Appendix A

Phase control module fault list

This Appendix documents the faults found in the phase control modules of the MF Doppler radar system during the maintenance period. Faults are grouped according to the source of the faults and individual entries are arranged as fault, effect and action/remedy/solution. All references to component numbers are in accordance with the MF radar system technical documentation.

- `IC faults`
  - Faulty comparator (IC406A), produced abnormal step waveform, replaced.
  - Low signal from eXclusive OR (XOR) (IC206B), produced no output at pin 5 of programmable delay (IC203), added 470 Ω resistor in parallel with 270 Ω (R201).
  - Short between pin 3 (60° ref) & supply voltage of multiplexer (IC201), loaded signal along the incoming control lines, replaced.
  - Short on pin 4 of programmable delay (IC203), produced undesired output, replaced.
- `Individual Component`
  - Failed resistor (R401), produced phase change between current sample from filter and XOR comparator (IC401A), replaced.
  - Failed Zener diode (D408) fitted, also lower breakdown voltage fitted (3.9 V) than specified (5.6 V), produced very high signal on pin 1 of XOR (IC401A),

  replaced.

  - Capacitor missing (C415) on multiple modules, unknown effect, added.
  - Failed 150 μH choke (L401 &/or L402) on multiple modules, significant circuit effect or no significant circuit effect, replaced or omitted.
  - Failed diode(s) (D401→D406) on multiple boards, balance of diode set is affected and produces a distorted step waveform or one that does not conform to nominal behaviour, replaced to re-balance diode set.

- `Modifications`
  - 10 kΩ resistor in parallel to 10 kΩ resistor (R406) on multiple boards, appears to improve function of fully-functioning boards, no action taken (modification used to standardise other modules).
  - 6.8 kΩ resistor added in parallel to 10 kΩ resistor (R406), produced non-standard behaviour, replaced with a 10 kΩ resistor.
  - 68 Ω resistor added in parallel to 10 kΩ resistor (R406), produced non-standard behaviour, replaced with 10 kΩ resistor.
  - Poor capacitor type used (C405), ceramic type used, this will vary its impedance among others problems, replaced with greencap capacitor type.
- `Manufacturer faults`
  - Hole through PCB not drilled properly resulting in XOR (IC401) failing, appears to have never been functional, produced undesired behaviour, hole corrected and XOR replaced.
  - 0.1 μF capacitor installed instead of the specified 0.01 μF (C406), produced limited dynamic range of step waveform, replaced with correct value.
  - Three boards had incorrect capacitor values, this affected the step waveform, replaced.
- `General`

  - Found ∼+12 V supply to each PC module in place of the specified nominal +15 V supply. The 3 V power loss is occurring within the PC module motherboard, no source found, recommemded for future work.

- `Unresolved`
  - PC module 10 of Tx-3 exhibits abnormal behaviour yet successfully calibrates and operates, no negative effect noted, recommended for possible future investigation.

Appendix B

Filter/TR switch module test

The repaired Filter/TR switch modules exhibited a consistent phase behaviour when positioned in their channel slots without their I/O ports loaded. A functioning Filter/TR switch maintained the complex impedance ranges detailed in Table B.1. To accurately measure the Filter/TR switch I/O impedance under load requires two diodes (D1 and D2) to be shorted on the actual Filter/TR switch board. To obviate the need for this the unloaded general values are detailed here. See *Woithe & Grant* [1999] for further details.

Filter/TR switch port	**Impedance** [Ω]	**Phase** [°]
Tx to ANT	35 → 45	-70 → -86
To 2 MHz Rx	60 → 80	-80

Table B.1: Expected impedance characteristics of the unloaded Filter/TR switch module as measured in their channel positions.

Appendix C

Clipper daughterboard

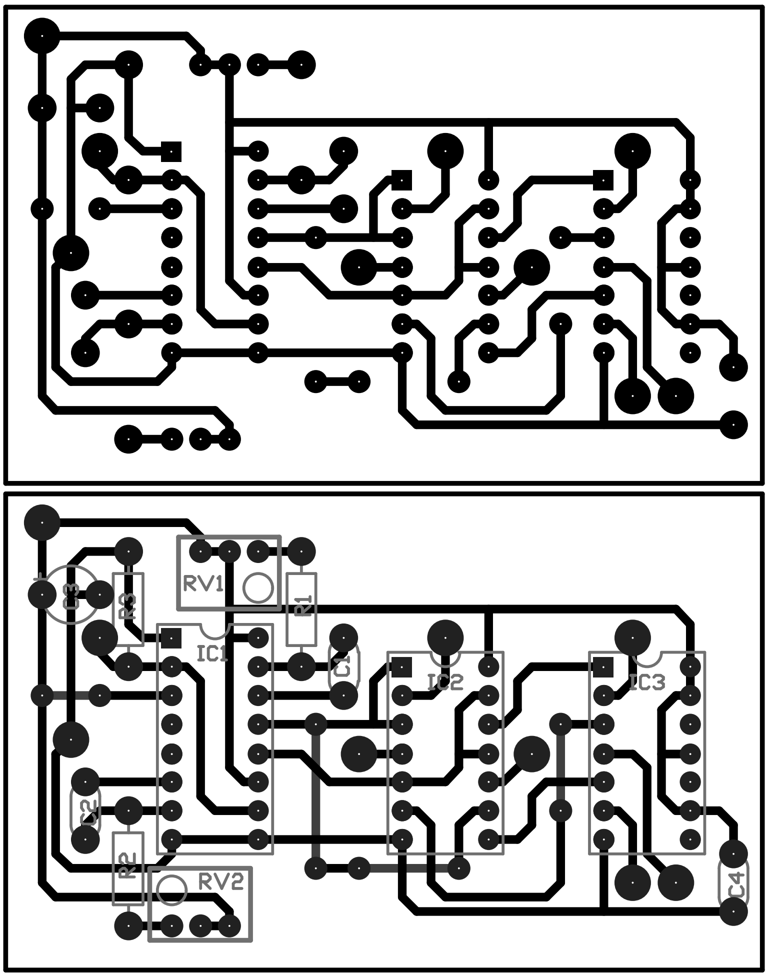

Figure C.1: PCB layout of clipper daughterboard (upper diagram) and with overlay (lower diagram) [$Woithe$, 2000*b*].

Appendix D

Aeraxial coaxial cable risetime

As mentioned previously, the system risetime can determine the practical discrimination limit of the TDR system. A significant component of the system risetime in this case is the risetime of the coaxial cable under test due to its significant length at 1.98 MHz, with risetime being proportional to the cable length. The risetime characteristics of the Aeraxial type cable were not known due to the lack of detailed information on this type of coaxial cable. A brief investigation into the risetime characteristics of different lengths of Aeraxial cable was undertaken for use in future calculations and is detailed here.

Using a modified configuration of equipment system II described in section 3.2.2 the risetimes of four different lengths of Aeraxial cable were tested ranging from 50 to 536 m. The shortest length of Aeraxial was a surplus off cut of the type used throughout the array and the remaining lengths were buried examples of CBA systems that were being assessed for faults at the time of the risetime investigation[1]. Each of the buried coaxial cable examples had a short inserted at the end of the Aeraxial length at the base of the antenna pole (as shown in Figure 3.13 on page 118). The risetime of the other components were taken into consideration when calculating the Aeraxial cable risetime.

An important consideration during these tests was the width of the pulse used in

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[1] Each of these cables was found to be free of faults and minor discontinuities.

the TDR system. Short pulse widths applied to long (>1 λ) cable lengths did not produce consistent results because the short pulse width did not allow the amplitude of the return pulse to reach its maximum height. Only by increasing the pulse width of the interrogating pulse allowed the return pulse to approach its maximum amplitude on the longer lengths of cable. All return pulses were visually checked for abnormal amplitude behaviour in order to maintain consistent results. Also, to limit the effects of pulses not being able to attain maximum amplitude, the 0 to 50% risetime was measured rather than the 10 to 90% risetime [*Strickland et al.*, 1970]. For these reasons different pulse lengths were used to determine the risetimes of the four different cable lengths. The result of this investigation is shown in the Figure D.1.

The theoretical risetime of coaxial cables can be calculated if the attenuation is known. The coaxial cable risetime (T_o) (in seconds) for a wavefront to attain 50% amplitude is given by *Botos* [1968]:

$$T_o = \frac{4.56 \times 10^{-7} \alpha_f^2 l^2}{f} \tag{D.1}$$

where α_f = attenuation of cable at frequency, in dB/100 feet
l = length of cable, in feet
f = frequency, in Hertz

The attenuation of the cable runs has been examined previously by *Rossiter* [1970] and *Vandepeer* [1993]. *Rossiter* found 6 dB attenuation on a 4.5 λ section (assumed to be measured at 1.98 MHz), while *Vandepeer* noted an attenuation for sections 0.5 - 4.5 λ of 0.49 to 4.45 dB at 1.98 MHz. *Vandepeer's* results were taken before the replacement of the 10 m pole section of Aeraxial with RG-11/U type [*Vandepeer*, 2001, private communication] and are values derived from a small sample of the total array. Due to the cable age and buried environment these values are best viewed as lower limits to the actual attenuation delivered by the cables at present. These attenuation values were used to calculate the Aeraxial cable risetime (solid line) in Figure D.1. Over the upgrade period initiated in 1992 the 10 m end section of the cable run was replaced with Belden 8213 RG-11/U solid-cored coaxial cable. This cable type was chosen due to its similarity to the original Aeraxial cable and because of this its relevant specifications are included here for comparison. Its theoretical risetime (dotted line), shown in Figure D.1, is calculated from its published attenuation value at 1.0 MHz [*Belden*, 1993]. The lower risetime exhibited by the RG-11/U may be partly attributed to its different physical makeup and hence differing electrical characteristics. Also, nominal published cable values may not be an accurate representation of actual examples installed. It should also be noted that the loss characteristics of coaxial cable are significantly dependent on the dielectric material between the conductors. The dielectric may be contaminated by exposure to moisture and chemicals when the outer insulating jacket, in its function as providing environmental protection, is impaired in some way [*Straw*, 1994]. This is only exacerbated by age and the RG-11/U is much younger than the Aeraxial cable. Also, attenuation increases with frequency and the risetime of the Aeraxial was calculated at 1.98 MHz as compared to the RG-11/U at 1.0 MHz.

Comparing the theoretical and experimental results in Figure D.1, the close agreement of antenna cable 6E10 (3000 ns pulse) and the significant variation of the other longer length cables determined with shorter pulse widths may indicate that these experimental two-way risetime values are still affected by the pulse width not attaining maximum height in the cable. This would explain the variation of the shorter pulse width determined risetimes. Another factor of less significance would the influence of the age on the cables. A further ten years of exposure to the environmental elements may have had some effect on the cables attenuation characteristics, considering *Straw* [1994] suggests that cable loss of outdoor or buried coaxial cable should be checked every two years for signs of deterioration. It should also be noted that increased cable temperature causes an increase in risetime and a decrease in amplitude [*Times Microwave Systems*, 2002]. This may have had some minor influence over the day time obtained risetime measurements of the buried cable.

It is assumed that an inappropriate interrogating pulse length was used for the cable AX4. A more complete picture could be obtained varying pulse width on this

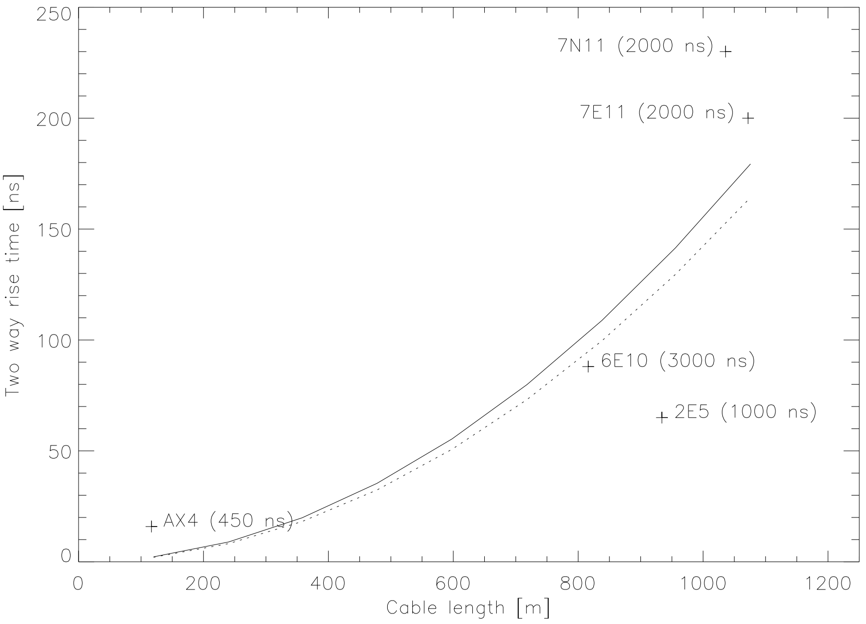

Figure D.1: Coaxial cable risetime. The graph compares experimental two-way Aeraxial cable risetimes with theoretical risetimes. The theoretical risetime of Aeraxial coaxial cable (solid line) is calculated using attenuation values from *Vandepeer* [1993] at a frequency of 1.98 MHz. Similarly, theoretical risetime values for an Aeraxial equivalent cable, Belden 8213 (RG-11/U) (dotted line), at 1.0 MHz are shown. Experimental risetimes of selected cable lengths are shown (crosses), as are the pulse widths in nanoseconds used to determine them. While the experimentally derived values may come from a distribution that is in coarse general agreement with the theoretical values there are obvious discrepancies. It is interesting to note that the cable with closest agreement (6E10) used the highest pulse width (3000 ns) to determine the risetime. This factor may be the main source of the disagreement. In this comparison it is assumed that two-way risetime is equivalent to a contiguous theoretical length of coaxial cable.

length of cable. Another factor influencing these results may be the small sample size used to determine the attenuation values. An alternate approach would utilise attenuation measurements from all CBA systems with like nominal wavelength cable values being averaged for a representative risetime value.

Due to the small number of experimentally derived risetime values for the Aeraxial cable it is difficult to attempt a fit to this data. Such a process would ultimately allow an estimation of actual current risetime for any length of Aeraxial cable to be obtained. This would be useful in order to accurately estimate the system risetime of any TDR system employed for fault identification. However, a suitable approximation to any Aeraxial cable risetime could be interpolated from the Aeraxial theoretical curve (solid line) and this technique was employed in later estimation of TDR total system risetimes.

It is surmised that the experimental results have also been affected by the coaxial cable's known distorting action on pulsed signals. *Matick* [1969] describes this pulse distortion as arising when various frequency components travel at different speeds due to dispersion and/or suffer different amounts of attenuation due to frequency-dependent losses[2]. In fact later studies of the risetime of increasing lengths of coaxial cable [*Strickland et al.*, 1970] indicate that the risetime behaviour of a specific cable type (i.e. RG213/U) differs from the commonly used guideline of doubling cable length translating to four times cable response. It was found that 3.3 times cable response is perhaps a better description with this ratio varying for lengths below 76 to 91 m (250 to 300 ft). This highlights the cable specific nature of cable risetime measurements and perhaps confirms that Equation D.1 is best viewed as an approximation to actual cable behaviour.

Further work to confirm and expand upon the risetimes found here could be aided by a dedicated study and improved equipment configuration. This would involve a second high bandwidth DSO placed at the short near the base of the antenna pole. Thus the one-way risetime of the Aeraxial cable could be obtained. Because the pulse is travelling a shorter distance, excessively long pulse widths would not be needed as in the normal TDR system for two-way measurement. Also, further measurements of cable attenuation could be made using the DSO if impedance matching is perfect. This could be done on all cable runs so as to build up a more complete picture of Aeraxial attenuation across the entire array and determine if the ageing of the cables is significantly degrading cable performance via increasing attenuation.

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[2] It may be possible to reduce these effects by using a suitable, frequency dependent correcting network [*Grivet*, 1970].

Appendix E

The accumulation of water in Aeraxial coaxial cable due to condensation

In order to establish if condensation in a fully functioning coaxial cable is alone responsible for the water amount found during water expulsion using compressed air techniques, it is necessary to calculate the volume of water expected in such a case. A method for this calculation is detailed by *Hughes* [1997] for a large diameter multi-core cable containing multiple paired conductors. This argument has been adapted here for the Aeraxial coaxial cable case.

It is assumed that the Aeraxial coaxial cable had a relative humidity of ∼50% at manufacture or preceding its burial. This cable type was then placed into the underground environment containing varying amounts of moisture and an often higher relative humidity. At a constant temperature there will therefore be a relative humidity difference from the outside to inside of the cable that will drive water vapour through the sheath into the cable [*Hughes*, 1997][1]. After a time period (i.e. a year at most) the relative humidity of the inside of the cable will have risen to 100%. Subsequently,

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[1] Vapour penetration into coaxial cable is mentioned in Chapter 3 and extensively in *Times Microwave Systems* [2002] and *Hughes* [1997].

when the temperature drops water will condense out into the cable.

Hughes assume that the water vapour acts as an ideal gas and follows Dalton's Law of partial pressures and behaves independently of other gases.

We will assume that there are two nominal temperature differences influencing any condensation, one representing local winter conditions and the other summer conditions.

Temperature	**Winter** [°C]	**Summer** [°C]
Minimum	0 (273°K)	15 (288°K)
Maximum	15 (288°K)	30 (303°K)

Table E.1: Seasonal temperature differences.

The Relative Humidity (RH) is given as [*Giancoli*, 1988],

$$Relaive\ Humdity = \frac{partial\ pressure\ of\ H_2O}{saturated\ vapour\ pressure\ of\ H_2O} \times 100 \tag{E.1}$$

The partial pressure of H_2O (P_{H_2O}) at 100% RH can be obtained from Equation E.1 as saturated vapour pressure is temperature dependent and is tabulated in *Giancoli* [1988, Table 19-1]. Table E.2 summarises these results.

T [°C]	**T** [°K]	$\mathbf{P}_{H_2O}$ [N/m^2]
0	273	611
15	288	1710
30	303	4240

Table E.2: Partial pressure of H_2O (P_{H_2O}) due to 100% Relative Humidity at a specific temperature (T).

If we look at a 1000 m section of cable and assume that the diameter of the free space of the air dielectric is 4 mm, the associated Volume (V) is 0.013 m^3/km.

The ideal gas equation can then be re-arranged to give the number of mols of H_2O (n),

$$n = \frac{P_{H_2O} V}{RT} \tag{E.2}$$

where, V = Volume (m^3), T is the Temperature (°K) and R is the Universal Gas constant, 8.314 J/mol·K. the molecular weight of water is 18 so the number of mols can be converted to grams per km.

T [°C]	**n** [mol]	**n** [grams/km of H_2O]
0	0.0035	0.0629
15	0.0093	0.1671
30	0.0219	0.3938

Table E.3: Moles (n) of H_2O according to temperature.

Assuming that all water condenses into the air-cored portion of the cable (instead of coating the total surface area of the cable components such as the outer shield etc.) then the mass of water condensing out and thus measured when forced out by air will be the difference of these values. So 0.10 grams/km of H_2O are condensed for a winter day and 0.23 grams/km of H_20 for a summer day. This translates approximately to the very small volumes of (winter) 0.10×10^{-6} m^3/km and (summer) $0.23\ \times10^{-6}$ m^3/km.

If the conditions necessary for this condensation occur daily then a steady accumulation of water in the cable will result neglecting any other direct moisture entry paths. If we assume that the conditions necessary for the winter cycle occur for half a year and the summer for the other half an estimate of the annual water accumulation can be obtained. This is approximately 6×10^{-4}m^3/km/year.

If the last upgrade in 1992/94 effectively forced all water from the cables then over the five years to the present survey approximately 3 cubic millimetres of water is expected to be forced out during the current water eradication process due only to the condensation behaviour of the cables at the Buckland Park site. In fact the cables showing a very low water level (see Figure 3.23) often had an estimated water volume not much larger than this forced out.

Appendix F

Automated array monitoring system

An Automated Array Monitoring System (AAMS) would interface with the functioning radar system at the antenna patchboards. Here, feeds from each CBA sub-system would be tapped allowing for either normal radar operation or array assessment to be initiated. Essentially, all necessary TDR and VIM diagnostic techniques, such as those described in Chapter 3, could be accomplished using various hardware components such as PCI cards contained within a PC in conjunction with software algorithms interpreting the data collected. Using the rejection criteria detailed in previous sections, including such parameters as complex impedance and theoretical cable length, a status of each CBA could be calculated and evaluated against current standards. Additionally, software algorithms may also identify common faults from their characteristic signatures (e.g. Figures 3.5 to 3.12 on page 113 and others contained in the MF CBAD) and then approximate the distance to the fault. This complete system is then networked with the existing radar controller for synchronising purposes and with the Automatic Weather Station (AMS) for recording of the local weather conditions which have some influence over the electrical behaviour of the array. The existing microwave link from the Buckland Park research facility to the University of Adelaide campus would allow the control and display of data from the AAMS to be incorporated into the existing radar configuration and display software. Note that some degree of automation can be achieved with the current equipment test system, however this falls short in terms of capabilities and versatility of a purpose designed system.

Because TDR is essentially RADAR operation in a medium, a more elegant solution to automating TDR/VIM array measurements is to use the existing atmospheric radar system, momentarily reconfigured to transmit and receive into the CBA sub-system. This would occur before an acquisition block, using TDR system frequencies and pulse lengths. This eliminates a doubling up on equipment to sample the atmosphere and CBA sub-system individually and integrates TDR/VIM function into the atmospheric radar system enhancing its self-diagnostic capabilities and providing a near completely self-sufficient radar system. This type of system would be applicable to other radars situated at remote locations. A more ambitious arrangement of monitoring CBA sub-system behaviour *during* data collection could utilise the broadcast of a second carrier frequency separated from the atmospheric carrier frequency and modulated by a short pulse [*Davidson*, 1978]. This second frequency would be chosen such that most signal is reflected at the balun/antenna. The received signal could be analysed in a similar fashion to all other TDR signals. The dramatic increase in complexity required of both the transmitter and receiver system preclude this arrangement from being implemented with any current generation radar system, however the progression towards multi-frequency, wideband radar systems indicate that CBA sub-system monitoring simultaneously with data collection is not far away.

Either method allows for data from the within the antenna array to be monitored together with atmospheric radar data in near real-time. A primary difficulty in implementing such a system into the current radar is that the current patchboards access three CBA sub-systems for each transmitter channel in the standard configuration. This prevents each individual CBA sub-system being probed for its characteristics, however this could be overcome with a different patchboard arrangement such as one that could switch in individual CBA sub-systems under radar control. This arrangement would also enhance the radar's versatility in terms of atmospheric observations.

Appendix G

Power combining system summary sheet

USE

The 1.98 MHz combining system allows summation of the 2.5 kW Power Amplifier (PA) modules of the 25 kW 1.98 MHz MF transmitter. The output can be directed to a $\frac{1}{4}\lambda$ helical whip antenna or any other system via the output transformer as required.

EQUIPMENT

The combining system consists of:

- Standard:
    - (3×) 2:1 combiner.
    - (1×) 3:1 combiner.
    - (1×) 90° phase delay.
    - (1×) 1:1.64 transformer (tap adjustable).
    - (32×) 50 cm RG-58 patch cables.
    - (1×) ~50 m $\frac{1}{2}\lambda$ UR67 transformer to antenna cable.
- Optional:
    - $\frac{1}{4}\lambda$ helical whip antenna and base.
    - antenna mount.

SPECIFICATION

Device Name	**Impedance I/O** [Ω]	**Power Rating** [kW]
2:1 combiner	25	10
3:1 combiner	25	15
1:1.64 transformer	25/41	15
90° phase delay	25	15
$\frac{1}{4}\lambda$ helical whip	50/41[a]	7.5 @ 1% duty cycle

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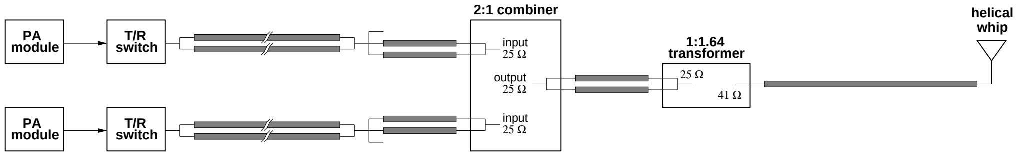
[a] Nominal/With Mount.

CONNECTION

A basic connection configuration is shown in Figure below.



Appendix H

Power combining system component list

Component	**Value**	**Type**	**Tolerance**	**Note**
		2:1 Combiner		
R1-R6	75 Ω	Wirewound	5%	6 W
C1	330 pF	Silvered Mica	1%	500 V d.c. working
C2	390 pF	“	“	“
C3	1.5 nF	“	“	“
C4	330 pF	“	“	“
C5	330 pF	“	“	“
C6	1.5 nF	“	“	“
C7	390 pF	“	“	“
C8	330 pF	“	“	“
C9	3.6 nF	“	“	“
C10-C12	390 pF	“	“	“
L1	2.35 μH	T-184-2 (toroid)	-	$9\frac{1}{2}$ turns
L2	2.35 μH	T-157-2 (toroid)	-	$12\frac{1}{2}$ turns
CBL1-CBL4	50 Ω	RG-58C	-	17.5 cm length
CBL5,CBL6	50 Ω	RG-58C	-	19.5 cm length
A1-A6	50 Ω	BNC panel mount		
		3:1 Combiner		
R7-R15	75 Ω	Wirewound	5%	6 W
C13-C18	3.6 nF	Silvered Mica	1%	500 V d.c. working
C19,C20	10 nF	“	“	“
C21,C22	390 nF	Silvered Mica	2%	500 V d.c. working
L3	3.5 μH	T-200A-2 (toroid)	-	$11\frac{1}{2}$ turns
L4	3.5 μH	“	-	“
L5	3.5 μH	“	-	“
CBL7-CBL12	50 Ω	RG-58C input cable	-	17.5 cm length
CBL13,CBL14	50 Ω	RG-58C output cable	-	19.5 cm length
A7-A14	50 Ω	BNC panel mount		
		1:1.64 Transformer		
C23	1.8 nF	Silvered Mica	1%	500 V d.c. working
C24	5.6 nF	“	2%	“
L6	223 μH (1.1 kΩ)	28-053-31 (toroid)	-	$19\frac{1}{2}$ turns
A15-A17	50 Ω	BNC panel mount		
		Phase Delay		
C25-C30	820 pF	Silvered Mica	2%	500 V d.c. working
C26-C29	1.5 nF	“	1%	“
L7	na (25 Ω)	na	-	$19\frac{1}{2}$ turns
CBL15,CBL16	50 Ω	RG-58 input cable	-	30 cm length
CBL17,CBL18	50 Ω	RG-58 output cable	-	30 cm length
A19-A22	50 Ω	BNC panel mount		

Table H.1: Combining system component list.

Appendix I

Radio frequency band designations

Band Designation	**Frequency Range**				**Wavelength**			
ELF		$<$	3	kHz		$>$	100	km
VLF	3	to	30	kHz	10	to	100	km
LF	30	to	300	kHz	1	to	10	km
MF	300	to	3000	kHz	100	to	1000	m
HF	3	to	30	MHz	10	to	100	m
VHF	30	to	300	MHz	1	to	10	m
UHF	300	to	3000	MHz	10	to	100	cm
SHF	3	to	30	GHz	1	to	10	cm
EHF	30	to	300	GHz	1	to	10	mm

Table I.1: Band designations for the radio region of the EM spectrum.

Appendix J

Atmospheric radar configurations for meteor detection

Various transmitting and receiving hardware configurations of atmospheric type radars have been effectively employed for meteor detection and analysis at frequencies below 10 MHz. For meteor wind measurements, the system at Saskatoon described by *Meek & Manson* [1990] used a transmitting array of folded half wave dipoles at 2.219 MHz producing a beam half power at 22° off-zenith. Peak pulse power of the order of 50 kW was transmitted in 20 μs pulses at a PRF of 60 Hz. For reception, an interferometer of four tuned loops arranged as an equilateral triangle plus a centre loop spaced at one half wavelength was used.

Earlier meteor studies employing the Buckland Park MF array, with transmitter hardware pre-dating that described in section 2.2.2, offer an alternate configuration. *Olsson-Steel & Elford* [1987] transmitted circularly polarised radiation vertically with a relatively wide beam to enable sufficient power at larger off-zenith angles. A 25 kW transmitter was used producing a 30 μs pulse at a PRF of 20 Hz. A more complex receiving system was used comprising five channels, one amplitude and four phase. To determine the presence of an echo (via the amplitude channel) two rows of collinear dipoles with a 180° phase shift between them produced an antenna pattern with maximum at 55° off-zenith and a null in the vertical to minimise ionospheric reflections.

The first two phase channels were used to determine the zenith angle of the meteor from comparison of signals from two rows of nine collinear antennas. The final two phase channels used the input from two single dipoles as a phase check. Similar multiple collinear antennas for reception had been used in earlier meteor studies from the BP site (e.g. *Brown* [1976]); this arrangement initially was employed to obtain a reasonable signal-to-noise ratio as compared to a single dipole [*Brown*, 1972]. Studies at 6 MHz using the BP array for reception and a different transmitting system have also taken place [*Elford & Olsson-Steel*, 1988]. Here, linear polarised radiation was directed vertically with a half power maximum at 40° off-zenith. A 10 kW peak power, 20 μs Gaussian pulse at a PRF of 20 Hz was used. Reception on the BP array at 6 MHz was via a vertically directed beam with grating lobes at 33.2° and 50.7°.

More recent meteor observations at the BP site have utilised sixty east-west aligned antennas for transmission to form a 10° pencil beam at an off-zenith angle of 25° in four consecutive azimuths (0°,90°,180° and 270°) switched every two minutes [*Tsutsumi et al.*, 1999]. Five dipoles of opposite polarisation to those used for transmission were arranged as an interferometer for reception.

Appendix K

Techniques to validate meteor echo height

1. **Decay times**. The decay time of an underdense meteor echo will decrease with increasing height. General decay time trends can be determined for height consistency or direct comparisons with theoretical models.

2. **Height range**. Shower echoes should be confined to a particular height range based on their mean speeds. *Weiss* [1955] has also used a range envelope technique to determine the reliability of the radiant determination.

3. **Winds**. Wind fields derived from meteor echoes, together with fields derived by other means such as FCA for example, may be examined for consistency. It is expected complementary wind fields contiguous or overlapping in height will exhibit compatible characteristics. Common atmospheric phenomena, such as the propagation of gravity waves, may also be observed through the adjacent wind fields. It should be noted however that this analysis is complicated by the fact that wind fields can change dramatically at around 100 km altitude, although this feature in itself can be exploited for a "gross" checking of heights.

4. **Ionospheric layer position**. The approximate position of local ionospheric layers (i.e. D, E, F-region) could be used as a frame of reference from which to

confirm meteor echo heights. The use of an ionosonde in real time will aid in accurately identifying the range and extent of layers from which to calibrate the meteor echo height, while ionospheric prediction services or models may provide a rough approximation of the local ionospheric environment. Data relating to each layer's capability in reflecting or retarding signals of specific frequency is particularly sought.

5. **Ray modelling**. Theoretical modelling of the transmitted radiation via ray-tracing techniques within a model ionosphere (such as the International Reference Ionosphere (IRI)) could be undertaken.
6. **Data self-consistency or logic validation**. Maximum use of the existing radar data could be initiated via examining the;
    (a) **Power return**. Typically the strength of a meteor echo at a distant range will be significantly less than that of an echo detected at close range. The calculated echo height and knowledge of radar beam geometry can then be examined for consistency with this information.
    (b) **Height distribution**. The general form and location of the meteor height distribution can be approximated by theory. Deviations from this may indicate ranging problems.
7. **Magnetic field effects**. At altitudes above 95 km the magnetic field increasingly affects the character of the radar meteor echo (see section 5.2.2). This can be modelled and compared with acquired echoes in order to confirm echo height.
8. **Range bracketing at higher frequency**. To overcome phase inaccuracies of previous configurations of the BP 2 MHz radar system, *Olsson-Steel & Elford* [1987] suggest operating the radar at 6 MHz to obtain grating lobes of 1.5° width. If suitable range brackets were searched for meteors, heights could be determined using range data only.

Appendix L

Abbreviations

Abbreviation	**Definition**
A$	Australian dollar
ANT	Antenna
AoA	Angle-of-Arrival
ch	Channel
deg	degree
EW	East-West
hr	hour
I	In-phase
I/O	Input/Output
min	minute
N	North
NS	North-South
Pk-to-Pk	Peak-to-Peak
Q	Quadrature
radarcfg	Radar configuration software
REF	Reference
Rx	Receiver
S	South
T/R or TR	Transmit/Receive
Tx	Transmitter

Acronym	**Definition**
AAI	Aerospace Airglow Imager
AC	Alternating Current
ADC	Analog-to-Digital Converter
ADS	Analysis and Display Suite
AGC	Automatic Gain Control
AMOR	Advanced Meteor Orbit Radar
AMS	American Meteor Society
ALTAIR	ARPA Long-range Tracking And Instrumentation Radar
AWS	Automatic Weather Station

Acronym	**Definition**
BL	Boundary Layer
BNC	Bayonet Nut Connector or British Naval Connector or Bayonet Neil-Concelman
BP	Buckland Park
BW	Bandwidth
CBA	Cable-Balun-Antenna
CCDS	Charge-Coupled Device Spectrometer
CD-R	Compact Disc-Recordable
CDROM	Compact Disc Read Only Memory
CEM	Computational Electromagnetics
CRO	Cathode Ray Oscilloscope
CST	(Australian) Central Standard Time
CW	Continuous Wave
DAE	Differential Absorption Electron (concentration)/Experiment
DBS	Doppler Beam Swinging
DC	Direct Current
DMS	Dutch Meteor Society
DoD	Department of Defence
DSO	Digital Storage Oscilloscope
DSpO	Digital Sampling Oscilloscope
DSTO	Defence Science and Technology Organisation
DTB	Down-the-Beam
DUT	Device Under Test
ED	Experimental Dry
EHF	Extremely High Frequency
ELF	Extremely Low Frequency
EM	Electromagnetic
EN	East North
EPROM	Erasable Programmable Read-Only Memory
EUV	Extreme Ultraviolet
EW	Experimental Wet
FCA	Full Correlation Analysis
FDR	Frequency Domain Reflectometry
FD-TD	Finite Difference Time-Domain
FEP	Fluorinated Ethylene Propylene
FIFO	First In, First Out
FMCW	Frequency Modulated Continuous Wave
GCM	General Circulation Model or Global Circulation Model
GPS	Global Positioning System
GUI	Graphical User Interface
HF	High Frequency
IAU	International Astronomical Union
IBM	International Business Machines
IC	Integrated Circuit
IF	Intermediate Frequency
IMO	International Meteor Organisation
IRI	International Reference Ionosphere
ISA	Industry Standard Architecture
ISEP	International Standard Equipment Package
ISR	Incoherent Scatter Radar
LAN	Local Area Network
LF	Low Frequency
LLLTV	Low-Light-Level Television
LO	Local Oscillator
LT	Local Time
MAS	Meteor Analysis Suite
MDR	Meteor Detection Radar

Acronym	**Definition**
MEDAC	Meteor Echo Detection And Collection
MF	Medium Frequency
MF CBAD	Medium Frequency Cable-Balun-Antenna Database
MoM	Method of Moments
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MS	Microsoft
MS-DOS	Microsoft Disk Operating System
MST	Mesosphere-Stratosphere-Troposphere
MU	Middle and Upper atmosphere (radar)
na	not applicable
NEC-2	Numerical Electromagnetics Code, Version 2
NMS	Nippon Meteor Society
O	Ordinary
O	Oxygen
OH	Hydroxyl group or molecule
OR	OR (logic gate)
OTH	Over-The-Horizon(-radar)
PA	Power Amplifier
PC	Personal Computer
PC	Phase Control
PCB	Printed Circuit Board
PEP	Peak-Envelope-Power
PRF	Pulse Repetition Frequency
PVC	Polyvinyl Chloride
RA	Right Ascension
RADAR	RAdio Detection And Ranging
RAM	Random Access Memory
RASS	Radio Acoustic Sounding System
RDAS	Radar Data Acquisition System
RF	Radio Frequency
RMS	Root Mean Square
SA	Spaced Antenna
SAPR	Spaced Antenna Partial Reflection
SHF	Super High Frequency
SKiYMET	all SKY interferometric METeor radar
SNR	Signal-to-Noise Ratio
SuperDARN	Super Dual Auroral Radar Network
SWR	Standing-wave Ratio
ST	Stratosphere-Troposphere
TDI	Time Domain Interferometry
TDR	Time Domain Reflectometry
TDT	Time Domain Transmission
TEM	Transverse Electric Magnetic
TE	Transverse Electric
TFP	Three Field Photometer
TN	True North
UHF	Ultra High Frequency
UT	Universal Time
UV	Ultra-Violet
VHF	Very High Frequency
VIM	Vector Impedance Meter
VLF	Very Low Frequency
VSWR	Voltage Standing-Wave Ratio
wrt	with respect to
X	Extra-Ordinary
XOR	eXclusive OR (logic gate)

Appendix M

Symbols

Symbol	**Definition**
a	Measure of column radius
A	Phase temperature coefficient
A	Effective antenna area
A_e	Cross sectional area
A_L	Inductance Index
$A(t)$	Amplitude
BW	Bandwidth
B_{max}	Maximum flux density
C	Capacitance
C_D	Core dimensional factor
CL	Cable Length
CL_A	Cable Length of Aeraxial cable section
$CL_{3.63}$	Cable Length of feeder cable section
$CL_{RG-11/U}$	Cable Length of upright cable section
CL_{Probe}	Cable Length of probe section
c	Speed of light
d	Distance between antenna elements
d	Inner conductor's outer diameter
dX	Time difference
dY	Voltage difference
D	Outer conductor's inner diameter
D	Distance to discontinuity

Symbol	**Definition**
D_a	Ambipolar diffusion coefficient
D_1	Distance to discontinuity 1
D_1	Distance to discontinuity 2
D_{12}	Distance between discontinuity 1 and 2
e	Partial pressure of water vapour
ED	Experimental Dry coaxial cable length
EW	Experimental Wet coaxial cable length
E_{pk}	Applied RMS volts
f	Frequency
f_{crit}	Critical frequency
f_{LO}	Local oscillator frequency
f_S	Signal frequency
$f_{scope\ bandwidth}$	The bandwidth of an oscilloscope
F	Frequency
h	Altitude
I	Luminous energy
l	Length of cable
l_1	Direction cosine of reflection point in celestial frame
l_A	Direction cosine of reflection point in observer's frame
L	Direction cosine of radiant in celestial frame
L	Inductance
m	Mass
m_1	Direction cosine of reflection point in celestial frame
m_A	Direction cosine of reflection point in observer's frame
M	Direction cosine of radiant in celestial frame
n	Integer
n	Number of mols of water
n	Refractive Index
n_1	Direction cosine of reflection point in celestial frame
n_A	Direction cosine of reflection point in observer's frame
N	Direction cosine of radiant in celestial frame
N	Number of components
N	Number of input ports
N	Number of meteors

Symbol	**Definition**
N	Number of samples
N	Number of turns
N_e	Critical plasma density
N_e	Number density of electrons
N_{max}	Peak electron density of the layer
P	Atmospheric pressure
PD	Path Difference
P_{AP}	Power aperture product
P_{H_2O}	Partial pressure of water
P_{pk}	Transmitted peak power
P_t	Transmitted power
P_{1R}	Received power from 1^{st} hop
P_{2R}	Received power from 2^{nd} hop
q	Line density
q_{max}	Maximum line density
r_e	Classical electron radius
r_0	Trail initial radius
R	Balancing Resistance
R	Discrimination of TDR system
R	Reflection coefficient
R	Resolving power
R	Universal Gas Constant
RA	Right Ascension
RH	Relative Humidity
R_1	Resistance in series with Z_O
R_2	Shunt resistance
s	Distance along trail
S	Meteor event ratio
$S(t)$	Signal from IF amplifier
t	Time
t	Elapsed time between initial and reflected pulse
t_i	Component risetime
t_{pw}	Pulse Width
t_r	System risetime

Symbol	**Definition**
$t_{system\ I}$	Total risetime of equipment system I
$t_{system\ II}$	Total risetime of equipment system II
t_{total}	Total time difference
t_1	Time period between initial and return pulse to discontinuity 1
T	Period
T	Theoretical coaxial cable length
T	Temperature
T	Absolute temperature
T_o	Coaxial cable risetime
v	Velocity of radio wave in air
v	Speed of meteoroid in m s^{-1}
V	Speed of meteoroid in km s^{-1}
VF	Velocity Factor
V_{pk}	Peak voltage
VF_A	Velocity Factor of Aeraxial cable section
$VF_{3.63}$	Velocity Factor of feeder cable section
$VF_{RG-11/U}$	Velocity Factor of upright cable section
VF_{Probe}	Velocity Factor of probe cable section
z	Scatterer height
Z	Complex impedance
Z_{in}	Input Impedance
Z_L	Load Impedance
Z_o	Line Impedance
Z_O	Characteristic Impedance
X_C	Capacitive reactance
X_L	Inductive reactance
α	Right ascension
α	Electron line density
α_A	Direction cosine angle in observer's frame
α_f	Attenuation of cable at frequency, in dB/100 feet
β	Ionising probability
β_A	Direction cosine angle in observer's frame
γ_A	Direction cosine angle in observer's frame
Δ	Cable length difference

Symbol	**Definition**
ΔCL_A	Error in Aeraxial. m cable length
$\Delta CL_{3.63}$	Error in 3.63 m cable feeder length
$\Delta CL_{RG-11/U}$	Error in 3.63 m cable feeder length
ΔCL_{Probe}	Error in 3.63 m cable feeder length
Δ(ED-T)	Experimental Dry cable length - Theoretical cable length
Δ(ED-T)	Experimental Wet cable length - Theoretical cable length
ΔH	Error in hour angle
ΔT	Change in temperature
ΔVF	Error in velocity factor
ΔVF_A	Error in Aeraxial velocity factor
$\Delta VF_{3.63}$	Error in feeder cable velocity factor
$\Delta VF_{RG-11/U}$	Error in RG-11/U cable velocity factor
ΔVF_{Probe}	Error in Probe cable velocity factor
Δz	Change in range gate
Δn	Change in refractive index
Δt	Pulse two-way time
Δt_{total}	Error in total time difference
$\Delta\delta$	Error in declination
$\Delta\phi$	Phase difference
$\Delta\xi$	Error in interferometer baseline angle
δ	Declination
δt	Time difference
ϵ	Relative dielectric constant (i.e. ϵ=1.0 (air), $\epsilon \sim$80 (water))
τ	Luminous efficiency
θ_A	Zenith angle of reflection point wrt radar site
κ	Calibration constant
λ	Wavelength (free space length)
λ	Wavelength (electrical)
λ	Latitude
μ	Permeability
μ	Average mass of an ablated meteoroid atom
ξ	Δ(EW-T) - Δ(ED-T)
ξ	Interferometer baseline angle
ϕ or $\phi(t)$	Phase

Symbol	**Definition**
ϕ_A	Azimuth angle of reflection point wrt radar site
ψ	Electrical length
ω	Angular frequency (2πf)
ω_0	IF carrier frequency

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Colophon

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