The History of The Flight Refuelling ARS Microwave EME system, G4RFR
March 2023

This is a brief summary of the FRARS EME system. FRARS had some experience of EME with Yagis on 432MHz and 1296MHz in the early 80s. This is the story of a project that began in 1985 when RSGB was offered a 12ft (3.65m) prime focus dish that had been removed from the 2GHz links on the Post Office Tower, London. It was gratefully received by G3YGF on behalf of FRARS, and was initially taken to G3OUR (Oxford University Radio Society) on G3WDG's road trailer for some unsuccessful tests, Figure 1. In 1989 the 4 quadrants were taken down to Wimborne, Dorset, on a boat trailer.

Figure 1 The Dish being taken to Oxford in 1985

The Mount

Figures 2 and 3 show the dish.

Figure 2 Front View of The Dish

Figure 3 Rear View of the Dish

It is rather heavy at 250kg. This, and a further 250kg of mild steel fabricated mounting, all sit on top of a 6" round steel pipe which is mounted on a large side-and-end thrust race, giving 360 degree Azimuth rotation. It is clamped to the original square section base post on a Strumech versatower trailer.

The Elevation axis is a shaft on a pair of 50mm pillow block bearings. Originally, the Azimuth axis was driven by two right-angle gearboxes and a DC motor, and the Elevation axis used a satellite telescopic jack which only covered about 20 degrees. The dish had protractor readouts on the Azimuth and Elevation axes, and we had a team of operators to manually steer the dish and read Az/El from the protractors, but it worked.

At 10GHz, the dish has a gain of 50dBi, and a 0.6 degree 3dB beamwidth, which is almost equal to the size of the sun or moon (0.52 degrees).

We were using G0API's 20W TWT and two single stage preamps, and could hear CW echoes. In 1994, we had the first inter-G 10GHz EME contact with G3WDG, then heard SSB from WA7CJO, and worked a few other stations. We were seeing 0.5dB of Moon noise.

1994 - 2011
There was then a short break of 12 years or so when we were building the Bell Hill beacon complex. Around 2006, with help from M0EYT, we managed to receive signals from the Mars Reconnaissance Orbiter on 8.4GHz, at some 120million miles. In 2007, we worked G4NNS on 10GHz, and in 2008, G4NNS and G3LTF on 3.4GHz.

2011 - 2016
Around 2011, enthusiasm regrew again, and M0GJR and G3YGF began upgrading the mount into the 21st Century, with machining help from G0NZO. With a view to developing our own control software, Selsyns were fitted to provide position Azimuth and Elevation readouts. Stepper motors were used to drive the two axes - Azimuth via the two gearboxes, and Elevation via a homemade jack, consisting of a 3m long piece of 25mm stainless steel studding and a bronze nut, which could take the dish through 90 degrees.

There was about 6 degrees of backlash in the right-angled gearbox on the Azimuth axis, and this was effectively reduced to zero by using heavy weights attached to steel cables which went round the mast to apply a torque to ensure the backlash was always taken up one way.

2017-2019
In 2017 we worked G4NNS on 3.4GHz who was at Goonhilly. By 2019, we had a fully working system, complete with 200W TWT which can be seen as the white object on the lower back of the dish in Figure 3. Since then, we have had many QSOs on 10GHz.

Software Control
Around 2016, John, M5AHQ volunteered to automate the tracking system. The custom dish control software, called Medii after the Moon crater "Sinus Medii", now runs on a Raspberry Pi with suitable driving/interface elements, and allows the dish to be positioned with our custom closed loop software. On-screen displays show all dish control options, and a listing of principal objects to track.

When the Selsyn decoder unit became unreliable, the replacement homebrew decoder showed up some issues around the cardinal points, so, recently, we replaced the Selsyns with two Sick 18 bit, 360 degree, Ethernet absolute position encoders on the axes, which improved the pointing accuracy of the dish to better than 0.1 degrees. The axis of the dish was also set to true vertical using a spirit level and theodolite.
This allowed us to track any object stored in its JPL derived memory.

It is now fully click and track, and can be controlled via a mobile phone for operations around the dish, such as bolting it down or mounting the TWT. Having a calibrated dish and autonomous tracking has reduced the demands on the operating team to the point where single handed operation is now normal.

The Current System

Figure 4 shows the Block Diagram of the current EME System.

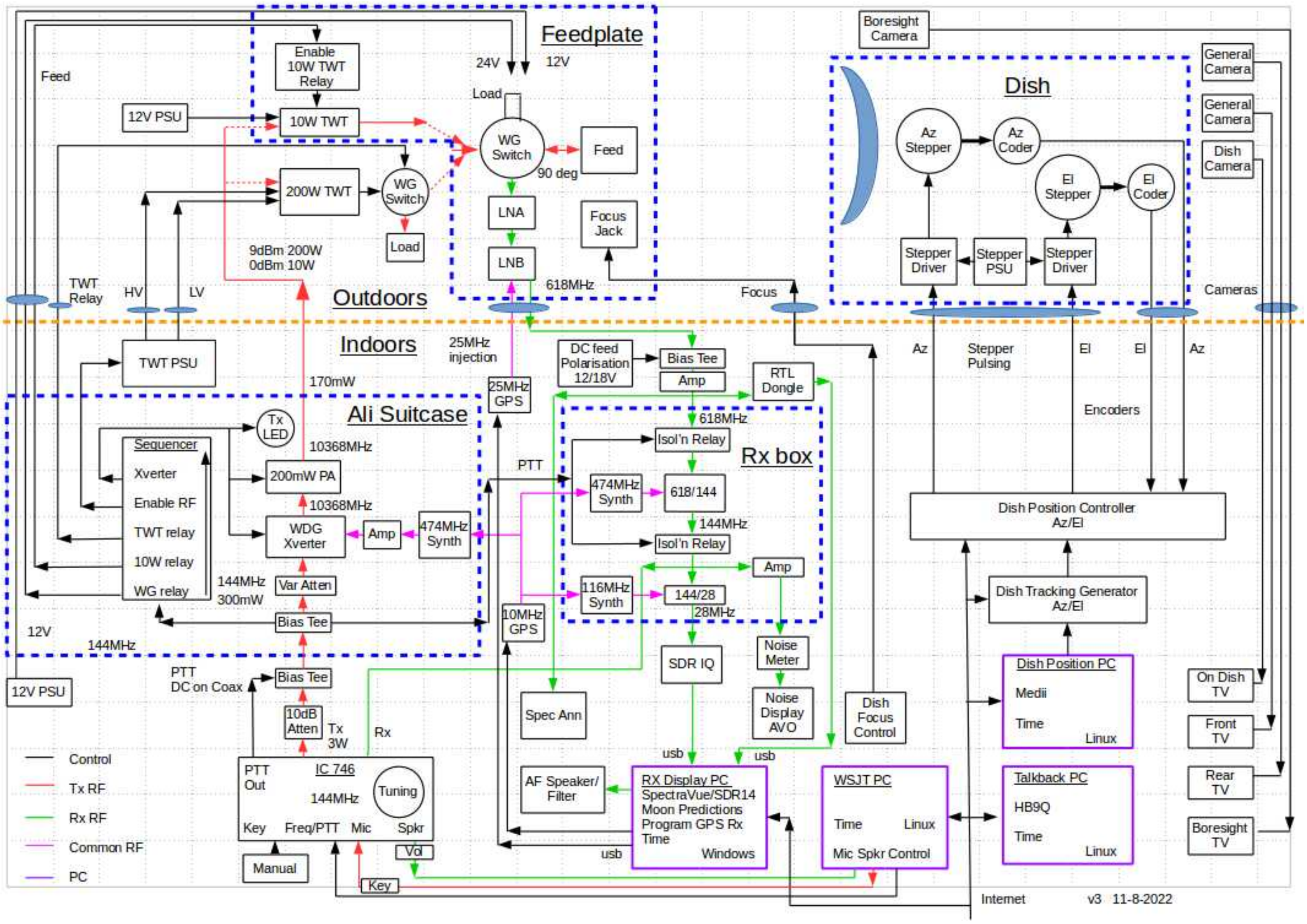

Figure 4 Block Diagram of the Current EME System

Transmitter

The transmitter is largely homebrew, apart from an IC746 on 144MHz with a separate receive port. On transmit, the 0dBm 144MHz signal drives an up-converter fed with a 2556MHz LO derived from a 10MHz GPS referenced synthesiser, into a G3WDG Tx module. The +10dBm 10GHz output feeds a solid state PA to produce +23dBm, which passes via 12m of LDF450 and some superflex out to the input of a Thompson TH3759A 300 W, 14GHz TWT. This is mounted on the back of the dish and powered by a shack mounted PSU which monitors its operation and is connected with a 16m x 32 way umbilical cable and a 5 way EHT cable carrying 8.5kV. We have re-matched the TWT to operate at 10,368MHz, and it also has a waffle plate harmonic filter in the output, together with a 3 stub waveguide tuner and a waveguide relay which is used to dump any noise from the TWT output during receive into a load. The beam current in the TWT is always "on" to avoid thermally stressing the tube, and to allow rapid TX/RX switching for echo testing. The TWT output to the dish feed goes via 3m of Andrew EW90 flexible elliptical waveguide (0.4dB insertion loss). The TWT is run at 200W during normal operation - this gives an EIRP of up to 20MW. It can be adjusted down to less than 1W should the need arise.

The Feed Plate

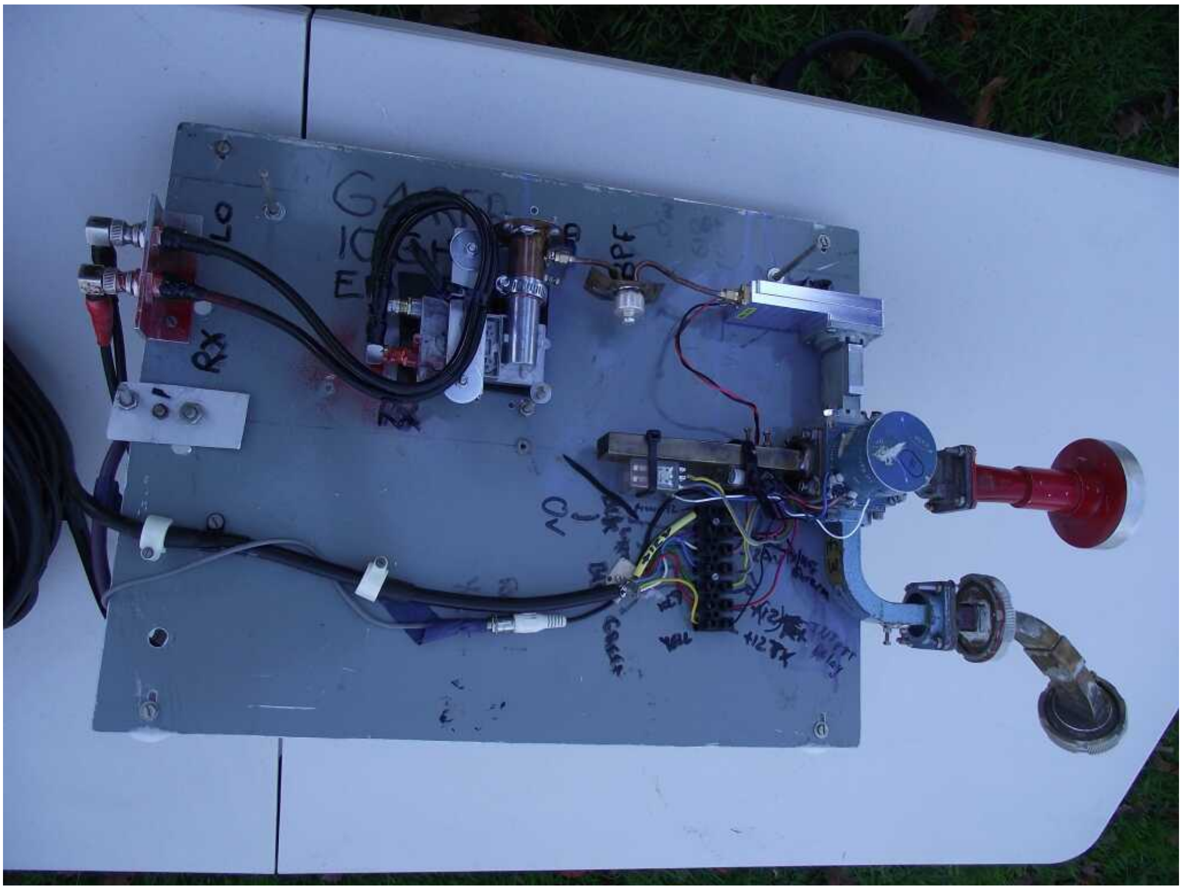

Figure 5 The Feed Plate

The feed is shown in Figure 5, and is mounted on a 4 wheeled trolley inside a cylindrical housing, so can be moved a small amount using a satellite jack to optimise the focus position. On this trolley is the main 4 port waveguide switch which gives 80 dB of isolation between ports. (Note that this isolation drops to about 35dB when the switch is changing state, so a sequencer is essential.) The Tx feeder connects to the waveguide switch, then the RF passes out through a 90 degree waveguide twist to give vertical polarisation (the norm), but which can be substituted by plain guide for horizontal polarisation. Several feeds have been evaluated, including the Super VE4MA and a Scalar Ring.

The changeover system is fully interlocked, with additional contacts on each relay to ensure operation in the correct sequence, and has LED indicators for fault diagnosis. Transmit is initiated by the IC746 - a manual Morse Key is used on CW, Mic pressel on SSB, and is under full CAT control from WSJT for digital modes. On CW, we can key the Tune tone from WSJT, so all modes can be used with all the benefits of Constant-Frequency-On-Moon (CFOM) operation. The system is fully linear to cope with any future modes.

Receiver

Also on the feed plate are a 0.7dB NF DU3T preamp and a modified 1.2dB NF LNB. A dummy load is mounted on the waveguide switch, which allows the receiver to be switched to the dummy load as a room temperature noise reference.

The LNA/modified LNB converts to an intermediate frequency of 618MHz, which feeds an RTL USB SDR dongle, a spectrum analyser and then further down-converters to 144MHz to feed the IC746 and 2MHz wide noise meter, and to 28MHz (all GPS locked) to feed an SDR-IQ running SpectraView, which provides a panoramic display of signals and an audio output, and another noise meter (Continuum mode). Audio from the IC746 feeds a PC running WSJT.

The Operating Position

The operating position is shown in Figure 6. There are currently 4 PCs and 6 monitors at the operating desk, running WSJT, the HB9Q chat facility/the internet, SpectraVue. the dish tracking software, and a split screen display for cameras monitoring the dish.

Figure 6 The Operating Position

Performance

The current system performance is: Moon noise 2.6dB (quite an improvement over the initial 0.5dB), Sun noise 15.7dB, Ground noise 5.5dB, and room temperature waveguide load 5.7dB, giving CW echoes of 16dB in a 200Hz noise bandwidth, after the 2.6 second round trip delay. (Libration is about 100Hz, so this contains all the energy). SSB echoes are quite normal, even with the 100Hz or so of Libration spreading.

We have now had some 200 contacts on 10GHz EME, including world firsts of G-China and G-Uruguay and have worked quite a few small stations, including GI7UGV at -21dB S/N/-13dB S/N (1.2m dish and 10W), G0OLX -19dB S/N/-3dB S/N (1.2m dish and 15W), and been received by KA1GT at -8dB S/N (0.85m dish), N1BUG at -9dB S/N (0.75m dish), G4HSK at -13dB S/N (0.65m dish), and GW4TKH (1.2m dish) at +4dB S/N. (WSJT S/Ns are given in dB relative to 2,500Hz). Obviously the figures from WSJT vary a bit, depending on the type of decoding and whether the receiving station's dish is exactly on the Moon, but they give an idea of what can be done with a small dish, and it illustrates the power of WSJT in digging out weak signals. We recently worked W7CJO again, who has a 4.8m dish and 300W, and had good 2-way SSB with him.

It has been an excellent learning experience for all to get to this stage, requiring attention to detail in all aspects of mechanical, electrical, radio and software design, and the dish has more than proven its worth. In the future, we intend to use other bands, and to use a chirp waveform to measure the distance to the moon more accurately.

Thanks

This project has been a team effort over the last 35 years, including (in order of involvement) G3JVL, G3YGF, G0API, G4JNT, G6NLC, G0NZO, M0EYT, M0GJR, M5AHQ, M5RAO, has had input from G3WDG, G3LTF, G4NNS, many other past and present members of FRARS, the company that helped us with the surplus 200W TWT, the RSGB and the Post Office who gave us the dish in the first place. To all these, we give our sincere thanks.