Aircraft Scatter on 10 and 24 GHz using JT65c and ISCAT-A

By VK7MO and David Smith VK3HZ

The authors have been using the digital modes JT65C and ISCAT-A to work aircraft scatter at distances of up to 842 km on 10 GHz and recently 462 km 24 GHz. The use of aircraft scatter extends distances significantly over tropo-scatter where our maximum distances worked are 526 km on 10 GHz and 268 km on 24 GHz. An advantage of aircraft scatter on 24 GHz is that much of the path is at high altitude where water vapour is lower and the atmospheric absorption losses are reduced.

Equipment on 10 GHz

VK3HZ

- 600 mm prime-focus dish
- Meade computerised telescope mount and tripod
- Qualcomm “Lambchop” converted to 10 GHz and to allow for GPS locking
- DEMI 8 watt PA
- Kuhne preamp
- FT-817 as 144 MHz IF, modified for 10 MHz locking
- Homebrew (G3RUH-like) 10 MHz GPS
- Asus Netbook with homebrew rig interface

VK7MO

- 640 mm offset-fed satellite dish
- Surveying tripod with homebrew Az-El mount
- Kuhne 10G3 Transverter
- Kuhne 10 watt PA
- Kuhne pre-amp
- ICOM IC-910-H as 144 MHz IF, modified for external frequency reference
- Fury double-oven 10 MHz GPS
- Homebrew GPS-locked PLL for IC-910-H
- HP Laptop with homebrew rig interface
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Equipment of 24 GHz

VK3HZ

- 380 mm prime-focus dish
- Thales module – 1.5 watts
- Other items as for 10 GHz

VK7MO

- DB6NT transverter, pre-amp and 3 watt PA
- 47 cm offset dish (should be 39 dBi but tests suggest it is somewhat lower say 37 dBi.)
- Celestron 8 inch telescope mount and builders tripod
- Other items as for 10 GHz

What is Aircraft Scatter?

In VK the term Aircraft Enhancement is used to describe the increase in signals that occur when an aircraft is closely in line between two stations. There has been much debate as to the actual mechanisms and readers are referred to the following URL.

http://www.vk3hz.net/ae.htm

Professional texts show that there are several mechanisms that contribute and form what is called the Radar Cross Section (RCS), which is a measure of how effectively the aircraft scatters in any particular direction. However, it seems that for the forward scatter direction (that is of interest to us) the main processes are diffraction (due to blocking of the radio wave by the aircraft) and reflection from flat surfaces. At VHF, diffraction probably dominates but at microwave frequencies things become much more complex with the signals breaking up into short bursts of a second or so which may well be due to different diffraction lobes and/or due to reflections from surfaces on slightly different angles. From our work, all we can say is that at 10 GHz scattered signals generally come in bursts of a second or so over periods of 10 to 30 seconds and that the bursts and periods tend to be shorter at 24GHz. We can also say that there are occasions when we get multiple periods that are separated by from tens of seconds up to a minute which allow more than one over per aircraft. However, often on 10 GHz and particularly 24 GHz it takes more than one aircraft pass to complete a QSO.

Doppler Shift

At microwave frequencies, the variation of frequency due to Doppler shift becomes a major issue. Doppler is close to zero if the aircraft fly closely in line with the path of propagation but can change by more than 1000 Hz per minute for paths that are at right angles to the path of propagation. K1JT's WSJT program (in JT65 mode) has an AFC system that allows it to track frequency variations of up to around 20 Hz in a transmission period. This still limits its use to paths where the aircraft cross at no more than around 15 degrees. We found that WSJT's ISCAT copes with the much more rapid Doppler changes and after discussion with Joe, K1JT, he kindly developed the ISCAT-A mode specifically for our microwave aircraft scatter work. While ISCAT-A is not as sensitive as JT65c, it copes better with the short bursts of signals such that the loss in sensitivity is not a significant factor. It also has the advantage that it can be run with 15 second overs compared to one minute overs for JT65c and this can often allow a QSO on one aircraft where two or three may be required on JT65c. Our rule of thumb on 10 GHz is to use JT65c if the aircraft cross the path of propagation at less than 15 degrees and to use ISCAT-A if the aircraft cross at greater angles. At 24 GHz the Doppler limits the use of JT65c to aircraft crossing at angles of no more than about 5 degrees. To date we have not attempted to use ISCAT-A on 24 GHz as with the increased absorption losses at 24 GHz and lower power available, this is unlikely to be viable – still something to experiment with in the future.

Aircraft Scatter v Tropo Scatter propagation 10 GHz

Figure 1 below shows distances for grid squares that were completed with aircraft scatter compared with those completed on tropo-scatter for 72 separate grid squares completed to date. It is seen that tropo-scatter is useful up to around 500 km but that aircraft scatter extends our range to beyond 800 km and has allowed us to almost double the number of grid squares completed.

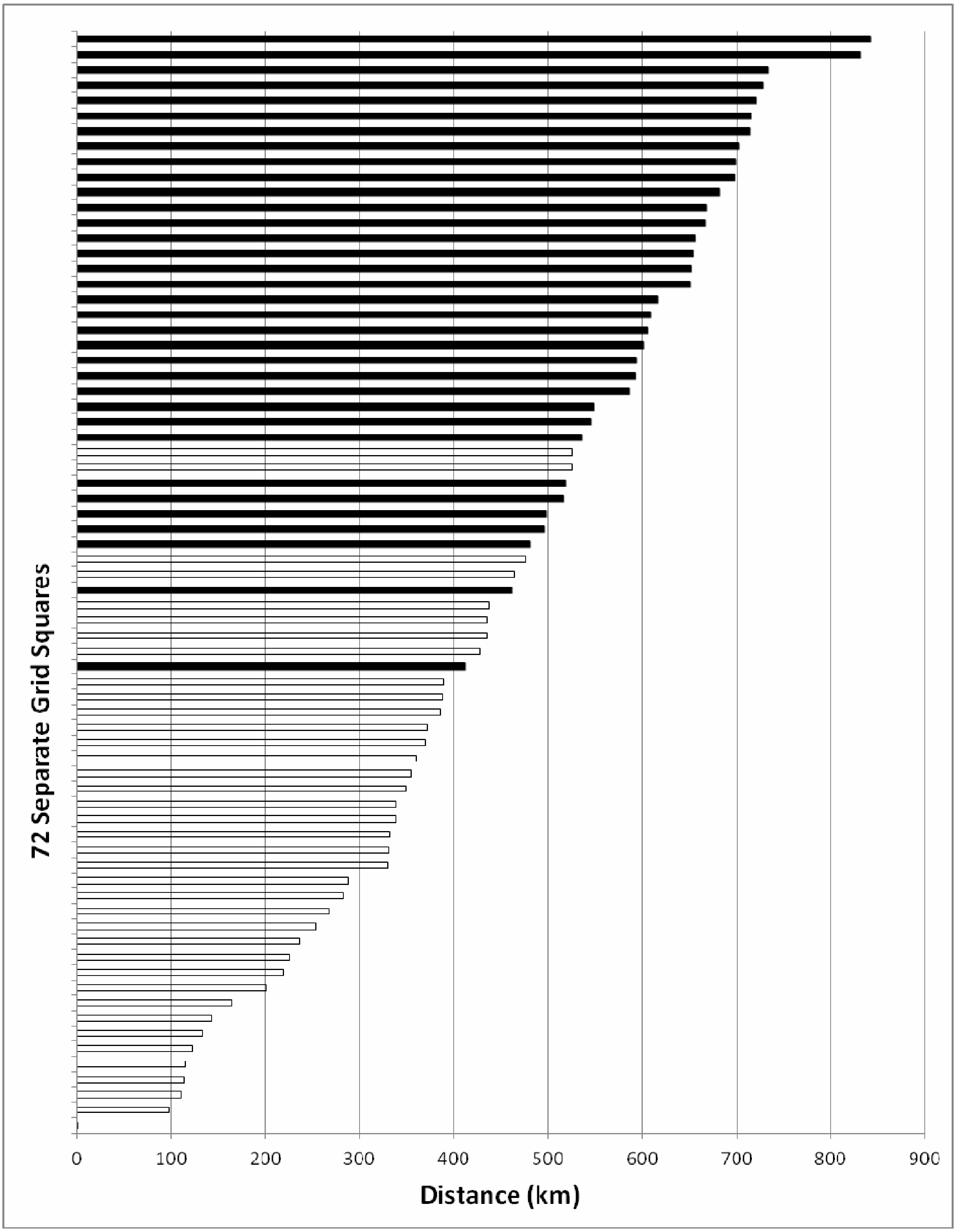

Figure 1 – Propagation Mode versus Distance for 10 GHz - Black filled Bars are aircraft scatter and unfilled Bars beyond 150 km are generally tropo-scatter.

The longest QSO of 842 km was initially completed by tropo-ducting on both JT65c and SSB, and when the duct faded a QSO was completed on aircraft scatter on JT65c. The second longest path of 831 km was completed only a day earlier. We suspect these two aircraft scatter QSOs might be examples of a situation where the improved radio refractive index that produces ducting can also extend the distance for aircraft scatter.

Aircraft Scatter v Tropo Scatter propagation at 24 GHz

To date we have only attempted and completed 24 GHz aircraft scatter QSOs on two paths of 251 km and 462 km. Both paths were planned to be closely in line with the aircraft paths (around 5 degrees crossing) so as to allow the use of the more sensitive JT65c. In both cases several aircraft were required to complete a QSO and for the 462 km path useful signals generally required larger international aircraft such as 747s. In comparison tropo-scatter works well to around 200 km and 268 km has been achieved when absorption is low.

SSB v Digital Modes on 10 GHz

Figure 2 shows the distance achieved with SSB compared to Digital modes JT65a and ISCAT-A. SSB will work well from good high locations up to 400 km on tropo-scatter but the distance reduces significantly on obstructed paths. The longest contact of 842 km was completed on SSB during the duct. SSB will also work on aircraft scatter up to almost 600 km providing the aircraft are flying closely in line with the path. Where a grid square was completed on both a Digital Mode and also SSB, the chart shows SSB. SSB was generally attempted where we thought it was possible. Even so, it is seen that over half of the grid squares required Digital Modes to complete. The majority of long distance squares required ISCAT-A reflecting the fact that this mode must be used if the crossing angle of aircraft is more than 15 degrees.

GPS Locking

The advantage of GPS locking is that it is unnecessary to tune to find a signal. Signals usually come-up within 10 Hz of the agreed frequency (other than as the result of Doppler as discussed earlier).

Finding where the aircraft crosses the Path of Propagation.

It is possible to add standard aircraft routes in VK to Google Earth by downloading the ICAO Asia Pacific Air Routes overlay file, available at:

www.vk3hz.net/radiosites/air_routes.kmz

One can then plot the path of radio propagation between the stations on Google Earth and determine the distance from each station to the point where the aircraft crosses the path. One can also measure the angle of crossing which is useful to establish the extent of the Doppler variation.

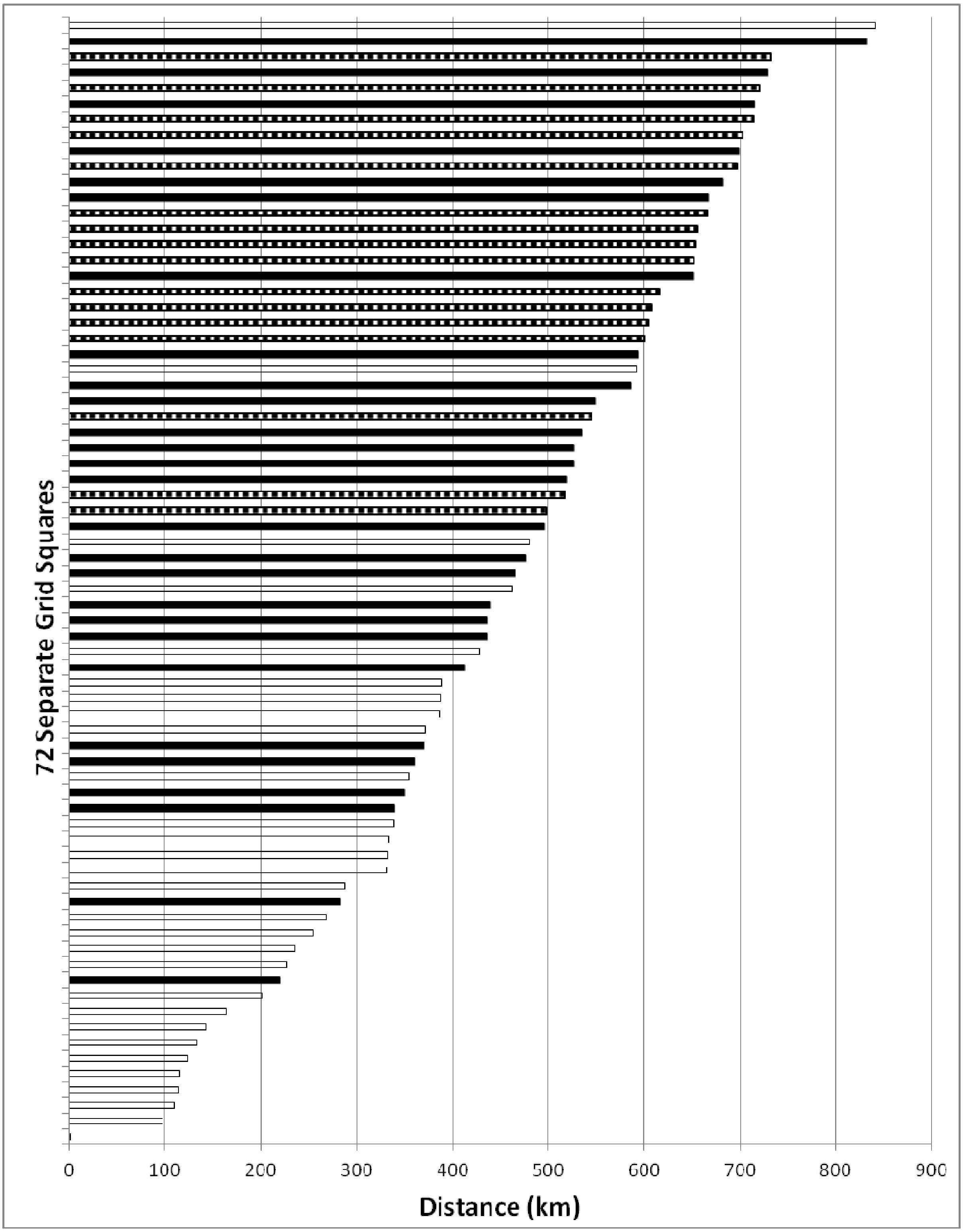

Figure 2 – Operating Mode versus Distance for 10 GHz. Black is JT65c, broken is ISCAT-A and unfilled is SSB Where a contact was first completed on a Digital Mode and later on SSB, the chart indicates SSB to show SSB was possible.

Radio Line of Sight to Aircraft

Aircraft scatter is only viable if the aircraft is within radio line of sight of both stations. This is affected significantly by the take-off angle of both stations and the distance to the point at which the aircraft crosses the path of propagation. For a situation where both stations have a zero degree take-off, an aircraft at a typical height of 36,000 ft can be seen for 430 km giving a maximum possible range for aircraft scatter of 860 km providing the aircraft crosses the path exactly in the centre. A simple calculator to check for possibilities is available on the web at:

http://members.home.nl/7seas/radcalc.htm

This calculator is based on the generally accepted 4/3rds Earth curvature rule that takes account of the radio refractive index of a normal atmosphere. In situations where there is enhanced radio refractive index the distance may be increased.

For more practical situations with hills on the path, it is necessary to fine tune the actual operating locations to ensure that both stations are in radio line of sight of the aircraft. For this purpose we have developed the Excel spreadsheet at:

www.vk3hz.net/microwave/radio_distance_to_aircraft.xls

To use the spreadsheet, the first step is to draw a path between the stations on Google Earth. Then right click on this path to show "Elevation Profile". The main features that control the radio line of sight to the aircraft will be at each end out to about 100 km. Using the print screen function copy the profile. Using a program such as MS Paint, cut out the relevant section of the profile and add to the spreadsheet as per the example. Follow the instructions in the spreadsheet to determine the distance from the station that the aircraft is visible. Repeat the exercise for the second station and establish that the aircraft is within line of sight at both stations for a reasonable period (at least a few minutes) at the time it crosses the path of propagation.

Beaming in Azimuth

In most situations we use forward scatter, which we define as the situation where the aircraft is directly in line in azimuth with the direction to the other station and thus it is only necessary to beam directly at the other station in azimuth. Even so, with antenna beamwidths that are around 3 degrees at 10 GHz (and less at 24 GHz), this means an error of 1.5 degrees puts one 3 dB down. Given that aircraft scattered signals are often very close to the margin one does not want to lose even 1 dB. Thus it is necessary to beam within a half a degree.

Antenna and rifle scope alignment

As the signals scattered from aircraft may only last a few seconds, it is impossible to align the antenna in both azimuth and elevation using traditional methods based on peaking for signal strength. In fact, one only needs to be a degree or so off to miss it completely. The technique we use is to have a rifle scope mounted to the antenna which is aligned using sun noise or moon noise. Sun noise is clearly easier to detect but one cannot look directly at the sun through the rifle scope. The solution is to place a thin piece of paper over the rifle scope and position the rifle scope so the image of the sun is centred at the time the sun noise is maximum. Sun noise is best measured with a broadband instrument such as a milliwatt meter at the IF frequency. While moon noise is much weaker, it has the advantage that one can look directly through the rifle scope at the moon and position the scope graticules, which are adjustable in both azimuth and elevation, directly on the centre of the moon.

Setting the Antenna in Azimuth

The rifle scope which has been aligned as above is used to set the azimuth of the antenna in the field. This is done by finding some reference that is visible and the position of which can be accurately determined with GPS for comparison with the GPS position of the field location. As a rule of thumb, any marker more than 500 metres away will allow a bearing to be derived from GPS references to an accuracy of better than 0.2 degrees. Distant hills with large TV installations often provide good references and road signs can also be useful. Farm houses, the position of which can be established accurately on Google Earth, are also useful. The GPS position of the bearing reference and the station location are inserted in the spreadsheet, which is available at the following URL, to define the bearing of the reference.

www.vk3hz.net/microwave/bearings.xls

The riflescope is aimed at the reference and then an azimuth indicator such as 360-degree protractor is set at that bearing. Given that the position of the other station is known, this can be added to the above spreadsheet which gives its bearing. The antenna can then be moved in azimuth to the bearing of the other station as indicated on the protractor or other bearing indicator.

Side Scatter on 10 GHz

In a few situations, it has not been possible for both stations to see the aircraft when it is directly in line and it is then necessary to use side scatter. We have found that side scatter is generally much weaker than forward scatter and is only useful for a few degrees either side of the direct forward scatter path. When using side scatter, one must beam to the actual position of the aircraft which means one must track it in azimuth.

Setting the Antenna in Elevation

To measure elevation we use an inclinometer mounted on the dish near the rifle scope. Recent developments in digital inclinometers mean that for around $100 one can obtain units on eBay with accuracies of 0.2 degrees and resolutions of 0.05 degrees. To determine the elevation of the aircraft, it is necessary to know its height and distance from the station (see next section). This information can be added to the spreadsheet at the following URL (which takes account of the normal radio refractive index of the atmosphere) to establish the elevation beaming angle:

www.vk3hz.net/microwave/aircraft_elevation.xls

As an example for an aircraft at 36,000 ft the elevation angles for various distances are as follows:

Aircraft Distance from Station (km)	Elevation angle (degrees)
300	1.3
200	1.5
100	5.8

Tracking Aircraft with ADS-B

Most modern domestic and international aircraft are equipped with ADS-B (Automatic Dependent Surveillance - Broadcast) which provides information on their exact position and height. Once a particular path is planned, the crossing distances from both stations are known and all one needs to do is make up a list from the elevation spreadsheet of the elevation angles in terms of aircraft height and adjust the elevation as soon as the aircraft is seen on ADS-B. In fact if one assumes a height of 35,000 ft one will generally be within the antenna beamwidth for longer distance paths (over 200 km from the aircraft) and elevation adjustment may not be necessary. It is also not necessary to track the aircraft in azimuth if forward scatter is being employed. For most situations tracking with ADS-B is not essential. Nevertheless, it is a very useful aid in that if one is aware that an aircraft has crossed the path and should have produced a signal then this is a good indication that one must check to be sure everything is working correctly. It is useful to set up the ADS-B system with the tracks of the aircraft and a line between the stations so one is aware when the signals should appear. Aircraft tracks are automatically provided by the ADS-B receivers and, at least with the Kinetics SBS-1 unit, one can add the paths of propagation by inserting the positions of the stations as waypoints joined by a boundary outline. An example of the output of the SBS-1 receiver with the line from QF53 to VK3ES representing the path of propagation and other lines representing aircraft tracks.

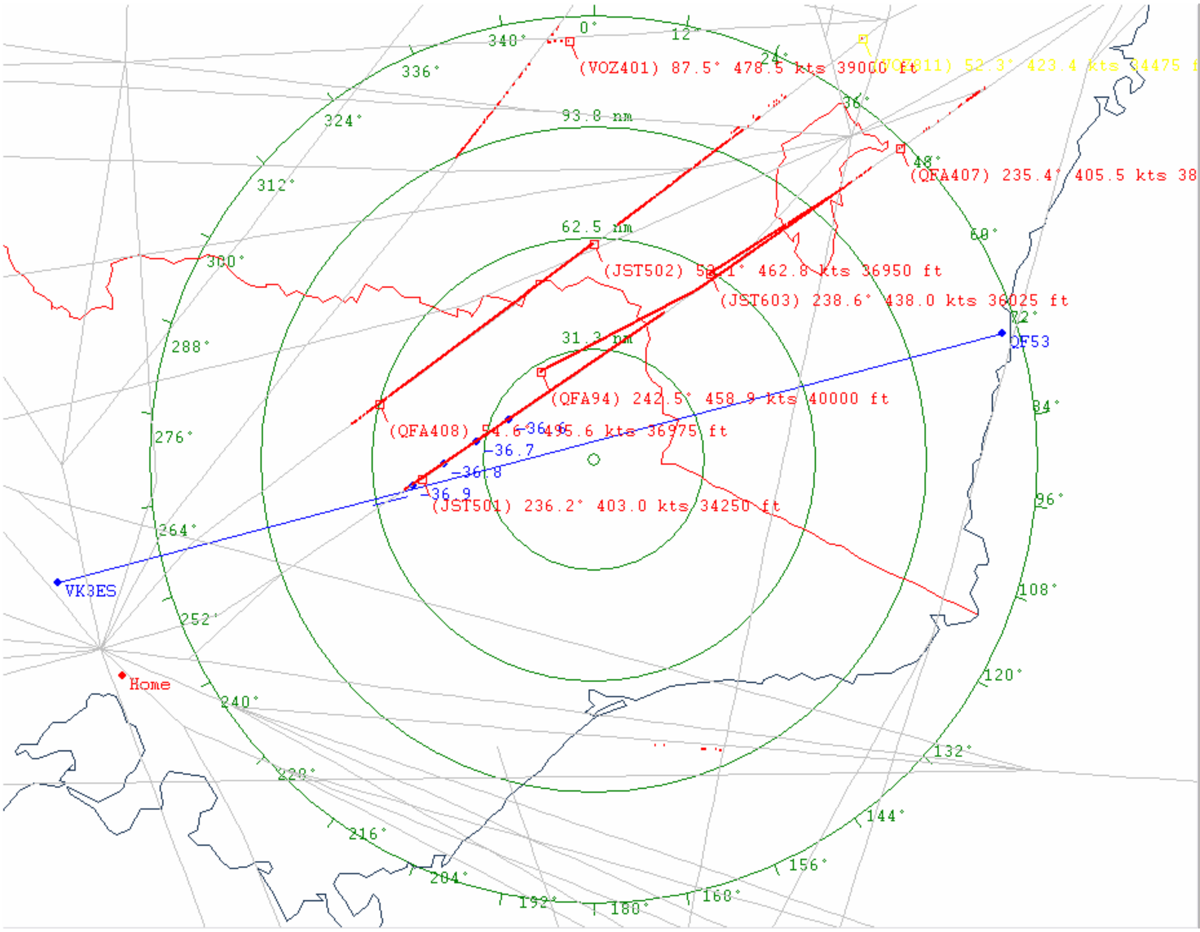

Figure 3 – Example ADS-B Radar Display

Some thoughts for US stations

With the large numbers of aircraft that fly across continental USA it seems there should be numerous opportunities for microwave aircraft scatter contacts. It would be very interesting to see the results that could be achieved with two 10 GHz home stations that have a common view across the same aircraft path and just run ISCAT-A continuously and see how many decodes are can be achieved.

Conclusions

It has been shown that aircraft scatter can be used to substantially increase the number of grid squares that can be worked on 10 GHz. While 24 GHz is much more difficult it has been shown that aircraft scatter can also be used to work up to 462 km. The key to successful aircraft scatter is to reduce the variables by:

- GPS locking of both stations
- Accurate alignment of antennas
- Accurate beaming of antennas in both Azimuth and Elevation

Careful planning is necessary to ensure there is a radio line of sight path between both stations.

Acknowledgments

Joe Taylor K1JT for specially developing ISCAT-A for our work.