# Entry Level AO-40 Capable Satellite Stations
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- **Abstract**

This article presents a means to communicate with the AO-40 satellite using minimum cost. Considered are both the currently observed operating procedures and example equipment required for successful two-way voice communication.

- **Introduction**

With the launch of AO-40 satellite there has been considerable interest about how to perform two-way communication at a reasonable cost.

A widely held perception is that a conventional satellite ground station requires complex and expensive equipment. Furthermore, there is an even wider held perception that the particular frequencies (2400MHz, or 'S band') currently available on AO-40 for communication require capabilities and financial resources beyond that of the average amateur.

A frustration for many new constructors of S band equipment is that there's not very much to be able to compare one's equipment with to determine how well it's working. Even having a local 2.4GHz beacon is not always helpful: beacon sub-bands are often not close enough to the satellite sub-band to be of use.

With AO-40 in mind in particular, presented here is a ground station which may be constructed without any existing equipment for a cost in the region of £300 (currently US$420). Of consideration is the ease in which AO-40 capability may be constructed by amateurs without any specialist knowledge, tools or equipment.

This article is based upon the real experiences of the first few months of AO-40 operation using both fixed and portable equipment. During this time, important operational considerations were discovered which are described below.

- **A Brief History of AO-40 so far…**

AO-40 was initially known as Phase 3D, or P3D. It's the fourth amateur Phase 3 satellite, hence the 'D'. Phase 1 amateur satellites were designed to last only a few weeks, having either no or limited means of power replenishment during orbit. Phase 2 satellites are in a Low Earth Orbit (or LEO), and lend themselves to communication over distances up to 4,000 miles or so. Phase 3 satellites are designed to operate over much longer distances because for most of their highly elliptical orbit they are at a much higher altitude than the LEO's.

AO-40's the most complex and feature laden amateur satellite ever flown.

When launched on November 16 2000, AO-40 seemed to be working correctly, or 'nominally', except for the 70cm transmitter.

Soon after being launched, the satellite started beacon transmission of telemetry data on the 2m band. And it sounded *very* loud!

AO-40 was left in an elliptical orbit, essentially in the same plane as the equator, as expected. For optimum use, the preferred orbit needed to be changed somewhat.

On December 13 2000, during some orbital manoeuvres using the 400N motor, AO-40 went silent.

To sighs of relief across the globe, on 25 December 2000 the 2401MHz (S band) beacon was switched on successfully, but a number of systems were now not working correctly, in particular the 2m transmitter.

Despite the setback, on May 5 2001 the transponder (the device allowing two-way communication) was switched on for a trial period until 30 May 2001. With reports from around the globe of worldwide contacts, this proved the satellite to be an unmitigated success.

Some further orbital manoeuvres ensued starting 21 June 2001, this time using the a second motor: the Arcjet (or ATOS). Designed for smaller orbital changes than the 400N motor, over a few orbits the Arcjet was programmed to fire for a couple of hours at perigee.

On 30 June 2001, the Arcjet firings were finished, and AO-40 was in a slightly better orbit, but unexpectedly all of the fuel had been consumed.

At the time of writing the spacecraft is being re-oriented to allow further two-way operation.

- **Early Experiences of AO-40 – Antenna Tracking**

The orbit attained from the combination of the launch and some post-launch manoeuvres is an elliptical orbit, shown below.
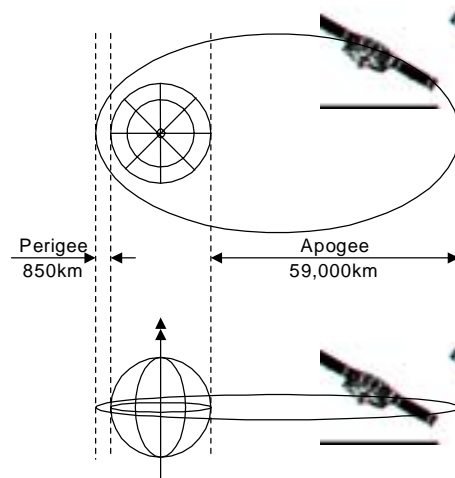


**Figure 1 Orbit of AO-40**

Note the two views: the top view is looking down directly from the North Pole. The lower view shows that the orbit is in almost the same plane as the equator. Each orbit takes 16 hours to complete.

The big difference between AO-40 and most other current amateur satellites is the orbit. At **apogee** (when the furthest point from the earth), the footprint (the area of the earth which can simultaneously access the satellite) is enormous.

**Perigee** is the point at which the spacecraft is closest to the earth. Because the orbit is almost in the equatorial plane, and at perigee the footprint has a radius of only 2,500km, relatively few amateurs will be in position to experience this.
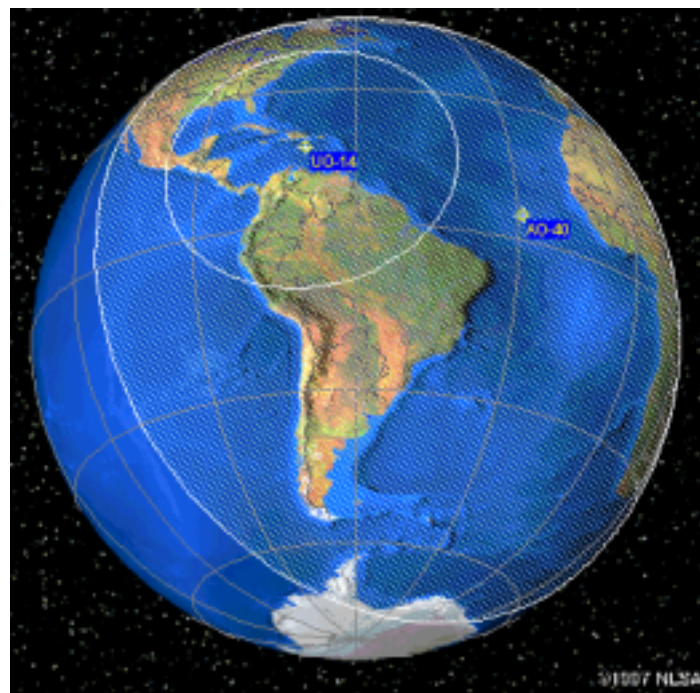


**Figure 2 Comparative footprints of UO-14 and AO-40**

The comparison of footprints is shown above: the small circle is the UO-14 footprint. AO-40's footprint completely engulfs UO-14, and carries on all the way around to the Middle East.

One of the benefits of a long orbit such as AO-40's is that for the majority of the time it doesn't appear to move very much in the sky. With the current orbit, where inclination is close to zero, only stations close to the equator can witness the swift perigee speed which affects LEO tracking, and this is for a very short period of the orbit.

Use of a camera tripod for mounting antennas for tracking LEO's is, in practice, often impractical as there is a requirement to continually track the satellite as it moves across the sky. Use of linearly polarised antennas manually mounted is practical for the majority of the time, as the rapid movement experienced with LEO's is not encountered.

This leaves us with some unanswered questions. How do we know (a) when AO-40 will be visible from the ground station's location and (b) where in the sky it will be?

The answer here is prediction software. There's many prediction packages, available either gratis or for a nominal fee, from the AMSAT web site[i].

- **Early Experiences of AO-40** – **Frequencies for analogue communications**

As with almost all amateur satellites, communications *to* the satellite from earth (or **uplink**) is performed on one amateur band, whilst reception *from* the satellite back to earth (the **downlink**) occurs on another amateur band. A **transponder** aboard the spacecraft is used to listen on the uplink and retransmit the received signal on the downlink.

Why? In order to be able to confirm that you're on frequency and to control the uplink power and configuration, being able to receive yourself back on the downlink is almost essential. If the uplink and downlink were on the same band, there would be a requirement for every station to have expensive filters to stop the downlink being de-sensed by the uplink.
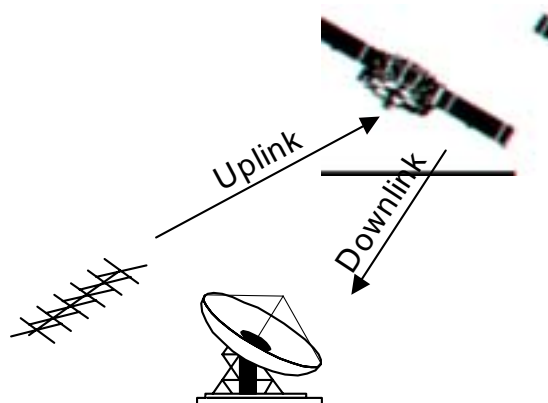


**Figure 3**

Initially AO-40's uplink bands have been 70cm (designated 'U band') and 23cm ('L band'). The downlink band is 13cm ('S band'). In order to specify which uplink and downlink combination a station is using, they will specify 'Mode U/S' (70cm uplink, 13cm downlink) or 'Mode L/S' (23cm uplink, 13cm downlink).

For voice communications, AO-40 includes a linear transponder which listens on its uplinks and retransmits on the downlink. A linear transponder listens on a frequency range (or **passband**) which is 350kHz wide for AO-40 – space for a lot of QSO's.

Voice QSO's on linear transponders must be conducted in SSB: FM is frowned upon due to its wide bandwidth requirements, 100% duty cycle (high power requirements) and low signal to noise ratio.

AO-40's linear transponder is inverting: this means that the low frequency end of the uplink corresponds to the high frequency end of the downlink. This also means that if you send LSB on the uplink it'll appear as USB on the downlink. On inverting

transponders, transmitting LSB on the uplink and receiving USB on the downlink is the accepted custom.

Where a concern arises during operation is just how to compensate for changing frequency on the uplink and downlink accurately, especially when the frequency passbands of uplink and downlink are inverted as described above.

In practice this can be done manually using charts similar to that shown below:

```
Uplink   435.772                                    435.522
          .747 .722 .697 .672 .647 .622 .597 .572 .547
          |    |    |    |   ||   |    |    |    |    |
          |    |    |    |   ||   |    |    |    |    |
          .250 .275 .300 .325 .350 .375 .400 .425 .450
Downlink 2401.225           2401.323              2401.475
                              MB
```

**Figure 4 Mode U/S frequency mapping table**

```
Uplink   1269.485                                  1269.235
          .460 .435 .410 .385 .360 .335 .310 .285 .260
          |    |    |    |   ||   |    |    |    |    |
          |    |    |    |   ||   |    |    |    |    |
          .250 .275 .300 .325 .350 .375 .400 .425 .450
Downlink 2401.225           2401.323              2401.475
                              MB
```

**Figure 5 Mode L/S frequency mapping table**

Note the MB, or Middle Beacon in the tables. This is currently being used for telemetry transmissions, and it essential to avoid transmitting on an uplink frequency which could retransmit close to the MB, corrupting the telemetry.

Rather than having to continually tune uplink and downlink frequencies, it would be preferable to have the two automatically follow each other. Indeed, this function is provided by the manufacturers of satellite radios.

A further consideration is **Doppler** frequency tracking. Due to the movement of the satellite relative to the ground station, there is a change in the observed frequency. This is akin to the situation when an emergency vehicle speeds past us and the siren appears to decrease in frequency as it passes. The amount of frequency change due to the Doppler effect is proportional to the relative speed of the satellite as seen by the observer and the source frequency in question.

One of the initial concerns was that a high rate of Doppler frequency compensation which would be required for an S band downlink, especially having analysed satellites such as UO-11 and AO-16.

In reality, unless it is possible to receive the satellite at perigee due to the latitude of the station, the Doppler is sufficiently slow to make manual frequency compensation easy to achieve.

- **Early Experiences of AO-40** – Uplink requirements

For the purposes of this article, the focus of the uplink will be on the 70cm uplink, and the empirical experiences on that band as an uplink for AO-40.

A number of different transmitter and antenna combinations were tried. What's important here is the *combination* of both the transmitter power at the antenna and the gain of the transmitter's antenna. By focusing the power of an antenna in a certain direction, similar to using a lens in an optical sense, the antenna can have **gain**. This is normally quoted in dB relative to either a dipole antenna (dBd) or relative to a point source, or isotropic antenna (dBi). We'll concentrate on dBi.

Another concept is the Effective Radiated Power relative to an Isotropic antenna, or **EIRP**. This is the combined power of the transmitter and gain of the antenna and can be quoted in either watts or dBW.

To convert gain quoted in dB into real gain, the following formula is used:

$$G = 10^{\,g/10}$$

Where g is the gain in dB, and G is the real gain.

For example:

| g (dB) | G |
|--------|------|
| 0 | 1 |
| 3 | 2 |
| 6 | 4 |
| 7 | 5 |
| 10 | 10 |
| 12 | 15.8 |
| 15 | 31.6 |
| 20 | 100 |
| 30 | 1000 |

**Figure 6 Gain represented in dB and as a proportion**

Further to the scenario is the question of **polarity** of the antenna system. Terrestrially, operations are performed with linear polarisation, usually either vertically or horizontally polarised. If the polarisation is mismatched between the transmitting and receiving station, losses of up to 30dB (1/1000th of the power) can be demonstrated. This is an identical situation to the optical demonstration of two pieces of polarised glass being turned against one another, and turning from transparent to opaque.

For satellite communications, **circular polarisation** is used. Because spacecraft often spin, use of linear polarisations will show fading as the antennas spin. Circular polarisation avoids this by providing a combination of vertical and horizontal polarisation correctly phased. There's two basic types of circular polarisation: right hand and left hand, or **RHCP** and **LHCP**. Similar to linear polarisation, there's a significant penalty mismatching RHCP and LHCP.

|  | Horizontal | Vertical | RHCP | LHCP |
|---|---|---|---|---|
| Horizontal | 0 | 30 | 3 | 3 |
| Vertical | 30 | 0 | 3 | 3 |
| RHCP | 3 | 3 | 0 | 30 |
| LHCP | 3 | 3 | 30 | 0 |

**Figure 7 Losses (dB) from polarisation mismatches**

AO-40 uses RHCP. As can be seen from the table above, in order to minimise loss, RHCP should be used at the ground station too. In practice, many stations are extremely successful without circular polarisation, suffering a loss of up to 3dB: it's by no means a prerequisite.

In order to differentiate between antenna gain of a circular polarised antenna to a linear antenna, the term **dBic** is often used. Similarly, EIRP is often written **EIRPc** for the same reason.

The following transmit configurations were tested with AO-40 under a number of different circumstances:

| Power (W) | g (dBic) | G | EIRPc |
|---|---|---|---|
| 20 | 7 | 5 | 100 |
| 50 | 10 | 10 | 500 |
| 50 | 15 | 31.6 | 1580 |

**Figure 8 Different uplink configurations and their EIRPc compared**

The most successful combination used by the author provided communications on SSB with between 100W and 500W EIRP. CW requires far less, of the order of 10 to 50W is sufficient. It should be noted that these figures allow for *reliable* communications under both normal and most sub-obtimal circumstances. A sub-optimal scenario, for example, occurs when the spacecraft's antennas are not pointing directly at the ground station (also known as off-pointing, and is measured as the **squint angle**).

Aboard AO-40 is a piece of equipment called **LEILA** which is a device designed to prevent the transponder uplink being desensed by strong signals in the passband. At a certain level, LEILA sends a siren on the downlink to an offending station, and if that station fails to decrease their uplink power, a notch is inserted into the passband.

Weighing up the costs of generating power on 70cm and the size and manageability of a hand pointed antenna, a well balanced system would include 50W of transmitter power and an uplink antenna gain of 10dBic in order to obtain the maximum 500W EIRPc suggested. Again, it should be noted that this power is sufficient for reliable SSB communications, and significantly less should be required for most of the time.

- **Early Experiences of AO-40 – Downlink requirements**

The downlink antenna and receiver front end are the most important part of the system: the old adage 'if you can't hear them, you can't work them' has never been truer. Currently the only available downlink on AO-40 is on 2.4GHz. Historically, this

part of the radio spectrum has been viewed by the amateur fraternity as a rather specialist area requiring expensive equipment and tools.

What's different at 2.4GHz is feeder loss. Losses are huge. A common method used to circumvent these losses is to place part of the receiver at the antenna. There's nothing new here: satellite TV dishes have had **downconverters** mounted on them for decades. The downconverter receives a range of frequencies and converts them into a range of lower frequencies. Not only is the signal amplified where it matters at the antenna, but also the lower frequencies suffer lower losses.
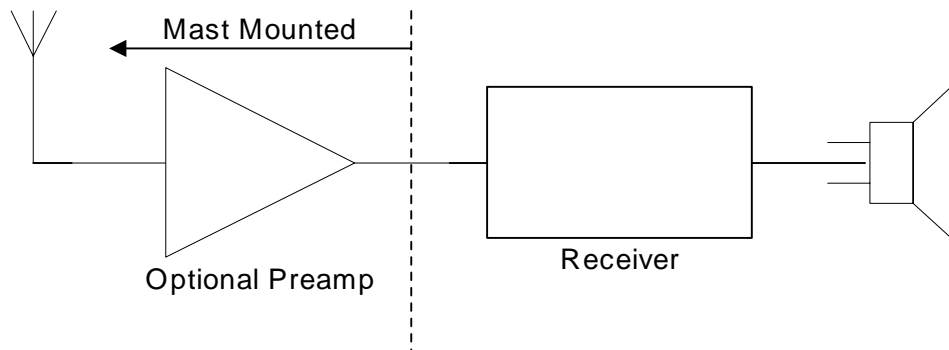


**Figure 9 Traditional receiving configuration**
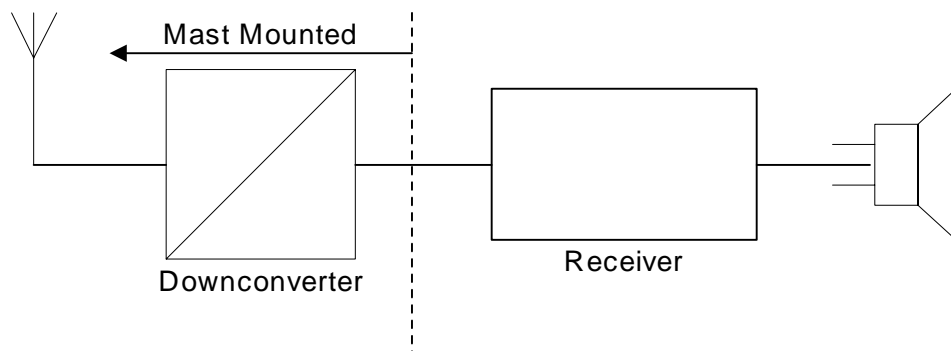


**Figure 10 Common equipment configuration for 2.4GHz**

A number of helices were used for the author's first experiments on AO-40, and indeed this was quite successful. However, as an experiment a surplus offset-fed TV satellite dish was tried and educated guesses made. The difference in signal strength was startling, showing 5dB or so better via the dish.

- **Building the Station**

There are many ways to achieve an AO-40 class station. More often than not, the station will already have equipment which can be modified or enhanced with the addition of new components. For the purposes of this presentation, the construction of a building a new station at reasonable cost with no prerequisites will be discussed.

- **Building the Station - Downlink Antenna Construction**

Until only recently, locating ready made specialised microwave antenna parts such as dishes, was neither easy nor cheap. With the phasing out of analogue satellite TV in many parts of the world in favour of digital transmissions, surplus offset fed dishes are available free of charge if the constructor is prepared to be vigilant.

In the United Kingdom, 60cm offset fed TV dishes are the norm for satellite analogue TV reception. Removal of the LNB from the dish and replacement with a helix feed such as that described by G3RUH[ii] is all that is required for a satisfactory downlink. In order to reduce the metalwork requirement, instead of using aluminium, for non-permanent use it is possible to use good quality single sided fibreglass PCB off-cuts for the reflector and for the ¼ turn shim.

The helix used is 3¼ turns rather than the original 2¼ turns recommended as the illumination angle is now significantly less then the original G3RUH dish. The helix is supported only by soldering it to the N connector feed point, and so care should be taken when moving the antenna not to disturb the helix.

The helix is wound using 40mm PVC waste pipe as the former. Close adherence to all the helix feed dimensions specified will help to ensure good performance is maintained.

In order to maintain the correct angle of the feed onto the dish, the LNB bracket should be retained. A helix to the G3RUH specifications will not fit through the standard LNB bracket without modification to the bracket, helix or alternatively fitting the helix reflector on the dish side of the bracket.

It is recommended that the LNB collar part of the bracket is sawn off with the remainder used to screw the reflector onto and maintain the correct angle into the dish.

Construction of the helix feed can be achieved in an hour, and a similar time to mount and test the feed is required.

Once a receiver is available (see below), testing the feed can be done with a signal source, which may be as simple as a diode multiplier, or indeed a harmonic of a radio: the fifth harmonic of a de-restricted radio tuned to 480MHz was used by the author.

Results without any adjustment gave around 5dB better than a 30 turn commercial helix antenna.

For a permanent installation, the use of PCB for the reflector is not recommended as it will corrode. An alternative is aluminium plate for the reflector, as suggested in the original G3RUH feed documentation. Further weather proofing of the feed point with RTV sealant is strongly suggested such that rain cannot interfere with the matching.

- **Building the Station - Downlink Receiver**

As has been noted previously by Ed Krome[iii] and James Miller[iv], obtaining reasonably priced off the shelf equipment from the major manufacturers at 2.4GHz is not an option. One main reason for this is that the cable losses at these frequencies are so high that it is normal to put part of the receiver at the antenna and send the received signals down the cable at a lower frequency. For further information there is a discussion of feed line losses and their effects documented by Dale Henkes AB4NJ[v].



| 60cm Offset fed dish | → 2.4GHz | Antenna Mounted Down Converter TransSystem AIDC 3733 | → 144MHz IF | Receiver FT-290 |
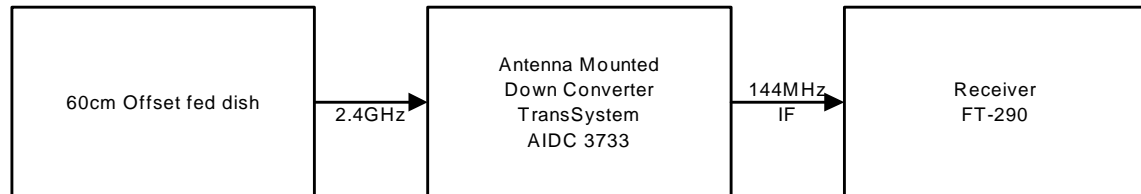
**Figure 11 The downlink receive chain**

A common method used at the present time is to use S band TV down converters into a suitable IF, with differing modifications dependent upon the sensitivity required and IF available. Normally the IF of choice is 145MHz because it is relatively easy to obtain equipment for this band. For the purposes of demonstration, a second hand FT-290 Mk I all-mode was purchased for £100. The availability of more advanced new all-mode portable equipment has produced a flood of reasonably priced used equipment.

For the down converter, there are a number of units available from TransSystem, CalAmp, Drake and Norsat. The example chosen for this presentation is the TransSystem unit which is easily available at the current time and has a number of easy modifications to improve performance. Freely available options for the TransSystem include a crystal to allow for a 2m IF, an N-type adapter to allow use with any antenna, a bias tee, and a replacement filter and PCB.

The total cost for a TransSystem 3733, 2m crystal, N-type adapter, replacement filter and PCB is £59 ($83). Neither the crystal nor the N-type adapter modification require any soldering: they are simply replacement plug in parts.

The replacement filter option improves the unit's noise figure by removing the second image: the TransSystem unit will receive two images on one frequency without this modification. A small amount of soldering with a fine tipped soldering iron is required.

Testing of the unit may be performed with a signal source such as a simple diode multiplier or a harmonic of a transmitter. In conjunction with the dish, pointing the unit at the ground should see an increase in noise heard. Similarly, a mild increase in noise may be heard by pointing the dish at the sun.

In a brief on-air weak signal direct comparison of the TransSystem unit to both a DB6NT converter and an AR-5000 receiver tracking AO-40 at large squint (ie weak),

empirically it was not possible to show any significant disadvantage of the TransSystem unit.

- **Building the Station - Uplink Antenna**

Kent Britain, WA5VJB, has published designs[vi] for several VHF & UHF Yagi antennas. The 8 element design provides 12.6dBi. A pair of these, orthogonally mounted on the same boom, can be used to provide 12.6dBic with a power splitter. Phasing for RHCP is performed by offsetting the elements by ¼ wavelength.



**Figure 12 Uplink antenna**

The antenna is built on 18mm by 18mm wood with 4mm solid aluminium rod for the elements. In order to connect a feed arrangement to the elements, the conducting parts of a 10 amp terminal block are used, which may be soldered to. Use of the terminal block in this manner allows easy movement of the feed point for tuning. Panel BNC socket terminals are soldered onto the terminal blocks as close to the feed point as possible. Alternative feeding methods are recommended for permanent outdoor use.



**Figure 13 Feedpoint close-up**

When tuning the antenna, due to coupling between the orthogonal elements it was found necessary to terminate one set of elements with a 50 ohm dummy load whilst

tuning the other set. The VSWR was minimised first by adjusting the position of the feed point and then, by finding the resonant frequency, the length of the driven element was adjusted accordingly. It was a simple matter to attain unity VSWR on both sets of elements in this manner.

In order to provide a 50 ohm match to two 50 ohm feeds, a power splitter is constructed using two ¼ wavelength cables made with RG-59 75 ohm cable terminated with 75 ohm BNC plugs. When calculating the length of the cables, both the velocity factor of the cable and the length of the BNC plugs should be taken into consideration. The two cables are joined with a T piece which must be of high quality. Many thin Ethernet T pieces and other parts have questionable UHF properties.



**Figure 14 Power splitter**

Assuming that the antennas have been tuned to near unity VSWR, the combined antennas with the power splitter should now have negligible mismatch.

Care should be taken if this antenna is to be used in a permanent installation for several reasons:

- o The electrochemical reaction between the aluminium and terminal block will lead to rapid corrosion.
- o Sealing BNC connections against weather conditions can be difficult.
- o The wooden boom should be properly varnished to protect against weathering, or alternatively another type of insulated boom should be considered.

- **Building the Station - Uplink Transmitter**

Assuming that we have an antenna gain of 10dBic (see above), we need to generate an EIRP of up to 500W for reliable SSB contacts, especially at sub optimal satellite squint angles. Thus a power input at the antenna of 50W is required. Generating SSB at 50W on the 70cm band can be expensive. The most reasonable method found by the author was to purchase a second hand Yaesu FT-790 Mk I all-mode transceiver and a separate second hand 50W linear amplifier: costs were £90 and £78 respectively.
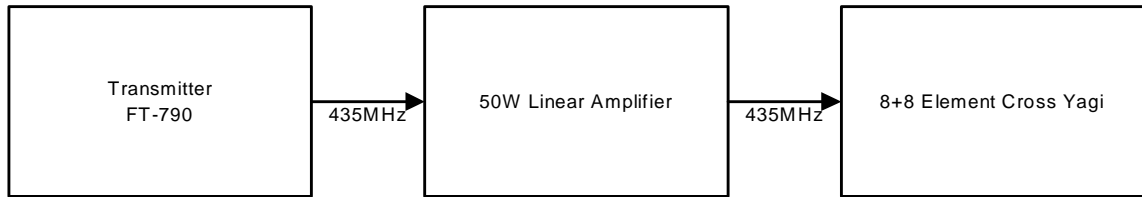
**Figure 15: The uplink transmit chain**

- **Building the Station - Frequency Tracking**

One of the downsides of using older radios is that they have limited, if any, computer control facilities. Certainly there is no computer interface on the FT-290 and FT-790. On the face of it this could make the practicality of (a) analogue passband tracking and (b) automatic Doppler compensation rather difficult.

The implementation of passband tracking between these radios turns out to be rather simple. These radios have three wire rotary encoders on the tuning knobs. It is a simple task to connect up the rotary encoder of one radio to both radios, and also allow for reverse tracking, as required on AO-40.

The rotary encoders have a clock and an up/down signal. The truth table is as shown:

| Clock | Up/Down | Function |
|-------|---------|----------|
| +5V to 0V | 0V | Up |
| +5V to 0V | +5V | Down |

**Figure 16 Truth table for the rotary encoders**

Analysis of the rotary encoders indicates that they may be wire-Ored, as the normal state is for both Clock and Up/Down to be at 0V, with a weak 330k pull down resistor. If these units are to be wired together, potentially with a short as a connecting cable is inserted, 3.3k resistors were inserted into the rotary controller lines on each unit, shown in the schematic below.
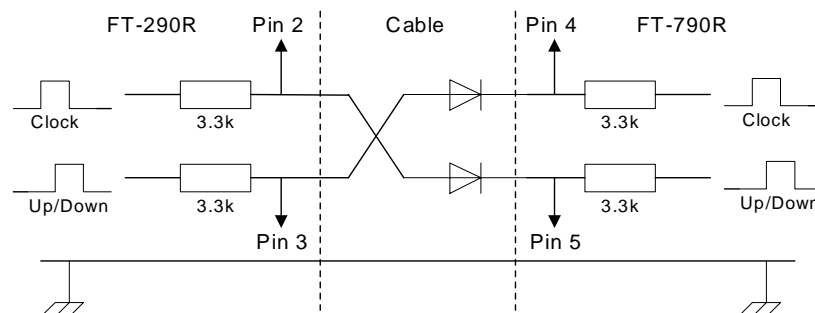


**Figure 17 Schematic of the frequency tracking modifications**

A 2.5mm stereo jack was placed in the side of each transceiver and a cable made with a crossover and two diodes as shown. The diodes allow the FT-290 dial to change

both frequencies whilst the FT-790 dial adjusts only the FT-790 frequency. The crossover makes the frequencies reverse.

Access to the rotary encoder on the Control Boards for the FT-290 and FT-790 is by removing upper part of the case.



**Figure 18 The position of the 3.3k resistors in the FT-790. The FT-290 is similar.**

| | FT-290 | FT-790 |
|---|---|---|
| Clock | Pin 2 Purple | Pin 4 Blue |
| Up/Down | Pin 3 Yellow | Pin 5 Purple |
| Gnd | Pin 1 Black | Pin 1 Black |

**Figure 19 Position of rotary encoder pins on Control Board**



**Figure 20 The cable and position of the 2.5mm stereo jacks**

- **Building the Station – Doppler Frequency Compensation**

Automatic Doppler compensation is also not as difficult as might first have been thought. As an example, the use of the InstantTrack and InstantTune combination can be used to achieve this with ease. A simple up/down microphone interface is all that is required connected to the computer's parallel port.

- **On the air – The Dish**

The performance of the dish, when compared to a helix, is excellent. But why?

Normally one would attempt to model an antenna *prior* to construction. However, in this case the reverse scenario has taken place. To see why the antenna worked so well, and what, if anything, might improve it further, the antenna was analysed using standard software techniques.

There is some very detailed information on how to calculate the geometry of an offset fed dish in an article published by Paul Wade N1BWT/W1GHZ[vii].

The dimensions of the dish can be put into the HDL_ANT[viii] program. The pertinent measurements of the dish used were as follows:

```
Diameter of large axis of dish in mm.  : 660
Diameter of small axis of dish in mm.  : 600
Depth of dish at deepest point in mm.  : 55
Distance of deepest point from bottom edge along large axis  in mm.  : 330
```

These dimensions give the following results:

```
Focal length = 401  mm.

This offset reflector is a section of a full parabola with a diameter
of 1232.2  mm.  whose vertex is at the bottom edge of the offset reflector

The full parabola has an f/D = 0.33, which determines criticality of focal
length.

The focal point of the dish is 401.03  mm.  from the bottom edge of the
reflector and 637.67  mm.  from the top edge of the reflector.

For operation with the main beam on the horizon with the feed at the bottom,
the dish must be tilted forward so that the large axis is 69 degrees
above horizontal.

Illumination angle for feed = 75.1 degrees on the large axis and 74.8 degrees
on the small axis.  A feedhorn with a 3 dB beamwidth of 43.1 degrees is
needed,equivalent to the feed for a conventional dish with f/D = 0.75

Gain at 50% efficiency = 20.6 dBi
If you do really well, you might get 60% efficiency for a gain = 21.4 dBi
```

These figures concur precisely with the position of the original X band feed, and now the position of the helix. There have been some suggestions that a rule of thumb for the phase centre of a helix feed is on the central one turn (~1") from the reflector, and by luck rather than judgement, that's exactly where it is. Another text[ix] suggests that the phase centre is about 1.5" from the reflector.

Furthermore, the tilt angle (69°) of the dish ties in with empirical measurements.

Ed Krome[x] recommends that for tuning purposes, the helix should be wound with an odd number of quarter turns.

What's important in the HDL_ANT results is that the 10dB beamwidth is concurred with rather than the 3dB beamwidth: a 3dB beamwidth for a horn is not necessarily the same as that for a helix. Indeed, modelling the G3RUH feed confirms this:

| Turns | Fwd Gain (dBi) | 3dB beamwidth | 10dB beamwidth |
|-------|----------------|---------------|----------------|
| 2.25  | 7.05           | 58.4          | 113            |
| 3.25  | 8.18           | 47.6          | 86             |
| 4.25  | 8.59           | 44.9          | 80             |
| 4.75  | 8.71           | 42.8          | 79             |
| 5.25  | 8.85           | 40.3          | 77             |
| 5.75  | 8.96           | 38.7          | 74             |

**Figure 21 Example G3RUH helix feed 3dB and 10dB beamwidths**

Thus, the 3¼ turn helix will be over-illuminating the dish. A 5.75 turn helix would provide a 10dB beamwidth consistent with the illumination angle of the dish.

It is likely that the over-illumination is not too big a problem. The amount of overspill area is about 22% with a 3.25 turn compared to a 5.75 turn helix. However, the power at the overspill area is between 7.8 and 10dB down on the main lobe. This implies that about 3% of the total power is overspilt, or about –0.2dB. This does not take into account any additional ground noise from the overspill which will add to the noise figure.
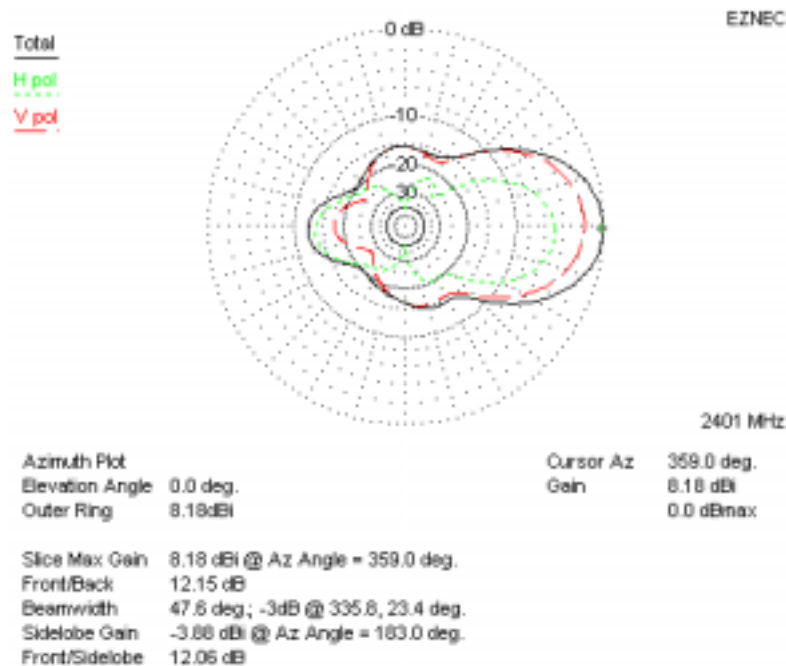


**Figure 22: Modelling the 3¼ turn helix feed**

- **Results - An Unexpected Benefit**

One big advantage the FT-290 and FT-790 have is that their combined current on receive is 200mA. Similarly, separate discrete linear amplifiers take little power on receive: 60mA for the unit under discussion. A 7Ah battery will last for many hours more than configurations using more modern high power portable equipment such as the FT-100 and IC-706, both of which have quiescent currents of over 1A.

- **Results - Apartment Dwellers' Delight**

One really exciting fact of AO-40 operation not often recognised is that this really is the apartment dweller's ultimate satellite. For the northern hemisphere, a South facing aspect is preferred, and for the southern hemisphere, a North facing aspect is optimum.

Even at latitudes above 50°, AO-40 appears in the sky for long periods above 20° and even 30° elevation. This means that even in fairly built-up areas, this satellite is visible to urban operators. Indeed, the author has received AO-40 from a basement garden with a southerly aspect in the heart of Central London, eight feet below ground level.



**Figure 23 AO-40 reception at 8' below ground level**

In many cities, both the ubiquitous satellite TV dish and UHF TV antenna have become an accepted part of the skyline: the antennas described in this article fit perfectly into the camouflage of modern living.

- **Further Options for Satellite Operations Other Than AO-40**

The addition of a reasonable gain 2m yagi antenna will allow the system to work AO-10.

The configuration described may be expanded for use with mode J satellites with the addition of a 2m antenna and 2m amplifier.

Minor modifications details exist in order to allow tuning of the FT-290 and FT-790 on FM at small increments for use on UO-14 and AO-27. Although this is possible without hardware modification it is tedious to operate.

Further radio modifications are available to allow the radios to be used as uplinks and downlinks on 9.6kbps digital satellites.

The only current satellites not covered by these options are RS-12/13 and RS-15 which have a 28MHz downlink.

- **Conclusion**

Here's the cost of the entire AO-40 station.

| | £ |
|---|---|
| TransSystem Rx Converter, N Type adapter, 2m Xtal, Filter + PCB | 59 |
| FT-290 2nd Hand | 100 |
| FT-790 2nd Hand | 90 |
| 50W 70cm Amplifier 2nd Hand | 78 |
| Dish + Feed | 0 |
| 70cm Yagi Elements | 10 |
| 70cm Yagi Boom | 2 |
| 70cm Power Splitter | 10 |
| **Total** | **349   ($489)** |

One should keep in mind when comparing the cost of this station, how much an average operator might spend on even a mobile FM repeater capable portable or mobile station.

With the configuration and minor modifications described above, there is little functionality missing. Perhaps the biggest component missing is a combined azimuth and elevation rotator. By itself an az-el rotator would have exceeded the budget, and in reality it is by no means a prerequisite.

It wasn't quite possible to make the £300 station, but the final total is not far off, and is certainly far lower than would normally be anticipated for a satellite station with reliable worldwide communication ability. Hopefully this will help encourage the concept that satellite operation can be conducted at a reasonable cost.

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[i] AMSAT web site software, http://www.amsat.org/amsat/ftpsoft.html

[ii] James Miller, G3RUH, "A 60-cm S-Band Dish Antenna" feed dimensions, http://www.amsat.org/amsat/articles/g3ruh/116fig02.gif

[iii] Ed Krome, KA9LNV/K9EK, "Mode S: The Book", AMSAT

[iv] James Miller, G3RUH, "A 60-cm S-Band Dish Antenna", http://www.amsat.org/amsat/articles/g3ruh/116.txt

[v] Dale Henkes, AB4NJ, "The AMSAT-NA Digital Satellite Guide – Digital Components", pp 6-8

[vi] Kent Britain, WA5VJB, edited by John Maca, AB5SS, "Cheap Yagi Antennas for VHF/UHF", http://www.clarc.org/Articles/uhf.htm

[vii] Paul Wade, N1BWT/W1GHZ, "More on Parabolic Dish Antennas", QEX December 1995 pp14-22, ARRL

[viii] Paul Wade N1BWT/W1GHZ, HDL_ANT program, http://www.w1ghz.cx/software/hdl_3b3.exe

[ix] Ed Krome, KA9LNV/K9EK, "Mode S: The Book 2001 AO-40/P3D Update", p119, AMSAT

[x] Ed Krome, KA9LNV/K9EK, "Mode S: The Book 2001 AO-40/P3D Update", p118, AMSAT