if one uses the same size dish then the beam-width reduces in proportion to frequency and compensates for the increase in spreading with frequency. Thus for the same size dish forward scatter spreading is similar for 10 and 24 GHz and is typically in the range of 10 or 20 Hz and QRA64D or E should work well.

Aircraft scatter is essentially from a point source and does not suffer from spreading.

Interestingly, our experience shows that tropo-ducting also does not suffer from spreading which suggests that the path length does not vary. Prior to the onset of ducting we have seen spreading of several Hz, which we put down to a combined tropo-scatter/tropo-ducting path. But once the path is fully tropo-ducting the spreading is less than 1 Hz and even the QRA64A sub-mode can be used.

Operational and Planning Issues

The secret to finding a weak opening such as a tropo-duct or aircraft scatter is to remove as many variables as possible while you wait for hours or more for the signal to rise out of the noise. Both stations must be exactly on frequency with GPSDO locking and both must be accurately aligned in azimuth and elevation. In looking for a duct to open there is advantage in using the integrated single tone facility on WSJT-X in conjunction with QRA64 - single tones are transmitted as 1000 Hz by ticking the "sh" box and using TX box 6.

You look for the integrated signal tones on the Spectrum Graph, set to linear average which gives around 6 dB more sensitivity than exchanging messages. To be sure you are seeing a real signal it is useful to have both stations within a few Hz which means locking both the 10 GHz transverter and the IF transceiver with good quality double oven GPSDOs. To ensure that both stations are accurately aligned we use a rifle scope which has been accurately aligned to the dish on sun noise.

In the past we have aligned on some geographic feature as a reference and used say Google Earth to find its bearing and then moved to the bearing of the other station with an accurate 360 degree protractor which is calibrated on the reference . However, if beaming over the sea it is sometimes not possible to find a suitable reference and our recent development of differential GPS allows accurate alignment to better than 0.1 degrees on just a 5 metre baseline and it thus much preferred [(3)].

It is important to be sure both systems are reliable and working before you spend hours waiting for an opening. In this respect it is useful to check cold sky to ground or sun as a check on receive system performance. To ensure both stations are in fact GPSDO locked it is useful to have an independent GPSDO locked weak signal source. To ensure one is in fact transmitting, one can monitor the PA current.

Hepburn Charts are important to plan portable operations when ducting is more likely to be present. For rain scatter, access to meteorological radar data on the web is important. For aircraft scatter we take an ADSB receiving system to monitor aircraft positions. We normally beam directly at each other and wait for the aircraft to pass between - but occasionally to get a rare grid locator it might be necessary to use side scatter (which is weaker) and both stations beam directly at the aircraft.

To date our 10 GHz tropo-ducting and aircraft scatter records have all been done with a 60 cm to 77 cm dish and 10 watts at one end[(4)]. On 24 GHz we have used only 4 watts at one end to a 60 cm dish and a 113 cm dish at the other. My more recent EME system runs 90 watts to a 113 cm dish on 10 GHz and 20 watts to a 113 cm dish on 24 GHz and if similar capability was available at both ends this should provide a useful improvement. All PAs are solid state for safe operation in the field.

Improvements in System Performance

Back in 1994 VK6KZ and VK5NY set the then 10 GHz terrestrial World Record across southern Australia at 1912 km. They used 40 cm dishes, 100 mW and SSB with drifting oscillators and used VHF signals align their antennas. With today's EME capable portable stations we can use 60 watts (+28 dB), 1 metre dishes at both ends (+16 dB), and digital modes (+ 30 dB) -- an improvement in system performance of over 70 dB.

Acknowledgements

To VK3HZ who has not only been at the other end of many contacts but also contributed to most of the development that has led to the equipment and techniques which are the subject of this paper. To VK6DZ who was at the other end of the world record terrestrial QSO's at 10 GHz. To VK7WLH for reviewing this paper.

CONCLUSIONS

EME capable digital and GPSDO locked portable stations offer good prospects for extending 10 and 24 GHz records with modes such as QRA64D. The single tone integration feature on WSJT-X can add around 6 dB sensitivity in finding the presence of a weak signal while waiting for an opening.

Ducting is the best prospect for 10 GHz but note that as the distance increases absorption losses become significant - particularly in tropical areas and it may be better to operate in temperate areas even if the openings are less frequent.

Forward rain scatter appears to be the best prospect at 24 GHz and digital modes should significantly enhance the capability.

References:

(1) Rex Moncur, VK7MO, et al, "10 GHz across the Great Australian Bight & New World Record (5 Jan 2015) DUBUS 2015 Volume 1 page 117.

(2) Rex Moncur, VK7MO, et al, "Extension of the 10 GHz terrestrial World Record to 2793 km", DUBUS 2016 Volume 1 Page 115.

(3) David Smith, VK3HZ & Rex Moncur VK7MO, " Differential GPS Azimuth Reference for Microwave Portable Operations" . Paper included with MUD proceedings 2019.

(4) Rex Moncur, VK7MO, and David Smith, VK3HZ, "Aircraft Scatter on 10 and 24 GHz using ISCAT", DUBUS 2014, Volume 4, Page 92.