Transequatorial Propagation: the Next Challenge for VK

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Transequatorial propagation (TEP) involves the reliable reception of signals, or the making of two-way contacts, over very long paths that cross the geomagnetic equator on frequencies well beyond the maximum useable frequencies expected for ionospheric propagation on those paths, often at unexpectedly high signal strengths.

There are two types, or modes, of TEP: afternoon-type TEP (aTEP) and evening-type TEP (eTEP), based on the hours they occur during a day.

Typical maximum observed frequencies (MOFs) for afternoon-type TEP reach 40-55 MHz, sometimes extending into the 60-70 MHz spectrum. Hence, for amateurs in VK4, VK6 and VK8, DX signals often appear on the 10m and 6m bands from Japan and Korea and occasionally from Hawaii, Mexico, Central America and southern USA states.

Evening-type TEP MOFs extend to at least 432 MHz. No upper limit has been established. Since radio amateurs first encountered and reported TEP in the late 1940s (Tilton 1947), MOFs for evening TEP climbed ever higher in following decades, reaching 102 MHz in the late-1960s. In 1977, YV5ZZ in Venezuala worked LU1DUA in Argentina on 144 MHz. The next year, 1978, southern Europe to southern Africa and Australia-Japan was bridged on 144 MHz. It was a good year for TEP, as amateurs in Venezuala and Argentina bridged that path on 432 MHz (Reisert and Pfeffer 1978). In 1979, a 432 MHz beacon in Rhodesia (now Zimbabwe) was recorded in Greece (Sampol 2002-2007). The “next challenge” for VK is to bridge the Australia-East Asia circuit on 432 MHz.

Afternoon-type TEP has the following general characteristics:

(a) Predominant occurrence between 1400 and 1900 local mean time (LMT) at the path mid-point. The duration of openings decreases with increasing frequency.

(b) Paths cross the geomagnetic equator and range from 4000 to 10,000 km in length, but longer paths have been recorded.

(c) The paths most often observed cross the geomagnetic equator at angles within 30^0 of orthogonal, but can be at quite oblique angles (think VK to XE).

(d) Path terminals commonly lie in a zone between about 20^0 to 40^0 geomagnetic latitude (roughly 32^0 and 62^0 magnetic dip angle).

(e) MOFs are typically in the 40-55 MHz range, occasionally extending to 60-70 MHz.

(f) A peak seasonal occurrence during the equinoctial months of March-April and September-October. On low VHF frequencies, openings may still occur through the solstitial months.

(g) The number of openings and MOFs increase during years around maximum solar activity, but openings never disappear during solar minimum.

(h) Mostly strong, steady signals with a low fading rate and long-term fades over tens of minutes.

(i) Small Doppler shifts and smearing, generally less than 10 Hz.

The propagation mode of afternoon TEP is 'chordal hop', having two F-layer reflections without an intervening ground reflection, known as “super mode’’. The reflection points occur at two

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zones of enhanced ionisation either side of the geomagnetic equator known as the 'equatorial anomaly'. For obvious reasons, afternoon TEP is also known as super-mode TEP.

I have included the above to highlight the contrasts and similarities between afternoon and evening TEP.

A more detailed description of afternoon or super-mode TEP is online at – http://home.iprimus.com.au/toddemslie/aTEP-Harrison.htm

About Evening-type TEP

Evening-type TEP has the following general characteristics:

(a) Predominant occurrence between 2000-2300 LMT (at the midpath, where it crosses the geomagnetic equator). The duration of openings decreases with increasing frequency.

(b) Paths are pretty much bisected by the geomagnetic equator and range from 3000 to 6000 km in length, although paths up to7500-8000 km have been observed.

(c) The paths most regularly observed cross the geomagnetic equator within a small range of angles close to 90 degrees. Paths having an obliquity of 15 degrees or more to the orthogonal experience considerably fewer occurrences, particularly in the bands above 50 MHz.

(d) Path terminals commonly lie in a zone between about 10^0 and 30^0 geomagnetic latitude (about 30^0 and 55^0 magnetic dip angle).

(e) MOFs predominantly observed extend to 144 MHz and beyond, and have reached 432 MHz.

(f) A peak seasonal occurrence during the equinoctial months of March-April and September-October. On low VHF frequencies, openings may still occur through the solstitial months.

(g) The number of openings and MOFs increase during years around maximum solar activity, but openings never disappear during solar minimum.

(h) Signal strengths can range from weak to very strong, although signals of weak to fair strength are more usually observed.

(i) Distinctive rapid flutter fading over long-term peaks and fades, along with wide Doppler shifts (ranging from +/– 20 Hz at low VHF to +50 Hz/-350 Hz on 144 MHz) and smearing (100s of Hz to kHz) that increases on the higher frequency bands.

The propagation mode of evening TEP is via 'ducting' or 'guiding' through field-aligned "bubbles" of depleted ionisation (equatorial plasma bubbles) which thread the equatorial ionosphere, extending symmetrically north-south across the geomagnetic equator. This is why evening TEP is also known as ducted-mode TEP.

There is a more detailed description of evening or ducted-mode TEP online at – http://home.iprimus.com.au/toddemslie/eTEP-Harrison.htm

The Australia-East Asia eTEP Circuit

It seems history granted VK4 amateurs the first opportunity to exploit evening TEP between Australia and the East Asian countries of Japan and Korea. Reports of VHF signals being reliably observed on this circuit by amateurs and SWLs appeared during the late-1940s and early-1950s. Operators on the 6m band have hammered this circuit over the decades since.

When reports of eTEP on 144 MHz on the South American circuit electrified VHFers the world over in 1977, amateurs in Darwin and northern Queensland quickly followed suit, bridging the VK-JA path first in 1978 and increasingly in subsequent decades.

The map of this sector shown in Figure 1 gives examples of the paths predominantly observed (blue lines). The short-dash black line running from Singapore to the Darwin-Southern Japan path (at 10^0S geomagnetic) indicates an observation made by a Defence Science Establishment (now DSTO) scientist who received and recorded Darwin VHF beacons in Singapore one evening using a handheld antenna pointing skyward. Those equatorial plasma bubbles can 'leak' signals! The long-dash blue line indicates the path for a 144 MHz VK6 beacon reportedly heard in Beijing.

The contours of geomagnetic latitude are derived from the dipole model of the Earth's magnetic field. Note that the path terminals generally lie between 20^0 and 30^0 geomagnetic latitude.

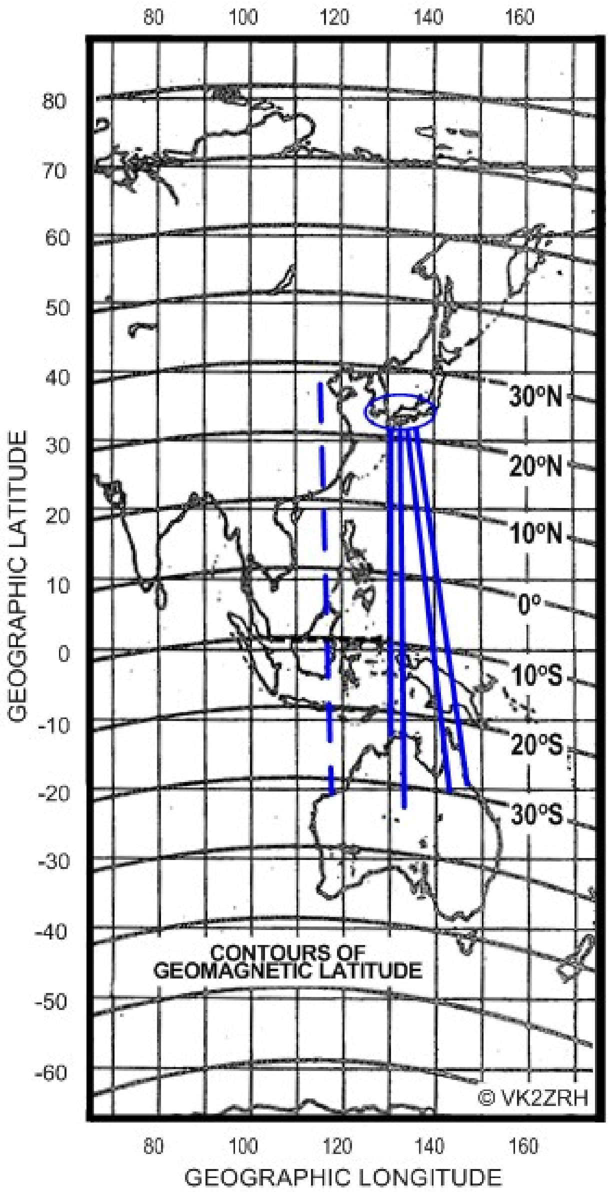


Figure 1. 144 MHz evening TEP paths between Australia and East Asia, showing their relationship with geomagnetic latitude. Note how the western paths cross the geomagnetic equator more closely to 90^0.

When 144 MHz TEP first emerged, Reisert and Pfeffer (1978) attributed it as a new mode of propagation. However, the characteristics of the 144 MHz reports were soon recognised as being evening TEP (Rottger 1978, Harrison 1979, and Heron 1979).

Stations heard and worked on evening TEP from Australia are generally from the Japanese islands of Kyushu, Shikoku and Honshu, and from South Korea – as shown by the blue oval in Figure 1; the northern-most island of Hokkaido is less commonly involved. Most 144 MHz eTEP contacts cluster within the JA 4-5-6 call areas (Harrison 1979, Sampol 2002-2007); 2m eTEP contact with JA8 (Hokkaido) and HL have not been reported, however reception of Korean VHF broadcast signals and 6m contacts have been commonplace.

The Northern Territory and the north eastern corner of Western Australia are more favourably located in relation to the geomagnetic equator as paths to Japan and Korea cross it more closely to orthogonal (90^0).

The longest path achieved on 144 MHz over the Australia-East Asia sector was a contact in 1991 between VK4BFO (Mt Isa) and JT7DMB, a distance of 6763 km, an Australian record which still stands (WIA 2007).

The Dynamic Path Geometry of eTEP

As outlined earlier, path lengths range from 3000 to 6000 km, but longer paths have been recorded, eg. a 144 MHz contact between I4EAT in northern Italy (JN54VG), and ZS3B in Namibia (JG73), about 7800 km (Sampol 2002-2007); reception of the 144 MHz ZE2JV beacon (Zimbabwe) by DC3MF in South Munich, Germany, a path of nearly 8000 km (Schippke 1982). It is significant that paths between Africa and Europe cross the geomagnetic equator in that sector very close to 90^0, more so than in the Australia-East Asia sector.

The general characteristics of the path geometry of evening TEP are illustrated in Figure 2. Under certain conditions, most often around the equinoxes, large ripples appear in the base of the equatorial ionosphere about an hour after the sun has set at that height (around 250-350 km), ie. about 2000 LMT. These ripples rise up and extend rapidly north-south along the curved magnetic field lines, becoming elongated equatorial plasma bubbles. The plasma bubbles drift eastward at speeds generally from 25-125 metres/second, while their upward motion is typically 125-350 m/s; some have been measured rising at supersonic speeds of more than 2 km/s! They can rise to peak heights of 1500 km or more at the geomagnetic equator and their ends can extend to more than 25^0 geomagnetic latitude; ie. south of Darwin and north of Sata in southern Japan (Shiokawa et al 2004). The reason for the observed flutter fading and the Doppler shift and spreading on VHF eTEP signals is now abundantly clear!

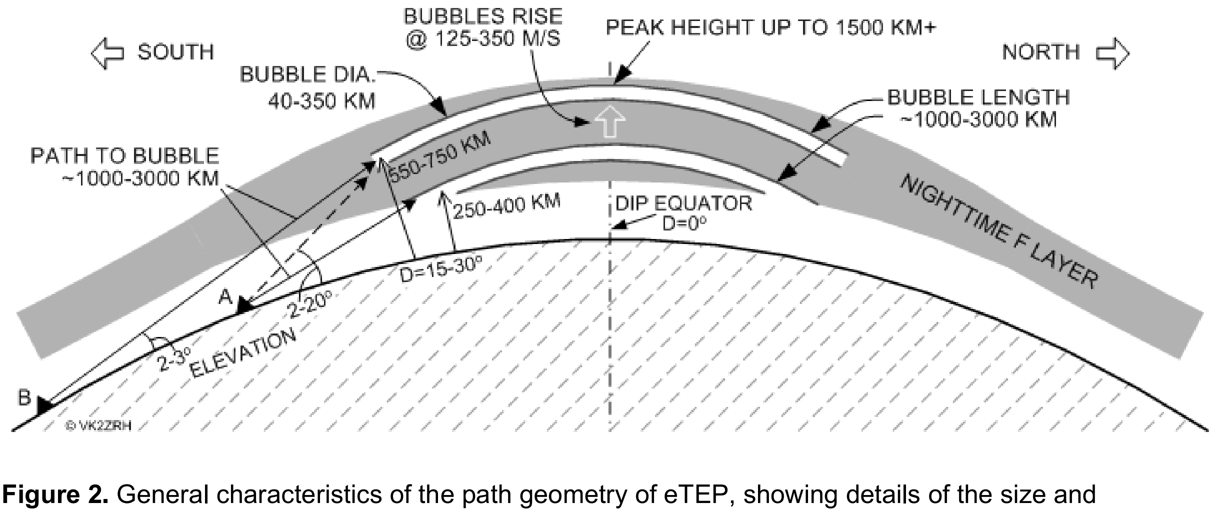


Figure 2. General characteristics of the path geometry of eTEP, showing details of the size and movement of the magnetic field-aligned equatorial plasma bubbles that support VHF-UHF propagation, together with ray path elevation angles experienced and the path dimensions. The critical factor for propagation is for the ray path to achieve tangency (or near-tangency) to the magnetic field line where it encounters a bubble. The circuits most likely to achieve propagation and to yield the greatest signal strengths have ray paths tangent to the field lines in the base of the F layer between 250-400 km height. Longer paths enter bubbles at heights of 550-750+ km

The bubbles may be 40-350 km in diameter and successive bubbles are generally spaced about 40-100 km apart. The walls are not smooth, except for the early phase of their development; bubbles can be bifurcated into several channels (Shiokawa et al 2004) – like looking up an elephant's trunk! – and sometimes remain open at the bottom (Heron and McNamara 1979, Tsunoda 1980).

Ray path elevation angles have been measured or estimated to range between a few degrees up to 20^0 (Fimerelis 1988, Kuriki et al 1968, McNamara 1973).

The role and influence of the Earth's magnetic field on evening TEP was realised by researchers in the late-1960s/early-1970s (McNamara 1973). Indeed, before the discovery of equatorial plasma bubbles, McNamara (1973) set out the conditions under which the ray path from a transmitter would be tangent to a field line in the equatorial F layer, its elevation angle and the height and latitude where it reached tangency, to yield the optimum probability for successful propagation.

Research over the past 30 years has shown that the requirements of path symmetry about the magnetic equator and orthogonality with it are more important during solar minimum years than solar maximum years. This applies all the more so at ever-higher frequencies above 100 MHz. Note that the first 2m eTEP contacts occurred near the minimum of Cycle 21.

QSO reports and reception observations over many years have shown that a station in one hemisphere will most often make contact with stations in the opposite hemisphere in an area surrounding its geomagnetic conjugate. Modelling of the propagation mechanism by Heron and McNamara (1979) developed the concept of a "cone of acceptance" for ray paths entering and leaving a plasma bubble, or duct. This acceptance cone establishes the scale of the communications zone on the ground. Heron (1981) developed a mathematical relation for determining the mean zone radius, which is inversely proportional to frequency. That is, the area of the communications zone reduces with increasing frequency.

For a transmitting station in one hemisphere, the mean radius of the communications zone at its geomagnetic conjugate location is given by:

$$r_o = 1.42 \times 10^{14}/f \qquad \text{– where } f \text{ is in Hz and } r_o \text{ in metres.}$$

This relationship was derived from 144 MHz reports of contacts in the Australia-Japan, Europe-Africa and South American sectors. On 2m, the communications zone mean radius is 987 km.

So, for 432 MHz, a little arithmetic gives us a value of 329 km for the mean radius of the communications zone.

However, Heron (1981) observes that, from logs of amateur contacts, the communications zone is compressed in latitude and extended in longitude, with the longitudinal axis being twice the latitudinal axis. This implies that r_o is a measure of half the length of the longitudinal axis of the communications zone.

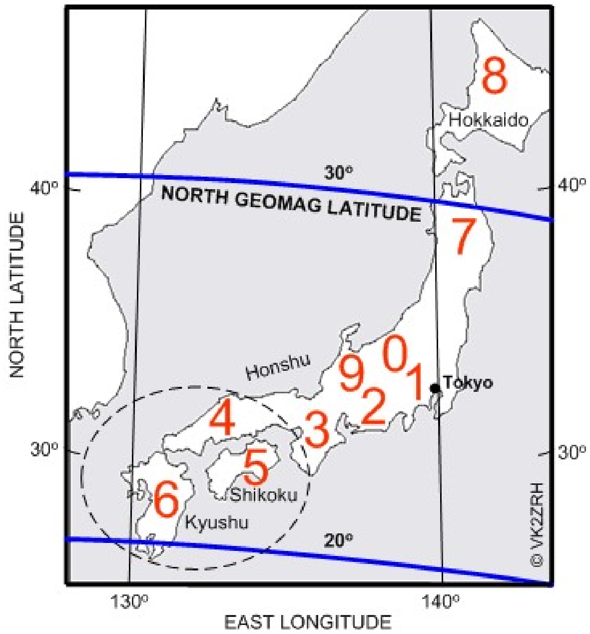
The Next Challenge: VK-JA 432 MHz eTEP

The successful efforts and experiments of amateurs on the South American and Europe-Africa circuits implies that we should be able to achieve 432 MHz TEP on the Australia-Japan circuit. So what would be the issues needed to be considered and the necessary factors that would contribute to success?

The Solar Cycle: Probably the first thought that springs forward in most amateurs' minds is: "we'll have to wait for the next solar cycle peak". Well, perhaps not. Recall that the first reports of 2m TEP were in 1977, the year after Cycle 20 minimum, when the mean sunspot number for the year was 27.5 (www.ips.gov.au/Educational/2/3/6). The first 70cm TEP reports came in 1978, for which the mean SSN was 92.5, but the monthly averaged SSN fluctuated between 30 and 98 (www.ips.gov.au/Educational/2/3/1). Now that Cycle 24 is apparently under way, the next few years should be prime time!

Certainly, past experience tells us that there will be more occasions on which 432 MHz evening TEP is possible as Solar Cycle 24 progresses to its peak.

Path Terminals: From where to where? Having determined above that the communications zone for 432 MHz TEP probably has a mean longitudinal extent of 658 km and thus a latitudinal extent of 329 km, we can consider the geography of path terminals in Japan for given locations in Australia with regard to geomagnetic conjugacy.



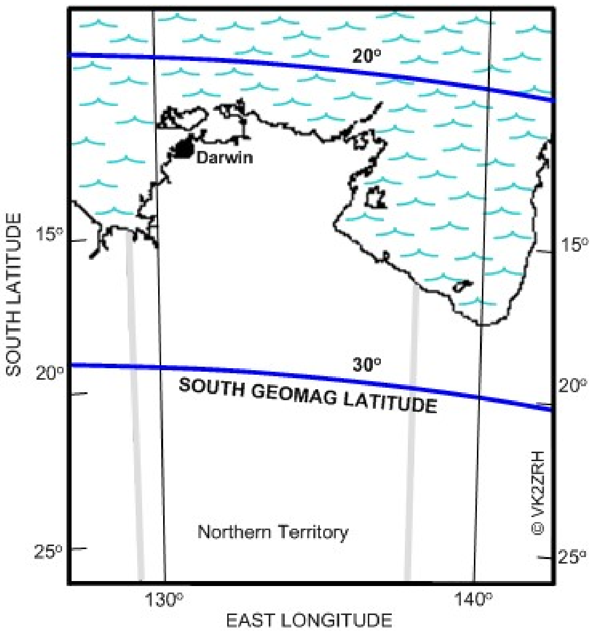


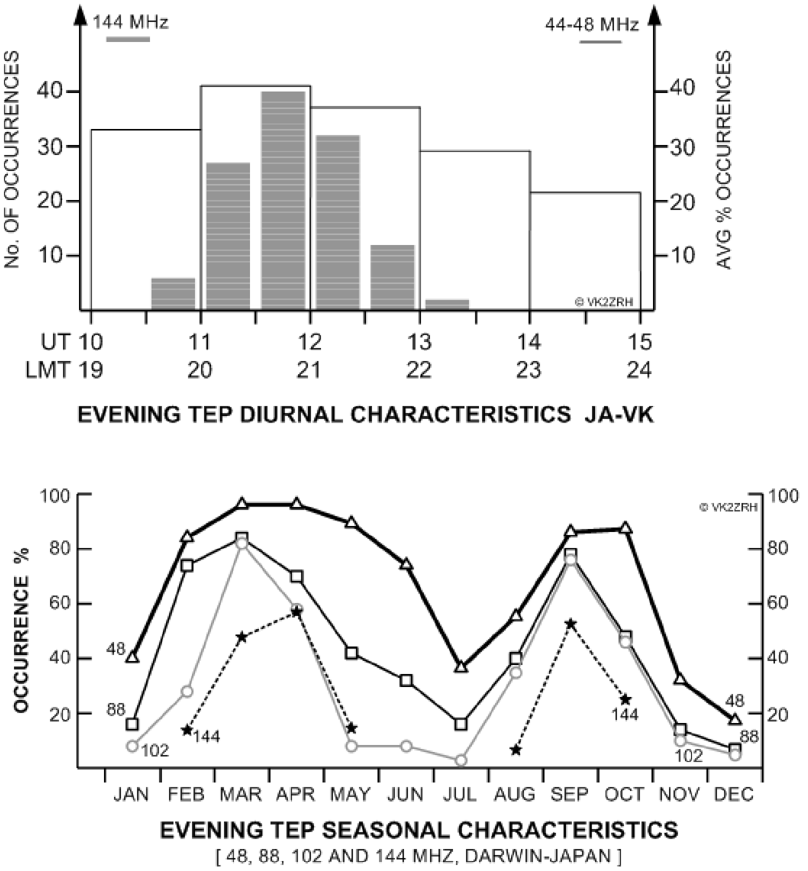
Figure 3. The general geographic areas in Japan and Australia that are close to geomagnetic conjugacy lie between 20^0 and 30^0 geomagnetic latitude. The dashed ellipse in the upper map delineates the call areas most often contacted on 144 MHz from Darwin, although some contacts have been made with call areas to the east. Reported 2m contacts from VK4 are mostly into call areas 0,1,2, 3 and 7 (Harrison 1979, Sampol 2002-2007).

It is clear from the Darwin-JA and VK4-JA paths for 2m that they cross the contours of geomagnetic latitude within a very narrow range of 90^0. The 432 MHz path will be even more constrained as the communications zone is considerably smaller than for 2m.

Darwin is the most populous centre north of 30^0 south geomagnetic latitude and offers obvious advantages as a 'prime' location to successfully achieve 70cm TEP to Japan. However, if portable operation is considered, locations around the Gulf of Carpentaria, in both VK4 and VK8, fit the criteria for geomagnetic conjugacy with call areas in central Honshu. The drawback is the general paucity of roads and possible camping places with suitable clear views to the north. For the truly adventurous, going maritime mobile offers unique possibilities unrestrained by geography.

Time and Seasonal Factors: The diurnal and equinoctial dependence of openings narrows with increasing frequency, as Figure 4 demonstrates.

Figure 4. Indicative diurnal and seasonal characteristics of evening TEP at different frequencies for the Australia-Japan circuit.



There are relatively few reports of 70cm TEP to date that could determine a statistically significant pattern of its diurnal characteristics. However, given that the diurnal pattern of 144 MHz TEP fits within that for low VHF, as seen in Figure 4, it could be anticipated that the 70cm diurnal pattern of openings would fit within that for 144 MHz, ie. openings would start later and last over fewer hours (Gibson-Wilde 1969, Harrison 1979).

Likewise, considering the seasonal characteristics of TEP, it is clear that as the frequency increases, the openings contract around the equinoxes (McNamara 1973, Harrison 1979).

As has proved successful with so many amateur communications experiments over the years, establishing skeds with a station or stations at the target path terminal is a primary factor for success. Hence, choosing dates and times to conduct experiments that accord with these diurnal and seasonal constraints will go a long way to achieving the goal of 432 MHz TEP on the Australia-Japan circuit.

Path Loss: Considering this parameter helps determine the likely station setup required to achieve success on 70cm TEP. The stations that worked 2m and 70cm TEP on the South American circuit in 1978 were generally set up for satellite operation (Reisert and Pfeffer 1978), so high power and large antenna arrays were not determinants of success.

On 2m, the best signal strengths reported on this sector reached S9+, although many contacts were several S-points lower. Free space path loss on 144 MHz for a 6400 km path is 152 dB. The estimated least path loss in this instance was about 145 dB (Harrison 1979). Further consideration would put the mean path loss at about 170 dB.

For the Australia-Japan circuit over various paths (4800-6700 km), signal strengths of -85 dBm to -110 dBm seem to be typical for common 144 MHz stations (Harrison 1979, Sampol 2007).

In both the above instances, experience says path loss would be greater at 432 MHz.

Fimerelis and Uzonoglu (1981) reported on TEP experiments over 1978-80 on the Europe-Africa circuit, involving the 28, 50, 144 and 432 MHz bands. They determined values for mean and minimum path loss below free-space for two paths: Athens to Salisbury, Zimbabwe (6260 km), and Athens to Pretoria, South Africa (>7000 km). Unsurprisingly, mean/minimum path loss increases with frequency:

Band	**Excess Path Loss** (below free-space value)	**Mean/Minimum**
50 MHz	15 dB	mean value
144 MHz	47 dB	minimum value
432 MHz	61 dB	minimum value

The 432 MHz beacon of ZE2JV ran 40 W out, to a 17 dBi gain antenna, while the receiver of SV1DH in Athens had a noise figure of 3 dB and was fed by a 21 dBi gain antenna.

For the likely circuits suggested in Figure 3, the anticipated mean path loss on 432 MHz could be around 195-205 dB.

Azimuth and Elevation Considerations: As detailed earlier, the equatorial plasma bubbles rise through the F layer after forming and drift eastward. A bubble will first come into 'view' to the west of the great circle path between stations and travel to the east of the great circle path before it rises too far for the ray path to support propagation, thus cutting off the opening (Heron 1979). While not essential, tracking the movement of a bubble will improve communications.

The primary factor to consider is the elevation, or range of elevations, at which tangency with a field line in the F layer is achieved. Modelling by McNamara (2005) provides a simple graphical means of estimating the elevation angles to achieve tangency from various geomagnetic latitudes, as shown in Figure 5.

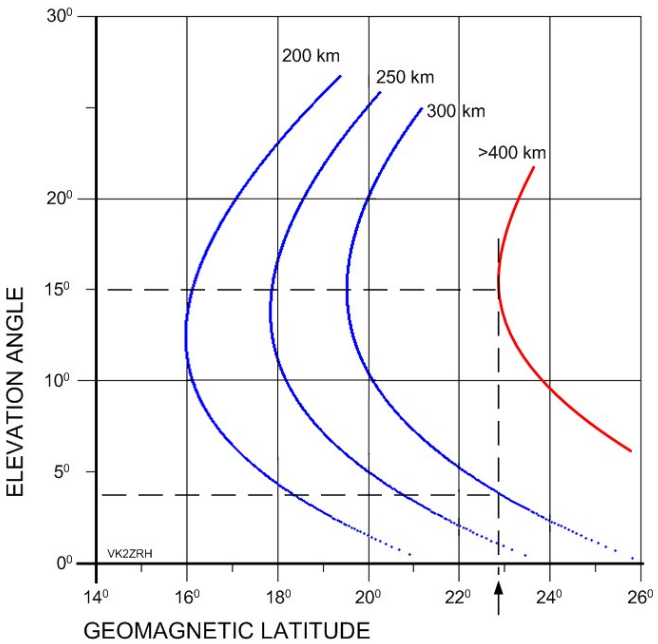


Figure 5. The elevation angles necessary to achieve ray path tangency with a field line from given geomagnetic latitudes.

The example illustrated here by the dashed lines is for a station near 23^0 geomagnetic latitude, eg. Darwin or west coast Cape York.

The 'nose' of the red curve indicates field line tangency is achieved at a height of around 400 km within a range of elevation angles around 15^0, which is readily achievable with practical antenna systems. Tangency at 300 km from the same location would be at an elevation of about 4^0, where practical antenna systems radiate less power than the peak of the main lobe.

Simple geometry tells us that, as a bubble rises, raising the elevation will maintain field line tangency, and swinging the azimuth from west of the great circle path to east, will keep the ray path following the bubble. Hence, from an Australian location as suggested in Figure 3, the antenna axis would describe a right-rising arc. As bubbles typically remain 'in view' for 20-40 minutes, it would only be necessary to move the beam about 5^0 every 10 minutes.

Transmission Mode: Given the severe fading and Doppler characteristics of 70cm TEP signals, choice of transmission mode is a factor critical to success. Hence, to date, all reported contacts have used Morse code. Some operators have commented that reception is reminiscent of auroral or EME signals. Any digital transmission mode that has proved successful for 70cm auroral communications would be a prime candidate, with the corollary that weak-signal handling capability may be superior to hand-sent Morse.

Conclusion

Who will rise to the challenge and be first to bridge the Australia-Japan circuit on 432 MHz via evening TEP? Accumulating contacts on 70cm will contribute to the body of scientific knowledge on equatorial plasma bubbles and TEP, continuing a tradition long-established by the radio amateur community.

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* Updated 2/2022.