Results and Analysis of Attempt at Extending the 10 GHz Terrestrial World Record on the Hawaii-California Path

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DUBUS Volume 2/2022 page 106 provided a planning document with the aim of extending the 10 GHz Terrestrial World Record from 2793 km between VK7MO and VK6DZ in Southern Australia to around 4000 km using the Hawaii-California path. The Hawaii-California path has provided all current microwave Terrestrial World records up to 5.7 GHz. The attempt was a failure in that nothing was detected on 10 GHz at the same time that WSPR signals transmitted along the same path on 432 MHz were decoded at plus 11 dB.

Our planning document noted that a key issue would be atmospheric gas absorption which was estimated at around 55 dB on 10 GHz. What we did not take into account at the time is that a characteristic of the Hawaii-California path is that propagation is mostly within a cloud layer which results in attenuation being significantly increased over that previously estimated, because of the liquid water content contained in the cloud layer. A second factor that may have contributed to our failure is that while plus 11 dB is a strong 432 MHz WSPR signal, it is much less than has been reported on this path in the past, suggesting that in fact we may not have had exceptionally good duct propagation during our attempt.

While we have attempted to compare the expected losses between 432 MHz and 10 GHz in order to explain the failure of this attempt there are a number of uncertainties, in particular as regards the liquid water content of duct contained within the cloud layer, and therefore the level of attenuation produced by the cloud layer. Given these uncertainties we cannot come to absolutely firm conclusions but we believe that we can state the following:

- The failure to detect signals on 10 GHz was most likely caused by higher-than-expected attenuation due to clouds.
- We likely did not experience optimal ducting conditions, based on our 432 MHz data.
- It is likely that optimal ducting conditions are associated with continuous cloud cover along this particular path.
- Continuous cloud cover will markedly increase path attenuation at 10 GHz and may make completing a QSO at this frequency extremely difficult, if not impossible.

1. Background on the Hawaii-California Path

As set out in Fig 1 (from OK2KKW web site[1]) all current amateur terrestrial World record distances on bands from 1296 MHz to 5.7 GHz were achieved on the Hawaii-California path. We have also included in Fig 1 some of the longer successful 10 GHz contacts.

1.3 GHz: Hawaii-Mexico, KH6HME to XE2/N6XQ 15/07/1989 CW 4151 km
2.3 GHz: Hawaii-California, W6IT to N6NB/KH6 19/06/2015 SSB 4024 km
3.4 GHz: Hawaii-California, W6IT to N6NB/KH6 19/06/2015 SSB 4024 km
5.7 GHz: Hawaii-California, N6CA to KH6HME 29/07/1991 CW 3983 km
10.3 GHz: Portugal to Cape Verde Islands, D44TXV/HB9RXV to CT7/F6DPH 10/07/2010 SSB 2696 km
10.3 GHz: Southern Australia, VK7MO to VK6DZ 05/01/2015 SSB 2732 km
10.3 GHz: Southern Australia, VK7MO to VK6DZ 08/01/2016 JT4F 2793 km

Fig 1: List of Amateur microwave Terrestrial World Records up to 10 GHz

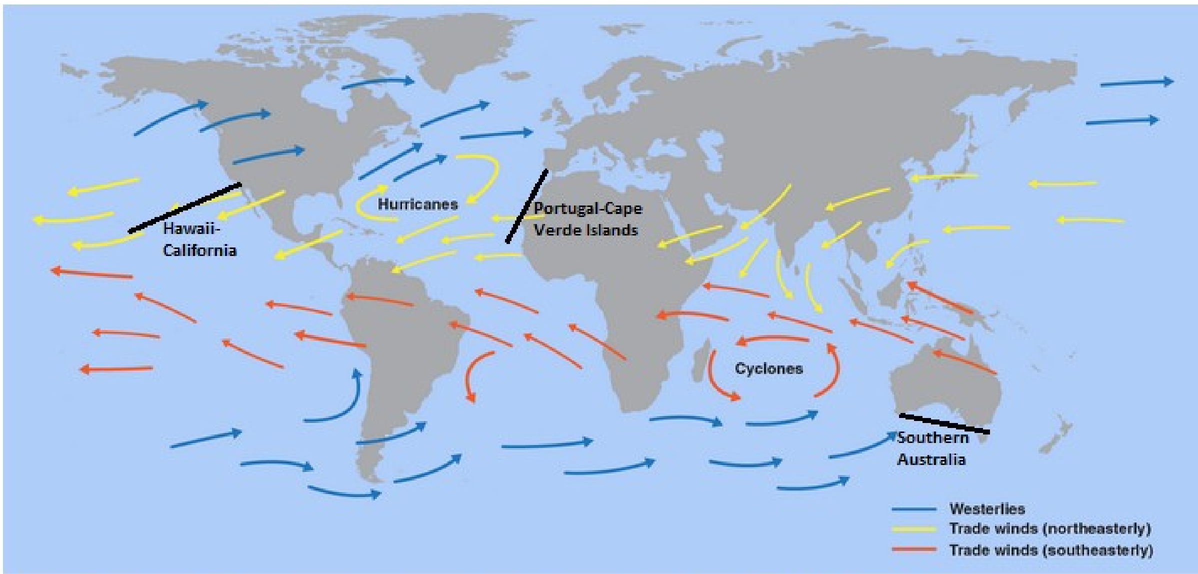
In the 1990s and 2000s N6CA and KH6HME undertook extensive testing to complete a QSO on 10 GHz without success. This work was terminated when KH6HME regrettably passed away in July 2012. The basis of the current attempt was to use digital modes and higher power (K6MG ran 500 watts to the feed) which we thought should make a 10 GHz QSO possible.

We will frequently refer in this article to a US Naval Research Laboratories report, 7725, by Purves[2] which summarized the results of extensive research on ducting over the Hawaii-California path conducted by the US Navy in the late 1950's and 1960's. The Navy research was conducted at either 220 or 435 MHz where atmospheric absorption and cloud attenuation is not a significant factor.

Some of the features of the Hawaii-California path and, where relevant, comparisons to the Southern Australian path and an earlier 10 GHz World Record between Portugal and Cape Verdi Islands are:

- As shown in Fig 2 the Hawaii-California path is in the Trade Winds region. Purves[2 page 12] notes:

The two most significant large-scale meteorological phenomena that cause the trapping of electromagnetic waves into an effective atmospheric waveguide are related to the trade winds temperature inversion and large-scale subsidence.



The trade winds blow from east to west near the equator. Credit: NASA/JPL-Caltech

Fig 2: Shows the Hawaii-California Path in the Trade Winds Region compared to the existing World Record in Southern Australia, in the Westerly winds region and based on large-scale subsidence. Also shown is the earlier 10 GHz World Record from Portugal to Cape Verde Islands which is partly a Trade Winds path.

- Ducts on the Hawaii-California path rise from a few hundred metres at the California end to 1500 to 2200 metres at the Hawaii end. The fact that the Big Island of Hawaii has high mountains makes it possible to access the higher-level ducts at the Hawaii end. The Southern Australian ducts are generally surface ducts up to a few hundred metres.
- A high-pressure system is generally present north of the Hawaii-California path which drives the Trade Winds so that propagation is potentially possible for days at a time subject to the right conditions at the California and Hawaii ends to enter and exit the duct. In contrast on the Southern Australian path high- and low-pressure systems move regularly across from the

west every few days and limit propagation to the period when a high-pressure system extends over the full path -- often less than a day on long paths. As the Southern Australian high-pressure systems are limited in extent to typically 1500 to 2000 km and only very occasionally extend to 2800 km this in turn limits the possibility of longer-distance propagation.

- The high-pressure system on the Hawaii-California path brings moist air from the Northern Pacific Ocean down the coast of California and then along the Trade Winds path from Southern California/Mexico across the Pacific Ocean to Hawaii. This moist air is evident at Hawaii where Hilo, near the western end of our path, is the wettest city in the USA with an annual rainfall of 4 metres. The Southern Australian path involves a high-pressure system over the dry inland continent of Australia. While the Portugal to Cape Verde Islands path is partly a Trade Winds Path, it is perpendicular to the Trade Winds and close to the coast so most of the air derives from the dry Sahara Desert.
- Purves[2 page 22] notes: *"One of the most significant meteorological findings related to the trade winds inversion was the apparent correlation noted between the extent of continuous radar signal ranges via an elevated duct layer and the extent of the continuous cloud haze layer conditions."*

  N6CA supports this in stating that a continuous cloud layer is necessary for strong signals on VHF/UHF such as 5/9 plus.

  By contrast in relation to subsidence ducts, which are generally accepted to apply in Southern Australia, Purves[2 page 12] notes:

  "Large-scale subsidence is associated with high-pressure areas. .... The statistically stable characteristics normally associated with high pressures are those of good weather conditions, generally weak winds and clear skies in the centre, and low stratus clouds around the peripheral regions."

We do not think the situation is as clear cut as indicated by Purves in that we have seen weak 432 MHz propagation beyond the continuous cloud layer and we have also seen some cloud on the Southern Australian path at the time of propagation.

Never-the-less the advice from N6CA and Purves supports the general proposition that it is necessary for continuous cloud to be present to produce strong VHF/UHF signals on the Hawaii-California path but this same cloud produces high attenuation at 10 GHz.

Fig 3 is an example of a satellite cloud image for about the time we received our best 432 MHz signals on 15 July 2022. It shows extensive cloud cover at the San Diego end of the path but this does not extend all the way to Hawaii.

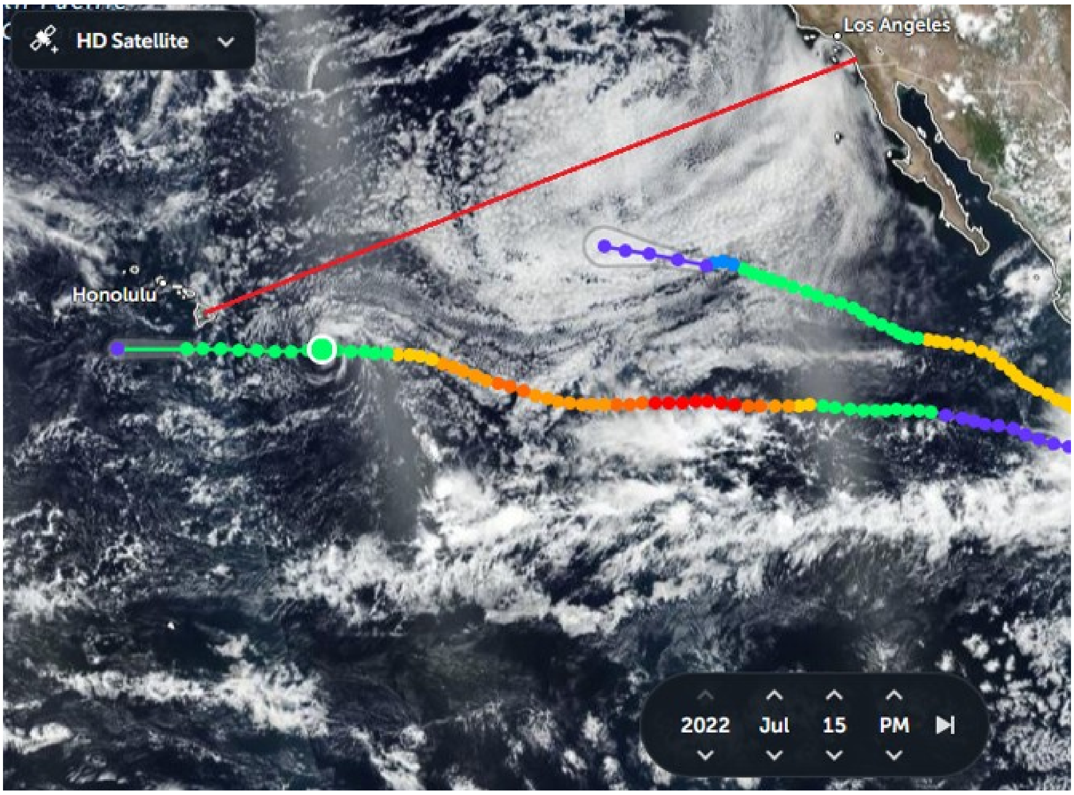


Fig 3: Example of satellite cloud image at the time we received the best WSPR signals on 432 MHz. Note the coloured paths are hurricanes and while these did not cross the path at this time they likely contributed to the disturbance of the duct during the period of our operations.

During the period of our operations, we had no examples of a cloud layer extending over the full path from California to Hawaii and this may explain why we did not get the very strong signals on 432 MHz that have been reported in the past.

- Purves[1 page 18] discusses the fact that propagation is restricted to the cloud layer in the vertical dimension. He supports this view with the following example:

"Several probes [with the aircraft flying] above and below the stratus cloud layer, .. resulted in loss of signal just above the cloud tops and again at the cloud-base level".

The above statement by Purves is supported by ham observations by KH6HME (SK) that FM radio signals drop out when one rises above the cloud at the Hawaii end.

As shown if Fig 4 the duct should in theory rise slightly above the cloud layer. The explanation for the difference could well that the tops of cumulus clouds, which generally occur at the Hawaii end, extend above the duct due to convection.

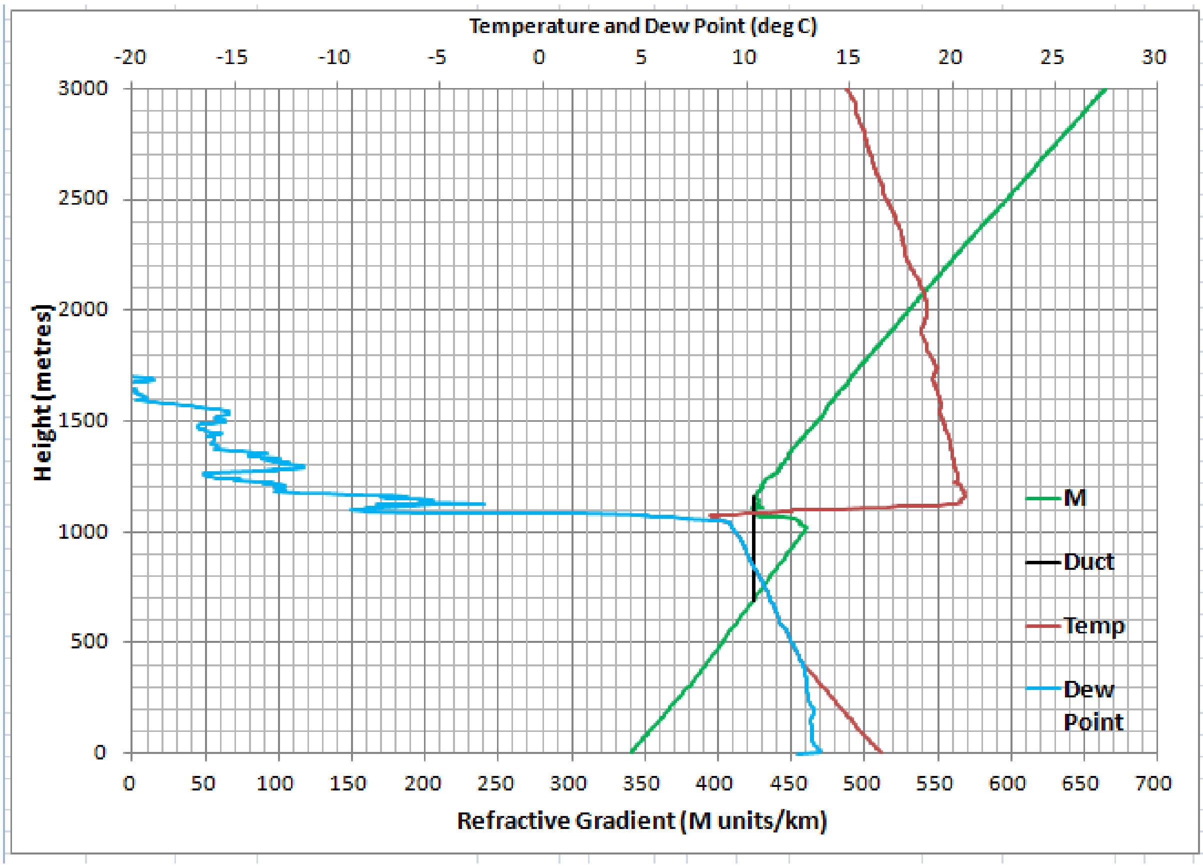


Fig 4: Example of a duct from Radiosonde data obtained from shipboard operations between California and Hawaii in July 2013. Data were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Climate and Environmental Sciences Division.

The green line on Fig 4 is what is called the Modified Refractive Gradient and from this the duct can be defined by the black straight line. The blue line shows the dew point is the same as the temperature over most of the duct and thus that cloud would be present.

An implication of the diagram at Fig 4 is that one should be operating in the cloud layer (or possibly just above it) to be within the duct. In general, we based our operating height on the heights of ducts based on radiosonde data at Hilo and expected the duct to be pushed up by the rising terrain. In most cases we could see the cloud on the horizon and on only a few days were we within rain and mist. With hindsight we now think that the cloud layer which we saw on the horizon was more likely the tops of cumulus cloud and it would have been better to operated lower down in the rain and mist to have a greater certainty that we were in the duct.

3. Site for Operations

At the Hawaii end the ducts are typically in the range 1500 to 2200 metres elevation. To access sites within the duct it is necessary to travel from Hilo some 35 km up the road bisecting Hawaii Island (Saddle Road) along which we found two accessible sites with good take-offs: one at 1580 metres elevation (as used previously by N6NB) and a second at 1691 metres. Each day as we travelled up the Saddle Road, we encountered mist and rain. For higher sites it is necessary to use the Mauna Loa Observatory Access Road where we found accessible sites with good take-offs at 2030 and 2151 metres. Fig 5 shows the sites we found most useful and also includes the KH6HME beacon site.

There are WSPR beacons on 144 and 432 MHz and a CW beacon on 1296 MHz at the KH6HME beacon site. The 432 MHz beacon had failed completely prior to our attempt and the 144 MHz and 1296 MHz beacons were suffering from power supply problems which produced 120 Hz AC hum birdies. In the case of the 144 MHz beacon there was no WSPR modulation. While the 144 MHz beacon was detected in California as a carrier and 120 Hz sidebands on a few occasions the beacons did not prove to be useful as a propagation indicator.

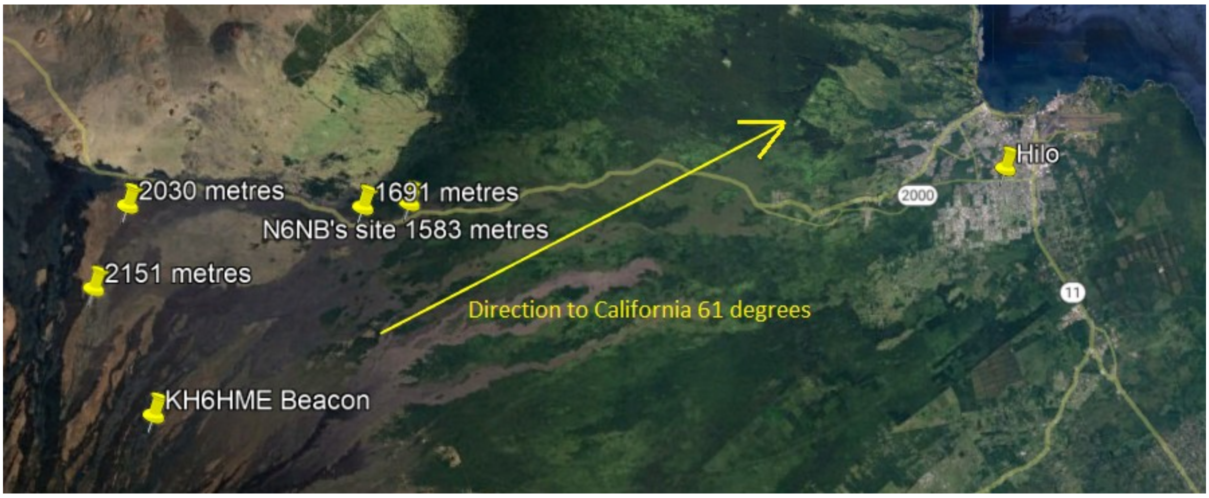


Fig 5: Location of Hawaii Sites with a good take-off where it is possible to get safely off the road

At the California end accessible sites with good take-offs were found at 320, 420, 450 and 765 metres but most operations were by K6MG from 320 metres. K6QPV operated from his home QTH at 265 metres but has some obstruction (estimated at 0.7 degrees) due to a nearby hill.

The original plan was for K6QPV, W3SZ and K6MG to operate on 10 GHz from around San Diego, N6CA from near Los Angeles and for VK7MO to go to Hawaii and look for support from hams on the Island. Bob WH6XM had volunteered to provide a location to ship equipment and facilities to assemble the 10 GHz and 432 MHz stations (Fig 6). He did warn in advance that he may not be able to travel up the mountain. Two other Hawaii Hams had tentatively indicated an interest in helping but it turned out that they were unavailable. When VK7MO came to the conclusion it would be too difficult to operate on his own W3SZ kindly volunteered to come over and help at the Hawaii end. He also set up a second station for 432 MHz which gave us the opportunity of monitoring propagation at sites at different heights to find the duct.

Fig 6. VK7MO's Equipment set up in Honda Odyssey Van. The 10 GHz dish slides out on a separate plywood base plate for removal.

4. Equipment

We took equipment for both 10 GHz and 432 MHz as set out below. 432 MHz rather than 144 MHz was chosen as a propagation indicator based partly on the fact that antennas for the higher frequency were smaller and easier to transport and partly to avoid the possibility that thin ducts might not support propagation at 144 MHz. The use of 432 MHz also avoids the possibility of Sporadic E being involved; for example, with double Hop E's or due to E's extending a duct. California stations sent WSPR one way as a propagation indicator.

10 GHz Equipment:

KH6/VK7MO, Hawaii: 77 cm dish, 62 watts (58 watts at the feed), sites from 1691 to 2151 metres. The dish and mounting hardware had been air freighted from Tasmania to Bob WH6XM who provided facilities to build the station in the back of a rental car (Fig 5). Murphy in the form of Bob and his wife going down with COVID delayed operations for more than a week.

K6QPV, San Diego: 120 cm dish and 150 watts, home station at 265 metres.

K6MG, San Diego: 180 cm dish and 725 watts (500 watts at the feed) portable station (see photo of installation at operating site of 320 metres at Fig 6)

W3SZ: Brought a 60 cm dish and 30-watt system from Pennsylvania but this system was not used when W3SZ moved to Hawaii to support VK7MO.

N6CA: 35 watts to a 90 cm dish – 432 MHz signals at his location did not justify setting up for 10 GHz.

432 MHz:

KH6/VK7MO received WSPR on a 12 element Yagi and was joined by W3SZ who received on an 11 element Yagi, sometimes set up at a different site to compare signal levels at different heights. WSPR signals were received from K6MG (using W3SZ's equipment and callsign, 60 Watts to 15 element antenna) and K6QPV (60 watts to a 22 element Yagi). 432 MHz WSPR signals were also transmitted by WA6MEM, and on one occasion each by N6CA and N3IZN. In general, propagation favoured the San Diego area which is closer to the Trade Winds region.

Fig 7: K6MG's portable station with 1.8 metre dish running a TWT at 725 watts; 500 watts to the feed. 432 MHz Yagi for WSPR is at top left of the photo.

5. Testing and Proving Equipment Performance

Testing was done with Sun noise to prove RX performance and antenna alignment at 10 GHz, an independent weak signal GPSDO locked frequency reference to confirm frequency, and TX power output checked based on PA current – all these tests showed that VK7MO's system was working correctly. KH6/VK7MO and K6MG completed EME contacts with W5LUA with signal levels that confirmed all systems were working properly and that frequencies were correct. Thus, we were confident that equipment performance was not the reason for the failure of the 10 GHz terrestrial attempts.

K6MG and K6QPV confirmed that each other's systems were on frequency and used power meters to check TX power.

A key issue for terrestrial is to point accurately. VK7MO and K6MG used differential GPS systems that are good to around 0.1 degree in azimuth and K6QPV used features on the horizon identified on Google Earth. During 10 GHz operations K6MG did vary his azimuth slightly in case this was an issue but still no signals were detected. There is also a question of the correct elevation to beam into the duct. The optimum should be zero degrees when we are within the duct. VK7MO did vary his elevation up and down by up to one degree but again this did not produce any detectable signals.

6. Results

432 MHz WSPR signals were received from California by either KH6/VK7MO or KH6/W3SZ as in Fig 8. In total some 373 WSPR decodes were received on 432 MHz with a best signal of plus 17 dB.

Date in Hawaii	Best Signal (dB WSJT Scale)	No of Decodes	10 GHz Operation and Decodes	Notes
2 July	-17	7		
3 July	-1	12	K6QPV - Nil	
4 July	Nil	Nil		
5 to 7 July				No Operations
8 July	Nil	Nil		

9 July	Nil	Nil		
10 July	+9	30	K6QPV-Nil	
11 July				No Operations
12 July	Nil	Nil		
13 July	Nil	Nil		
14 July	+5	71		
15 July	+11 (+17)*	88	K6QPV & K6MG -Nil	
16 July	-9	56		
17 July	+2	70	K6QPV & K6MG -Nil	
18 July	-3	36		
19 July	-24	3		
20 July	Nil	Nil		
21 July	Nil	Nil		
22 July	Nil	Nil		
23 July	Nil	Nil		

Fig 8: Results of Tests.

* While the best signal received was at +17 dB, there was no simultaneous 10 GHz transmission at this time. The plus 11 dB signal noted above is the strongest 432 MHz signal that we can directly compare with 10 GHz.

7. Losses due to the atmosphere, cloud and rain

The International Telecommunications Union (ITU) provides methods for calculating the attenuation due to atmospheric absorption, cloud and rain(3). We look in more detail at each of these losses in Appendix A(4) but in summary the issues are:

Attenuation due to Atmospheric Gases: At 10 GHz this attenuation is significant and can be of the order of 60 dB on the Hawaii-California path. This attenuation can be calculated from radiosonde data using ITU recommendation P.676-11(4). While we have radiosonde data at each end of the path at San Deigo and Hilo we have no data on the middle of the path. We can get some idea of what happens in the middle of the path from an experiment conducted in 2012/2013 with radiosondes being launched every 6 hours from a ship travelling from Los Angeles to Honolulu, as well as from from satellite data that is available from the 2007 to 2010 time frame. All of these 3 approaches give similar values of ~ 60 dB atmospheric gas attenuation across the San Diego-Hawaii path at 10.368 MHz. Even at 432 MHz there is some loss due primarily to oxygen estimated at 8 dB. In Appendix A(5) we have estimated the relative increase in attenuation from atmospheric gases between 432 MHz and 10.3 GHz to be in the range 49 to 57 dB.

Attenuation due to Cloud Liquid Water Content (LWC): ITU Recommendation P.840-5(4) gives a method of calculating this loss but it requires data on Cloud LWC over the full path which is not available for the time of our tests. Satellite data on LWC is available for July for the four years 2007 - 2010 inclusive that suggests this loss is likely in the range 37 to 74 dB based on monthly means for this data obtained both for typical and 100%-cloud-cover conditions (see Appendix A(5)). Attenuation due to LWC drops away rapidly below 5 GHz and is negligible at 432 MHz.

Attenuation due to Rain: It is possible to estimate the attenuation due to rain from satellite data as we have done in Appendix B(5). At the time of our best signals on 432 MHz there was little rain on the path and we estimate this loss at less than 1 dB and thus it can be ignored.

Overall, our estimates of the losses due to Atmospheric Gases and LWC at 10 GHz are in the range 86 to 131 dB greater than at 432 MHz. Given that strong signals occur when there is more cloud along the path as occurred when we received the best signals on 432 MHz then it is likely that at this time the losses were nearer the upper end of this range.

8. Relative 432 MHz and 10 GHz Signal Levels

In comparing 432 MHz and 10 GHz it is straight forward to allow for differences in TX power and RX sensitivity. In the case of a duct the situation is complicated by the fact that it is only possible to enter a duct at very shallow angles of less than about 0.7 degrees and we have very different beamwidths on 432 MHz and 10 GHz. Attenuation due to atmospheric gases and cloud is considered separately at the end for this Section. To simplify this analysis, we have assumed that both antennas are within the duct and that all the transmitted energy is distributed evenly across the 3 dB beamwidth (errors due to this assumption should be no more than a few dB). This analysis is based on the systems we used to measure the strongest 11 dB WSPR signal on 432 MHz when nothing was detected on 10 GHz at the same time. The distance was identical for both systems which simplifies the comparison.

The energy at the receiver is proportional to the capture area of the receive antenna. The capture area can be derived from antenna gain taking also account of the fact that gain is referenced to an isotropic antenna which has a much lower capture area at 10 GHz compared to 432 MHz. While the gain of the 432 MHz RX antenna is only 13.4 dBi compared to 36.2 dBi at 10 GHz this difference is more than offset by the lower capture area of a 10 GHz isotropic antenna, given by 20*LOG(432/10368) or -27.6 dB. The result is that at the receive end the signal level at 10 GHz due to the relative capture areas is some 4.8 dB less than for 432 MHz.

At the transmit end the energy in the horizontal dimension it is spread by the beamwidth of the transmitting antenna which is around 32 degrees at 432 compared to 1.1 degrees at 10 GHz giving 10 GHz an advantage of 10 Log10(32/1.1) or 14.6 dB. In the vertical dimension the energy entering the duct is restricted to about +/-0.7 degrees or 1.4 degrees so the energy at 432 MHz is reduced by 10*LOG10(32/1.4) or 13.6 dB. While the beamwidth of the 10 GHz transmitting antenna is 1.1 degrees and thus less than the 1.4 degree all of the energy is still within the duct so no extra advantage is gained by the reduced beamwidth. Thus, at the TX end 10 GHz has an advantage of 28.2 dB.

The best signal we received on 432 MHz at the same time we were listening on 10 GHz was plus 11 dB. As a single tone can be detected at around -34 dB this means the signal level on 432 MHz was some 45 dB higher than necessary to detect a single tone.

All of the above factors are taken into account in Fig 9. Fig 9 shows that excluding attenuation due to atmospheric gases and cloud we had some 82 dB in reserve to detect a single tone on 10 GHz when the signal level was 11 dB on 432 MHz. The fact that we received nothing at all on 10 GHz can be explained by estimated losses in the range 86 to 131 dB due to atmospheric gas and cloud as set out in Section 7.

	CA to HI	CA to HI	Advantage of 10 GHz relative to 432 MHz (dB)
Frequency (GHz)	0.432	10.368	
Wavelength (cm)	69.4	2.9	
TX Power to the feed (watts)	50	500	
TX Power to the feed (dBm)	47	57	10.0
Boltzmann's Constant	1.4E-23	1.4E-23	
External Noise Deg K due to atmosphere	290	290	
RX Noise due to RX noise figure and feed line losses	651	72	
Total Noise Temperature Deg K	941	362	
Reference Bandwidth (Hz)	2500	2500	
RX system sensitivity in 2.5 kHz BW (watts)	3.29E-17	1.27E-17	
RX system sensitivity in 2.5 kHz BW (dBW)	-164.82	-168.97	4.1
RX Antenna Dish Diamenter (cm)		77	
RX Antenna Gain (dBi)	13.4	36.2	
Relative isotropic capture areas (dB)	-7.3	20.3	
Relative RX Capture Area (dB)	20.7	15.9	-4.8
TX Antenna Beamwidth	32	1.1	
Relative TX Antenna energy in the horizontal plane (dB)			14.6
Relative TX evergy in the Vertical plane (dB)			13.6
Advantage of 10 GHz relative to 432 MHz (dB)			**37.6**
Best Signal on 432 MHz cf single tone on 10 GHz	11	-34	45
Detectable 10 GHz single tone relative to best 432 MHz signal (dB)			**82.60**

Fig 9: Relative advantage of 10 GHz with no allowance for losses due to Atmospheric Gases or Cloud

Some have argued that leakage losses increase with frequency to explain why ducting propagation is so much more difficult at microwaves than at VHF. Comparative tests on the VK-ZL path (DUBUS V1/2020 page 120) show no significant increase in ducting losses with frequency once one takes account of losses due to atmospheric gases. Accordingly, we have assumed that leakage losses do not vary significantly with frequency.

9. Radiosonde Data

Radiosonde data is available every 12 hours at 00Z and 12Z from Hilo Airport and the San Diego/Miramar Naval base. We used this data to produce charts (such as in Fig 4) to get an indication of the height and thickness of the ducts at each end of the path. Two important limitations in using radiosonde data are [1] it is only available every 12 hours (2 to 3 hours after a sounding) and the situation can vary significantly in the intervening period and [2] its reported data reflect conditions along the (roughly vertical) path travelled by the radiosonde from its point of launch, and conditions at our station sites and within the RF duct likely differed from the radiosondes' conditions.

An example of the second issue just mentioned is that, particularly at the Hawaiian end of the path, the rising terrain can force the temperature inversion up to higher altitudes, causing the radiosonde data to substantially underestimate the height of the temperature inversion and thus of the RF duct.

10. Hepburn charts

Hepburn charts give a useful indication of ducts at the California end but no information on the height of the ducts. We often saw a duct on the Hilo radiosonde data that did not show up on the Hepburn charts. We believe the explanation is that the Hepburn charts do not show ducts at altitudes as high as that of typical ducts at the Hawaii end of the path.

11. Is it possible to complete a 10 GHz QSO on the Hawaii-California Path?

While we cannot give a definitive answer to this question some of the issues that bear on this question are as follows:

- The equipment we had available in this case with 500 watts to a 1.8 metre dish in California and 58 watts to a 77 cm dish in Hawaii is probably the practical limit as to what is possible given the difficulty of operating portable at Hawaii and transporting the equipment to the Island.
- Our tests showed nothing at all from a single tone from K6MG's 1.8-meter dish and 500 watts. To complete a QSO will require two-way communication, with about 10 dB less transmit power available for the Hawaii-based station than was available from our California-based station, and the use of Q65-60B which is about 5 dB less sensitive than the level at which single tones can be detected. Thus, we need at least a 15 dB improvement.
- The 432 MHz signals show very significant variability and for a QSO to be completed there have to be decodable signals for several periods; thus, some further increase in system performance is required.
- Much stronger signals have been reported on 432 MHz in the past. N6CA suggests at least plus 30 dB, on the WSPR Scale. However, he also considers that such strong signals only occur when the cloud layer extends over the full path which further increases the losses at 10 GHz.
- N6CA considers that such strong signals may no longer occur. A recent paper indicating that there has been a decline in cloud cover over the eastern end of our path over the past 20 years provides some support to this statement given that consistent cloud cover along the path may be a necessary condition for optimal RF duct performance(6).
- Positioning the stations within the cloud layer will maximise the likelihood that the stations are within the RF duct and thus maximise the strength of the UHF signals received.
- Given the low probability of success, any attempt at 10 GHz would likely require spending much more time on the mountain at Hawaii and much more time in the heat in California. The logistics of arranging this would be substantial, particularly at the Hawaii end.

12. Acknowledgements

WH6XM for providing a QTH to send equipment and facilities to assemble VK7MO's station.

WA6MEM for running his WSPR station most of the time we were operational. WSPR signals were also received from N6CA and N3IZN on one day.

N6CA for providing useful comments based on his experience.

Dr Andrew Klekociuk for useful discussions and preparing satellite data

Data citation: Atmospheric Radiation Measurement (ARM) user facility. 2012. Balloon-Borne Sounding System (SONDEWNPN). 2012-10-01 to 2013-10-03, ARM Mobile Facility (MAG) Los Angeles, CA to Honolulu, HI - container ship Horizon Spirit; AMF2 (M1). Compiled by K. Burk. ARM Data Center. Data set accessed 2022-10-24 at http://dx.doi.org/10.5439/1595321.

13. Conclusions

- We think the prime reason for the failure to detect even single tones is attenuation due atmospheric gases and cloud.
- A second factor was that 432 MHz signals were much weaker than have been observed in the past, making 10 GHz doubly difficult.
- At 10 GHz there are competing issues, in that the evidence is that cloud is necessarily along the full path for a strong duct but this necessarily means high attenuation.

References:

(1) OK2KWW Web site, https://www.ok2kkw.com/dxrecords.htm

(2) Purves, “Geophysical Aspects of Atmospheric Refraction”; available on F5LEN’s web site at:

http://f5len.free.fr/PDF/index.html

(3) ITU Recommendations on attenuation due to Atmospheric Gases and Cloud

P.676-13 Attenuation due to Atmospheric Gases
https://www.itu.int/rec/R-REC-P.676-13-202208-I/en

P.840-5 Attenuation due to Clouds and Fog
https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.840-5-201202-S!!PDF-E.pdf

(4) Appendix A: Estimation of Losses due to atmospheric gases and cloud
https://w3sz.com/DUBUS_Ca-Hi_Duct_2022.html

(5) Appendix B: Estimation of Losses due to Rain
https://w3sz.com/DUBUS_Ca-Hi_Duct_2022.html

(6) P. R. Goode et al, “Earth's Albedo 1998–2017 as Measured From Earthshine”, Geophysical Research Letters, 48, e2021GL094888. https://doi.org/10.1029/2021GL094888