How Good Were the EME Systems of the 1960s and 70s?

Peter Blair, G3LTF

Working with Doug VK3UM on his *EME Calculator* software, reference [1], I found myself thinking how useful this system analysis tool would have been in the early years of amateur moonbounce. That is not to imply that we didn't know how to calculate the basic parameters, there were published papers that carried a full analysis of the signal budget and the Radar Equation was well known. But one area about which we had much less information was antenna characteristics – the sort of information that W1GHZ and SM6FHZ have provided in recent years, see references [2] and [3].

Knowing that I had quite good records of many of the early tests, I thought it would be interesting to apply some of the modern analysis tools to the systems of the 1960s and 70s to see how good they actually were. The paper is mainly about 432 and 1296 MHz but there is some reference to the 144 MHz work.

Of course there were many things we didn't have in those days, so we had to develop them. Even today, EME continues to be the driving force behind new developments in LNAs, power amplifiers, frequency stability and weak-signal operating techniques that most VHF/UHF/microwave amateurs take for granted.

Why 432 MHz and 1296 MHz?

Looking at the curve of sky noise against frequency (Figure 1) we see that the noise from the galactic background contribution falls rapidly with increasing frequency, levelling off to a low-noise window starting at about 1 GHz. Because technology for the microwave bands was much more difficult in the early days, the early developments in EME were mostly at the lower edge of this window, on 432 and 1296 MHz.

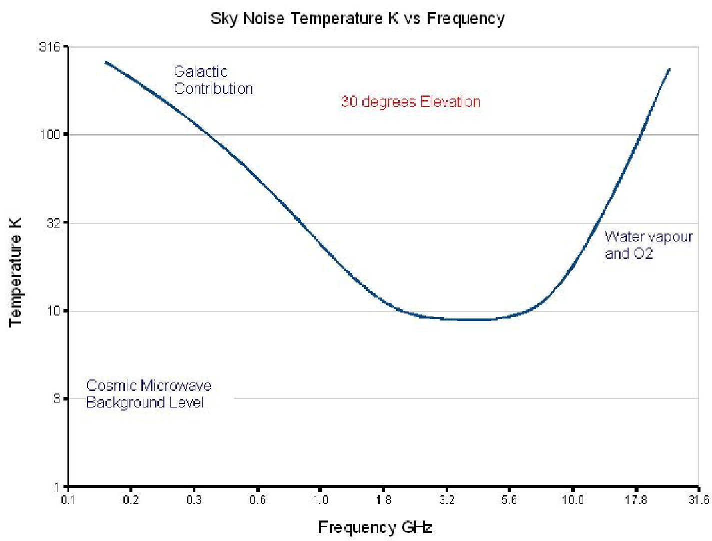

Figure 1: The sky noise ' window' between 1 GHz and 10 GHz

The 1950s were a time of tremendous progress in microwave technology and the emergence of high quality varactor diodes made it possible to achieve noise figures of about 1 dB within the low noise window by using a parametric amplifier. The 144 MHz EME efforts were pretty much unaffected by this but the UHF and microwave community got a big boost.

The Early Years, 1953–1980

The first amateur signals detected after moon reflection were on 144 MHz and were received in July 1953 by W3GKP and W4AO. Several groups tried to build on this and make a QSO but without success. In July 1960 the first amateur EME QSO was made on 1296 MHz by W1BU and W6HB – ‘amateur’ in name, but in fact supported by two major US corporations. In essence, Microwave Associates had paramps and Eimac had power klystrons, so by swapping one for one, and after an enormous amount of hard work with dishes and mounts, the QSO was made.

At this distance in time, it is hard to convey the impact of this news. VHF/UHF enthusiasts everywhere opened their *QST* for September 1960 (Figure 2) and immediately thought: **“How can I copy that? What do I need?”**

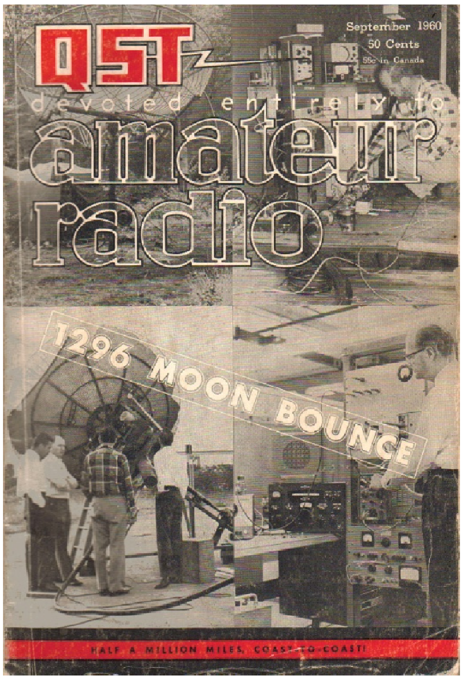

Figure 2: The inspirational QST *cover, September 1960*

Over the next twelve months several stations built dishes of between 16 and 26 ft diameter and some of these copied transmissions from W1BU; but the next full QSO was not until March 1962 when W1BU worked W2CXY. Soon afterwards, in August 1962, W1BU worked KH6UK, extending the 1296 MHz distance record again. The 144 MHz workers had not given up, of course, and the first QSO on 2 m was made in April 1964 by W6DNG and OH1NL.

The small number of 1296 MHz QSOs actually completed in the three years since the initial W1BU effort was principally due, I believe, to the real problems of generating sufficient power on 1296 MHz using only amateur resources. As a result, several people (including me) had turned to 432 MHz and EME on this band was about to get a tremendous boost. Following the lifting of the 50 W power restriction in the USA, W5SDA and K5KDN heard the first echoes on 432 MHz in January 1963 but the first QSO on this band was again between W1BU and KH6UK.

On June 13th 1964 the 1000 ft radio telescope at Arecibo was activated on 432 MHz as KP4BPZ by a team including Sam Harris W1FZJ (the driving force behind W1BU). Six stations were worked, and HB9RG and I were the only non-US stations. This was my first EME QSO using my 15 ft wood frame dish (Figure 3).

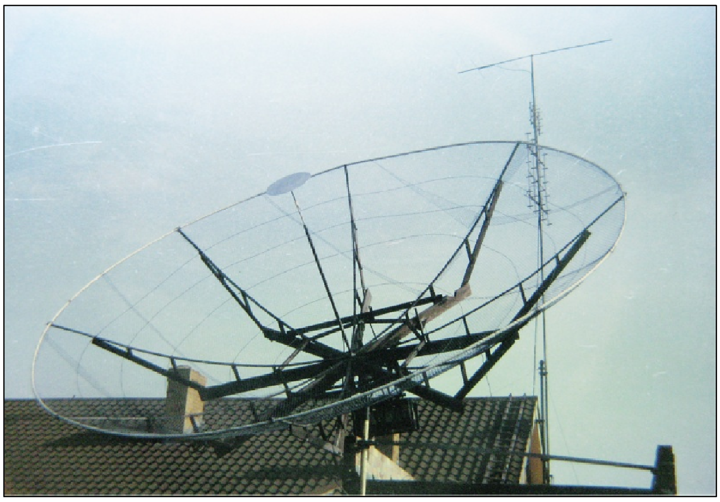

Figure 3: G3LTF 4.6 m dish, 1964 with 432 MHz dipole feed

The next day, 14th June, the Arecibo dish was used on 144 MHz with another host of firsts, including the first EME QSO on 144 MHz from G by G2HCG. In September 1964, HB9RG and W1BU finally made it on 1296 MHz for the first NA-Europe QSO on that band.

KP4BPZ was the first of the 'big dish' operations that characterized the 1960s and 70s, and it achieved several things: it gave a tremendous boost to stations who already had systems under way; it generated wide publicity for EME operations; and it even provided the opportunity for near-random QSOs, just like tropo! When KP4BPZ came on 432 MHz again in July 1965 there were far more stations ready for them, and in addition they were on SSB. They made 28 QSOs. Several stations also heard WA6LET which was the Stanford 150 ft dish (Figure 4) and so in September 1965 WA6LET ran their own big dish test and worked 12 stations (all in NA except for me). In October 1965 the 60 ft Crawford Hill dish of Bell Labs at Holmdel, NJ (Figure 5) was activated for the first time on 432 MHz as K2MWA/2, working W1BU, W9HGE and W3SDZ.

Meanwhile on 144 MHz, VK3ATN had erected a massive 3-stack rhombic array, 342 ft each leg, and in November 1966 he worked K2MWA/2 for the first NA-VK EME contact. VK3ATN also worked K6MYC. The first *EME Newsletter* also started at this time, compiled and distributed by Vic, W3SDZ; I think it ran to about 10 issues.

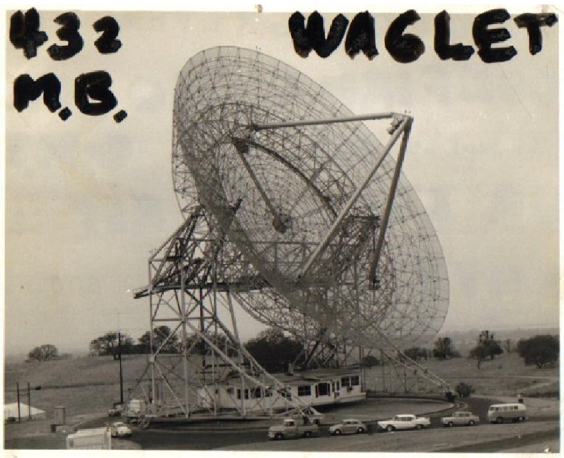

Figure 4: WA6LET, 150 ft dish at Stanford, CA

Figure 5: W2IMU/2, 60ft dish at Crawford Hill, NJ

A group led by Dick Turrin W2IMU then started to activate the Crawford Hill dish two or three times a year on 432 or 1296 MHz in a series of pre-advertised tests or "activity weekends" and this bought an increasing number of stations onto the bands. Tests then started between smaller stations who could just about hear each other during the Holmdel dish tests. One of these was WB6IOM in Los Angeles who had a very well developed 1296 MHz system, and in April 1969 I made a QSO with him which set a new distance record for that band.

The Crawford Hill operations started on April 15th 1967 on 432 MHz and K2MWA/2 worked HB9RG and G3LTF. On April 12-14th 1968 W2NFA was on 1296 MHz, and made QSOs with HB9RG, G3LTF and WB6IOM. Between then and December1973 their 1296 MHz system was gradually improved and QSOs were made with a number of stations including PA0SSB, VK3AKC, WA6LET, OZ9CR and probably others such as K4QIF, VK2AMW, W9GAB, W9HGE and W5LGW. Then in December 1973 the operation closed down and the dish was dismantled and sold. Dick W2IMU produced an excellent set of technical notes at this time. They are still highly relevant and a useful source for data and designs (reproduced in the Proceedings of the Dallas 2010 EME Conference).

In early 1973 the 150 ft dish at the US Naval Research labs was used for a series of receiving tests on 144, 432 and 1296 MHz, with about 25 stations participating (see *QST* January 1973).

Meanwhile the number of stations equipped for 432 MHz had been steadily growing and in early 1973 Cor VE7BBG started to produce a monthly sked list on 432 MHz with K2UYH, W9WCD, W6FZJ (later W1JR) F8DO VK2AMW and G3LTF. By early 1974 the list had grown to about 10 stations and Al K2UYH had taken over the monthly distribution – together with the first, handwritten, EME NL in June 1974! In February 1975 WA6LET came up on 432 MHz again and worked 15 stations. The list of active stations on 432 MHz now totalled 50, and in November 1975 another WA6LET activation worked 84 stations. VE7BBG was already testing with circular polarization and in Sept 1977 the first amateur SSTV QSO took place on 432 MHz between KP4RF and K3NSS (who used an 85ft dish).

1976 had also seen the first EME DXpedition to HK1TL. This was also the first EME activation from SA, and allowed K2UYH to complete the first EME WAC on 432 MHz.

432 MHz EME was now well and truly established and in April / May 1978 the ARRL organised the first EME contest. 1296 MHz activity levels still lagged a long way behind but in early 1980 the first monthly CQ periods were started with PA0SSB, W6YFK and VE7BBG.

So much for the early EME activity. Now, what about the early EME technology?

Early EME Technology

Low noise amplifiers

Amateur EME could not have started without the parametric amplifier. ‘Low noise’ tubes like the 416B and 417A were available but the NF was nowhere near low enough for amateur EME, and low noise VHF/UHF transistors were still a distant dream.

The principle of parametric amplification was understood from the pre-electronics era but it was the emergence of varactor diodes with cutoff frequencies above 100 GHz that made the technology feasible at microwave frequencies. The diode is ‘pumped’ by a frequency Fp that is much higher than the signal frequency Fs, and the difference (‘idler’) frequency Fi must also be present. There are thus three resonant circuits to be arranged around the diode. Losses in the signal and idler circuits have to be kept to a minimum for low noise amplification.

The absolute minimum noise figure is given by $F = 10 \log_{10}(1+ Fs/Fi)$, so Fp and Fi must both be as high as possible. The paramp is a two-terminal device and so to avoid noise from the output port limiting the noise figure, the output had to be much more loosely coupled than the input. This meant running the whole paramp at a much higher gain which made it even more tricky to tune... and so on. A circulator solves those problems but they certainly were not readily available for amateurs in those days.

The first amateur paramp designs, by W6AJF, appeared in *QST* in 1959 and these were for 144-432 operation. Pump frequencies were 600-1400MHz but these designs were really hard to get working as they depended on multiple resonances in the line, and a series of traps to contain the pump and idler frequencies. We struggled with them because – when they worked – they were better than tubes. In January 1961 an infinitely better design for a 1296 MHz paramp was published in *QST*. This used a 3 cm klystron for the pump, and had separate cavities for the pump and idler with a coaxial line for the signal. I built two of these, for 432 and1296 MHz, but added radial chokes at pump and idler to completely isolate the signal line which was made in an adjustable coaxial form. This arrangement worked extremely well. I fired up the 1296 MHz version (Figure 6) recently and it measured 1.5 dB NF with about 20 dB of gain… not bad at all, and superb by the standards of those days. These paramps were followed directly by a trough line or cavity diode mixer, typically with a 7 dB NF.

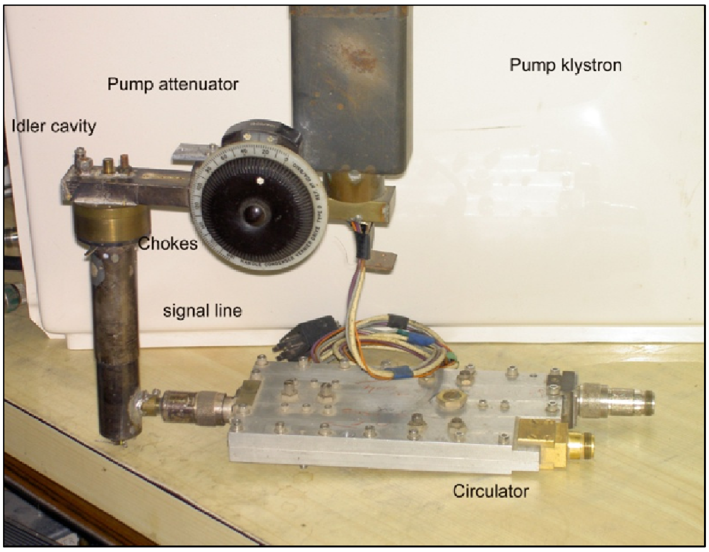

Figure 6: G3LTF 1296 MHz paramp, used from 1965 to 1974

So parametric amplifier technology was just about possible in those days, but by no means easy. In 1969 Rusty K4QIF had a paramp mounted at the edge of his 10 ft dish, which was hugely impressive – most people had enough problems with running them in the shack!

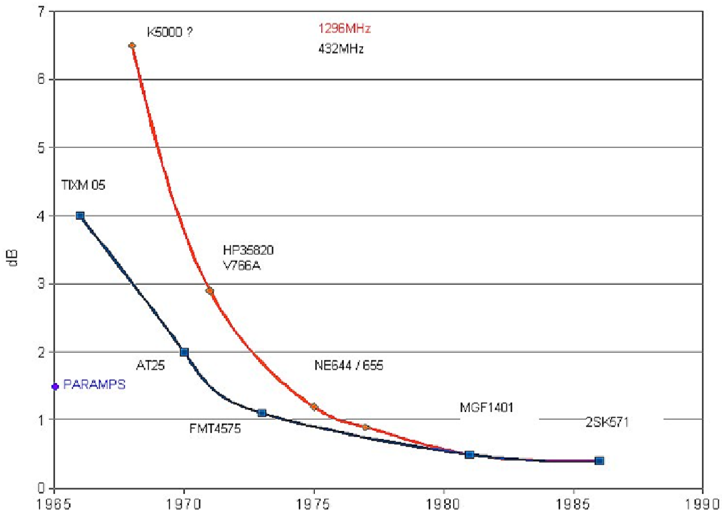

Figure 7: Noise figures, 1960-1986

At the time of the first EME contacts there were no transistors that would approach a paramp, but progress was rapid. **Figure 7** shows the noise figure of transistor preamps over the period 1960-1986 taken from the archive material. Several of these data points are from designs by professionals like W1JR and WB5LUA with access to proper measuring equipment, and they also agree with the data sheets. If one takes the paramp NF and adds 0.5-1 dB for feedline loss, then by 1970-72 the transistor mounted at the feed would outperform a paramp at the bottom of the feedline… but only if you could obtain (and afford) the precious transistor. By the mid-1980s 0.5 dB was obtainable on both 432 and 1296 MHz and noise figures have continued to fall to the 0.2 dB region today. Two other interesting points from the archives: the first use of inductance in the source of transistors to improve S_{11} and enhance noise figure in an amateur design was by W1JR in early 1975, in a preamp using the MRF902. The second is the publication in the *432 and Above EME Newsletter* for February 1981 of a circuit designed by the US NRO for an LNA at 1400 MHz. This uses exactly the circuit now commonplace in the VLNA designs of today, although obviously with values re-optimised for today's devices and frequencies.

We did have ways of measuring noise figure at 1296 MHz in the 1960s, or at least of estimating it and quantifying improvements. In 1964 *QST* published a design for a small gas-discharge tube inside a coiled stripline, terminated at the far end. This was based on a commercial design and had a typical ENR of about 15dB. I built one and added about 8dB of attenuation cable to reduce errors due to the on/off VSWR change (which was also known about!). A 24 dB return loss termination could be made with a carbon resistor inside a piece of tube on an N-type connector. At 432 MHz, thermionic noise diodes could be used, but with a lot of stray inductance these were only good for very roughly indicating 'better' or 'worse'! The proof of the pudding was always by comparative sun noise measurement. In 1976 G4COM published a design for an automatic noise figure indicating system which used the receiver audio output. It had limitations but it was a lot better than nothing. I used one for many years until the DJ9BV PANFI design appeared.

Obviously we worked extremely hard to minimise cable loss from the feed and this meant trawling the scrapyards for large diameter air-spaced cable and devising schemes to pressurize it. Typically the cable loss was 0.6-1.0 dB at 1296 MHz but it was always hard to hold it down, minimizing any jumper leads and keeping moisture out.

Transmitters

432 MHz

In the early 1960s there were few big tubes around for 432 MHz. Most people were either using a single 4CX250B or struggling with the output coupling of the push-pull parallel line version. These amplifiers would give 300-400W at best. When I was visiting the US in about 1965, Dick Turrin W2IMU gave me a GL6942, a 1.5kW tetrode (as used at W2NFA) and I designed a square radial cavity for it which gave me 850 W. In 1972 K2RIW published his wonderfully simple parallel 2x 4CX250B design which was compact and efficient and delivered 800-900 W. I imagine that hundreds of these were built; mine still runs as a standby. In the USA the RCA 7213 1.5 kW tetrode was obtainable in the 1960s and 70s, and a design by K2CBA was described in the *EME Newsletter* in 1981.

1296 MHz

Power at 1296 MHz was much more difficult to generate than on 432 MHz. The first contacts were made with Eimac klystrons with 300-400 W output but these were rare even in the USA. A few stations had the RCA 7650, which was right at the limit on 1296 MHz but would give 350 W with about 100 W drive. This was the tube used by HB9RG for his QSO with W1BU in 1964. The only other tube around was the ceramic 3CX100A5 (the glass 2C39 versions were useless for anything above 50W). This tube and similar variants were used very extensively in civil and military airborne navigation systems, DME, TACAN etc so they were obtainable and the early single tube designs would give 70-80 W.

This general lack of transmitter power was the principal reason that the early 1296 EME QSOs from W1BU were not followed through. In early 1968 Peter Laakman WB6IOM came up with a 2 x 3CX100A5 design using a box cavity that could be made from sheet metal and would deliver about 150W, so then you could combine two of these with ring hybrids and drive them with a third amplifier to generate 300W – which, at last, was enough power to get you into 1296 MHz EME. WB6IOM also designed and published in 1968 an 8-tube ring using 3CX100A5s. This brute would deliver 800W but I don't think many of this particular design were built.

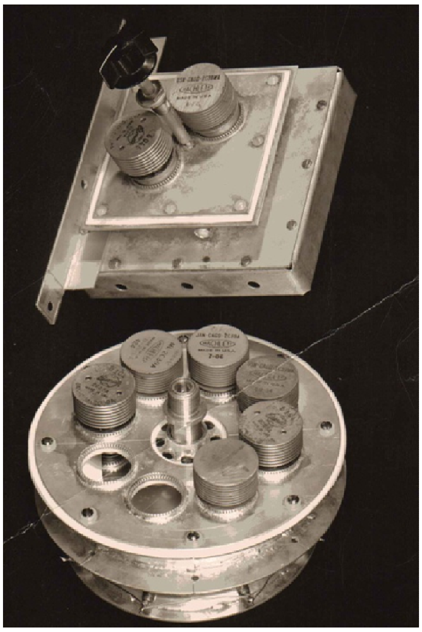

Figure 8: WB6IOM 2- and 8-tube PAs for 1296 MHz

At about the same time the UPX4 units appeared which used a 6-tube ring of 3CX100A5s and would deliver 600 W or more. The dimensions of this cavity were also published in the Crawford Hill W2IMU notes and OZ9CR manufactured some as well. Rusty, K4QIF produced a 4-tube design in a square cavity and in 1971 the Crawford Hill group (W2IMU) described a new 2-tube design with improved construction techniques which produced 200 W with 10 dB gain.

These 3CX100A5 designs, either singly or hybrid combined, fuelled 1296 MHz EME throughout the period 1968-1980 and beyond. It was accepted that the voltage limits of the tubes had to be stretched a bit (the W2IMU design ran at 2 kV) but the real trick was the use of water cooling to increase the power dissipation and reduce tuning drift. I think that Mike K6MYC was the first to do this, and the trials and tribulations of water cooling the 3CX100A5 would make a paper in itself. We should just note that Mike's method, although simple and effective, meant that due to dissimilar metals and high voltage the tube seal corroded through after a while with spectacular results! Better, more sophisticated, methods of fitting the cooling caps soon emerged, so as well as scavenging the scrapyards for heavy duty coax, we had now added old washing machine pumps to the shopping list!

Frequency accuracy and stability

In the early 1960s most UHF/VHF systems used multiplier chains from low frequencies like 8 MHz and we soon graduated from FT243 crystals to B7G evacuated types. The first EME QSOs reported problems with frequency stability, especially with the narrow receive bandwidths of 100 Hz and lower. Those of us who were doing meteor scatter on 144 MHz at this time were already well aware of the stability problems. Johnny, G3CCH had a buried 8 MHz crystal oscillator and I built a special double walled wooden container for my oscillators. We used varactors to trim to frequency against a standard frequency transmission.

Getting on the right frequency for skeds was not too difficult. Like other meteor scatter and EME operators such as Ivo OK2WCG (now ZS6AXT) and Karl SM3AKW, we already had dividers from 1 MHz crystals giving 100 and 10 kHz, and multipliers to make these markers audible in the VHF and UHF bands. By about 1970, British hams also had calibration systems with 1 MHz oscillators locked to the BBC's 200 kHz transmitter. I imagine that much the same was done by the US and other European operators. By the mid-1970s most were using mixer VFO systems and transverters, much the same as today.

Antennas

This section is going to be predominately about dishes because in the early days they were very much the antennas of choice. In early 1973 there were six stations active in the 432 MHz sked lists, and all used dishes. By April 1974 that list included 47 stations, of which 75% used dishes; but a year later the list had 81 calls with 63% using dishes. In both lists there were a few colinear arrays. The smallest dish was 4.8 m and the majority were 6-9 m. The reasons for this mix were (a) that good Yagi designs at 432 MHz were not yet well established; (b) signals were weak at best, and Faraday rotation easily wiped them out, so rotatable or switchable polarization was considered almost essential; and (c) as power and LNAs became available on 1296 MHz, EMEers wanted to be able to work that band as well.

At the start the predominant driver of dish design was to maximise efficiency. Simple dipole type feeds were the first choice and so we looked at the WW2 reference books (especially *Microwave Antennas* by Silver in the MIT Radiation Lab series) and went for F/d ratios of 0.3 or thereabouts. On 1296 MHz the W2IMU Crawford Hill operation moved to circular polarisation in 1968 with crossed dipoles and a 90 degree hybrid with a relay to switch, but a lot of the early work was done with fixed circular polarisation, reversed at each end to cope with the Moon reflection. As echoes to begin with were non-existent, reversing polarisation was an unnecessary complication but there were a few nail-biting moments when you weren't really sure that you'd got it the right way round. By measuring the field distribution across the dish surface we soon realised that dipoles were not the best choice and very quickly moved to the 150 mm (6 in) circular waveguide feed (literally a coffee can) with probe excitation. Selecting the guide diameter to optimize illumination was the next step, and the first choke to minimize surface current on the outside of the guide was fitted in 1971. As soon as good transistors arrived, which had noise figures better than a paramp at the end of about 1dB of feeder, the preamp moved up to the feedpoint at the output of the hybrid. This first happened in about 1970-71.

In 1970 Dick Turrin W2IMU published a design for a relatively shallow 6 m (20 ft) dish with an associated feed – the now famous W2IMU dual-mode horn. Before the days of really low noise transistors the best dish to build for this horn was one with an F/d of 0.5 to 0.6 and a lot of stations followed that design. A few months later Dick came up with a waveguide polarizer which could be added to the horn and eliminated the need for the comparatively lossy hybrid coupler. Many of these W2IMU horns are still in use and in 2008 the design was updated by N2UO with a septum polarizer section instead of the original with multiple adjustable posts.

On 432 MHz the feed situation has progressed much less, starting with single dipoles and then moving to the dual dipole design around about 1970, after this had been published by the EIA as a gain standard having equal E- and H-plane patterns. Most 432 MHz dish stations had fully rotatable feeds from the very early days. 432 MHz also benefited from the concept of the stress dish pioneered by K2UYH and first described in *QST* in 1966. See figure 26 for an example built by VE7BBG.

With the relatively poor 'low noise' amplifiers of those days, the only way to further increase the received signal was to increase the antenna gain – or in other words, to increase the dish diameter. In the USA there seemed to be a supply of Kennedy 28 ft dishes (see figure 18) but in most cases it was very much 'build your own'. In a following section I will give more details of some home-built dishes.

But by the 1970s a large Yagi array was becoming a serious alternative to a dish for 432 MHz (and of course for 144 MHz). F9FT's 1975 system comprised 16 x21 element Tonna yagis and Jan DL9KR had 16 quagis with a precision low loss phasing system. See figure 22. By the late 1970s, stations with big antennas (both dishes and Yagis) were making contacts with two-Yagi and even single-Yagi stations, the latter perhaps with some help from ground gain.

Finally we should mention colinear arrays. The notable ones were built by W6FZJ (later W1JR) and ZE5JJ. They had 64 one-wavelength driven elements with reflectors, end fed with open wire feeders, and were about 4.2 x 4.5 m with a gain about the same as a 5m dish. W6FZJ's array was also rotatable in polarization. See figure 23.

Using archive data together with estimates from EMEcalc I have put together a chart (Figure 9) showing how the typical system noise temperatures changed between 1960 and 1980 due to the combined effect of improvements in LNAs and feed systems. The advent in the early 1970s of the W2IMU feed horn and transistors at the feedpoint is very obvious in the 1296 MHz curve.

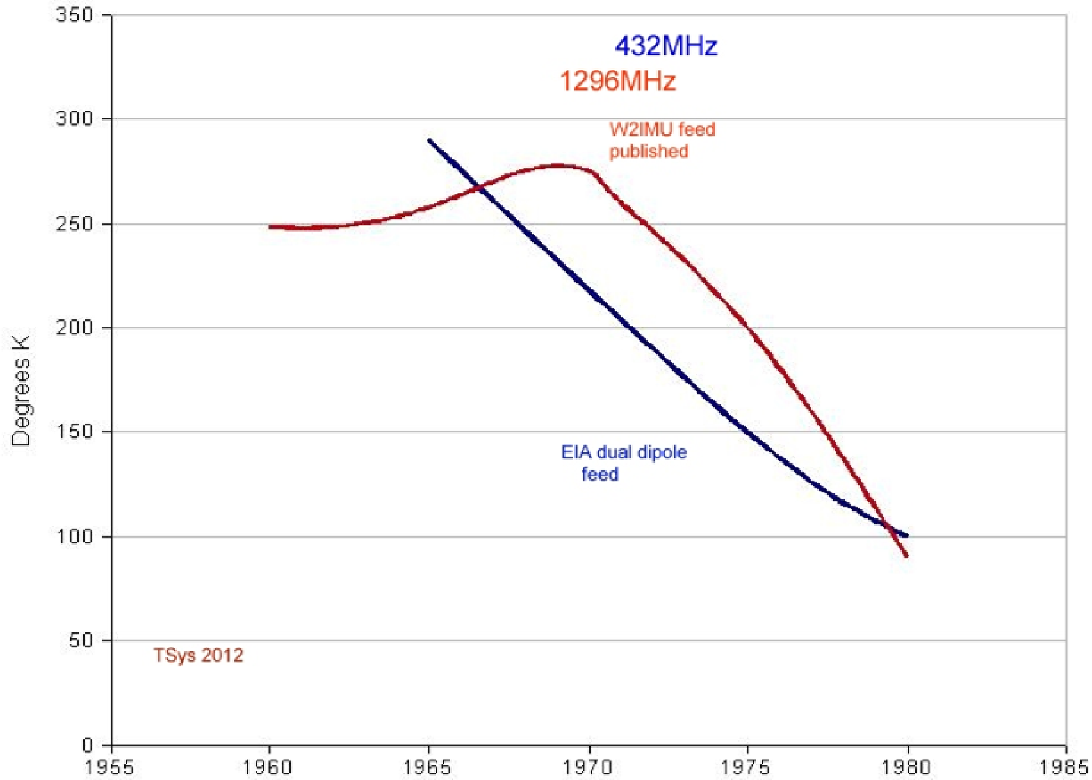

Figure 9: Typical system noise temperatures, 1965-1980

Where is the Moon?

It is pretty certain that a lot of skeds and tests failed in the early days because one or both antennas were not accurately aimed at the Moon, or aiming was lost during the contact. The only Moon data readily available in the early years were from Nautical Almanacs, and *QST* in the 1960s and early 1970s published several articles on how to turn this data into elevation and azimuth using graphs and simplified calculations. People with access to laboratory computing systems (like WB6IOM at Hughes Aircraft and the Bell labs group under W2IMU) distributed print-out data for specific tests. By the mid-1970s the early PCs allowed programs to be written to give El/Az data, but there were very few automatic tracking systems around at that time, if any.

A popular alternative in the early days was the polar mount, which is simply an El / Az mount tilted back so that its axis is parallel to that of the Earth. This then becomes the Hour Angle axis which only needs to be rotated at a constant rate. The polar mount simplified Moon tracking enormously and was used in very many stations at this time, again supported by several *QST* articles on how to build one. Everyone had a sighting tube and/or a TV camera fitted to the antenna, because a big attraction of the polar mount was that if you got one fleeting view of the Moon, you could then start the Hour Angle drive and be pretty sure of keeping on the Moon for the next hour at least. Because many stations needed a visible Moon to start their polar tracking, skeds tended to be set for night-time, or at other times with a large angular separation between the Sun and Moon.

Station Profiles

In this section I will briefly describe some of the best known 432 and 1296 MHz stations of the 1960-1980 era. The System Temperature data in figure 9 has been obtained by analysis of their performance with the help of references [4] and [5]. These are obviously estimates in hindsight, but I have also tried to correlate Sun noise data and signal strengths received where possible.

1296 MHz stations

W1BU, 1960: 18 ft Kennedy dish (Figure 10) estimated 0.4 F/d, feed was L-band waveguide with flange, feedline loss 0.5 dB; Microwave Associates paramp MA2-1000B 1.5 dB NF; Tx power 400W. Estimated Tsys 248 K, echoes +3 dB in 300 Hz, G/T +11 dB.

KH6UK, 1962: 28ft Kennedy dish, other details the same as W1BU. Estimated G/T +15 dB. Reported that “KH6UK’s signals run 15-18 dB over noise in 30 Hz at W1BU”; the predicted level is 18 dB.

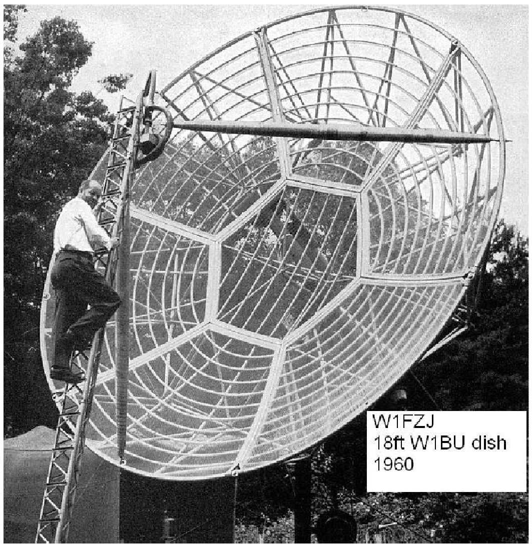

Figure 10: Sam Harris W1FZJ with the W1BU 18 ft dish, 1960

WB6IOM, 1968: 10 ft dish, 0.375 F/d, 6 in (0.66 wl) coffee can feed, 0.6dB feedline loss; paramp 1.5 dB NF; Tx power 500 W. Estimated Tsys 267 K, G/T +6 dB.

WB6IOM, 1969: 16ft dish, 0.525 F/d, same feed as 10 ft dish, 0.8 dB feed line; paramp 1.5 dB NF. Estimated Tsys 300K, G/T +7 dB.

Figure 11 shows both of WB6IOM’s dishes. The 16ft dish at the rear was made from honeycomb off-cuts glued together on a massive concrete mould; it was on a polar mount with a fixed declination and a movable feed. Unfortunately the feed was never optimized.

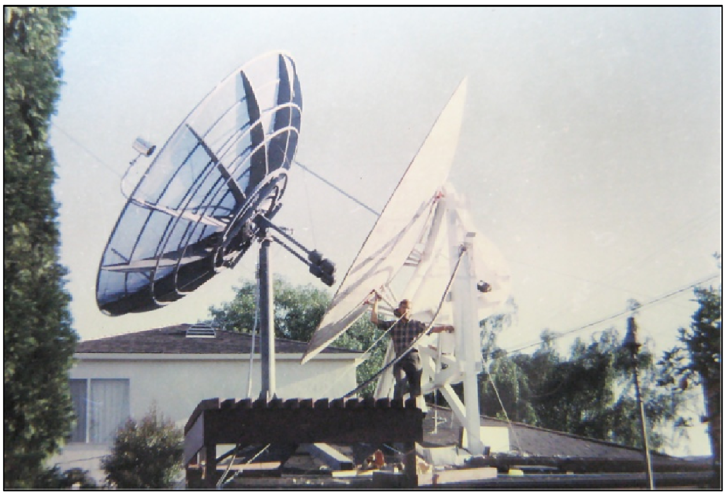

Figure 11 WB6IOM 10 ft and 16 ft dishes, 1969

K6HCP / K6MYC, 1968: 15 ft dish, F/d probably 0.4, feed probably 6 in coffee can; Tx power 500 W. Estimated Tsys 290 K, G/T +6 dB.

G3LTF 1968-70: 15 ft dish (Figure 3), 0.3 F/d, 0.83 wl circular guide feed, 0.7 dB feedline; paramp 1.8 dB NF; Tx power 280 W. Estimated Tsys 280 K, G/T +7.3 dB.

G3LTF, 1975: 19 ft dish, 0.5 F/d, W2IMU feed + hybrid; transistor 1.5 dB NF. Estimated Tsys 200 K, G/T +16 dB. This dish (Figure 12) was enlarged from the previous 15ft version. The arms were made from marine plywood and lasted 17 years, surviving the two UK hurricanes.

Figure 12: G3LTF 19 ft wood framed dish

W9WCD, 1971: 16 ft dish (Figure 13), 0.35 F/d; circular guide feed with short flare, 0.9 dB feedline; paramp 1.5 dB NF; Tx power 500 W. Estimated Tsys 260 K, G/T +9.5 dB. This was an amazing system built on his own from *QST* and *HR* articles, with an own design feed which when modeled today has very good characteristics.

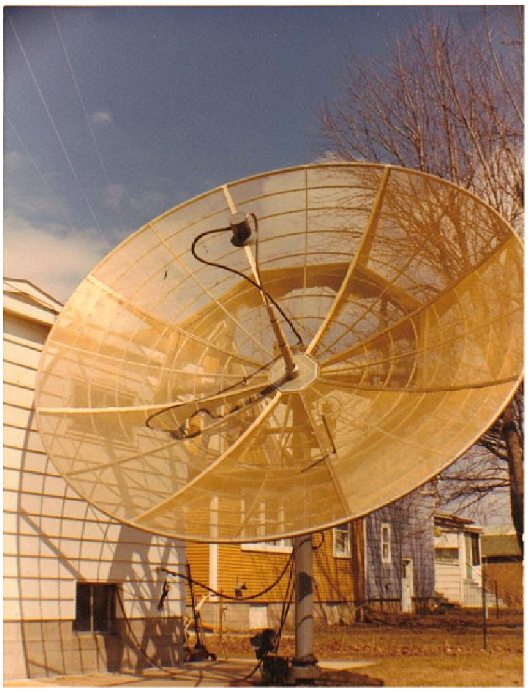

Figure 13: W9WCD 16 ft dish

W2NFA, 1969: 60 ft dish (Figure 5), 0.6 F/d, crossed dipoles feed, 2.1 dB feedline, paramp 1.8 dB NF; Tx power 200 W. Estimated Tsys 540 K, G/T +17 dB.

W2NFA, 1972: now 0.5 dB feedline, but 2.5 dB NF (V766A transistors); Tx power 250W. Estimated Tsys reduces to 400K, G/T increased to +18 dB. Reported echoes of +13 dB in 1.2 kHz agree exactly.

PA0SSB, 1972: 20 ft dish, 0.6 F/d, W2IMU feed; Tx power 480 W. Estimated Tsys 200 K, G/T +14 dB. Figure 14 shows this beautifully constructed dish with 48 ribs, which could slide down the tower to protect it from the winds. See reference [6], AS-49-14 for full details of this beautifully made dish.

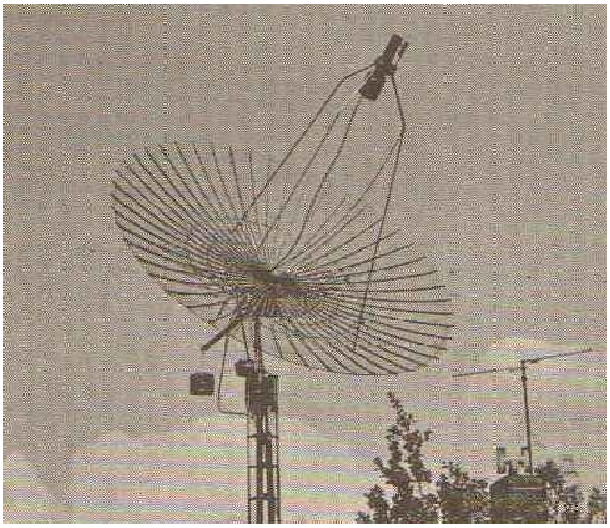

Figure 14: PA0SSB 20 ft dish in elevated position

432MHz stations

G3LTF, 1965: 15 ft dish as above, 0.4 dB feedline, dipole feed; paramp 2 dB NF. Estimated Tsys 290 K.

G3LTF, 1980: 19 ft dish as above, dual dipole feed; preamp 0.5 dB NF. Estimated Tsys 120 K.

VK2AMW, 1975: 30 ft dish (Figure 15), 0.4 F/d, dipole feed; MT4578 transistors. Estimated Tsys 140 K. G/T +8 dB.

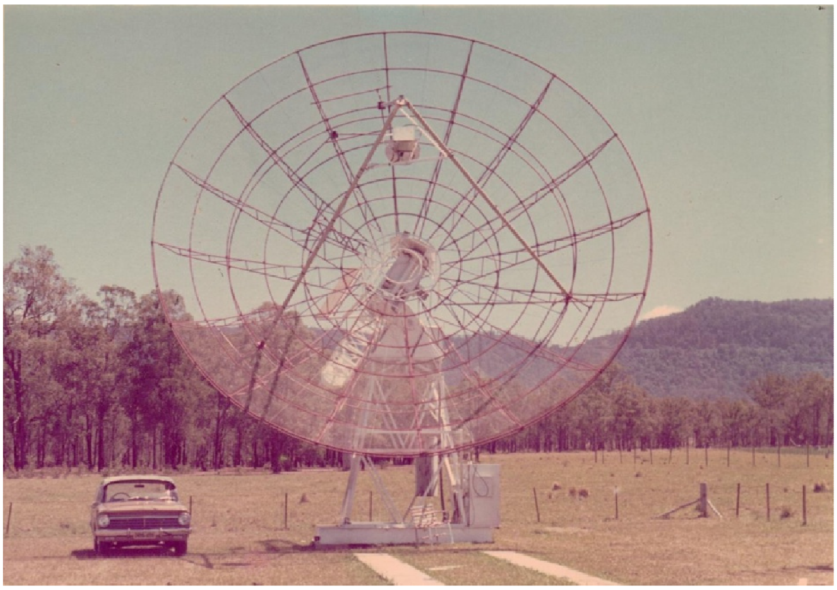

Figure 15: VK2AMW 30 ft dish

F9FT, 1975: 16 x 21 element yagis, 33 dBi gain. Estimated Tsys 150K. This antenna (Figure 16), which was in use from 1975 until 1992, is typical of the big Yagi arrays of the 1970s and 1980s.

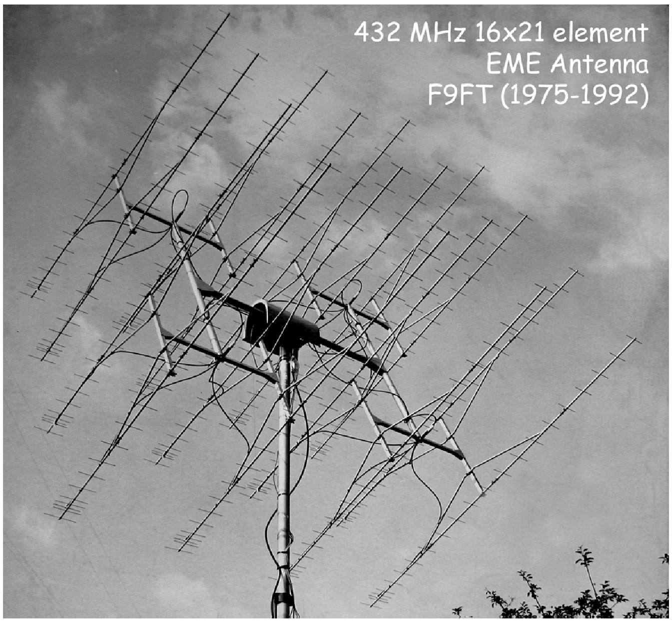

Figure 16: F9FT 16 x 21 element Yagi array

JA1VDV

JA1VDV made the first 432MHz QSO from Japan in 1975 using a 20 ft mesh dish, F/d 0.6 with a dual dipole feed. Estimated Tsys 160 K, G/T 4.6 dB

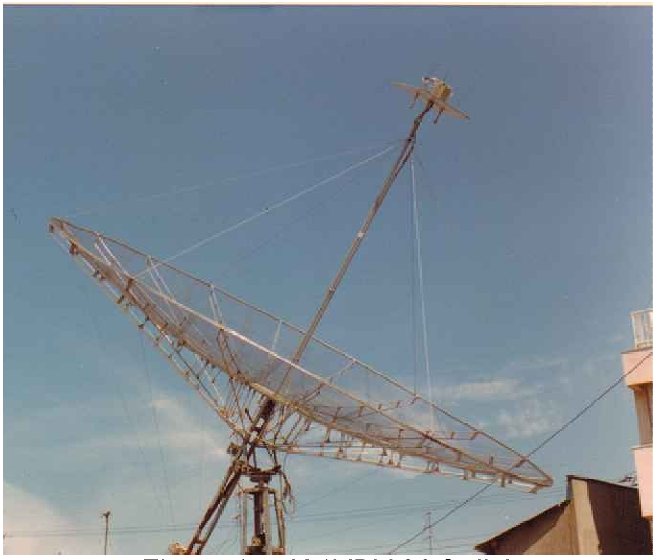

Figure 17: JA1VDV 20 ft dish

K2UYH

Figure 18 shows Al's 28 ft Kennedy dish in the 1970s, before the trees grew! Estimated G/T about the same as VK2AMW, 8 dB.

Figure 18: K2UYH (L) and his 28 ft dish

I5MSH

A prominent station in the 1970s, run by Piero, I5TDJ, now sadly SK, was this 38 ft dish in Florence shown in Figure19. F/d 0.35 and in this picture with its first feed, a simple dipole.

Figure 19: I5MSH with the famous 38ft dish

FY7AS

For a few weeks in early 1977 the dish shown in Figure 20 was operated on 432 MHz EME before it was dismantled. 13 stations were worked and my QSO with them gave me WAC #2! The dish was originally built for satellite tracking on 250 MHz and was 13 m x 17 m, 0.5 F/d with an estimated gain of 33 dBi. The sun was very quiet then and so from their sun noise measurements I estimate the Tsys as about 350 K and the G/T as 7.5 dB. The big problem was the transmitter which gave between 150 and 600 W depending on “Old Murphy” as a letter from F5SE of February 1977 says!

Figure 20: The big dish used by FY7AS in early 1977

LX1DB

Another big signal in the 1970s (and ever since), Willi's dish at that time is shown in Figure 21. 8 m in diameter and 0.6 F/d the estimated Tsys is 140 K and the G/T 7.5 dB. The box on the mast contained a K2RIW PA. In 1980 the same dish was also used on 1296 MHz with a W2IMU feed.

DL9KR

Another one of the big signals from the 1970s onward comes from the antenna of DL9KR, 16 x 24 element Yagis, see Figure 22. Note the neat phasing line system, some useful guidance and information can be found here in the *DUBUS* archives: http://dpmc.unige.ch/dubus/9101-3.pdf

Figure 21: LX1DB 8m dish 1975

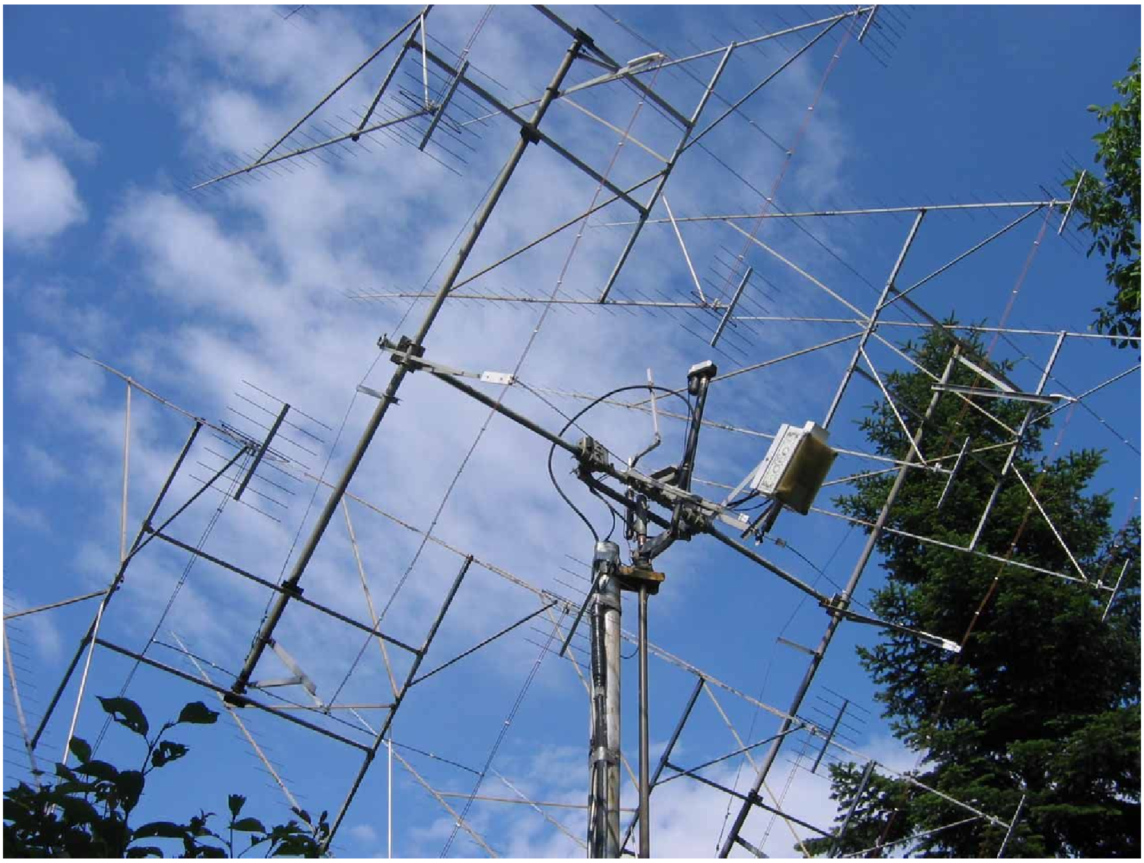

Figure 22: DL9KR 16 Yagi array

Figure 23: W6FZJ (W1JR) 128 element colinear array, polarization rotatable
See reference [6] AS-49-8 for more details

G3LQR

Figure 24 shows the 20ft dish built in 1975 by G3LQR , his first QSO was with W3CCX the station operated by the Mt. Airy group, the Packrats. The estimated Tsys is about 130 K and the G/T 5.5 dB. Sadly the dish was destroyed by a major storm a few months later

Figure 23 G3LQR 20ft dish, 1975

OZ9CR

Another of the early EME stations was the late OZ9CR, he also operated as OZ3FYM on both 1296 and later 432 MHz. He had a 12 m dish and was probably the first to experiment with a circularly polarized feed horn on that band, see Figure 25. The feed was constructed of perforated sheet to reduce weight and used a post type polariser similar to that used in the W2IMU feed horn. Note the nulling post on the rear face of the waveguide.

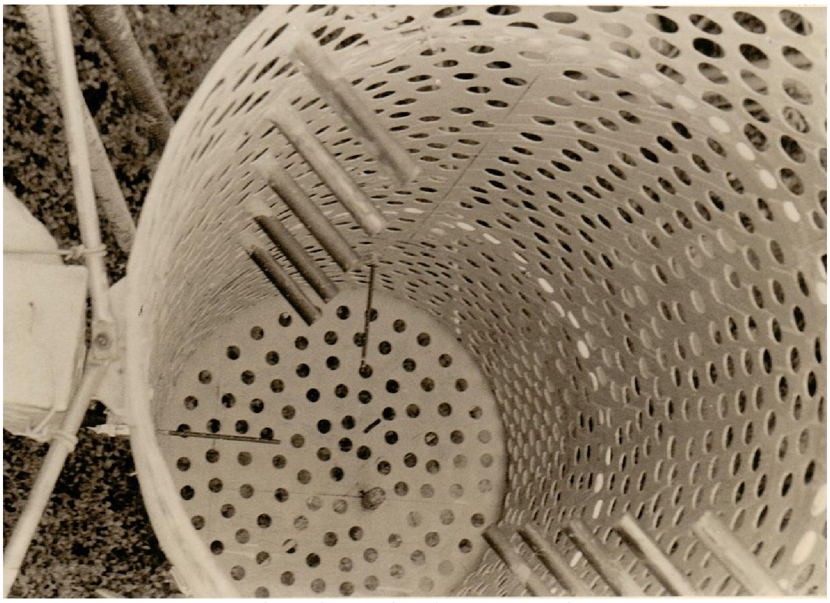

Figure 25: OZ9CR's CP feed horn for 432MHz.

VE7BBG

Figure 26 shows Cor's first dish, used from about 1971 until he moved to Victoria Island in 1974. It is a stress dish with wooden arms, 20 ft diameter with 0.5 F/d and at this time used a simple dipole reflector feed which was rotatable to combat Faraday rotation. Cor, who sadly passed away this year, produced the mailed out sked list for the EME community from about 1971, before the *432 and Above Newsletter* started, and continued that for many years. He was a major contributor to the growth of EME activity.

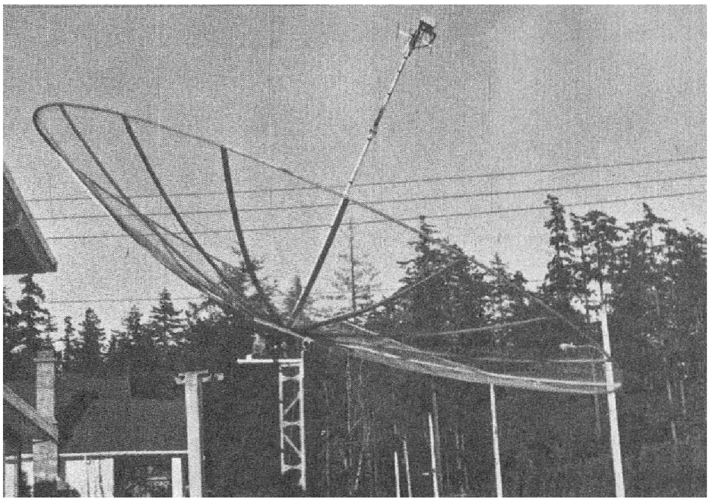

Figure 26: VE7BBG's 20 ft stress dish

This has obviously not been intended to be a complete list of those active, but is based on stations for which I had reasonable archive data available. Other callsigns who were active on 432 MHz in the 1974-5 sked lists were F8DO, W4NUS, W0EYE, W0DRL, W3CCX, WA6HXW, K0TLM, W1SL, and ZE5JJ. If I missed someone out then please forgive!

Conclusions

So… how good ***were*** the EME systems of the 1960s and 70s?

It is quite hard to provide a simple answer the question that I asked myself when I thought of putting together this paper. It has been quite difficult to extract the data from the archives and to come up with some meaningful trends, but fortunately the early EMEers were reasonably good at recording their results and describing their systems and nearly all of their communication was by letters (which I have kept).

On both 432 and 1296 MHz the major change from 1960 to 1980 has been in the LNAs, from paramps to germanium transistors, followed in turn by silicon bipolars and then FETs. But at the same time there was also a change to better, more complex, feed systems as the improvements in LNAs forced us towards a better appreciation of the effects of spillover and the benefits of more uniform illumination. I have tried to show this with extracted data in the curves of noise figure and system temperature.

One other issue comes through as I have gone back through the data and the letters: that of antenna aiming. The margins for many of these early contacts were extremely small, for example the W9WCD-G3LTF contact on 1296 MHz was made with signals of around 4-6 dB over noise in 100Hz, quite a typical level for that time. The -3 dB beam-width of the dishes was about 3.5 degrees so you needed to point within 2 degrees at least. This implies an update every 8 minutes, and we used to run 10-minute Tx/Rx periods to give plenty of time for searching. And as someone so memorably said, there was also a very big difference between listening to your own tiny echoes, and searching for someone else's signals while at the same time scrambling to keep everything working, tuned up and pointed correctly!

As 1980 arrived, there were a lot of developments just around the corner which would transform the capabilities of our EME systems on 432 and 1296 MHz: much better low-noise transistors, the evolution of Yagis with much improved G/T, the availability of powerful modelling tools and the wider availability of large tubes for both bands.

Looking back I conclude that with limited budgets (and many of us were then comparative youngsters bringing up families!) we did build stations which were pretty close to the state of the art, and with mainly homebuilt test equipment. The homebuilt antennas of those days, especially DL9KR's Yagi arrays, were truly amazing, while PA0SSB's dish construction and performance stands comparison with any of today's big dishes.

References

1. VK3UM EME Calculator: http://www.vk3um.com/eme%20calculator.html
2. W1GHZ Online Microwave Antenna Book: http://www.w1ghz.org/antbook/contents.htm
3. SM6FHZ 432 MHz feed modelling http://www.2ingandlin.se/Feed_comp_432_MHz.html
4. Historic solar flux data: http://www.solen.info/solar/history/
5. Moon distance: http://www.jgiesen.de/moondistance/index.htm
6. A very useful sources has been the series of Eimac EME notes which Geert, PA3CSG has scanned in here http://pa3csg.hoeplakee.nl/joomla/index.php?option=com_content&view=article&id=71:the-eimac-eme-notes&catid=43:old-stuff&Itemid=63 and where there is much more data on some of the systems described above. Geert also mentions the great contribution to EME information distribution made by the late Henk Ripet of VERON.

Also see http://www.ok2kkw.com/eme1960/eme1960eng.htm for a lot of information from *QST* extracts on the early years, including more on 144 MHz.

Acknowledgements

I am very grateful to Paul W1GHZ for modelling some of the older feeds used in the early days, and to John G8ACE for his great help with some of the illustrations.