The NERC MST Radar Facility at Aberystwyth http://mst.nerc.ac.uk

A Detailed Analysis Of The NERC MST Radar At Aberystwyth After Twenty Years Of Operation

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1 Introduction

The Natural Environment Research Council (NERC) Mesosphere-Stratosphere-Troposphere (MST) Radar at Aberystwyth (UK) is a 46.5 MHz, 160 kW peak-power, Doppler Beam Swinging, wind-profiling instrument (Slater et al., 1992; Vaughan, 2002; Hooper et al., 2008). It was designed (Bowman et al., 1983) and built by the Rutherford Appleton Laboratory, albeit making use of a number of third party modules. The hardware has remained virtually unchanged since part-time operations began in 1989. The radar has been operated on a quasi-continuous basis since late 1997 and its performance has noticeably decreased in that time. As can be seen from Figure 1, whereas the maximum useful altitude for ST-mode wind-profiling purposes was typically around 20 km in 1999, it is now closer to 15 km a decade later.

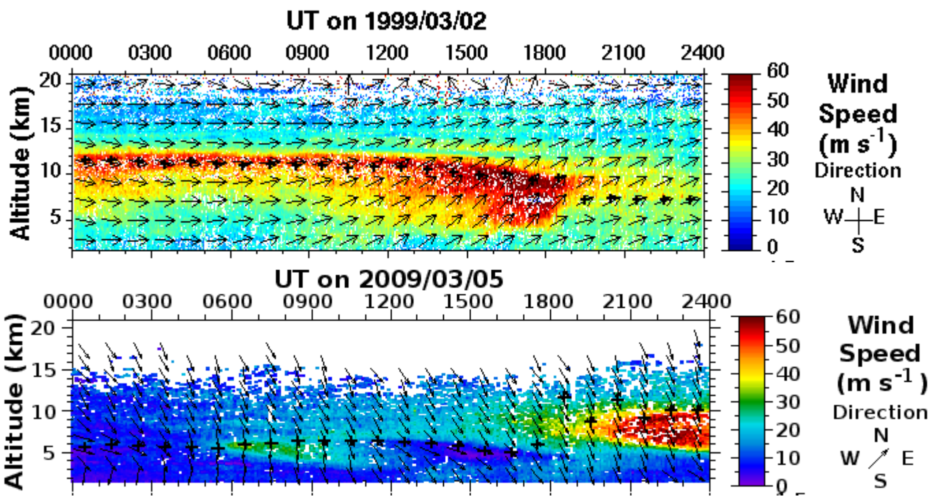

Figure 1: MST radar derived horizontal wind data from (top) March 1999 and (bottom) March 2009 demonstrating how the maximum useful altitude for wind-profiling purpose has decreased over the last decade.

Two detailed studies of the entire radar system were undertaken during the second part of 2008. These had the aim of establishing the cause of the reduction in performance. This document is primarily concerned with the results. Owing to the lack of pre-existing official documentation for the radar system, this opportunity has been taken to record miscellaneous additional technical information which might otherwise become lost.

The layout of this document is as follows. An overview of the radar system is given in Section 2. An analysis of individual components is given in Section 3. Finally, the requirements for component replacement are discussed in Section 4. The document is aimed at readers who have some familiarity with the principles of operation and of the hardware used by wind-profiling radars.

2 System Overview

Figure 2 shows the principal functional components of the Aberystwyth radar. The design is fairly typical of an instrument of late 1980s vintage (c.f. Schmidt and Czechowsky, 1986; Röttger, 1989; Tsuda, 1989). The Radar Control Unit contains a 10 MHz TTL crystal oscillator. This is used to generate a 1 MHz clock signal from which all of the signals for controlling the other radar components are derived. A dwell is initiated when a 16 bit control word - encoding the beam pointing direction, the pulse length, the sub pulse length (i.e. the baud length when complementary coding is used), the inter pulse period, and the receiver bandwidth (see Table 1 for further details) - is passed from the Radar Control And Data Acquisition PC to the Radar Control Unit.

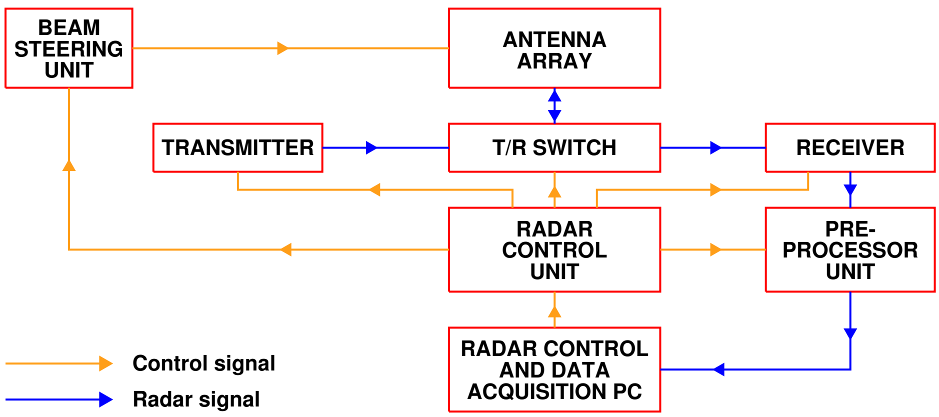

Figure 2: The principal functional components of the Aberystwyth MST radar.

For each transmitter pulse, the Radar Control Unit generates a control signal which simultaneously sets the T/R Switch to transmit mode and blanks the Receiver. This extends 2 μs either side of transmitter pulse. During the transmission of a pulse, the phase of the transmitter signal can be shifted by 0° or 180° every 1 μs if complementary phase coding has been selected (e.g. Schmidt et al., 1979). Under such circumstances, the Radar Control Unit selects the Receiver's bandwidth to match the sub-length, i.e. the baud length, of the transmitter pulse. This determines the range resolution. The Radar Control Unit will automatically alternate the phasing sequence between that of the code and that of the complementary code from pulse to pulse. The code sequences which can be used by the Aberystwyth radar are shown in Table 2 **[need to check whether this begins with the LSB or the MSB]**.

The Radar Control Unit controls the sampling of the Receiver output (as In-phase and Quadrature components) every 1 μs (i.e. at 150 m range intervals), irrespective of the range resolution selected. The Receiver samples are not acquired by the Radar Control And Data Acquisition PC for every individual transmitter pulse. Instead they are coherently integrated (separately for each range gate

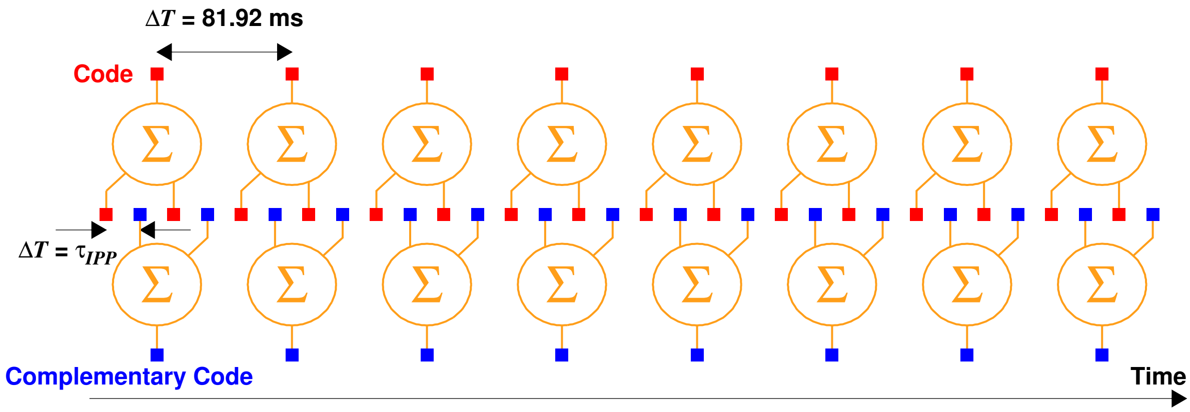

Figure 3: The method by which Receiver samples from alternating coded and complementary coded radar pulses are coherently integrated independently over 81.92 ms. For ST-mode observations, which make use of a 320 μs inter pulse period, τ_{IPP}, this equates to integration over 256 transmitter pulses is required, although integration over only 4 pulses is shown here for simplicity.

and separately for the In-Phase and Quadrature components) in a hardware Pre-Processor Unit for a set period of 81.92 ms (approximately 1/12th s). This is a legacy of the relatively limited computer power available when the radar was first built. In fact, as shown in Figure 3, the Pre-Processor unit independently integrates the samples for alternate pulses. This allows decoding to be carried out in software by the Radar Control and Data Acquisition PC when complementary coding has been used. If no coding has been used, the two sets of samples can simply be added together. Similarly additional coherent integration can subsequently be carried out in software if 81.92 ms is insufficient. Standard ST-mode observations make use of an 8 μs transmitter pulse which is coded with a 2 μs sub pulse length, an inter pulse period of 320 μs, and 512 point coherent integration (i.e. covering 163.84 ms). Consequently both decoding and additional coherent integration must be carried out in software.

The Pre-Processor Unit additionally employs a standard technique for eliminating any dc biases introduced by the Receiver's phase detectors and/or analogue to digital converters (ADCs). A signal from the Radar Control Unit causes phase of the transmitter signal (or of the coding sequence) and the output of the ADCs to be inverted every 1.28 ms.

As shown in Figures 4, the antenna of the Aberystwyth radar is composed of a 20 by 20 array of 4-element Yagis at 0.85λ spacing, where λ is the radar wavelength. The orientation of the array is rotated 17.5° anticlockwise from the cardinal directions. For the sake of convenience, except where they are quoted in units of degrees, azimuths will refer to the nominal directions which are -17.5° relative to the actual ones. The Yagi elements are aligned along the NW-SE direction. From a control point of view the antenna is configured as a 10 by 10 array of Quads, i.e. 2 by 2 sub-arrays of Yagis which act collectively as a single unit. Quads are numbered from 1 to 100 starting in the NW corner, increasing first by column and then by row. Each Quad belongs to one of five variable-sized sectors and each sector has an equal power weighting. The central sector (labelled "C" in Figure 4) is composed of just 4 Quads; two inner half-ring sectors ("B" and "D") are composed of 16 Quads each; two outer half-ring sectors ("A" and "E") are composed of 32 Quads each.

The tapering of power across the array helps to minimise the width of the main lobe of the radar beam. The Aberystwyth radar has a one-way half-power half-width of 1.5°. This value has been confirmed from observations of the transit of known celestial radio sources through the beam (e.g. Kingsley, 1989; Jones and Kingsley, 1993). The best source is Cassiopeia A (also known as Cass

A), a supernova whose emissions are significant within the VHF band and which passes close to the centre of the NE6.0 beam at around 17:30 UT on 17th December each year. The transit, which lasts for less than an hour, is marked by a peak enhancement of approximately 8 dB in noise power. This is superimposed on a diurnal noise power variation of approximately 4 dB which is associated with variations in the galactic background. Special observations were made in 2005 so that NE6.0 beam observations were made every other dwell rather than once a cycle (Hooper, 2008). This means that the appropriate data are available at intervals of just 47 s rather than at intervals of a few minutes, which is typical for standard mode observations. Cygnus-A is another potential radio source.

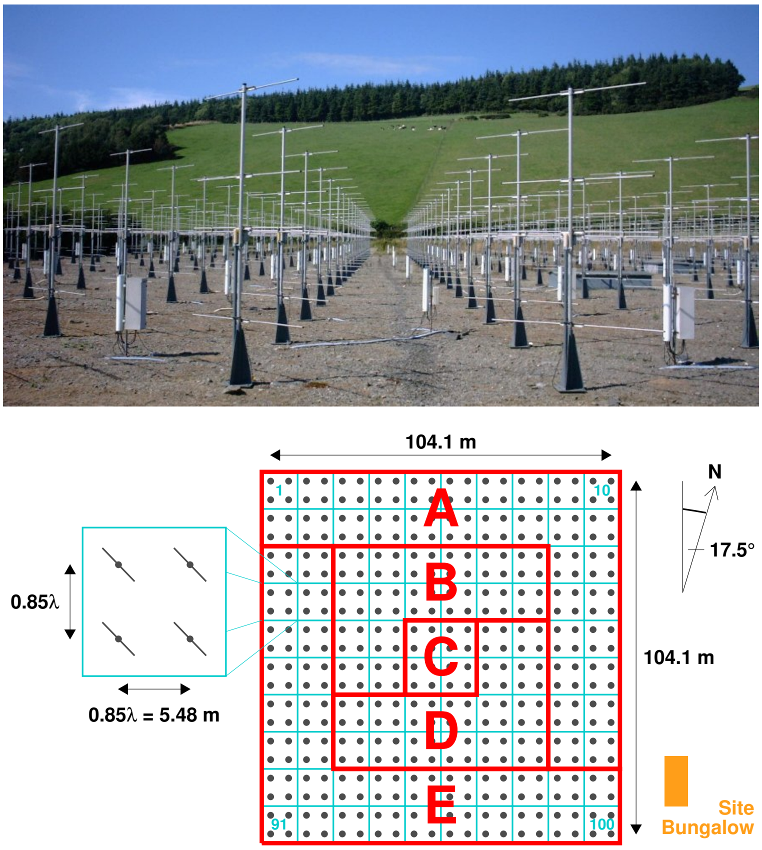

Figure 4: The antenna array of the Aberystwyth radar, (top panel) looking towards the north, (bottom panel) is composed of a 20 by 20 array of 4-element Yagis (grey dots) at 0.85λ spacing. From a control point of view, the antenna is configured as a 10 by 10 array of Quads (turquoise boxes), which are numbered from 1 to 100 starting in the NW corner. The Quads belong to 1 of 5 variable sized sectors (outlined in red) which have equal power weighting.

In the transmit mode, each antenna sector is powered by an identical 32 kW peak-power transmitter. All five transmitters are phase-locked to a single unit. As shown in Figure 5, cascades of Power Splitters are used to distribute power equally to each Quad within a sector. In the receive mode, the collective signals from each sector are combined before being fed to the Receiver.

As shown in Table 3, slightly different cable lengths are used for each of the outputs from the final Primary Power Splitter within each sector. This compensates for the different phase changes (shown in yellow in Figure 5) accumulated by the signals following each of the available paths through the network. In order for the radar beam to be directed towards the vertical, the signals must be in phase for all Quads. The radar beam can be steered off-vertical, and towards a specific azimuth, by

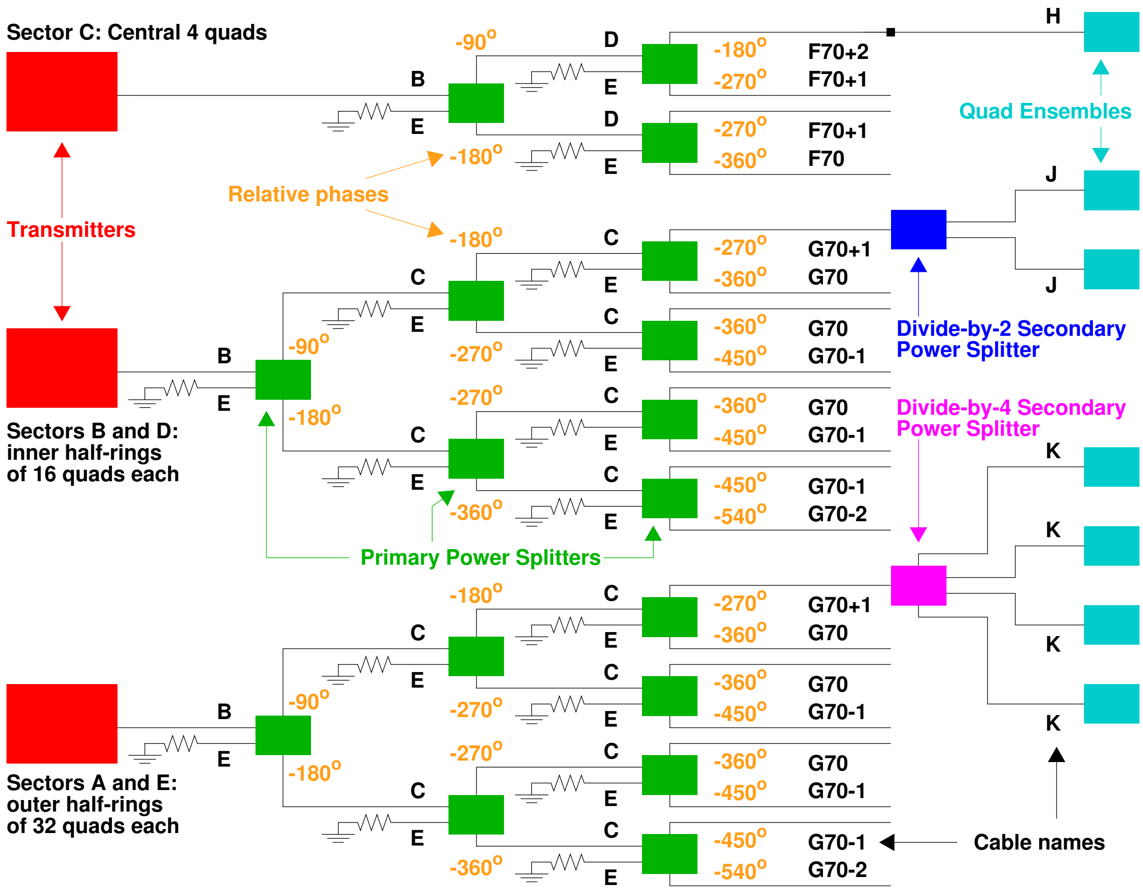

Figure 5: Power is distributed equally to each Quad within an antenna sector through a cascade of Power Splitters. All load resistors are 50 Ω. For the sake of simplicity, details are only shown for a single output from the final Primary Power Splitter for each type of antenna sector. The details are identical for each of the other outputs. The load resistors are not shown for the Secondary Power Splitters - see Section 3.5.4 for further details. Technical details of the different cable types are given in Table 3.

deliberately varying the phase of the signal fed to each Quad. For this purpose, each Quad has a dedicated Phasing Unit, which allows combinations of effective cable lengths of $\lambda/2$, $\lambda/4$, and $\lambda/8$ to be switched in to the feed using electro-mechanical Relay Units. Each Relay Unit of each Phasing Unit can be activated individually by a dedicated control signal from the Beam Steering Unit. The latter contains a look-up table of the necessary Relay Units to activate in order to allow the radar beam to be steered to one of the 17 possible directions shown in Figure 6 and in Table 4. Each Phasing Unit is followed by a divide-by-4 Final Power Splitter in order to distribute power equally to each Yagi within the Quad.

3 Details Of Individual Components

3.1 The Radar Control and Data Acquisition PC

The radar was originally controlled by a PDP-11 computer with a DSP card. The following is taken from an internal report (entitled “MST System Upgrade Options” - no author details or date are given): *“An upgrade of the PDP is needed because the system is dated and difficult to use. Maintenance is increasingly more expensive. Although the PDP is fairly reliable it does crash about every 2 months.”*. The software was ported from Fortran to C and began operations on a WindowsNT PC in

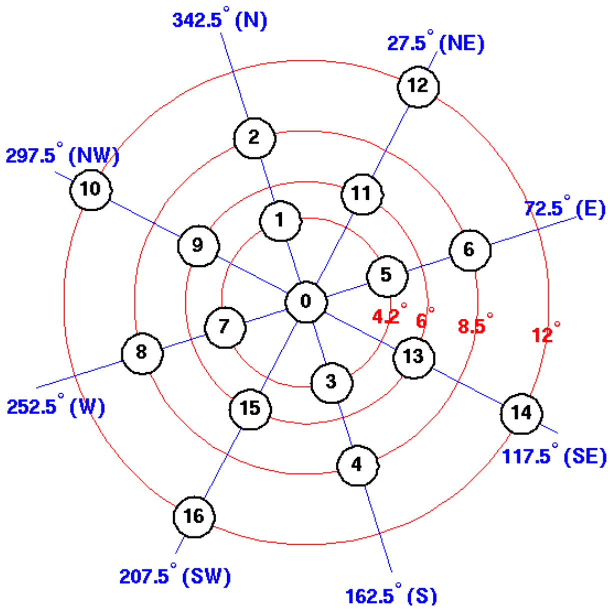

Figure 6: The 17 available beam pointing directions for the Aberystwyth radar.

2000. The new system used a PCI-7200 digital I/O card (manufactured by ADLink Technology Inc.) for passing the control word to the Radar Control Unit and for acquiring data from the Pre-Processor Unit. It used a C168H/PCI 8-port RS-232 PCI Board (manufactured by Moxa) to interrogate the microprocessors for each of the 5 transmitters for status information. The Windows-NT PC would crash if it was left running continuously for more than approximately 10 days between reboots.

The WindowsNT software was later ported to a (Debian) Linux PC, which began operations on 6th February 2007. This latest system is much more flexible and robust than its predecessor. It typically runs continuously for 6 months or more between reboots. However, as described in Section 3.8, a misinterpretation of the range gating convention used by the Pre-Processor Unit initially lead to an underestimate of ranges.

The new Linux PC uses the same models of interface cards as the WindowsNT system. It is anticipated that the software will need to be ported to a new PC approximately every 5 years in order to keep pace with changes in PC hardware. As long as the same interface cards remain available, this should be a relatively simple task.

Modern PCs are sufficiently fast that Receiver samples can be acquired directly for each transmitter pulse, i.e. obviating the need for a hardware Pre-Processor Unit. Coherent integration can subsequently be performed entirely in software or not used at all (e.g. Hocking, 1997). Some progress has already been made to implement pulse-by-pulse acquisition for the Aberystwyth radar - this requires a much faster I/O card than the PCI-7200. However, a lack of manpower has means that this project has seen only limited progress.

3.2 The Radar Control Unit

This hardware unit is designed around standard 7400 series TTL integrated circuits. It is relatively well-documented and full circuit diagrams are available. It should be possible to maintain it for at least another decade. The unit is so fundamental to the operation of all of the other radar components that modifying or replacing it would be a serious undertaking. There are no plans to do so in the near future.

As shown in Table 1, this unit allows the inter pulse period to adopt 1 of only 4 fixed values. The two lowest of these, i.e. 80 and 160 μs, imply maximum unambiguous ranges of 12 and 24 km, respectively. Neither of these values is adopted for ST-mode observations, in part, because they could lead to range aliased signals interfering with the desired ones. In the case of a 160 μs inter pulse period, there is a possibility of mesospheric summer echoes being range-aliased down to lower-stratospheric altitudes. Although mesospheric echoes are typically weak and only sporadically-occurring, those observed during June and July of each year are unusually strong and persistent (e.g. Thomas et al., 1992, 1996; Hooper and Astin, 2007). They are similar in nature to the Polar Mesosphere Summer Echoes (PMSEs) seen at higher latitudes (e.g. Cho and Röttger, 1997). They typically occur at altitudes of around 85 km and so would be range aliased down to an altitude of around 13 km - the tropopause above Aberystwyth is typically between altitudes of 8.0 and 12.5 km (Hooper et al., 2008). Owing to the fact that these echoes tend to be considerably stronger than lower-stratospheric echoes, they would constitute a source of contamination of the ST-mode Doppler spectra. For reasons which will be described in Section 3.4, the inter pulse period for standard ST-mode observations is 320 μs. Consequently the implications of the shorter inter pulse periods are never a problem in practice. Nevertheless, the fact that the Radar Control Unit can only accept a limited number of values for the pulse length, sub pulse length, inter pulse period, and beam pointing direction unnecessarily restricts the inherent flexibility of the other radar components.

3.3 The Transmitters

The 5 transmitters are of type WPT-50, formerly manufactured by Tycho Technologies of the USA. They operate at 46.5 MHz, each with a peak power of 32 kW, and a maximum duty cycle of 5%. As will be described in Section 3.4, in practice the maximum duty cycle is limited to 2.5%. All 5 transmitters are phase-locked to a single unit. Approximately 2 s is required before the start of a dwell in order to ensure that phase locking has been achieved.

The reliability of the transmitters has improved considerably since a 3 kVA Uninterruptible Power Supply (UPS) unit was installed for each transmitter in 2007. Fluctuations in the mains supply, as opposed to black outs, had previously proved to be the primary cause of component failure. Consequently the UPS units are principally relied upon to smooth out the mains supply. They additionally allow the transmitters to continue operations for approximately 30 minutes in the event of a black out.

The transmitters were originally designed to be powered from a 110 V and 60 Hz supply. Modifications were needed to allow them to operate at 240 V and 50 Hz. The mains voltage supplied in the UK nominally changed from 240 to 230 V during the 1990s (although in practice there was no real change). Consequently an attempt was made to supply the transmitters with 230 V when the UPS units were first installed. However, it was found that a few of them auto-shut-down at this lower voltage and so the UPS output voltage had to be raised back to 240 V. Owing to the modifications which have already been made to the transmitters, it would be undesirable to revert to a 110 V 60 Hz supply, even though this is now technically possible.

The transmitters are valve-based, with a 3CX800 driver stage and a 4CX3000 output stage. During almost 20 years of operation, only 10 tubes have needed to be replaced. Of these, the first 7 or 8 suffered performance degradation, but not failure, due to cathode poisoning. This was a result of operating the tubes at too low a heater voltage. This in itself was a result of the fact that the transmitters were designed for operation at a mains supply of 60 rather than 50 Hz. Four of the five transmitters have subsequently been modified to increase their heater voltages. This has also allowed them to re-use the valves which had previously become inoperable **[how do we know which one was not modified?]**.

The high-voltage chokes supplying the anode of the driver stages fail from time to time. They have, in effect, acted as EHT fuses - sacrificing themselves to prevent more serious damage occurring to other transmitter components. Although the choke is thought to be well-designed from an RF point of view, it would be desirable to add a dedicated EHT fuse in series with the anode supply to the driver stage.

The bearings on the original blower motors (model number 4C006B) were prone to wearing out. Owing to the fact that they were designed to operate at 60 Hz, European replacement units were hard to find. Consequently the original motors were were repeatedly reconditioned by replacing the bearings. During the middle of 2009, all blower motors were replaced with new units - model number 1TDR6 from Grainger of the USA. At the same time, the 110 V extractor fan motors were changed (to model number MF67644 from CPC). The outlets from the extractor fans are vented out of the site bungalow through plastic pipes which emerge from the west-facing wall. These fans are only just able to overcome the back pressure from the main transmitter room extractor. Moreover, it appears that some transmitter failures have been associated with very strong low-level westerly winds, which would have prevented the fans from operating effectively. An experiment is currently being undertaken to see if these fans are more effective if they simply vent air into the transmitter room and not to into the outside air. Surprisingly, two of the new extractor fans have failed within their first 2 months of operation.

The following details of out of band emissions are taken from an internal report ("MST Radar - Out Of Band Emissions", by K. Slater, dated 10th October 1991). *"Out of band emissions from the MST Radar at the second and third harmonics of the transmitted frequency may cause interference and prevent licensing by the DTI. Filters exist to reduce these emissions but would be difficult to fit into the rigid cables and would also add phase shifts and extra vulnerable cable connections at the highest voltage part of the system. The transmitter T/R switches are being modified by the addition of an extra quarter wave section. This modification also has a filtering effect on the harmonics of the transmitted frequency and may well be enough to eliminate the need for further filtering. On the 11th Sept 1991 measurements were made on the transmitters to determine the level of harmonic emission using the forward pickup point of the VSWR monitor on the front of the transmitters. Measurements were also made at the second and third harmonic frequencies of the cable losses out to the Quad boxes."*

Harmonic	*2nd (dB)*	*3rd (dB)*	*4th (dB)*	
TX1	*-48*	*-55*	*-*	*(modified)*
TX2	*-42*	*-48*	*-60*	
TX3	*-46*	*-53*	*-*	
TX4	*-49*	*-48*	*-*	
TX5	*-46*	*-55*	*-*	*(modified)*
TX6	*-47*	*-52*	*-60*	
Cable losses				
	-9	*-7*	*Central section Quad*	
	-17	*-6*	*Inner ring (×2 Tx's)*	
	-21	*-7*	*Outer ring (×2 Tx's)*	

"The above figures show that the harmonic emission level from the transmitters is very low, a modified transmitter showing a second harmonic level of about -47 dB and a third harmonic level of -55 dB. The cable loss figures also show the cabling system to be very inefficient at the second harmonic. Every transmitter has a peak output level of +75 dBm and a maximum average output level of +68 dBm when operated at a 5% duty cycle. Power output levels would then be for modified transmitters:"

Second Harmonic

Peak (dBm)	*Average (dBm)*	
+19	*+12*	*Centre section*
+14	*+7*	*Inner ring (×2 Tx's)*
+10	*+3*	*Outer ring (×2 Tx's)*

Third Harmonic

Peak (dBm)	*Average (dBm)*	
+13	*+6*	*Centre section*
+17	*+10*	*Inner ring (×2 Tx's)*
+16	*+9*	*Outer ring (×2 Tx's)*

"These power levels are quite low, at the second harmonic most of the emission would be from the centre section of 16 antennae and would largely be screened by the outer antennae. Under the worst condition of 5% duty cycle the average power level is only in the order of 20 milliWatts for both harmonics. The above figures also do not take into account the fact that the four element Yagi antenna used in the array are not very efficient at frequencies other than 46.5 MHz. Observation has shown that one can listen to Radio Wales on 93.1 MHz, the station closest to the second harmonic, sitting next to the antenna array while the Radar is operating at 5% duty cycle and not notice any interference."

3.4 The T/R Switch

The T/R switch is implemented as a PiN diode on the output of each transmitter. Although the transmitters can nominally be run at duty cycles of up to 5%, such a high value was found to lead to frequent failures of the PiN diodes in the early years of operation. Consequently the duty cycle is now limited to 2.5%. This, rather than the possibility of range aliasing described in Section 3.2, is the primary reason for using a 320 rather than a 160 μs inter pulse period for ST-mode observations. For standard ST mode observations - i.e. made using an 8 μs transmitter pulse (corresponding to a range of 1200 m), albeit with 2 μ sub pulse coding - Doppler spectra are only considered to be useful at range gate 18 and above, i.e. at a range of at least 1.644 km from the radar.

3.5 The Antenna Array

Figure 7 indicates the physical locations of the Primary and Secondary Power Splitters shown in Figure 5. The outputs (cables "B") from each of the transmitters are routed through a concrete cable duct towards the centre of the antenna array. Thereafter the cables are primarily routed underground. Although the collective routes taken by the underground cables are known from a field survey carried out a few years ago, nothing is known about the specific route followed by each individual cable.

The Primary Power Splitters for each sector are housed in a separate wooden shack. It is a matter of speculation as to which shack belongs to which of the 5 antenna sectors. However, it seems likely that the Divide-by-2 and Divide-by-4 Secondary Power Splitters are located within the sectors to which they belong. Moreover, it seems probable that the Divide-by-4 splitters are centred between the four Quads which they feed. It is not so clear precisely which Quads are fed by each of the Divide-by-2 splitters. Nevertheless, it is again likely that each pair (they are always mounted in pairs) collectively feed the four Quads which surround them.

Figure 7 omits to show the Phasing Unit and Divide-by-4 Final Power Splitter associated with each Quad. These are mounted back-to-back and are located at the centre of the Quad. All Secondary Power Splitters, Phasing Units and Final Power Splitters are mounted using U-bolts on standard 2.4 m long, 5 cm (2 inch) diameter scaffold poles, such as the one shown in Figure 8. These are partially-sunk into the ground leaving 1.73 m remaining above.

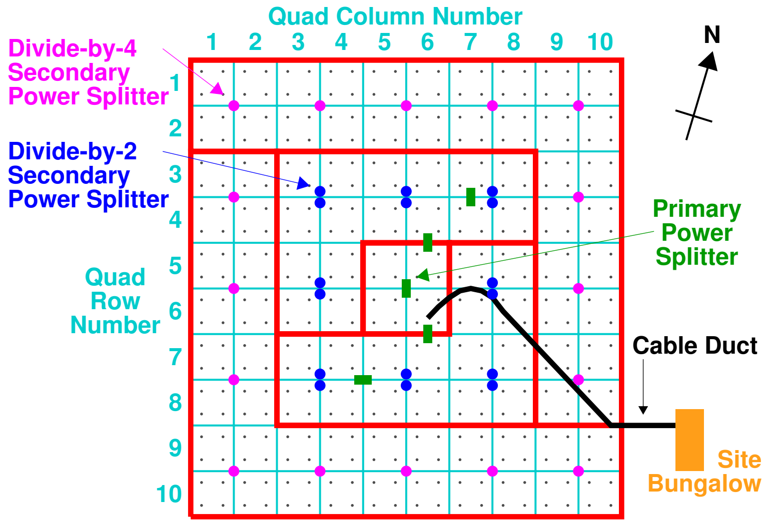

Figure 7: The physical locations of the various Power Splitters shown in Figure 5. Not shown here are the locations of the Phasing Units and Final Power Splitters associated with each of the Quad. These are mounted back-to-back and are located at the centre of each Quad.

3.5.1 Cables "B": from the outputs of the Transmitters

These 5 LCF-7/8 cables run from the transmitters in the site bungalow, via a concrete cable duct to the centre of the antenna array. The cables are terminated with 7/16" plugs at the transmitter end and with 7/8" EIA flanges at the Primary Power Splitter end. The cables appear to be in good condition.

3.5.2 The Primary Power Splitters, including cables "C", "D" and "E"

These are full-scale hybrid-rings made from rigid coaxial line sections in the form of a square. They were manufactured by Jaybeam of the UK. Connectors for 7/8" EIA flanges are fitted at each corner. Three hybrid-rings are stacked one on top of each other for the central antenna sector ("C") and, as shown in Figure 9, 7 hybrid rings are stacked together for all other sectors. The divider stacks for each antenna sector are housed in a separate wooden shack, which is approximately 1 m high, 4 m long and 2 m wide. These shacks also house the high-power "Bird" dummy loads, also shown in Figure 9, which are used to terminate the 4th port of each hybrid.

The following description is taken from a Jaybeam antenna design study (Hanna, 1986) under the heading of "High Power Hybrid": *"A coaxial quadrature hybrid, manufactured from 1.25" aluminium outer tubing and brass inner conductors. All input and output connectors 7/8" EIA accessed from the sides, thus permitting a number of units to be stacked vertically in a suitable enclosure. Additional cables will be required to equalize the phase between the two outputs. Again, an external 50 ohm load will be required at the difference port marked 'L' for correct operation. It has a narrower bandwidth compared with the low power version but it still displays excellent performance data as follows:*

Figure 8: An example of one of the scaffold poles which are used to mount all Secondary Power Splitters, Phasing Units and Final Power Splitters within the antenna array.

Jaybeam Type No.	*6141*
Impedance all ports	*50 ohm*
Connectors all ports	*7/8" EIA side entry*
Power	*50 kW peak, 15 kW av.*
Voltage	*10 kV DC & AC (available equipment limit)*
Voltage Peak Operational	*5 kV, 2:1 safety margin*
Frequency Bandwidth	$\pm$ *1 MHz*
SWR	*1.1:1 maximum, 1.03:1 centre frequency typical*
Amplitude balance	$\pm$*0.1 dB*
Insertion Loss	*0.2 dB over 3 dB split*
Phase Balance	$\pm 1^\circ$
Phase AE1	*-90° nominal*
Phase AE2	*-180° nominal*
Isolation Between AE ports	*-18 dB* $\pm$*1 MHz*
(same between TX & L ports)	*-22 dB* $\pm$*0.5 MHz*
	-35 dB centre frequency
Finish	*Natural*
Mounting	*None, to be stacked*
Weight	*?*

Although the external appearance of the shacks is quite weathered, the insides appear to be relatively dry. The hybrids are in generally good condition, although some corrosion of the aluminium tubing is evident - especially around the connectors. All of the heliax cables of types "C", "D" and "E", which are located within the shacks, appear to be in a good condition.

3.5.3 Cables "F" and "G": from the outputs of the Primary Power Splitters

At the Primary Power Splitter ends, all cables are terminated in 7/8" EIA flanges. For the central sector "C" of the antenna array, these cables run straight to the Phasing Units of the corresponding Quads, where they are terminated in HN jacks. For the inner half rings "B" and "D", these cables run to the Divide-by-2 Secondary Power Splitters, where they are terminated in N plugs. For the outer half rings "A" and "E", they run to the Divide-by-4 Secondary Power Splitters, where they are terminated in N plugs. All of the cables of type "F" and "G" appear to be in a good condition.

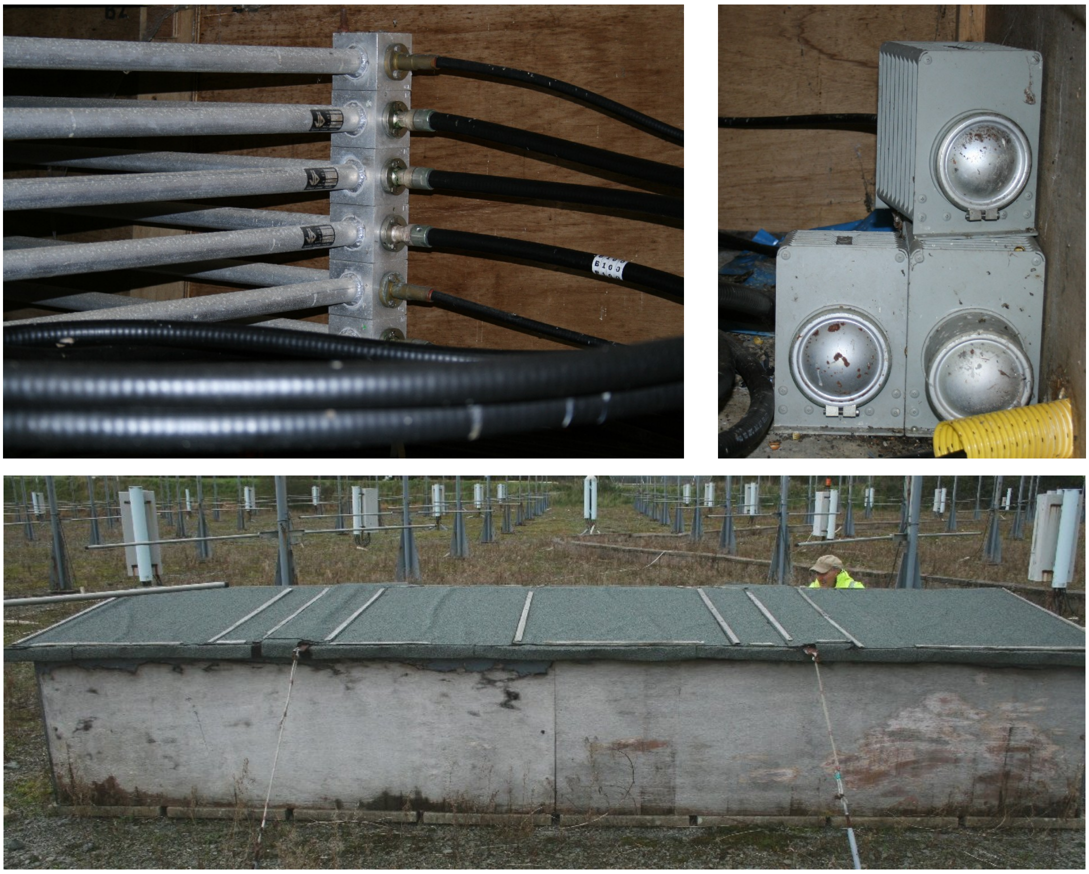

Figure 9: (top-left) The Primary Power Splitters for one of the non-central antenna sectors and (top-right) some of the dummy loads. All are housed within a wooden shack (bottom).

3.5.4 The Secondary Power Splitters

The Divide-by-2 Secondary Power Splitters are of part number 6108, manufactured by Jaybeam of the UK, and the Divide-by-4 Secondary Power Splitters are of part number 6109. As will be described in Section 3.5.6, the latter models are also used as the Final Power Splitters, which distribute power equally to each of the four within a Quad. As shown in the left and centre panels of Figure 10, both splitter types are contained within identical, sealed, aluminium, cylindrical assemblies, which are approximately 1.5 m long and 10 cm in diameter. They are mounted vertically on the scaffold poles. All Divide-by-4 Secondary Power Splitters are mounted singly, whereas all Divide-by-2 Secondary Power Splitters are mounted in pairs. Although it is not possible to open the splitters in order to inspect their contents, it is assumed that they are based on quadrature hybrid rings - possibly implemented as folded-up lengths of flexible coaxial cable. The Divide-by-2 splitters require a single external dummy load. Since they are mounted in pairs, a single fibre-glass box, which is mounted to the same pole, houses both dummy loads. The Divide-by-4 splitters require 3 external dummy loads, which, as shown in the right panel of Figure 10, are mounted in a single fibre-glass box attached to the same pole. The load connections are all via short, hard-wired, RG-213 cable tails.

The following description, taken from a Jaybeam antenna design study (Hanna, 1986), relates to the divide-by-2 splitters under the heading "Low Power Hybrid": *"A conventional 1.5 wavelength rat race, made from 10 mm diameter coaxial cables. Inputs and outputs via RG213 coaxial cables fitted with 'N' type connectors. The hybrid is housed in a 1.1 metre long 6" diameter aluminium welded enclosure. It is coated with a durable polyester coat for outdoors use; the mounting hardware is galvanized steel."*

Figure 10: (left) Examples of (left) a Divide-by-4 Power Splitter, (middle) a pair of Divide-by-2 Power Splitters, and (right) the load resistors for a Divide-by-4 Power Splitter.

"The input and output tails extend from a PVC spacer at the lower end of the enclosure. The unit is large enough to house 3 similar hybrids connected together to feed four yagi antennae. For correct operation, a 50 ohm load per hybrid is required, to be fitted externally and connected to the 'L' port. The performance and a brief list of specification is derailed below:"

Jaybeam Type No.	*6108*
Impedances, all ports	*50 ohm*
Connectors, AE ports	*'N' socket (antenna ports)*
Connectors, TX & load ports	*'N' plug*
Tail lengths	*1 m*
Power rating	*500 W average, 3 kW peak*
Voltage breakdown	*4 kV peak AC or DC*
Voltage Peak Operational	*2 kV 2:1 safety margin*
Frequency Bandwidth	*$\pm$ 1 MHz*
SWR	*1.05:1 maximum*
	1.03:1 centre frequency typical
Amplitude balance	*$\pm$0.1 dB*
Phase Balance	*$\pm 1^\circ$*
Insertion Loss	*0.3 dB (over -3 dB split)*
Isolation between AE ports	*-30 dB minimum, -40 dB centre frequency typical*
(same between TX & L ports)	
Dimensions	*1.1 m 6" by 6" excluding tails*
Finish	*Polyester duck egg blue*
Mounting	*2 off 2 3/8" U bolts or 4$\times$M12 35 mm bolts (both galvanised)*
Weight	*8.5 kg*

The divide-by-4 splitters are described as follows, under the heading "Quad of Yagis": *"A quad of 4 yagi antennae can be fed centrally by three low power hybrids in a single enclosure as described earlier. The measured performance data of the network over and above a single unit is as follows:"*

Jaybeam Type No.	*6109*
Port markings	*AE1, AE2, AE3 & AE4 for the antennae*
	L1, L2 & L3 for the loads
	TX for the transmit port
SWR at TX port	*1.1:1 maximum, 1.07:1 typical at centre frequency*
Amplitude balance	*±0.1 dB*
Insertion Loss	*0.5 dB over 6 dB split*
Phase Balance	*±1°*
Isolation	*24 dB minimum, 26 dB typical*
Insertion Phase	*70° at centre frequency*
Weight	*13 kg*

Owing to the fact that the Power Splitter assemblies are sealed, it has not been possible to determine their internal condition. However, since the cylindrical aluminium casings are fitted with a welded end-plate at the top and with a tight-fitting plastic bung (complete with a drain-hole) at the bottom, it is expected that the contents will have been well-protected against water-ingress.

3.5.5 Cables "H", "J" and "K" - the inputs to the Quad Ensembles

All cables are of type RG 213. In the case of the central antenna sector "C", cables "H" are terminated with an HN plug and sleeve at both ends. Cables "J" and "K", for the inner and outer half-ring sectors, respectively, are terminated with an N jack and sleeve at one end, and an N plug and sleeve at the other end. This appears to be a design error, though not a very important one. The ends of cables "J" and "K" arriving at the Phasing Units (i.e. the first components of the Quad Ensembles) should terminate with an N plug and sleeve, not an N jack and sleeve. This error has been mitigated by inserting an extra back-to-back N plug adaptor inside the Phasing Units. This adaptor is installed between the N jack on the ends of cables "J" and "K", and the N type bulkhead jack which forms the input RF connector of the phasing unit.

Figure 11: Examples of vermin damage to RG 213 cables.

All of these cables run in underground ducts. Consequently, it has only been possible to inspect them for the short sections, near their termination points, which are above ground. Some of these sections show evidence of vermin damage. Moreover, the outer PVC jackets of all the RG-213 cables in the array show signs of degradation due to solar UV light and leaching of plasticiser.

3.5.6 The Quad Ensembles

Each Quad Ensemble is composed of a Phasing Unit (contained with the rectangular cross-section box in the left panel of Figure 12), followed by a Divide-by-4 Final Power Splitter (contained within the cylindrical unit), followed by four Yagis (described in the next section). The Phasing Unit and Final Power Splitter are mounted back-to-back on a scaffold pole within the centre of the four Yagis which they serve. The fibre glass Phasing Unit boxes have approximate external dimensions of 100 cm in height, 40 cm in width and 30 cm in depth. Although the door-seals have severely degraded through weathering, the boxes appear to still provide adequate protection against the weather. The boxes are not fitted with a cable-gland plate but - as seen in the middle panel of Figure 12 - have an approximately 6 cm diameter hole in the bottom for cable routing. This provides easy access for small invertebrates resulting in many of the boxes containing snail shells and in a few of them - such as the one pictured - containing wasps' nests. Although such invaders do not appear to affect the performance of the units, the unexpected discovery of an active wasps' nests (i.e. during the summer months) has potential Health and Safety consequences.

Figure 12: (left panel) The (rectangular cross-section) phasing units are mounted back-to-back with their corresponding (circular cross-section) final divide-by-4 power splitters. (Middle panel) A view of the contents of a Relay box. (Right panel) An example of a wasps' nest inside a phasing unit box.

The Phasing Units are composed of three electromechanical Relay Units, which can switch equivalent cable lengths of $\lambda/2$, $\lambda/4$, and $\lambda/8$ in to or out of the signal feed. As shown in the right panel of Figure 12, these are mounted at the top of the Phasing Unit boxes. The Relay Units are N-type, DPDT transfer relays, of part number R 563703230, formerly manufactured by Radiall of France. They are fitted with tell-back indicators in the form of a reed relay switch, which is activated by the magnetic field of the main relay. In principle this should give an indication as to whether or not a Relay Unit has performed a switching operation. However, during the early years of operation the reliability of this information was found to be so low that no use has been made of it ever since. The relays are designed to switch from a dc control signal of between 24 and 30 V. The power rating of the associated beam steering unit, which is described in Section 3.6, suggests that an allowance of 0.13 A has been made for each Relay Unit.

The Relay Units (top-left panel in Figure 13) each perform approximately a million switching operations a year. Consequently they are subject to continuous, albeit gradual, degradation. All 300 Relay Units are tested on a 6-monthly basis and faulty units are replaced with reconditioned ones. The most common problem is an increase in the mechanical resistance experienced by the rotor mechanism (top-right panel of Figure 13). This can be solved by simply removing the accumulated

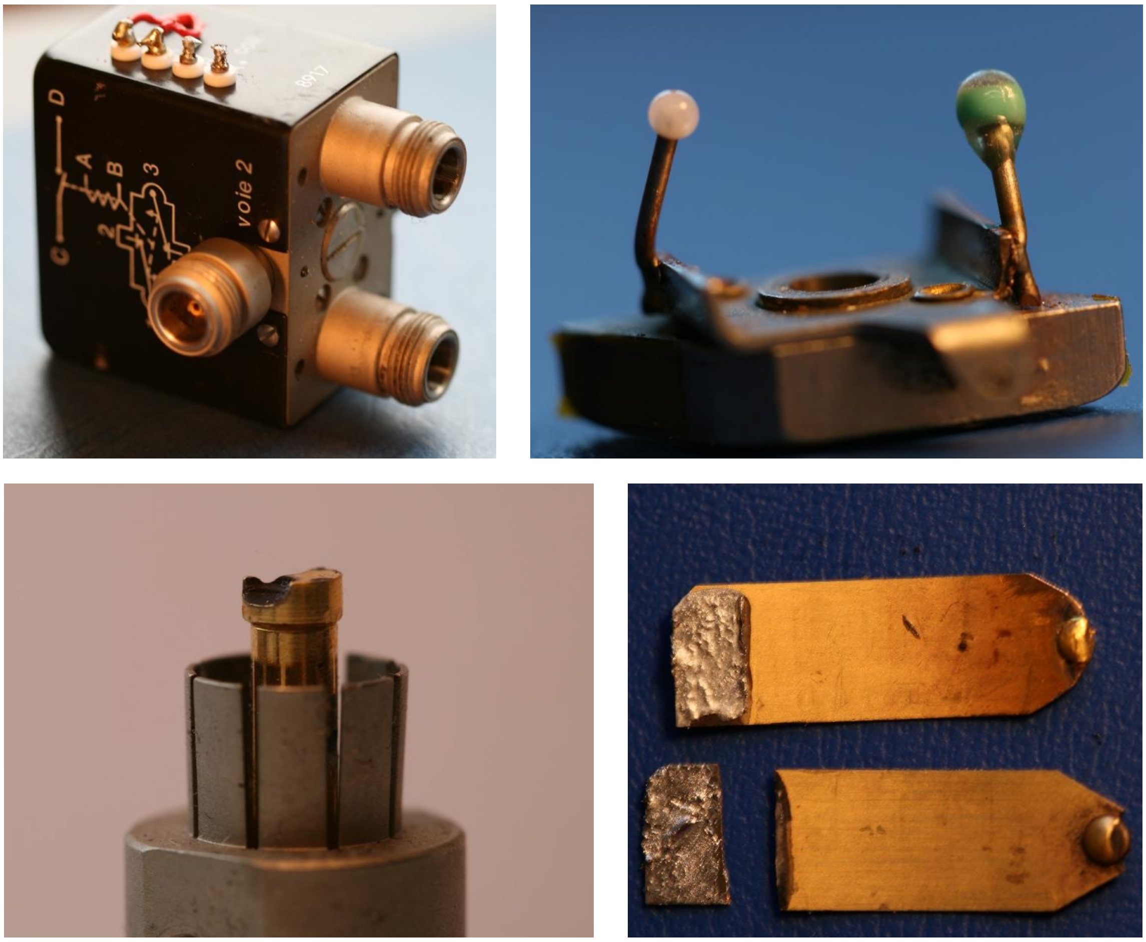

Figure 13: (top left) A complete relay unit; (top-right) the rotor mechanism; (bottom-left) an RF cable connector contact pin which has suffered from severe contact erosion; (bottom-right) an intact and a snapped contact blade.

debris (principally metal filings) from around the mechanism. Occasionally the rotor pins (i.e. the vertical components seen in top-right panel of Figure 13) snap off. A new pin, which uses the plastic bead from a child's toy necklace as an insulator, can be welded back on as a replacement. The pin with a white bead in the top-right panel of Figure 13 is an original, whereas the one with a green bead is a replacement.

A more serious problem is that Relay Unit contacts are prone to erosion. RF arcing, which leads to evaporation of the contact metal, is believed to be responsible. It is to be expected that as the quality of the contacts degrades, the potential for arcing would be increased and erosion would be accelerated. As shown in the bottom-left panel of Figure 13, this is a particular problem for the contact pins at the back of the RF connectors. The degree of erosion can range from being superficial through to the loss of material to a depth of over 1 mm (the contact pins are approximately 3 mm in diameter). The lifetime of a connector can typically be extended by rotating it slightly so as to present a more pristine portion of the pin to the contact blade. Nevertheless, a number of connectors have become so badly eroded that they have had to be removed from service. Moreover, the transmission efficiency of Relays Units which show even minor signs of contact erosion must be questioned. Consequently, all Relay Units are deemed to have reached the end of their useful lives. The contact blades (bottom-right panel of 13) are also prone to contact erosion, albeit to a lesser degree. Nevertheless, they also have a finite lifetime and must be removed from service when they snap (as in the lower case).

The Relay Units in use today are all from the original stock, which included a number of spare units. It appears that Radiall no longer manufacture the same model. In their current catalogue they state that a new relay actuator and contact design has been adopted in later models. These were introduced in order to combat contact damage, which appears to have been a widespread problem for high-power VHF and UHF applications.

The Divide-by-4 Final Power Splitters are identical to the Divide-by-4 Secondary Power Splitters described in Section 3.5.4. As can be seen in the right panel of Figure 12, the three dummy loads are mounted at the bottom of the Phasing Unit boxes. In the case of the inner and outer half-rings of the antenna ("A", "B", "D" and "E"), the N plug of the input cables mates with a bulkhead N jack. Each of the N plugs of the cables connected to the dummy load resistors mates with a bulkhead N jack. Each of the N jacks of the 4 outputs to the Yagis mates with an N plug fitted to the cable tails from the Yagis. In the case of the central antenna sector "C", where power levels are higher, the input and output connectors of the 4 Phasing Units are HN, rather than N-type, bulkhead jacks. Therefore, in the input cable is modified to terminate in an HN plug, rather than an N plug. The other connector types are as for the inner and outer half-rings. In all antenna sectors, the final connections to the Yagis are via RG-213 cables, each of which is approximately 7 m long.

3.5.7 The Yagis

The individual 4-element Yagi aerials are in good condition. The dipole elements (and possibly the whole units) are of part number 7352, manufactured by Jaybeam of the UK. They are rated for a frequency of 46.5 MHz and an impedance of 50 Ω. The 4 elements of the Yagis are made from 2.5 cm diameter aluminium alloy tubes which are mounted on a 4.92 m tall, 6.2 cm diameter (3 mm thick) pole. Stainless steel fittings are used for the element clamps and mounting brackets. The lengths of and vertical separations between the elements are shown in Figure 14. The elements contain lengths of string, which are designed to damp wind-induced oscillations. In a few cases the element-end bungs are missing and some string can be seen protruding. Some minor maintenance will be required to restore these. The materials used for the antenna construction are inherently corrosion-resistant. The concrete bases for the antenna supports also appear to be in good condition. On this basis, it is expected that the array will be serviceable for at least another 5 years before any significant refurbishment is required.

A Jaybeam design study for the antenna array (Hanna, 1986) lists the following as the specification for individual Yagis:

- to withstand 75 mph wind speed
- Frequency 46.5 MHz
- Bandwidth $\pm$ 1 MHz
- Coaxial balun
- 50Ω coaxial feed, 7 m long, 'N' type plug termination
- SWR 1.3:1 in isolation, 1.5:1 in the array
- 500 W CW; 10 kW pulse; duty cycle 5%
- flat gain response
- maximum front/back ratio
- minimum radiation along the horizontal
- measured performance

The same document lists the lengths of the Yagi elements (from bottom to top) as being 341.3 cm, 308.6 cm, 295.8 cm, and 271.0 cm. These values are slightly different from those shown in Figure 14, which was taken from a paper copy diagram within the legacy documents. Given that this report was produced 3 years prior to the installation of the first Yagis, it is likely that the values

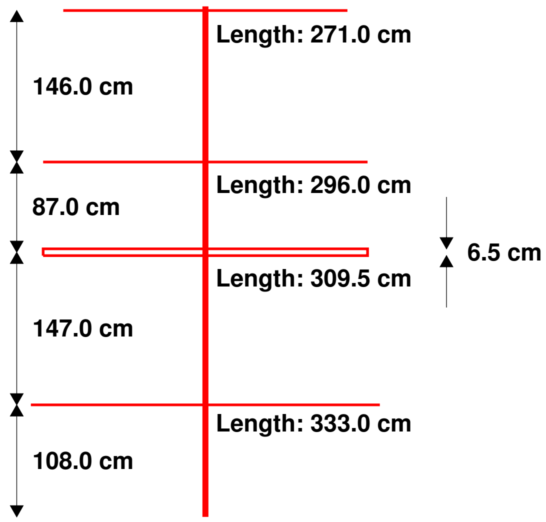

Figure 14: The 4 elements of the individual Yagis are made from 2.5 cm diameter aluminium alloy tubes which are mounted on a 4.92 m tall, 6.2 cm diameter pole. The lengths of the elements refer to full rather than half lengths. The lowest element is the reflector, the next is a folded dipole (i.e. the driven-element), and the top two are directors.

shown in Figure 14 are the ones which were finally adopted. As part of the design study, Jaybeam originally constructed a half-sized Yagi for test operations at 93.0 MHz. They later constructed 9 full-sized units, arranged in a square array, for tests at 46.5 MHz. Spacings between the Yagis were varied between 4.2 and 5.8 m at approximately 0.3 m intervals. This corresponds to separations between 0.65λ and 0.90λ at 0.05λ intervals. The report concluded: *"It does appear that the sum of the natural return loss of an individual Yagi in isolation, together with that from eight units around it, combine favourably to provide an SWR of better than 1.3:1 at 46.5 z and for a spacing of 0.85 wavelength. As will become clear in the next section,m this is also the recommended spacing for the array to provide near optimum directivity."*

One possible weak area is the driven-element feed-point. The cable connection point is encapsulated in solid plastic. Based on experience gained from other Jaybeam-manufactured aerials, it is anticipated that these will be susceptible to UV degradation which could result in cracking and subsequent water-ingress. All feed-points which were inspected appeared to be in a good condition. The existing RG-213 cables connecting the Yagis to the Final Power Splitters are approximately 7 metres long. The Final Power Splitter end terminates in an N plug. At the driven-element feed-point, the cable terminates in an epoxy-potted box. In some cases, the cables have been mildly damaged due to chewing by vermin. This is likely to have resulted in water-ingress, which will have affected their RF performance. Consequently the cables should be replaced.

3.6 The Beam Steering Unit and Relay Control Cables

The role of the Beam Steering Unit is to energise the Relays Units of the Phasing Units. Power is supplied by four 28 V dc, 10 A units. The primary input to the Beam Steering Unit from the Radar Control Unit is the 4-bits of the control word (described in Table) which encode the required beam pointing direction number. A 2k by 8 bit EPROM (model number D2716D) contains the details of the corresponding Relay Units which need to be activated in order to achieve the required phase delay for each Quad. It appears that an allowance of 0.4 A has been made for each Quad, i.e. 0.13 A per Relay Unit. The whole Beam Steering Unit draws 1.7 A of mains (i.e. 240 V) current when the radar is directed to observe in the vertical direction, i.e. when no Relay Units are activated. It draws 3.7 A when the radar is directed to observe in an off-vertical direction.

Attention is drawn to the fact that 4-bits only allow 16 possible beam pointing directions whereas 17 are listed in Table 4. Beam pointing direction number 16 (SW12.0) was not part of the original design specification. It was subsequently created as a substitute for beam pointing direction number 12 (NE12.0), which was found to be particularly prone to ground clutter contamination. Rather than increasing the number of bits used to encode the beam pointing direction number (one bit of the control word remains unused), a new EPROM was blown which changed the interpretation of beam pointing direction number 12 to that of the new number 16. Correspondingly, the Radar Control and Data Acquisition PC substitutes beam pointing direction number 12 into the control word whenever number 16 is requested. A better alternative will be described in Section 4.

The original Beam Steering Unit appears to have been designed and built by the Rutherford Appleton Laboratory, although virtually no documentation can be found for it. This will make it difficult to repair in the event of a failure. The worst damage that it has ever suffered was associated with a very close (and possibly direct) lightning strike on December 25th 1999. This strike also damaged the PDP-11 computer, the Transmitters, the Receiver, and the Pre-Processor Unit. As a result, the Beam Steering Unit was slightly redesigned to use a set of 7 simplified circuit boards and more-modern components. These boards contain 20 ICs each, compared with 60 each on the originals. The boards, together with an LED display panel, were designed and produced by Aberystwyth IMAPS. However, again, virtually no information for this can be found. The display panel indicates which Relay Units are being energised. It is of little value for identifying problems with individual Relay Units. However, it has proved to be highly effective at indicating problems with the Beam Steering Unit as a whole. For example, the unit has occasionally become stuck in a single beam pointing direction. This has caused the display pattern to remain unchanged from dwell to dwell rather than changing.

The Beam Steering Unit first suffered lightning damage during a storm on 20th November 1990. The following paragraph, which is taken from an internal report ("Report on Antenna Control Unit Lightning Strike", by K. Slater, dated 16th January 1991), contains the only description which can be found of how the unit works. It is not clear how much of this might have changed when the circuit boards were redesigned following the 1999 lightning damage.

"The relay activation pattern for each of the 16 beam directions is contained in an 2K $\times$ 8 bit EPROM in the ACU [Antenna Control Unit, i.e. the Beam Steering Unit]. Each memory location controls two Quad boxes and the data from the EPROM is clocked out and latched into 50 8 bit latches (74ACT377), address decoders determine which which latch receives data from which memory location. The latches interface with 50 octal darlington driver ICs (ULN2803A) which provide the current to turn on the relays via the 28 volt supplies. Each latch output also goes to one input of a 74ACT86 EXOR gate, the other input of the gate is connected to the back indicator of the relay which would be activated by the latch output. The back indicator input to the gate is held high by a 10k pull up resistor which the reed relay shorts to ground when the relay is activated. If the reed relay does not activate when the relay is operated an error light (LED) activates on the front of the ACU, there is one LED for each Quad box. 100 4 gate EXOR ICs are required to perform this function. The circuitry is contained on six 6U circuit boards, five of which are identical with the sixth having the EPROM and its clocking system and the LEDs on the front panel. The antenna pointing direction is change by altering the binary input to four of the address lines on the EPROM."

"Additional protection was added to the circuit boards by placing 5.6 volt zener diodes across the power supply lines and the four address lines to EPROM which control the antenna direction. Large value electrolytic capacitors were added across the power supply lines on all circuit boards. The outputs and inputs to the 100 Quad boxes of the antenna system including the 28 volt and earth

return lines and unused lines number about 1000 lines. It is difficult therefore to provide adequate protection from further damage of this kind.

Figure 15: Examples of (left) a vermin-damaged relay control cable and (right) one of the probable culprits.

There is a 15-way D-type socket on the back of the Beam Steering Unit for each of the Quads. The connection to the Phasing Units is made via a dedicated 18 core cable for each Quad (4 core cable would suffice). These exit the Site Bungalow slightly to the north of the cable duct for the RF cables - see Figure 7. They are almost immediately routed underground (the exact paths are not known) and do not emerge again until they are in the vicinity of their destination Quads. Despite the fact that cables are only exposed for a short section of their entire length, many show signs of vermin damage. In mild cases, only the braiding wire is exposed. However, in a few severe cases, such as the one shown in the left panel of Figure 15, the copper of the individual wires is exposed. Most of this type of damage appears to be confined to the NE quadrant of the array. Rabbits, which are plentiful on the site (right panel of Figure 15), are thought to be the primary culprits. No active steps have been taken to control the on-site population owing to fact that it would be difficult to prevent re-colonisation at this rural location. Stoats and foxes, which are both expected to predate on rabbits, have been seen on site. Indeed, a family of stoats briefly took up residence in the attic of the site bungalow in July 2008. They appear to have entered through the cable duct. They were quickly persuaded to leave by subjecting them to a weekend of Radio 2 at loud volume.

Some of the longest relay control cables, which run over 100 m to the western side of the antenna array, have been found to significantly attenuate the voltage (28 V) generated by the Beam Steering Unit. The Relay Units have a specified minimum of 24 V for switching to take place, whereas some of the measured voltages are as low as 21 V. It is not clear whether or not this is a (partial) result of the vermin damage. Regardless, such low voltages are likely to result in sub-optimal contact pressure of the Relay Units and so could be aggravating the problems highlighted in Section 3.5.6. As a result of the two problems highlighted above, all Relay Control Cables will need to be replaced.

3.7 The Receiver

The radar has two nearly-identical solid-state Receivers, both manufactured by Tycho Technology Inc. of the USA. Only one of these is in operation at a time. One of the Receivers is an official WPR-50, designed specifically for use with a wind-profiling radar. The other appears to have been designed for operation at 27 MHz, for use with an Ocean Surface Current Radar (OSCR) radar, and to have been modified to operate at 46.5 MHz. It appears that both Receivers were made to almost identical designs, both of which allow operation with a mains supply of 110 or 230 V ac. The only recorded damage to either Receiver was associated with the direct lightning strike of December 25th 1999. The original Receiver was put back into operation in April 2000.

The Receiver input signal is first amplified and then split with a quadrature hybrid to provide two signals which are 90° out of phase. These are fed into separate phase detectors before being fed through Bessel filters which are matched to the bandwidth of the transmitted pulse - or to the length of the sub-pulse if complementary coding has been used. The bandwidth is described in terms of its reciprocal time constant, τ_{RX}, which can take values of 1, 2, 4, or 8 μs, i.e. corresponding to range resolutions of 150, 300, 600 or 1200 m. It is assumed that the Receiver bandwidth should be set to 8 μs for uncoded pulses of greater length (such a pulse scheme is never used). The Radar Control Unit selects the required bandwidth via a 9-pin D-type connector. Pin 1 relates to the least significant bit of the bandwidth address, pin 2 to the most significant bit, and pin 9 to ground. The address lines, which link to bits 12 and 13 of the radar control word (Table 1), are active high.

The noise level of the receiver output undergoes a characteristic non-sinusoidal diurnal variation with a peak to peak amplitude of approximately 4 dB. This pattern shifts in phase by 360° over the course of a full year. This is evidence that the overall noise level is dominated by galactic noise rather than by Receiver noise (Hooper et al., 2008), suggesting the current Receiver is more than adequate for the job.

3.8 The Pre-Processor Unit

The primary role of the Pre-Processor Unit is to reduce the rate at which data must be acquired by the Radar Control And Data Acquisition PC. This is a consequence of the relatively-limited computer speed available when the radar was first built. As for the case of the Radar Control Unit, it is principally designed around standard 7400 series TTL integrated circuits, it is relatively well-documented, and circuit diagrams are available. Nevertheless, the legacy documentation is not always unambiguous. It seems to suggest that the number of the lowest range gate returned from the Pre-Processor Unit, n_{RG1}, should be interpreted as 0, i.e. representing a sample taken in the middle of transmitter pulse. This lead to a range gating error when the new Linux-based Radar Control and Data Acquisition PC began operations on 6th February 2007. Although it was immediately obvious, from Met-Office-provided monthly comparison statistics of MST radar derived and model wind fields, that something was not right, it was not until 8th April 2008 that the source of the problem was identified and corrected. The source code written for the WindowsNT Radar Control and Data Acquisition PC indicates that the value of n_{RG1} is given by $l_{TX}/2$, where l_{TX} is the total length of the transmitter pulse in (integer) units of μs. This is not documented elsewhere.

The range of the centre of a given range gate (number), n_{RG}, from the radar, r_{RG} (m), is then given by:

$$r_{RG} = (n_{RG} - n_{RG0}) \times \frac{c\Delta t_{RG}}{2} - 50.0 \tag{1}$$

where n_{RG0} is the number of the equivalent range gate whose centre is at mean sea level, c (m s^{-1}) is the speed of light, and Δt_{RG} (s) is sampling interval between range gates (always equal to 1.0 μs). The radar is located at 50 m above mean sea level, explaining the final factor in Equation 1. The value of n_{RG0} is determined by the Receiver bandwidth, τ_{RX} (μs), as shown below:

Receiver bandwidth time constant, τ_{RX} (μs)	Transmitter pulse length, l_{TX} (μs)	Sea level range gate number, n_{RG0}
1	1	5.2
1	>1	5.7
2	any	6.7
4	any	8.7
8	any	12.7

For the purpose of ST-mode observations, it is sufficient to assume that the speed of light is equal to 3.0 $\times 10^8$ m s^{-1}, i.e. that the separation between range gates is 150.0 m. However, this will lead to an over-estimate of the range by approximately 130 m (i.e. by almost a full range gate) at the highest of the M-mode range gates compared with the range derived using $c =$ 299,792,458 m s^{-1}.

For observations made with an inter pulse period of 640 μs, i.e. with a maximum unambiguous range of 96 km, the Pre-Processor Unit automatically eliminates data from range gates 192 - 385 inclusively, i.e. from ranges between 28.95 and 57.60 km from the radar. This was presumably introduced in order to reduce the volume of data which must be passed to the Radar Control and Data Acquisition PC, based on the (apparently-valid) assumption that no detectable radar signals will be returned from the corresponding range of altitudes.

4 Conclusions

In conclusion, the following components have reached the end of their useful working lives and are in urgent need of replacement:

- The Phasing Units - in particular the Relay Units but also the fibre-glass boxes which contain them.
- The Relay Control Cables.
- All RG-213 RF cables, i.e. those marked "H", "J" and "K", as well as those connecting the outputs of the Divide-by-4 Final Power Splitters to the Yagis.

Moreover, it would be highly desirable to replace the Relay Control Unit since its almost-complete lack of documentation will make it difficult to repair in the case of a failure.

The testing, replacement and refurbishment of Relay Units is currently the single most time-consuming of recurrent maintenance tasks. Replacement units will need to have suitably low VSWR, low insertion loss, and high power-handling characteristics. Although they should have a long anticipated lifetime (the radar will continue to operate until at least 2015 and, depending on the funding situation, this could subsequently be extended to 2020), they must be capable of being easily tested and of being easily replaced by the site technician. Identical units should be used throughout the antenna array so that a single stock of spares is needed. Attention is drawn to the fact that the power rating for the central antenna sector is 8 kW per Quad (it is 2 kW per Quad in the inner half-rings and 0.5 kW per Quad in the outer half-rings). Modifications may be needed in order that low-power rated Relay Units can be used throughout. It might be convenient to integrate a Divide-by-4 Final Power Splitter into the replacement Phasing Units. Ideally, stainless steel boxes with door and gland-plate gaskets rated at IP65 or IP66 would be used to house the Phasing Units.

All new RF cabling should be of type FSJ2 - 50A in order to provide enhanced protection against vermin damage. N-type input and output connectors should be used. It will probably be difficult to bury new cables. Owing to the relatively low level of vermin damage accumulated by these cables over the course of 20 years, additional protection is perhaps not entirely necessary. However, at the

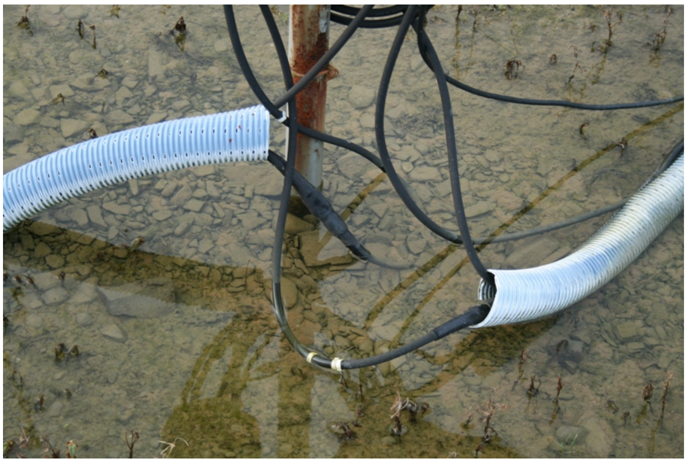

Figure 16: An example of the plastic cable ducting already used to protect both RF and relay control cables. Note that some parts of the antenna field are prone to the accumulation standing water.

very least, flexible plastic cable ducts, such as those shown in Figure 16, will be required for the new Relay Control Cables. These are both more-prone to severe vermin damage and they must cross long distances - over 100 m to the western-most parts of the antenna array. Note that, as shown in Figure 16, some parts of the array are prone to the accumulation standing water. A disadvantage of on-the-surface ducts is that they may interfere with insecticide spraying operations. The latter are needed in order to control weed growth within the array.

Ducts already provide protection for the underground portions of the cable runs. However, the buried option can present a problem if a cable has to be replaced. It is sometimes difficult to extract a cable from an underground duct, particularly if the duct has partially collapsed over time due to the pressure of the overlying soil. Also, pulling a defective cable out of, or a replacement cable into, a duct can actually cause damage to other, previously undamaged, cables sharing the same duct. These factors tend to argue for any replacement cables to be installed on the surface, rather than in underground ducts.

Above-ground installation of cabling would typically require either a network of cable trays or conduits. The tray-work would have to be high enough above ground to be clear of ground-based vermin. Owing to the high cost of providing cable trays, and the requirement to install supports for them (which would probably have to be concreted-in), plus the fact that a significant amount of elevated metalwork might have an undesirable effect on the antenna radiation patterns, it is considered that cable trays are probably not a viable option.

If a new Beam Steering Unit is to be installed, now would be a good time to transfer its control from the Radar Control Unit to the Radar Control and Data Acquisition PC. The former's use of only 4 bits to encode the beam pointing direction allows only 16 of the 17 specified options to be used. Although it is not anticipated that a large number of additional beam pointing directions will be required in the future, the addition of even a single extra bit would allow all 17 specified directions to be accessed. Only 5 of the available ports on the C168H/PCI 8-port RS-232 PCI Board are currently used by the Radar Control and Data Acquisition PC in order to interrogate the status of the transmitters. One of the spare ports could be used to send an 8-bit beam pointing direction number to the Beam Steering Unit.

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Bit number	Bit content	Interpretation
0	Pulse coding status	0 = On, 1 = Off
1	Sub pulse length bit 0	00 = 8 μs
2	Sub pulse length bit 1	11 = 1 μs
3	Inter pulse period bit 0	00 = 80 μs
4	Inter pulse period bit 1	11 = 640 μs
5	Pulse length bit 0	000 = 1 μs
6	Pulse length bit 1	101 = 32 μs
7	Pulse length bit 2	110 and 111 = 1 μs
8	Beam pointing direction number bit 0	Described in Table 3
9	Beam pointing direction number bit 1	
10	Beam pointing direction number bit 2	
11	Beam pointing direction number bit 3	
12	Receiver bandwidth bit 0	00 = 1 μs
13	Receiver bandwidth bit 1	11 = 8 μs
14	Mesospheric mode	0 = False, 1 = True
15	Unused	-

Table 1: Composition of the radar control word where Bit 0 is the least significant bit and Bit 15 is the most significant bit. The implied values of the pulse length, the sub pulse length (i.e. the baud length used for complementary phase coding), the inter pulse period, and the Receiver bandwidth change by a factor of 2 from one bit encoding to the next.

Range Resolution (m)	Pulse Length (μs)	Binary code sequences	Hexadecimal equivalent
150	4	1110	0xe
		1101	0xd
	8	11101101	0xed
		11100010	0xe2
	16	1110110111100010	0xede2
		1110110100011101	0xed1d
	32	11101101111000101110110100011101	0xede2ed1d
		11101101111000100001001011100010	0xede212e2
300	4	1111	0xf
		1100	0xc
	8	11111100	0xfc
		11110011	0xf3
	16	1111110011110011	0xfcf3
		1111110000001100	0xfc0c
	32	11111100111100111111110000001100	0xfcf3fc0c
		11111100111100110000001111110011	oxfcf303f3
600	8	11111111	0xff
		11110000	0xf0
	16	1111111111110000	0xfff0
		1111111100001111	0xff0f
	32	11111111111100001111111100001111	0xfff0ff0f
		11111111111100000000000011110000	0xfff000f0
1200	16	1111111111111111	0xffff
		1111111100000000	0xff00
	32	11111111111111111111111100000000	0xffffff00
		11111111111111110000000011111111	0xffff00ff

Table 2: Details of the complementary code sequences which can be used by the Aberystwyth radar. A “0” represents a phase flip of 0° and a “1” represents a phase flip of 180°. Each digit represents an interval of 1 μs, which is equivalent to 150 m in range. In the right hand column the same sequences are encoded as hexadecimal numbers, taking the leftmost digit of the binary sequences as the most significant bit.

Cable Name	Cable Type	Nominal Length (m)	Actual Length (m)	Termination TX end	Termination Yagi end
B	LCF 7/8" CU2Y	100	102.00	7/16" Plug	7/8" EIA
C	LCF 7/8" CU2Y	3	3.06	7/8" EIA	7/8" EIA
D	LCF 7/8" CU2Y	6	5.95	7/8" EIA	7/8" EIA
E	LCF 4/50 1/2"	2	2.00	7/8" EIA	N Plug
F70	LCF 1/2" CU2Y	70	71.40	7/8" EIA	EIA HN Jack
F70+1	LCF 1/2" CU2Y	70	72.85	7/8" EIA	EIA HN Jack
F70+2	LCF 1/2" CU2Y	70	74.30	7/8" EIA	EIA HN Jack
G70-2	LCF 1/2" CU2Y	70	68.50	7/8" EIA	EIA N Plug
G70-1	LCF 1/2" CU2Y	70	69.95	7/8" EIA	EIA N Plug
G70	LCF 1/2" CU2Y	70	71.40	7/8" EIA	EIA N Plug
G70+1	LCF 1/2" CU2Y	70	72.85	7/8" EIA	EIA N Plug
H	RG 213 U	16	16.04	HN Plug + Sleeve	HN Plug + Sleeve
J	RG 213 U	12	11.84	N Jack + Sleeve	N Plug + Sleeve
K	RG 213 U	8	8.16	N Jack + Sleeve	N Plug + Sleeve

Table 3: Technical details of antenna feed cables shown in Figure 5.

Beam pointing direction number	Beam name (nominal azimuth)	Azimuth angle (°)	Zenith angle (°)
0	Vertical	-	0.0
1	N4.2	342.5	4.2
2	N8.5	342.5	8.5
3	S4.2	162.5	4.2
4	S8.5	162.5	8.5
5	E4.2	72.5	4.2
6	E8.5	72.5	8.5
7	W4.2	252.5	4.2
8	W8.5	252.5	8.5
9	NW6.0	297.5	6.0
10	NW12.0	297.5	12.0
11	NE6.0	27.5	6.0
12	NE12.0	27.5	12.0
13	SE6.0	117.5	6.0
14	SE12.0	117.5	12.0
15	SW6.0	207.5	6.0
16	SW12.0	207.5	12.0

Table 4: Details of the available beam pointing directions for the Aberystwyth radar.