

Report No. HA-41

# Centre for Radio Science

DESIGN, CONSTRUCTION, TESTING AND APPRAISAL  
OF A MULTI-ELEMENT MICROWAVE INTERFEROMETER.

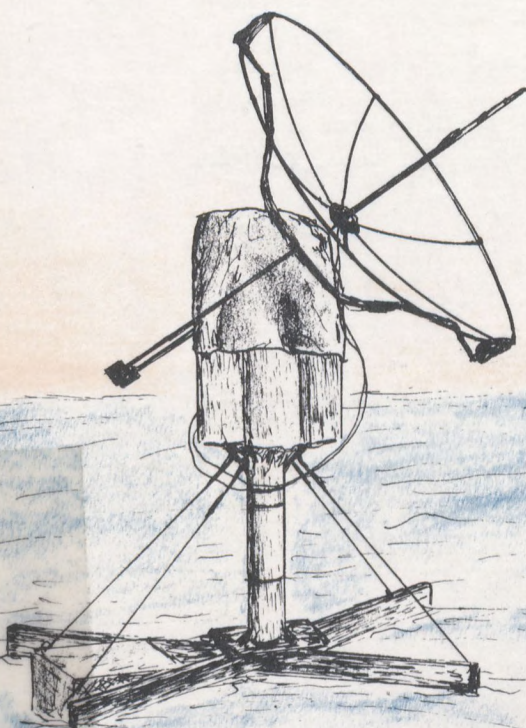
A.R. Webster and A.M. Scott

Final Report

D.S.S. Contract No.

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July, 1984



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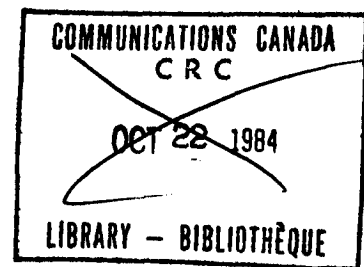
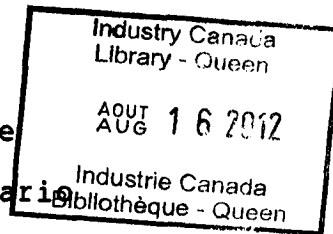
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Design, Construction, Testing and Appraisal  
of a Multi-element Microwave Interferometer

A Final Report under  
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London, Canada



Principal Investigator: A.R.Webster  
Research Associate: A.M.Scott  
Report prepared by: A.R.Webster

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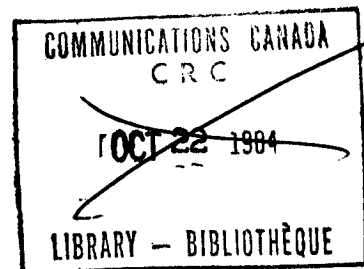
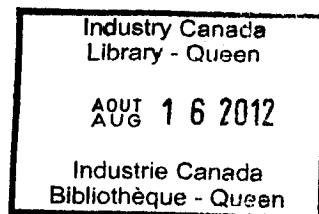
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## 1. INTRODUCTION

As a result of extensive experimental observations on tropospheric microwave propagation (see DSS report #03SU.36001-2-1480), the suggestion was made that a real need exists for a system to measure characteristic parameters of such propagation in a manner that lends itself easily to both its operation and the analysis of the resulting data. Parameters of importance include: amplitude, angle-of-arrival and delay-times of separate rays at the receiver under single- and multi-path propagation conditions, as appropriate.

A previous diagnostic system was designed to measure all of these quantities and indeed proved capable of doing so. However, the main draw-backs with that system proved to lie in the two criteria mentioned above; that is, ease of operation and analysis of data. As a result of all of this, a simpler, and in some ways more sophisticated, system was suggested which is capable of measuring amplitude and angle-of-arrival of separate rays at the expense of delay-times. The development and testing of such a system, a multi-element vertical array, forms the basis of this report.



## 2. THE BASIC PRINCIPLE OF THE SYSTEM.

Since the troposphere tends to stratify into horizontal layers, variations in refractive index occur in a vertical plane containing the ray-path. As a result, movements in angle-of-arrival and the breaking-up into several rays all tend to take place in this vertical plane.

The measurement of the resultant complex amplitude across a wide vertical aperture gives immediate access to the amplitudes and angle-of-arrival of the constituent rays by way of the Fourier Transform. The transformation is from the linear to the angular domain and is illustrated in fig. 1.1 for a single ray displaced in angle relative to the (horizontal) normal to the array. It will be noted that the resolution is essentially inversely related to the total aperture width, while the unambiguous range in angle-of-arrival is determined (again inversely) by the spacing between adjacent sampling elements. Separation of two or more rays is directly dependent on the resolution.

Since both the resolution and the range are determined by the appropriate dimensions in wavelengths, limits are placed on the array design in that the aperture must be sufficiently wide to provide adequate resolution and sufficiently "filled" to avoid ambiguous results. In the light of experience, a resolution of 0.1 deg. or better and range of 1.0 deg. or wider is appropriate.

A further constraint is that the array must be of reasonable dimensions.

Based on this reasoning, a system has been designed to operate at a frequency of 16.65 GHz, that is, at a free-space wavelength of 0.018 m. This results in a reasonable physical size in that a resolution of 0.1 deg. requires an aperture (unweighted) of 680 wavelengths, or 12.25 m. In order to accommodate a 1.0 deg. range, a spacing of 57 wavelengths, or less, between elements is needed so that 12 elements so spaced meets the stated criteria.

The purpose of the work described here is to design, assemble and study the performance of a somewhat smaller (8-element) array with a view to expansion to the full array described above. Such a 12-element array forms the basis of a current (1984-1985) D.S.S. contract.

### 3. THE SYSTEM HARDWARE.

#### 3.1 The Overall System

Fig. 3.1 shows the basic concept. Rather than build separate receiving systems for each element, one receiver is switched rapidly between elements. In addition to the obvious economy that this provides, any phase shift due to the receiver is common to all measurements, a decided advantage. The relative phase between elements, the quantity of interest, is determined by comparing the phase of each element to that of a separate reference channel. A high-gain antenna is used for this channel to provide resistance to signal loss during severe fading, though sufficient beam-width is retained (about 2.5 deg.) to accommodate anticipated fluctuations in angle-of-arrival.

Amplitude and phase values for each element are determined under microprocessor control and ultimately stored on 9-track magnetic tape.

#### 3.2 The Transmitter

The heart of the transmitter (see fig. 3.2) is a Frequency West phase-locked oscillator in which a basic crystal frequency of 102.778MHz is essentially multiplied to the operating frequency of 16.6500GHz C.W. Previous measurements indicated a remarkable



stability of about  $\pm 5\text{kHz}$ , medium-term, at the microwave frequency; this has important ramifications as far as the receiving system is concerned. The power level is boosted from about  $+15\text{dBm}$ , via an amplifier and isolator, to about  $+20\text{dBm}$  (the small attenuation limits the power input to the amplifier), and thence fed to the antenna, a  $0.6\text{m}$  diameter dish.

In the interest of electrical and mechanical simplicity, only limited access being available once installed, the power supply is kept separate at ground level and  $+25\text{VDC}$  fed through a coaxial cable. This arrangement has the added advantage that the basic oscillator frequency and power can be monitored readily at ground level via the same cable.

### 3.3 The Receiving Array

The receiving array consists of 8 vertically spaced horns, of  $20\text{dB}$  gain each, as shown in fig. 3.3. Mixers are placed at the end of a symmetrical waveguide run and close to the respective horns. This waveguide arrangement is designed to split the available local oscillator power equally between mixers and to provide paths of equal length to the mixers. This latter point is of some importance in that it may be shown readily that the wavelength in the guide is temperature sensitive to the tune of  $1$  deg. in phase per  $1$  deg. in temperature per  $100$  wavelengths. Considerable attention has been paid to the matching of the feeding system in order to minimise reflections and hence phase uncertainties.



### 3.4 The Switch

Fig. 3.4 shows the switching arrangement. Based on MPN3401 PIN diodes, the system is designed to provide a minimum of 40dB isolation between channels; 50dB or better typically is found in practice. An overall gain of 25dB is built-in through the use of MWAl10 amplifier modules, each channel having its own amplifier in the interest of reduced noise. The switch itself is controlled by signals sent from the micro-computer which directs the whole operation (see fig 3.1).

### 3.5 The Main Receiver

Two virtually identical channels are used to provide the main amplification and frequency conversion down to the final frequency of 83kHz (see fig 3.5.1). The bandwidth of each channel is determined at 10.7MHz using crystal filters and set at 30kHz for the reference channel (to accommodate the anticipated phase-locking range) and 10kHz for the signal channel (reduced noise). Automatic Gain Control (AGC) around the 53/10.7MHz stages provides a direct measure of the signal amplitudes.

In a somewhat novel arrangement, a single master oscillator (MO) provides all of the fixed frequencies needed by the system. These frequencies essentially stem from the basic intermediate-frequency of 10.7000MHz and the stability of these frequencies is about 1 in  $10^6$ . This in turn means that the

(filtered) 10.7MHz signal is held to within about  $\pm 10\text{Hz}$ , thus circumventing the problem of the large phase-shift across the band which is a feature of such multi-pole filters.

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A frequency of 21.23MHz (256 times the final signal frequency) is automatically provided to facilitate the subsequent phase measurements. It might be noted in passing that the choice in these frequencies was influenced by the speed capabilities of the low-power Schottky TTL devices used.

The phase-locking of the system is achieved by detection at the final signal frequency (83kHz) and control at the first local oscillator (66.8MHz) of the main receiver. The stability of this oscillator is such that phase-lock is easily achieved and maintained with a stable 120MHz input signal (an equivalent drift of less than  $\pm 1\text{kHz}$  is observed).

For reference purposes, an overview of the signal levels in the whole system (for a 50km link) is shown in fig 3.5.2.

### 3.6 Amplitude and Phase Measurements

The main receiver presents as outputs two voltages, representing the signal amplitudes on the two channels, and two 83kHz signals whose phase difference gives directly a measure of that at the antennas. Additionally, a frequency 256 times that of the signals and phase-locked to the reference signal is provided. Operation of the amplitude and phase meters, and the recording of

the resultant values, is carried out under the control of a (much modified) Altair 8800 micro-computer.

The actual measurement of the amplitudes is very straightforward, involving simply a standard A.D converter with appropriate timing provided by the computer.

In order to measure the phase difference between the signals from the two receiver channels, Schmitt-triggered square waves are generated and a gate derived from the respective leading edges as shown in fig 3.6. A count is made of the 21.23MHz signal during this gate interval so that a count range of 0 to 255 corresponds to a range of 0 to 360deg in phase. An average count is established over 16 such intervals (the 16 is somewhat arbitrary) by the computer. At this stage, a check is made in case the phase is hovering around the 360 deg. mark such that erroneous values would be obtained (see right-hand side of fig 3.6); in such instances, the computer adds or subtracts an appropriate integer multiple of 360 deg. (that is, counts of 255). In this way an accurate estimate of the required phase is obtained and the computer moves on to the next element.

The timing of these operations is of some importance under rapidly changing fading conditions, since the entire sweep of the array must be completed before any significant changes occur. For this reason all of the raw measurements are made for all of the elements before any manipulation takes place. This initial period amounts to about 25 ms for a full 16-element array, including a

somewhat conservative 1ms wait after each operation of the switch to allow for receiver settling. Following this, a further 20ms is used to manipulate the data and store in a form ready for recording. In this way, up to 20 sweeps per second of a full 16-element array are possible which is expected to be sufficiently quick to accommodate most fading conditions. The required time is reduced proportionately for fewer elements.

#### 4. THE SYSTEM SOFTWARE.

Two computers are involved in the overall project. The first is a small micro-computer (Altair 8800) whose primary function is to oversee the data gathering operations of the system. The second, a somewhat larger LSI 11/23 machine, provides the facilities and speed necessary for a detailed analysis of the data.

In performing its duties, the Altair computer looks after the switching of the antennas and accumulates amplitude and phase information in a form suitable for recording on 9-track tape in a manner described in section 3.6. All of the soft-ware needed to do this, including the actual recording, has been developed and is in place. The advantage of such computer control is that changes can be made in short order so that, for example, some limited decision-making capability can be quickly incorporated in the light of experience.

On the analysis side, Fast Fourier Transform (FFT) routines have been put in place on the LSI 11/23 in preparation for rapid detailed analysis. Subject to testing, some real time analysis seems to be well within the capabilities of the machine and it is envisaged that this will be investigated.

### 5. THE OVERALL POSITION.

All of the equipment described in the previous sections has been developed, built and tested in the laboratory.

Considerable attention to detail has been paid in the development of the antenna systems, not only from the point of view of electrical integrity but also from that of the mechanical properties; for example, the receiving antenna mounts allow for differential expansions in the waveguide (brass), horn supports (aluminum) and tower (steel). All of the antennas are in place for a field trial of the 8-element system, with the additional hardware needed for expansion to 12 elements in place or on order.

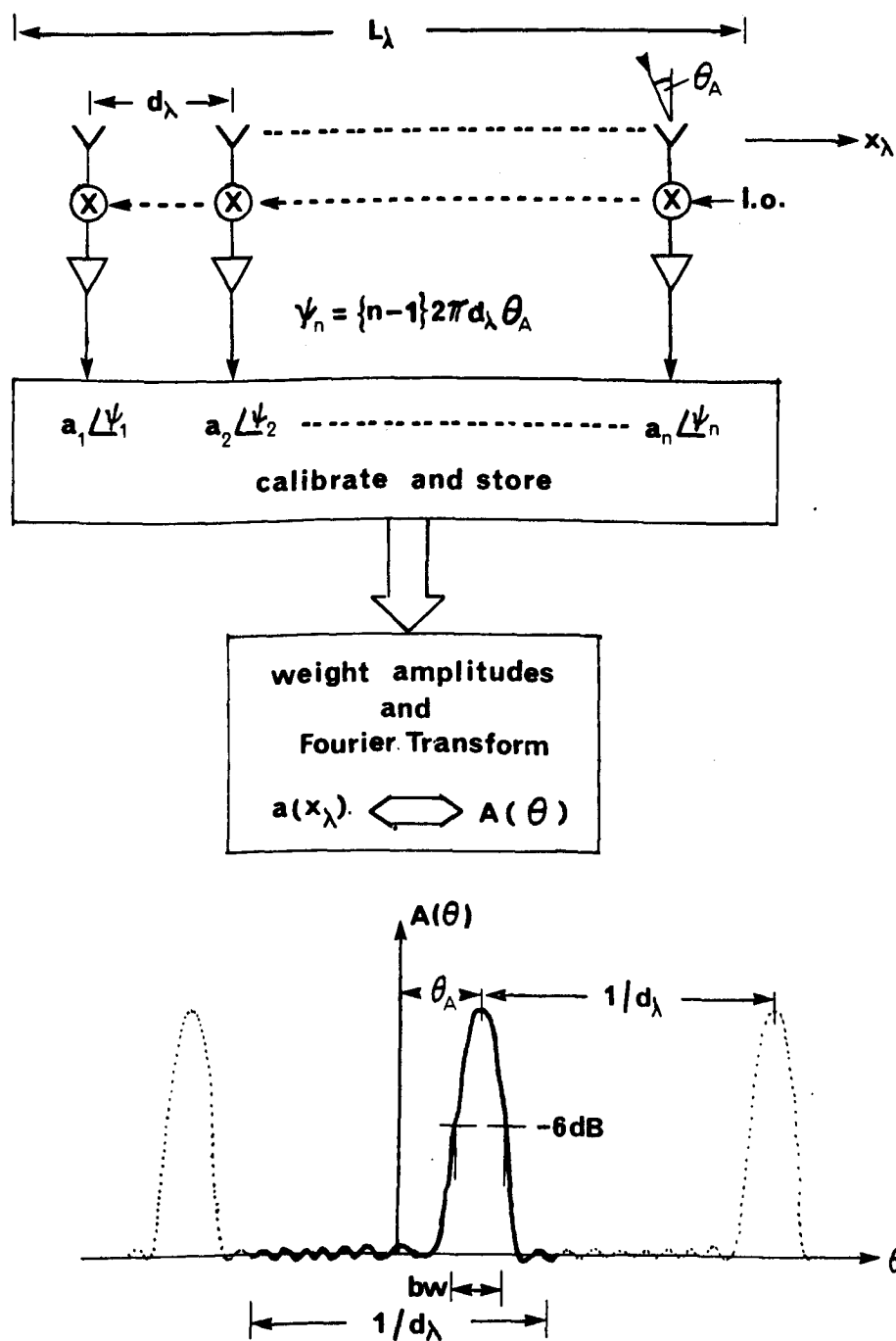
The transmitter has been installed on the Ontario Hydro microwave tower at Uniondale with the receiving antennas on the roof of the Centre for Radio Science (CRS); the geographical layout is shown in fig. 5.1.

The link is established in the sense that the signal is currently being received at CRS on the reference channel. Some difficulties have arisen in that the transmitter amplifier failed immediately before installation and the initial orientation of the transmitting antenna appears to be slightly off optimum. The amplifier has been returned to the manufacturer for repair and both deficiencies will be corrected upon its return (a full

Given the reduced received power level at the moment, encouraging performance of the system has been observed. The phase-locking part of the system is working well although it has been noted that difference in frequency (120MHz) between the two microwave oscillators drifts slowly (hours) over a range of about  $\pm 20\text{kHz}$  as opposed to the expected  $\pm 10\text{kHz}$ . The potential is there for loss of lock under a very deep fade should the frequency drift outside the 30kHz receiver bandwidth (when unlocked) but this can be readily accommodated by incorporating a long time constant "follower" circuit. No problems are anticipated from this area.

Final installation of the remaining equipment, for example the antenna switch and associated cables, is currently in progress and full operation of a 12-element system is expected within the next few weeks.





$$\text{Beam-width (bw)} : \begin{cases} \text{Unweighted} & > 1.2/L_\lambda \\ \text{30dB Dolph-Tcheb.} & > 1.5/L_\lambda \end{cases} \text{ rad.}$$

Fig 1.1 Angle-of-arrival ( $\theta_A$ ) from a wide-aperture array

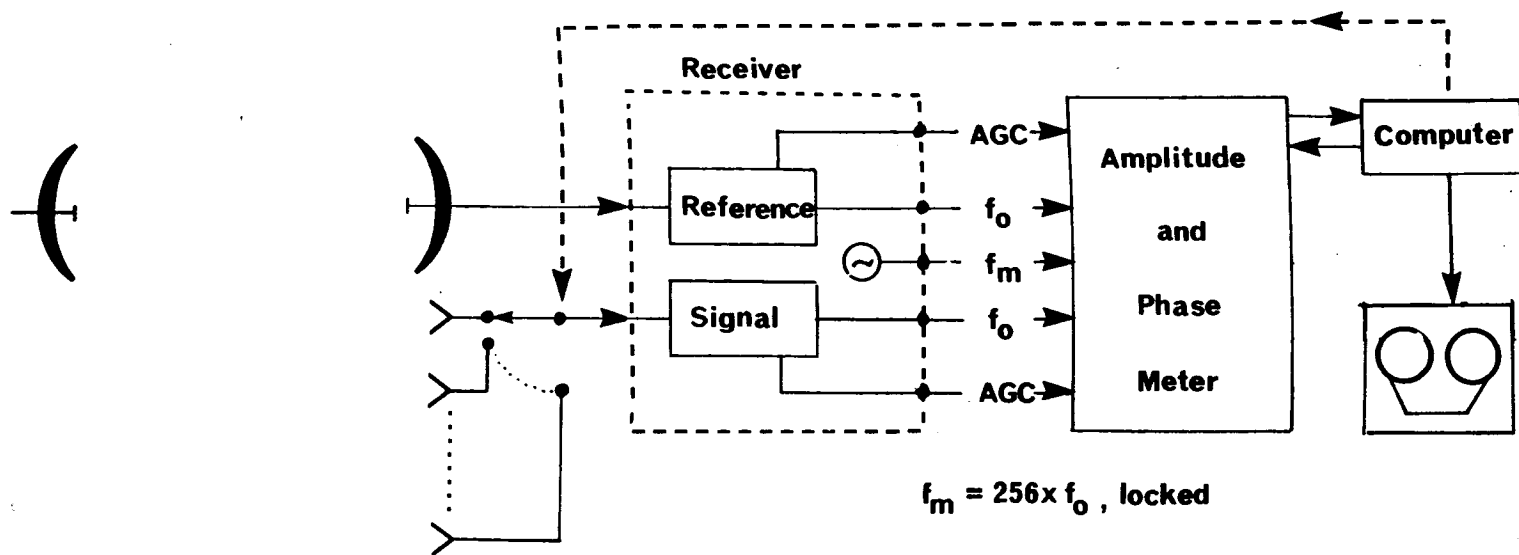
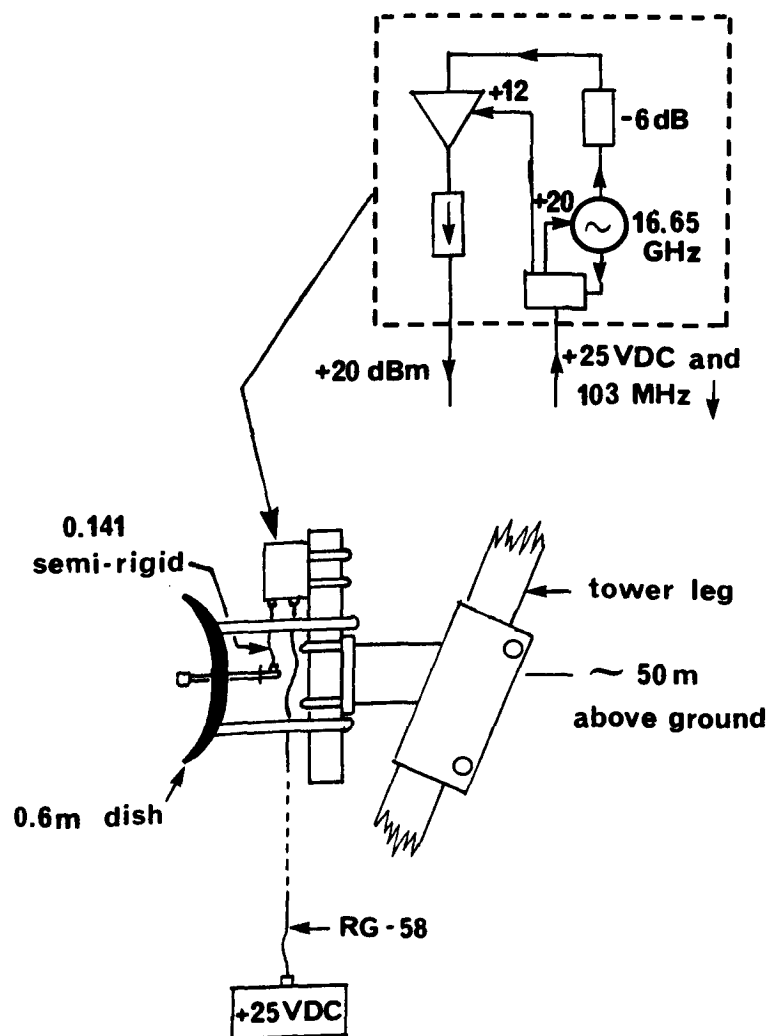


Fig 3.1 The basic system



**Fig 3.2 The transmitting arrangement**

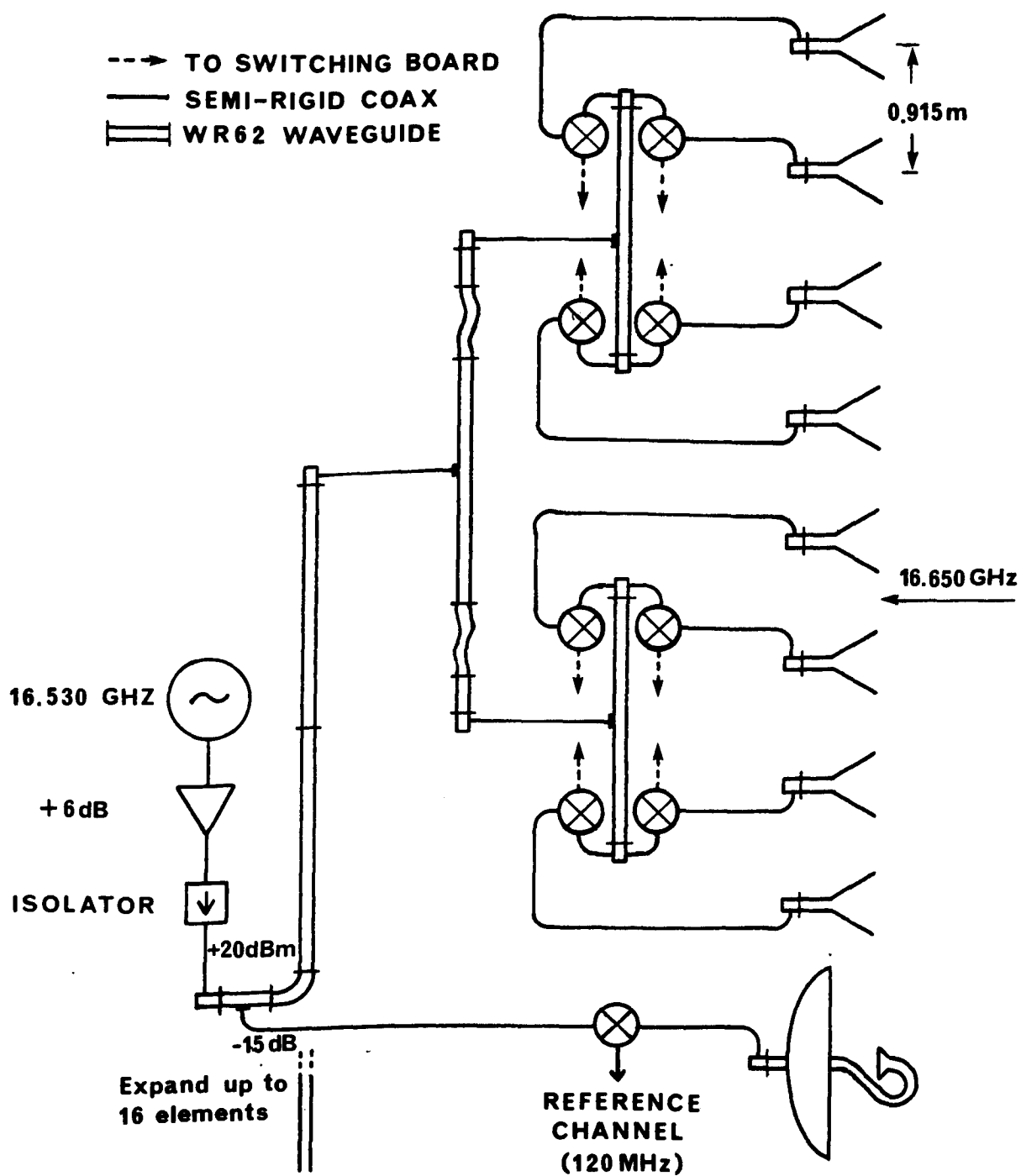
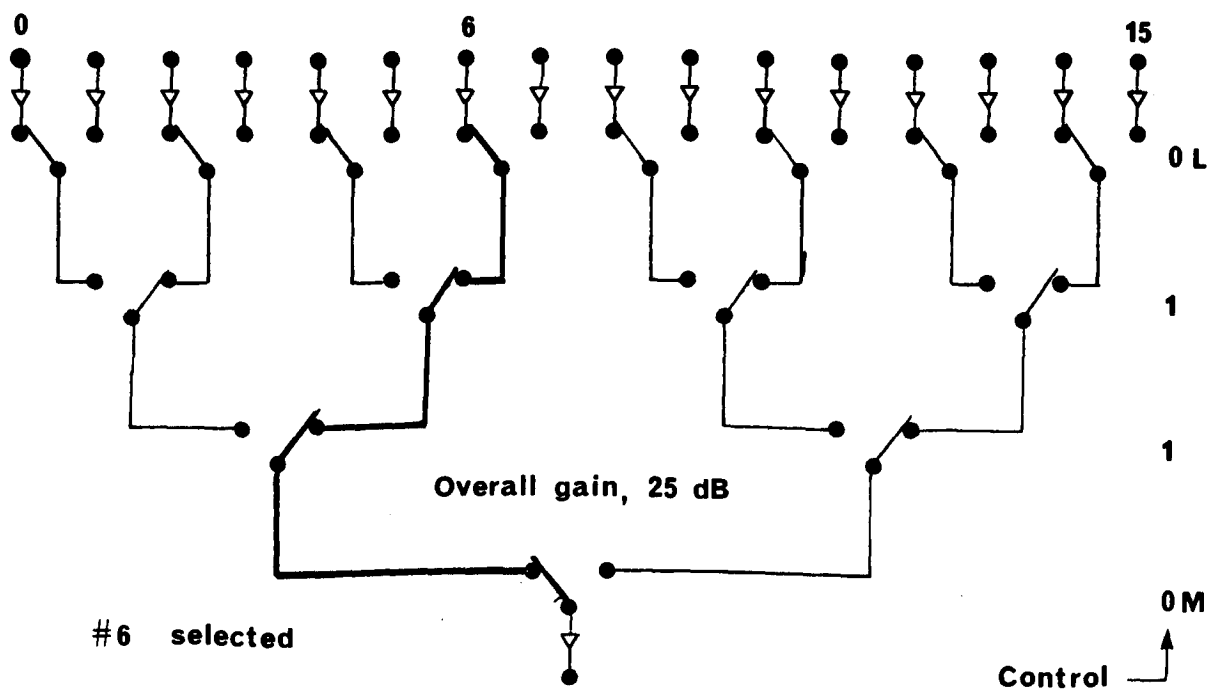


Fig 3.3 The receiving antenna system



MWA 110  
14 dB gain  
at 50  $\Omega$

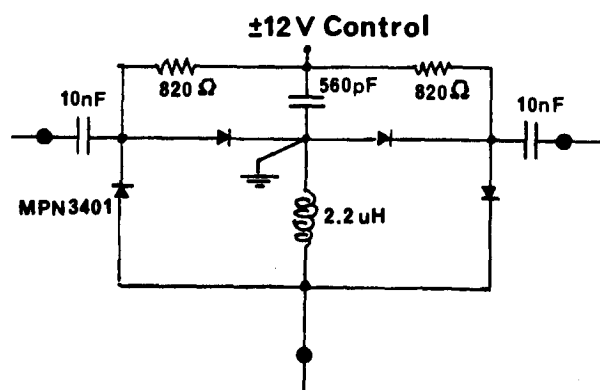
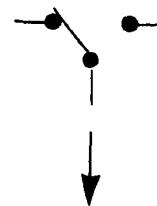
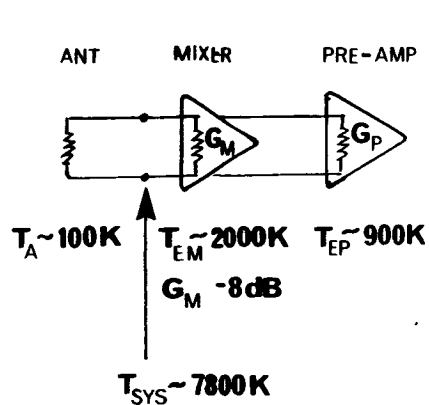
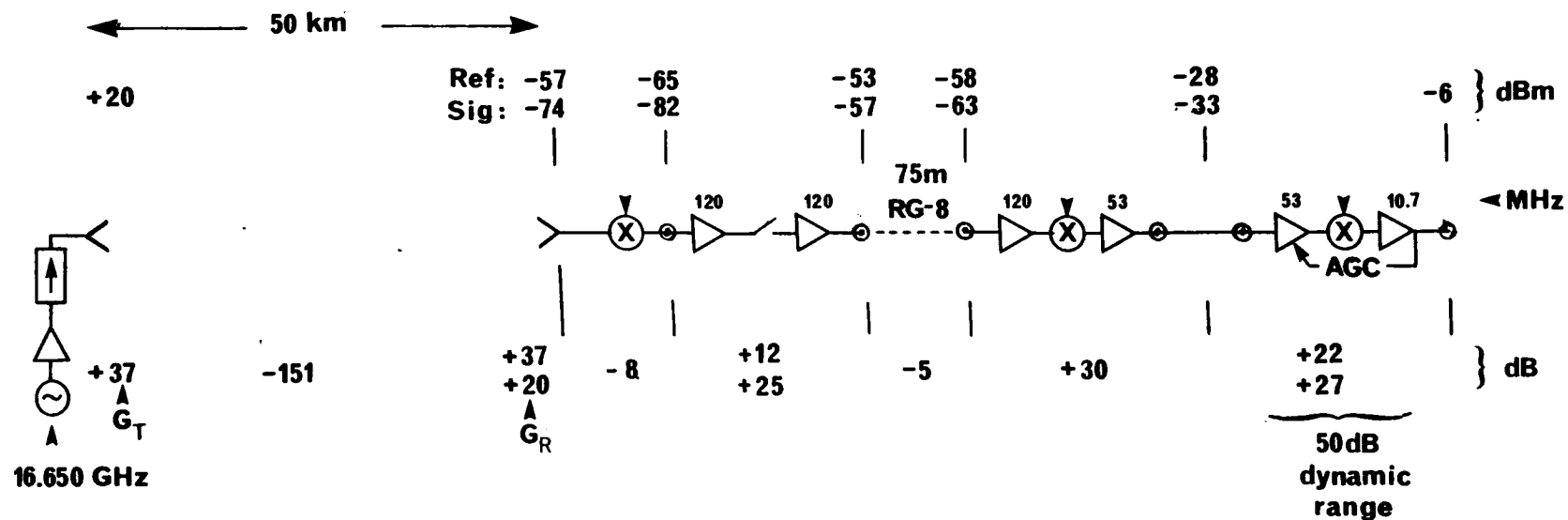


Fig 3.4 The switching board





Signal: noise referred to antenna

s, dBm	b.w., kHz	n, dBm	s:n, dB
-57	30	-115	58 < Ref.
-74	10	-120	46 < Sig.

Fig 3.5.2 An overview of signal levels



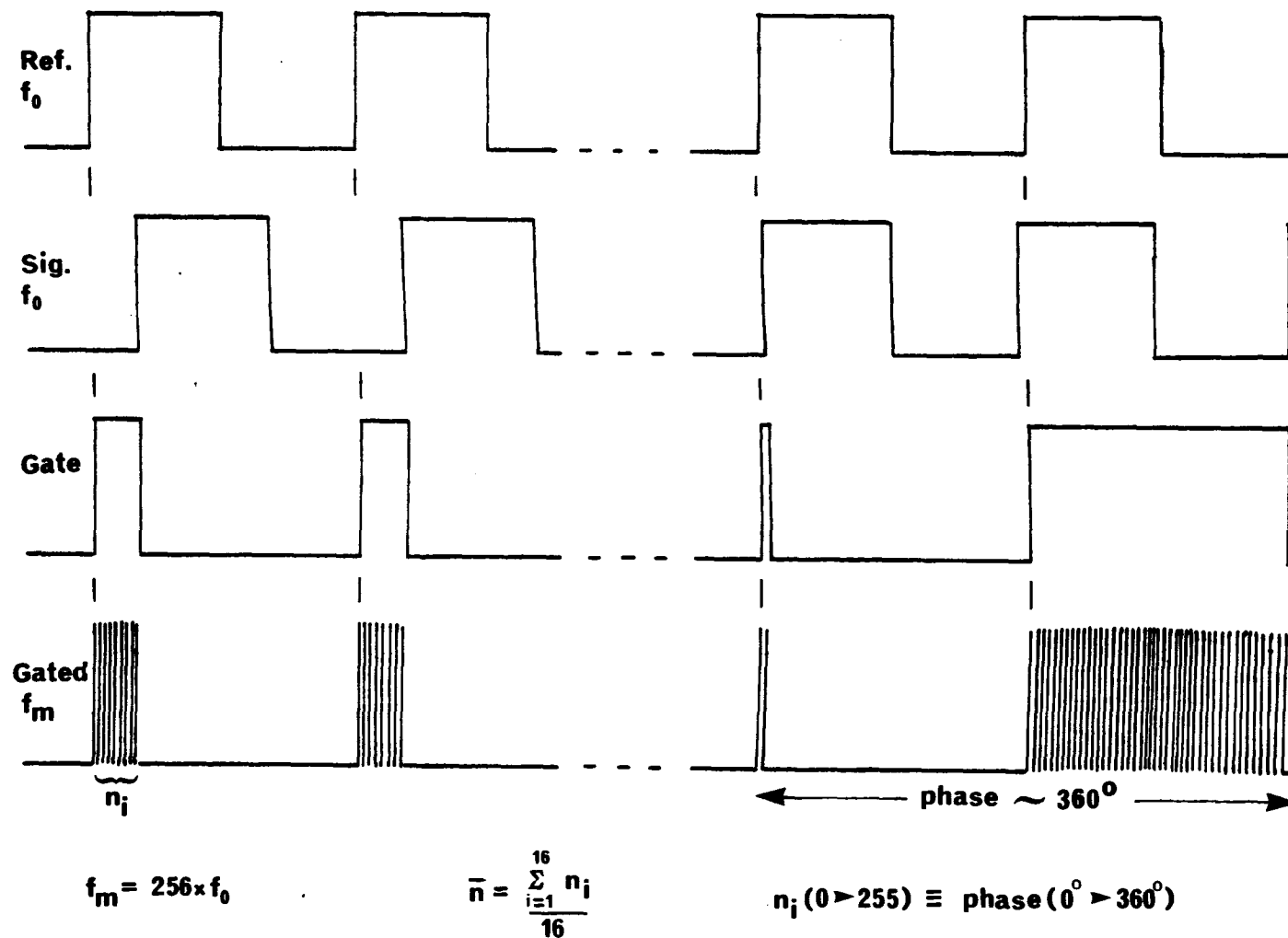


Fig 3.6 Illustrating the phase-meter principle.

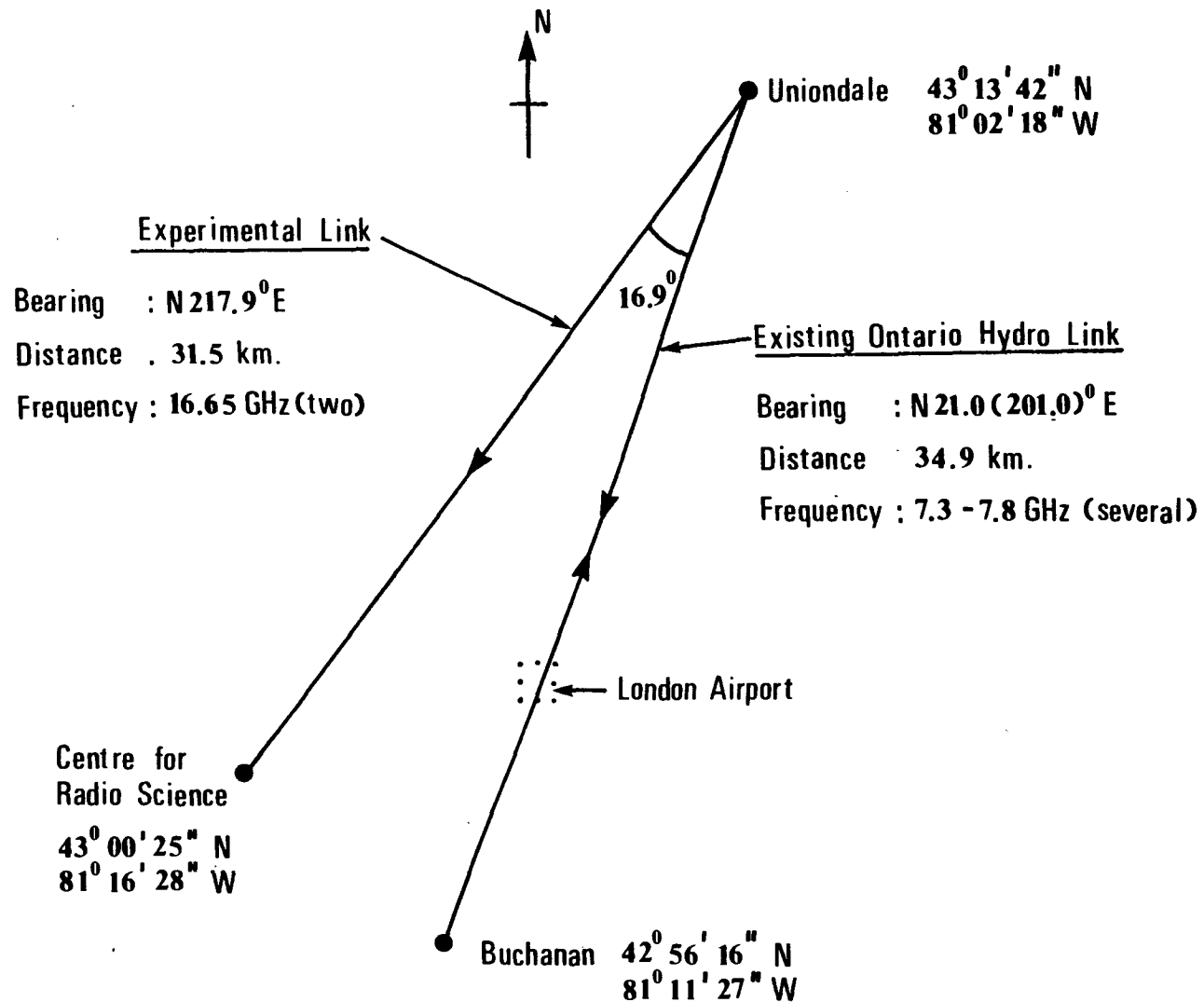


Fig 5.1 The geographical layout .

ACKNOWLEDGEMENTS

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The cooperation of Ontario Hydro in allowing access to the microwave tower at Uniondale is greatly appreciated.

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