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EISCATs VHF-Antenna and Receiving System

by
Kristen Folkestad

KIRUNA
Sweden

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KRISTEN FOLKESTAD

EISCAT Scientific Association
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1. INDTRODUCTION

The VHF-antenna and its feed system has been described in several contexts (Kärcher, 1980; Kildal, 1982; Hagfors et al, 1982). This report intends to provide some practical information for those who are going to use the VHF-antenna in their experiments.

The antenna is first briefly described, its location, physical area, effective aperture, modes of operation and bandwidth restrictions while being phased off - broadside. A set of formulas is given relating the azimuth and elevation of the antenna beam to the antenna's pointing parameters: the phase steering- and the mechanical rotation angles. Plots are presented to allow the experimenter to determine which parameters to select to be able to access a given region in the ionosphere. The third chapter deals with the signal path configurations in the two modes of operation and points to some practical limitations which exist within the present system in combining experiments in the split beam option.

Since the steering capabilities of the UHF- and VHF-antennas are different, the procedures adopted for beam pointing during the execution of experiments must also differ. For the fully steerable UHF-system the antenna handling is well established within the existing real time operating system, EROS. For the VHF-antenna the set of pointing instructions is not yet worked out in detail. To complete this task one must know how the pointing constraints within the VHF-system are to be treated in planning and preparing experiments. These problems is the subject matter for the penultimate chapter. The final chapter discusses the adequacy of the present real time command structure in dealing with the VHF-system and points to modifications which must be made.

2. ANTENNA AND POINTING

2.1 Antenna configuration and location

The antenna is designed as a parabolic cylindre, consisting of four independently movable panels of dimension 30m x 40m. The panels can be operated together as one antenna, or panel pairs 1 & 2 and 3 & 4 can be used as independent antennas. The two ways of operating the antenna are termed mode I and II respectively, or "single-beam" and "dual-beam" configuration. The change of operating mode is effected by a coupling network know as the "switch-yard", located underneath the antenna. The essentials of the UHF-antenna are given in the following table.

Location:	
- Latitude	69°35'11.9408" N
- Longitude	19°13'13.230" E
- Height above sea level	85 m
Orientation of plane of mechanical movement	0.5° west of north
Effective aperture area in mode I, broadside:	
- Circular, calculated	3250 m^2
- Horizontal, measured	3330 ± 240 m^2
- Vertical, measured	2890 ± 210 m^2
Beamwidths, calculated for broadside:	
- Mode I	0.6° east/west 1.7° north/south
- Mode II	1.2° east/west 1.7° north/south
Range of steering in transit plane	30° south to 60° north of zenith
Speed of mechanical movement	5°/min.

Table 2.1 VHF-antenna specifications.

The primary feed system is an array of 128 crossed dipoles mounted on a feeder bridge along the focal line of the cylindrical trough. If the feed paths for all dipoles are identical the antenna is said to be "broadside". By systematically interchanging phasing cables to the individual dipoles the antenna beam can be steered up to 21.3° off broadside, in steps of approximately 1.25°.

The relation between the steering angle, γ, and angle number (index) N at the centre frequency f_o is given by:

$$\gamma = \arc \sin \left(\frac{N}{67 \cdot 0.7} \right) \tag{1}$$

For the usable steering range N may vary from -17 to +17. Changing of phasing cables must be done manually and it takes the full staff several hours to complete this job. The cable connectors are worn by these actions and it was envisaged when the feed system was designed that no more than 10 phasing operations a year should be performed.

To avoid excessive cable lengths a phasing system modulo 2π is adopted. As explained by Hagfors (1978) and Folkestad (1981) this has the consequence that the antenna has a frequency dependent bandwidth. To explain this problem in some more detail let us assume that a frequency f_o is transmitted and a frequency f_1 is received. For ion line observations $|f_1 - f_o|$ ranges below a few tens of kHz. For plasma line returns f_1 may differ from f_o by as much as 10-15 MHz. With the phasing arrangement selected the steering angle depends upon frequency. Let us denote the steering angles γ_o and γ_1 at f_o and f_1 respectively. The bandwidth is defined as the frequency deviation $\Delta f = |f_1 - f_o|$ which makes $|\gamma_o - \gamma_1|$ equal to half the beamwidth. The relationship between the antenna bandwidth and the steering angle is shown in figure 1.

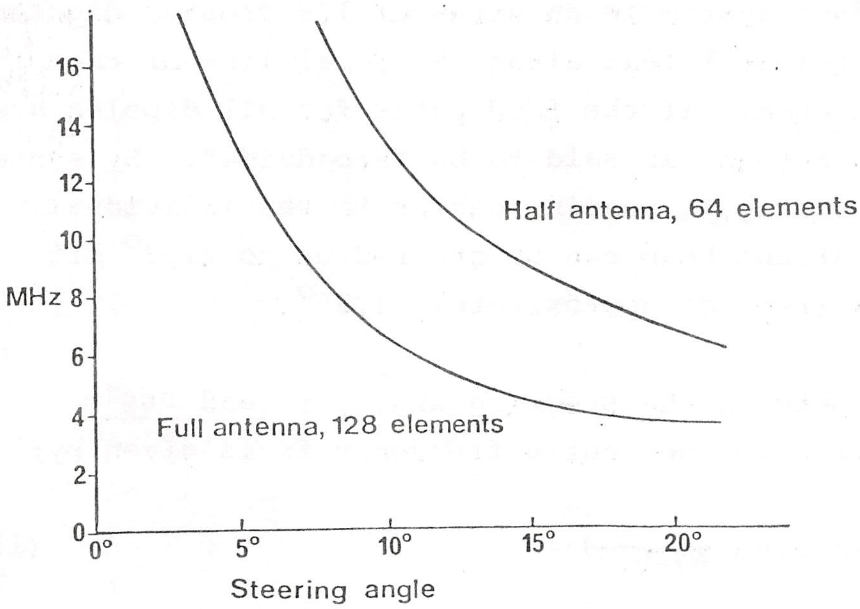


Figure 1 Antenna bandwidth as function of steering angle

We note that for broadside there is no change of the main beam direction with frequency. In this case the bandwidth is determined by other elements in the feed system. The bandwidth restriction is of no significance for ion line observations, but may be a severe limitation for plasma line measurements.

2.2 Coordinate systems and pointing relations

With reference to the figures given in this section we introduce the following list of notations:

LA_T: latitude of transmitter

LO_T: longitude of transmitter

LA_O: latitude of point of observations

LO_O: longitude of point of observations

α : bearing (azimuth) of antenna beam

α_O : azimuth of transit (broadside) plane (= 0.5^O)

t_O : angle subtended at the center of the earth by the great circle arc between the transmitter and the foot point of the radial line through the point of observation

β : mechanical steering angle. The complementary angle, $90^O - \beta$, is displayed on the antenna steering panel as "Position"

β_O : beam zenith angle

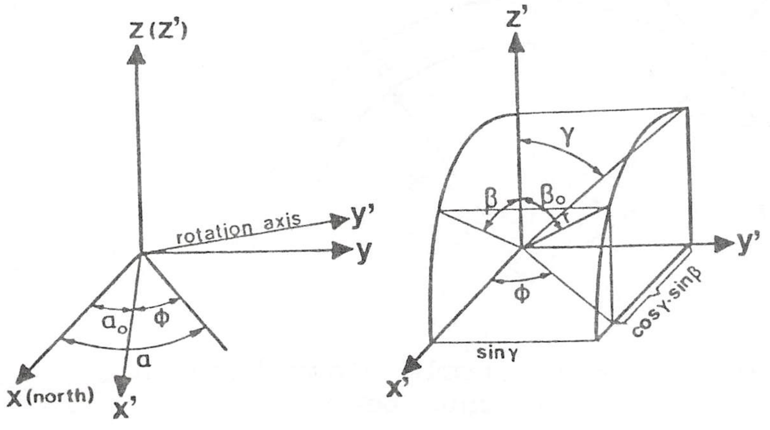
γ : steering (phasing) angle ($\leq 21.3^O$)

$\bar{r}$: unity vector along beam

r_O : distance from the transmitter to the point of observation

h : height above the earth of the point of observation

R_O : radius of the earth (assumed sperical)



(a) (b)

Figure 2 Coordinate systems and pointing geometry

In figure 2a the xyz-coordinate system is oriented with the x-axis pointing north and the z-axis directed vertically upwards. It turns out to be convenient to work in the coordinate system x'y'z', rotated so as to let the y'-axis coincide with the antenna rotation axis. In figure 2b the beam is specified by the unity vector $\bar{r}$. When the antenna is rotated the $\bar{r}$-vector describes a conical surface.

Noting that the length of the projection of the $\bar{r}$-vector in the x'z'-plane remains fixed, equal to cos γ, during the rotation on the antenna, we easily derive the relationships:

$$tg\ (\alpha - \alpha_o) = \frac{\sin\gamma}{\cos\gamma \cdot \sin\beta} = \frac{tg\gamma}{\sin\beta} \qquad (2)$$

$$\sin \beta_o = \frac{\cos\gamma \cdot \sin\beta}{\cos\ (\alpha - \alpha_o)} = \frac{\sin\gamma}{\sin\ (\alpha - 0.5^o)} \qquad (3)$$

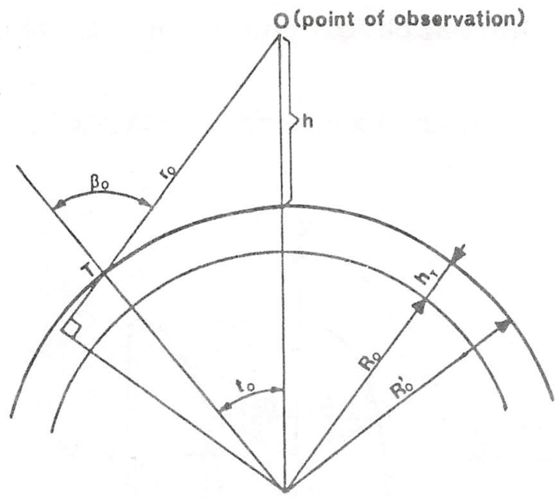


Figure 3 Great circle plane through the antenna beam

Figure 3 shows a great circle plane through the transmitter and the point of observation. We assume a spherical earth.

The height of the transmitter above the sea level, given as h_T in figure 3, is only 85 m and is neglected in the following formulas. Simple geometrical considerations give:

$$r_o = \sqrt{(R_o \sin t_o)^2 + \left[(R_o + h) - R_o \cos t_o\right]^2} \quad (4)$$

$$r_o = \sqrt{R_o^2 \cos^2 \beta_o + 2 R_o h + h^2} - R_o \cos \beta_o \quad (5)$$

$$\sin \beta_o = \frac{R_o + h}{r_o} \sin t_o \quad (6)$$

$$\mathrm{tg}\, t_o = \frac{r_o \sin \beta_o}{R_o + r_o \cos \beta_o} \quad (7)$$

Standard formulas in spherical geometry give us the relations between the azimuth of the antenna beam and the coordinates of the transmitter and the point of observation.

$$\cos t_o = \sin LA_T \sin LA_O + \cos LA_T \cos LA_O \cos (LO_O - LO_T) \quad (8)$$

$$\sin \alpha = \cos LA_O \sin (LO_o - LO_T)/\sin t_o \quad (9)$$

$$\sin LA_O = \cos t_o \sin LA_T + \sin t_o \cos LA_T \cos \alpha \quad (10)$$

Introducing numerical values for LA_T and LO_T (given in table in 2.1) we obtain:

$$\cos t_o = 0.93720 \sin LA_O + 0.34879 \cos LA_O \cos (LO_O + 19.22034) \quad (11)$$

$$\sin \alpha = \cos LA_O \sin (LO_O + 19.22034)/\sin t_o \quad (12)$$

$$\sin LA_O = 0.93720 \cos t_o + 0.34879 \sin t_o \cos \alpha \quad (13)$$

In formulas (11) - (13) eastern longitudes are taken as being negative.

In figure 4 and 5 are shown the fields of view of the VHF-antenna at 300 and 500 km above the ground.

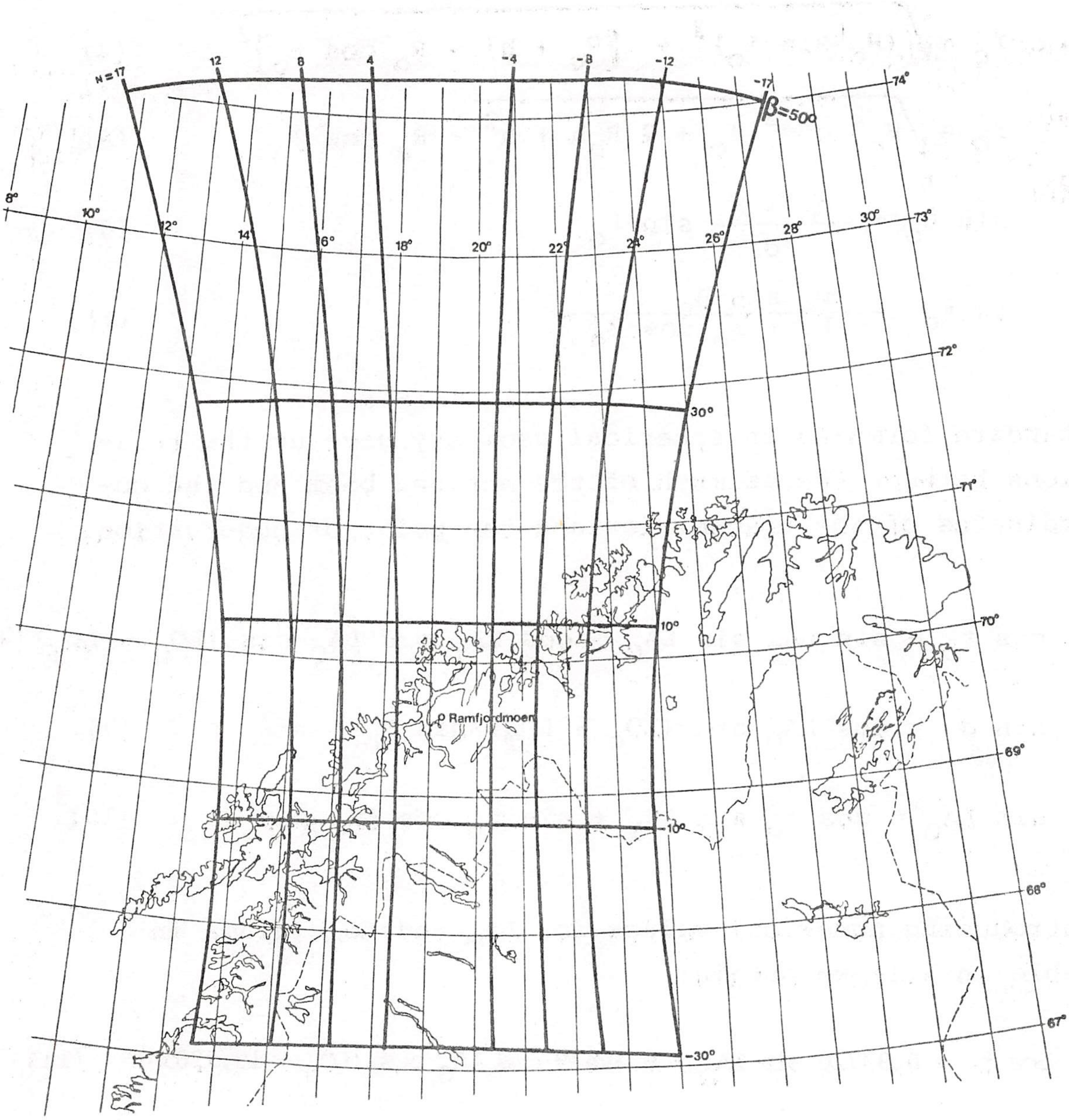


Figure 4 Field of view of VHF-antenna at a height of 500 km above the ground. The mechanical steering angles, β, are indicated, along with the angle indices, N, associated with the trajectories shown.

The relation between the phase steering angle, γ, and N is given by formula (1). For completeness the values of γ are quoted in table 2.2 for N ranging from 0 to 17 at the centre frequency f_o = 224 MHz.

N	0	1	2	3	4	5	6	7	8	9
γ, degrees	0	1.22	2.44	3.67	4.89	6.12	7.35	8.58	9.82	11.06

N	10	11	12	13	14	15	16	17
γ, degrees	12.31	13.56	14.82	16.09	17.37	18.65	19.95	21.25

Table 2.2 Corresponding values of γ and N

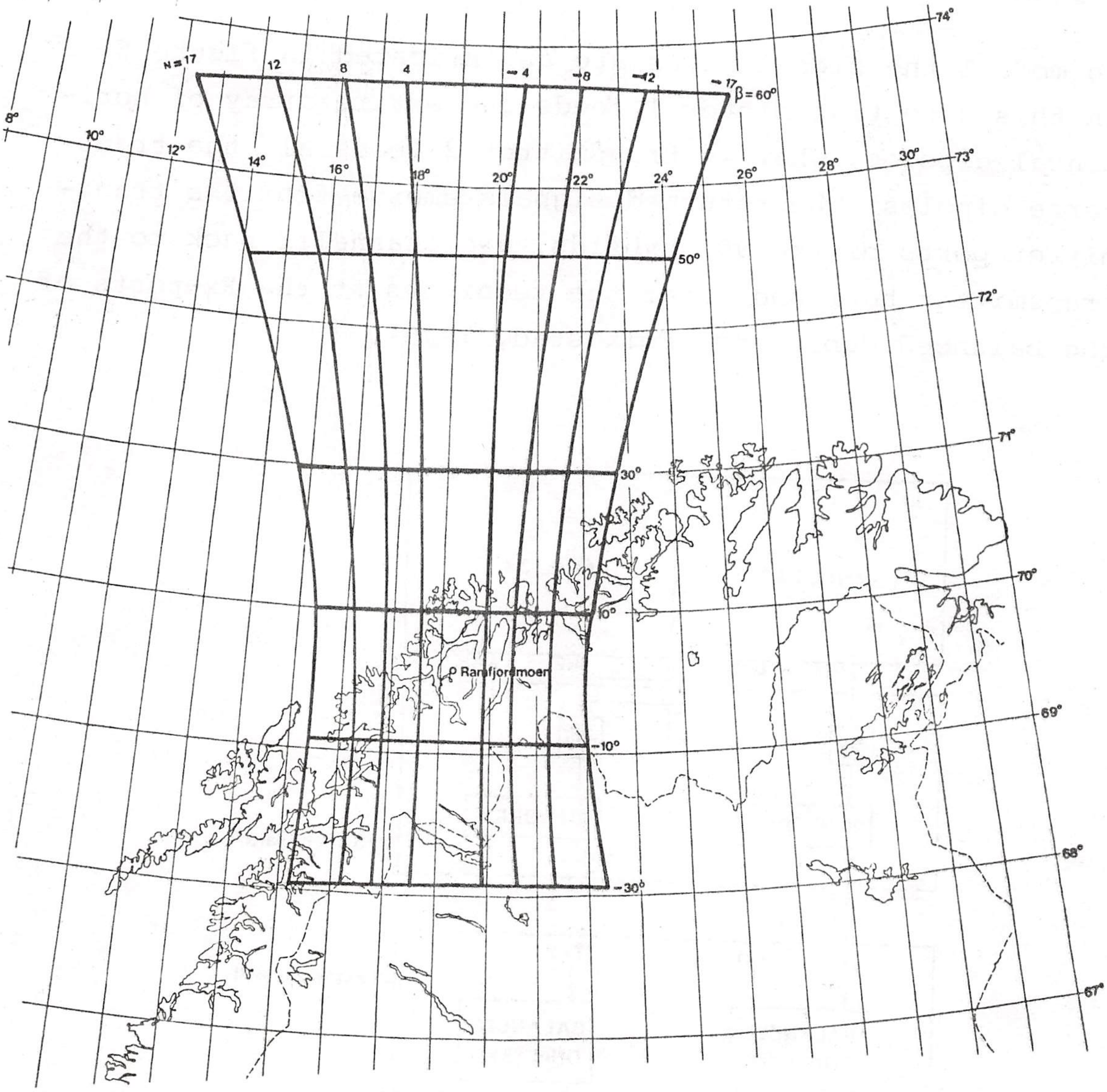


Figure 5 Field of view of the VHF-antenna at a height of 300 km above the ground.

In all graphical presentations in this report phase steering is specified in terms of the beam index N. In a computer programme available for organizing the interchange of cables in changing from one angle to another the angles are specified by their indices. Orthographically it is also simpler to use the integer presentation of the index notation than the decimal format required for specifying the angles themselves with sufficient accuracy. Users are asked, therefore, to follow the same convention and apply the indices N rather than the angles γ in describing their phase steering schemes.

3 SIGNAL PATHS AND RECEIVER CONTROLS

In mode I the signal paths are as indicated in figure 6. In this case transmitter 1 feeds the entire array of horizontal dipoles, whereas transmitter 2 feeds all the transverse dipoles. The returned signals emerge from the transmitter ports of the 90° hybrids, are channeled back to the transmitter hall and enter the receivers at the Rx-ports of the balanced duplexers (Folkestad, 1979).

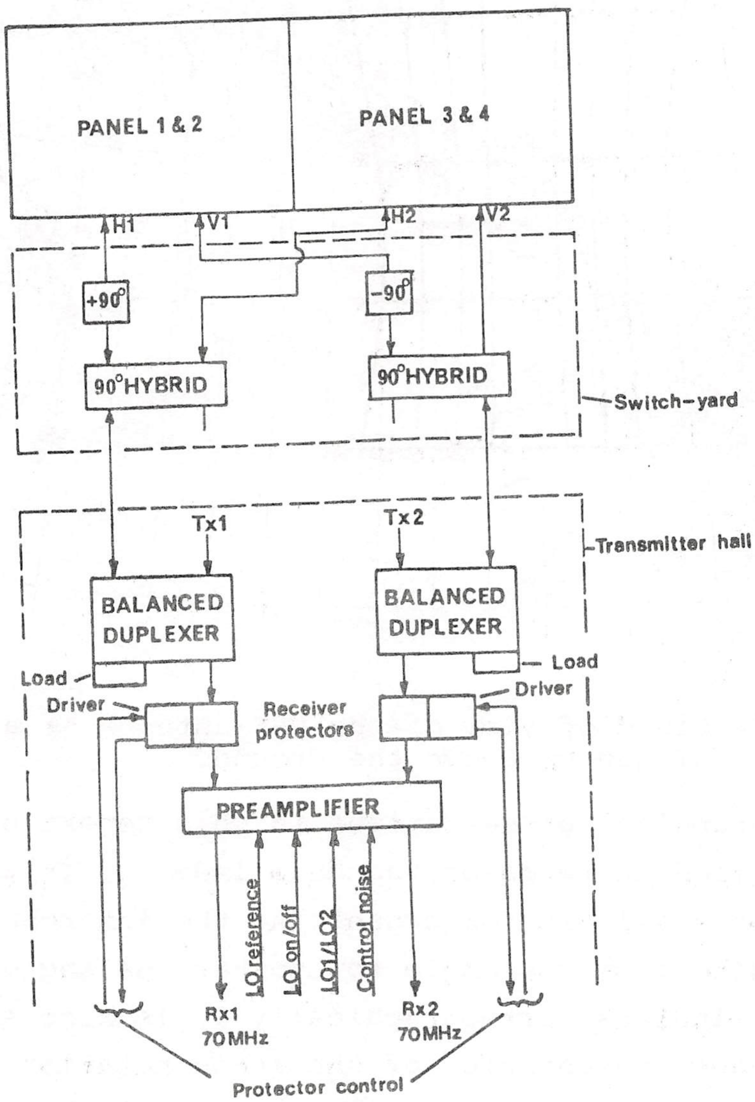


Figure 6 Signal paths in single-mode operation

In mode II the scattered returns are fed into the dual channel preamplifier through the Rx-ports of the hybrids in the switch-yard, as shown in figure 7.

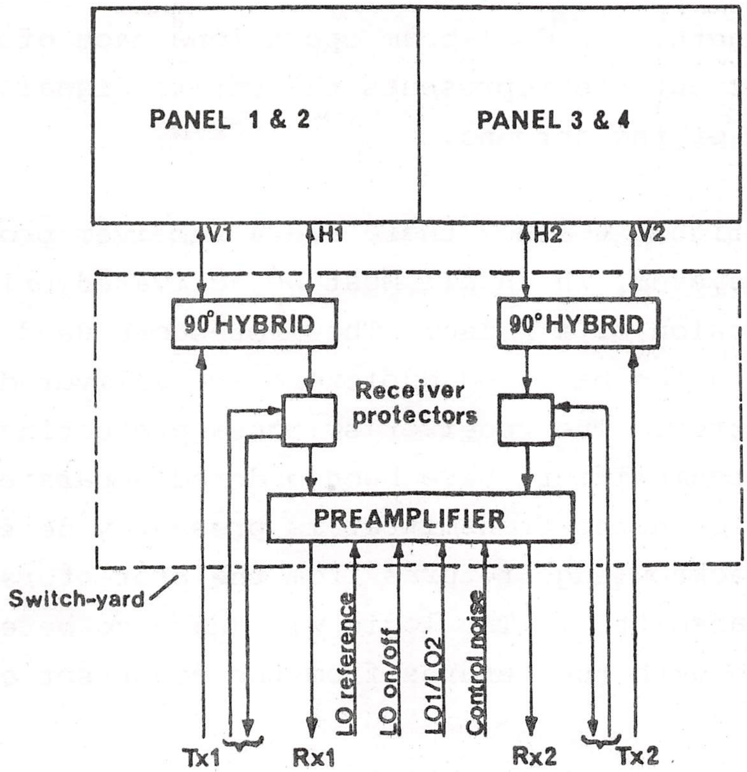


Figure 7 Signal paths in the split beam (mode II) option.

Altogether there are four receiver lines entering the back-end receiver chain. In the present system the first stage of the back-end receiver is designed with two input terminals. To avoid replacing cables when shifting from one mode to the other we will need two coaxial switches in addition to the equipment alreay provided. We believe that manually operated switches are sufficient for this purpose.

It may be noticed that in single-beam applications (all panels acting as one antenna) the two outputs from the preamplifier give the horizontal and vertical components of the signals. Both are required to reconstruct the total signal strength. In dual-beam operations each of the two preamplifier outputs represents the entire signal received by one half of the antenna.

As seen in figure 6 and 7 there are 4 receiver protectors in the VHF-system, which all must be activated prior to the transmission of a pulse. The protectors used in conjunction with the balanced duplexers are delivered with the transmitter. The receiver switches protecting the dual-beam preamplifiers have been ordered separately. The control logic in the transmitter is presently designed to handle the acknowledge returns from the protectors coming with the transmitter. The logic will have to be extended to deal also with the returns from the other set of protectors.

For the control signals required to operate the first local oscillators and the noise injections it will simplify the command structure if both systems are addressed in parallel, even if only one system is used at a time.

Being controlled by the same RF exciter the signals from Tx1 and Tx2 are phase coherent. When the signals feeding the duplexers in mode I have the same phase, the vertical and horizontal components of the transmitted signals differ by 90°, yielding circular polarization. By changing the phase of the low power RF modulating signal of one of the transmitters by 180° between pulses the hand of the circular polarization of the outgoing signal alternates from pulse to pulse. This feature is exploited in conducting electron density measurement by means of the Faraday rotation technique (Farley, 1969). The phase flipping is controlled by one bit in the radar controller. It is noted that the Faraday measurements can only be made as single-beam experiments. In the dual-beam configuration the signals transmitted by each antenna half have left-handed circular polarization irrespective of the phases of the klystron outputs. The Faraday rotation experiments will require special Correlator programmes.

4. USE OF RADAR CONTROLLER/CORRELATOR

In each of the two radar facilities at Ramfjordmoen, the VHF- and the UHF-radar, there is one radar controller and one correlator. It has been inquired whether the two VHF-transmitters in dual-beam experiments could possibly be operated with different modulation waveforms. This appears to require a modification of the exciter and, in some cases, probably also the use of two radar controllers. Such complications do not seem to be justified at the time being and we can reasonably assume that whenever the VHF-radar is used in a split-beam experiment the same programme is employed in both systems.

Duplication of the correlator processing for simple programme combinations, f. inst. ACF- and power profile measurements, in dual-beam applications is readily handled by existing correlator routines. For more involved programmes it may prove desirable or necessary to develop special correlator routines for handling of the twin experiments.

In dual-beam experiments the two systems have to share the correlator memories and the possibility for selecting number of gates, lags and frequencies is more restricted than in single-beam operations.

After the recent breakdown of the correlator at the Kiruna site, due to a fire disaster, one has started to discuss whether the correlator built for the VHF-radar should be permanently assigned to the UHF-system, considering the possibility of an updated correlator design for VHF. Should EISCAT deside in favour of this option, the remarks above about restrictions imposed by the correlator memories may not be relevant.

5. ANTENNA POINTING IN PREPARING OF EXPERIMENT

In the EROS system in its present form there are the following commands for pointing the antennas:

(a) POINT-DIRECTION <AZ> <EL>
(b) POINT-GEOGRAPHIC <LAT> <LONG> <HEIGHT>
(c) POINT-REFERENCE-RANGE <AZ> <EL> <RANGE>
(d) POINT-REFERENCE-HEIGHT <AZ> <EL> <HEIGHT>
(e) POINT-UNCORRECTED <AZ> <EL>

In addressing the fully steerable UHF-antennas the command parameters are all independent variables which the experimenters can freely select within the fields of view of the antennas. This is not generally the case for the VHF-system with the antenna movable in one plane only. We are led to conclude that the present EROS pointing command structure is not readily applicable for steering the VHF-antenna.

With the VHF-antenna in broadside ($\gamma = 0$) the azimuth is fixed (.5° west). For non-zero values of the phasing angle, γ, azimuth and elevation are not independent. In discussing phase steering there are two features, mentioned in previous sections, but worth re-emphasizing:

(i) Since γ can only assume discrete values, the beam can not be pointed in an arbitrary direction within the overall field of view, or, phrased differently, an arbitrary point within the antenna subspace can not be accessed. Once γ is set, the beam is confined to intersect constant height surfaces along north-south lines similar to the ones shown in figure 4 and 5 (intersection between cones and spheres)

(ii) Any change of γ entails a laborious manual procedure prior to the experiments. During the experiments γ is to be considered a constant and not a free variable.

In preparing experiments using the VHF-antenna, it seems reasonable to assume that the experimenters are sufficiently familiar with the system that they can specify the antenna pointing in a way compatible witht the inherent constraints.

In addressing the VHF-antenna encoder the relevant quantity is the rotation angle, β (or rather the complementary angle $\pi/2 - \beta$) and the experimenters are requested to specify their pointing sequences in terms of this parameter.

Once γ and β are given, the beam azimuth and elevation are easily derived from formulas (2) and (3). If the user is not prepared to specify the β's directly, but intends derive the angles from certain latitudinal or longitudinal preferences, a graphical approach is recommendable.

Figure 8, 9 and 10 have been prepared to guide the users in working out the antenna pointing in their EROS programmes. For instance, should the user like to sample points equidistantly spaced in latitude at 500 km at the extreme phase steering ($N = 17$, $\gamma = 21.3^{o}$) he can use the second graph from the top i figure 8 to derive the relevant mechanical steering angles. We note that the

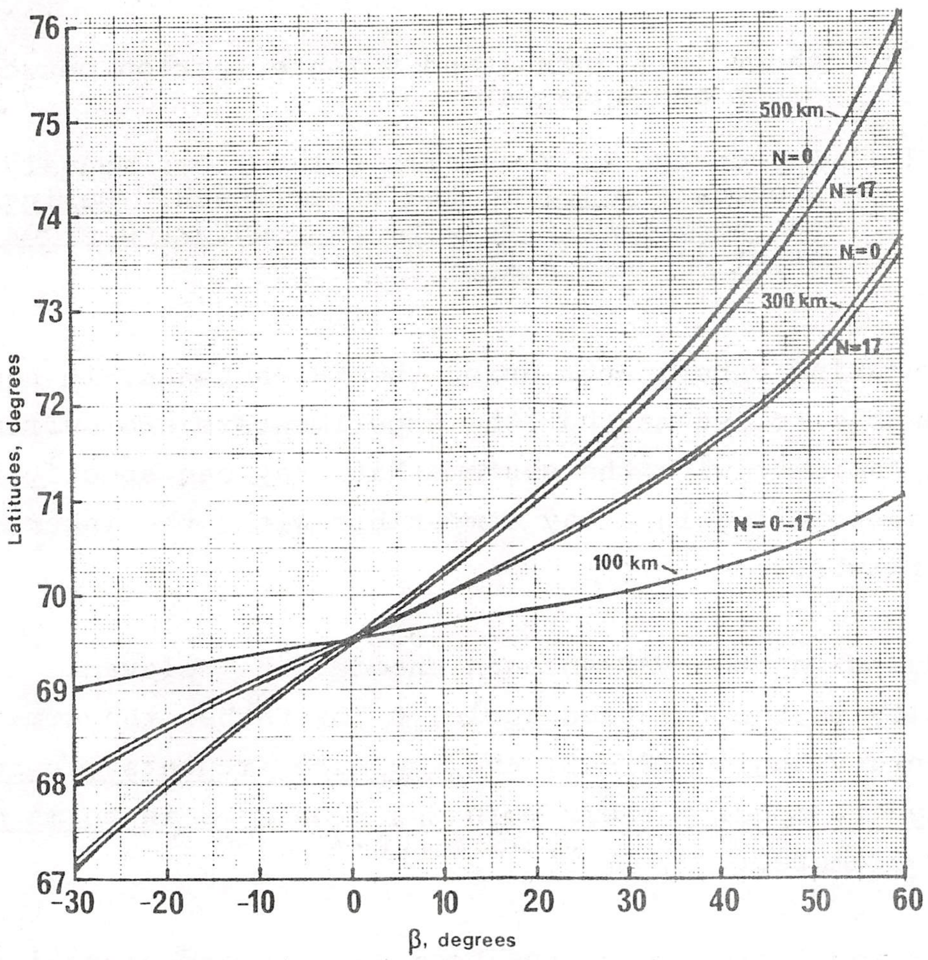


Figure 8 Latitudinal coverage as function of mechanical steering angle for 100, 300 and 500 km.

variation in latitude with varying phase steering angles for given values of β is small, amounting to less than 0.5° at $\beta = 60^{\circ}$ for N varying from 0 to 17 (the graph for N = -17 is between the two curves displayed). At a height of 100 km there is no significant spread in latitude as N varies for given values of β. Should the experimenter wish to space his opservation points in longitude according to a prescribed pattern, figure 9 and 10 indicate the

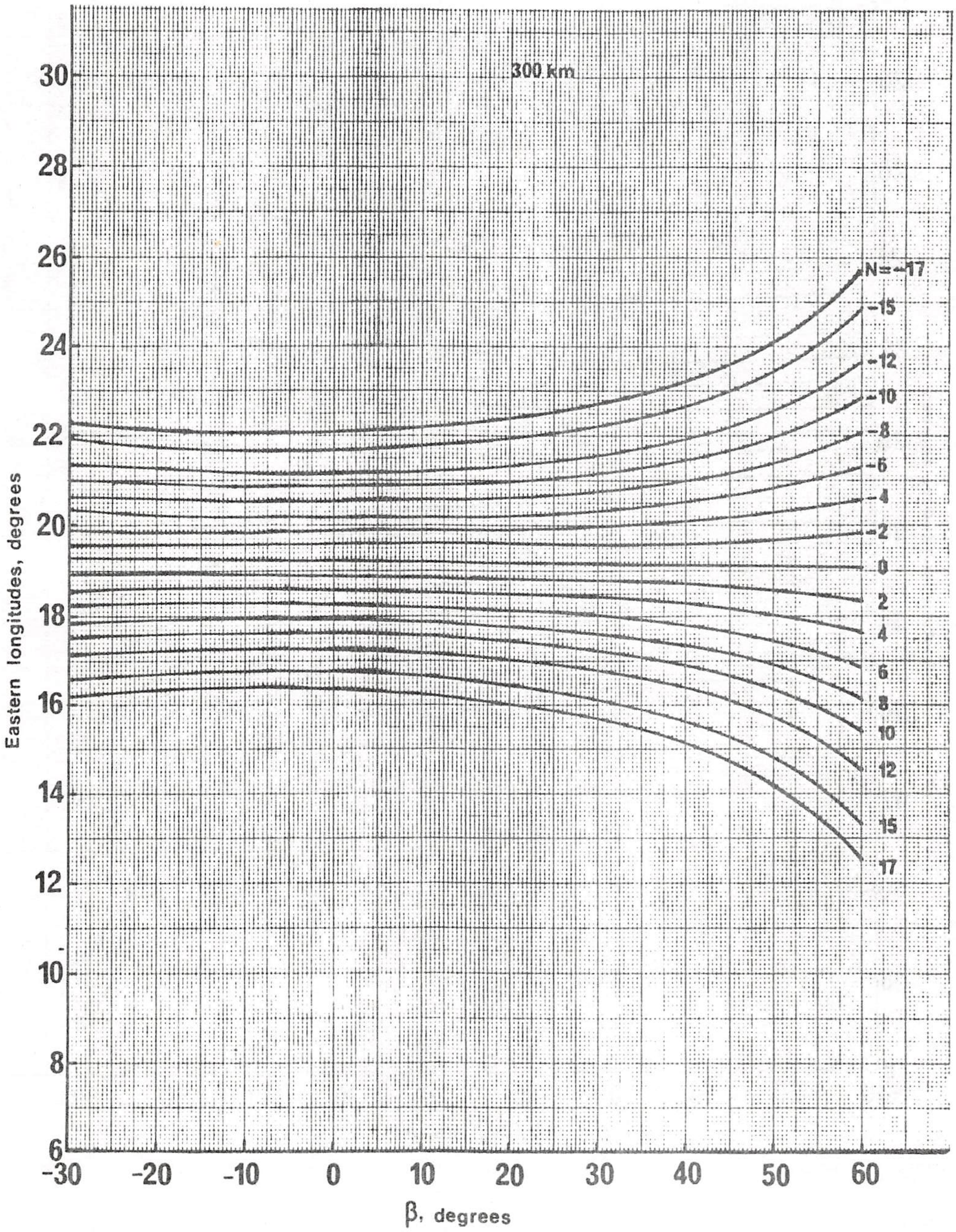


Figure 9 Longitudinal coverage as function of β at 300 km.

possibilities which exist for the two heights 300 and 500 km.

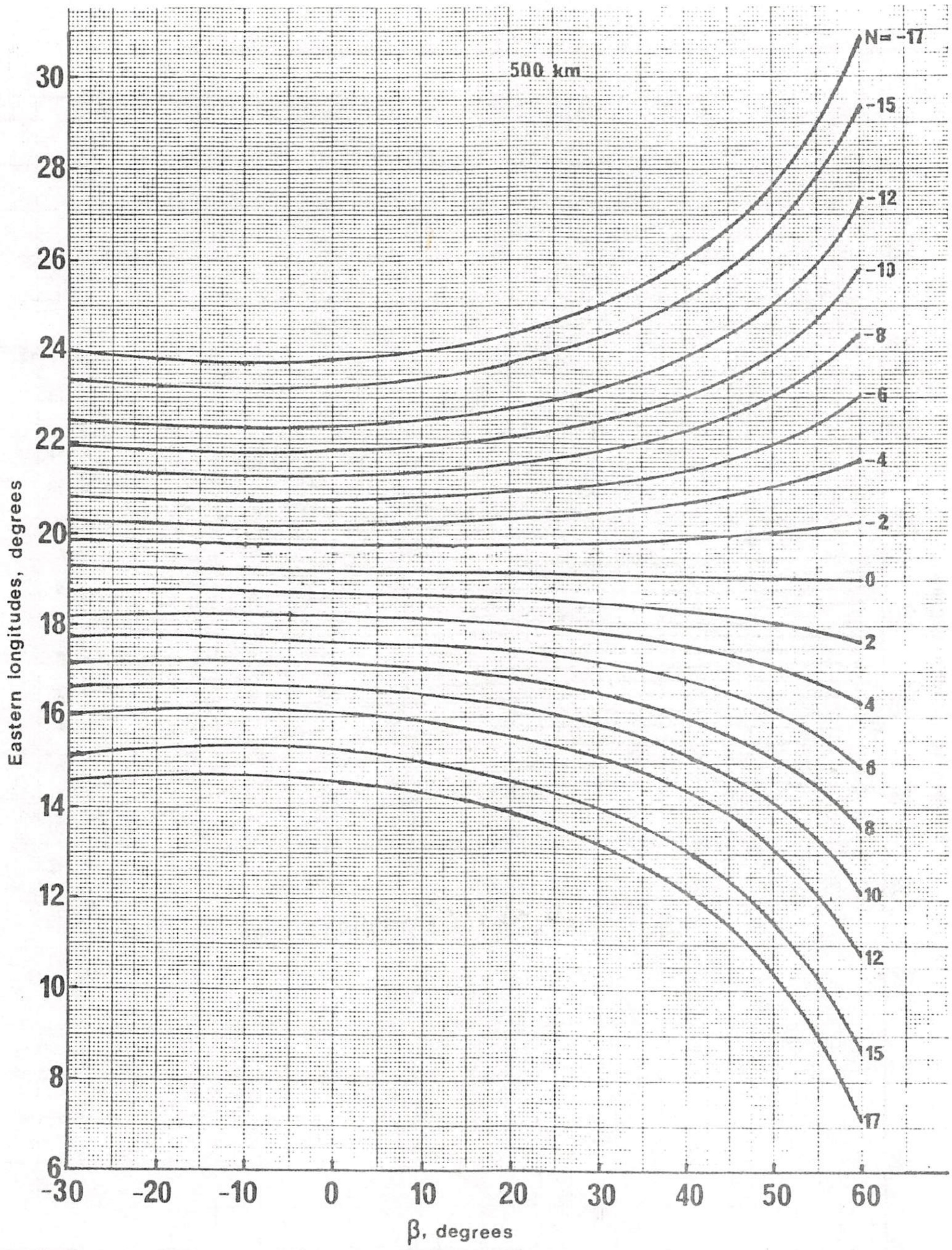


Figure 10 Longitudinal coverage as function of β at 500 km.

To summarize the procedure outlined as a practical approach in preparing the antenna pointing in VHF-experiments:

(i) From the geographical extension of the physical phenomenon to explore the experimenter may use maps like the ones shown in figure 4 and 5 (more detailed if necessary) to determine which angle γ gives the best fit. The angle should preferably be given by its number index (ranging from 0 to 17)

(ii) From graphical plots similar to the ones displayed in this section of the report, or alternative computations, the user is requested to specify the sequence of mechanical steering angles to use, either in the form of an array β_1, β_2, β_3... or, in case of a uniform angle increment, by β_{min}, β_{max} and $\Delta\beta$.

As mentioned in chapter 2, the phase steering angle, γ, depends upon frequency. In the VHF-radar, as well as at UHF, there are several discrete working frequencies available, 16 altogether, spaced at 0.3 MHz, yielding a maximum frequency deviation of 4.8 MHz. Using the programme outlined in Folkestad (1981), assuming a centre frequency of 224 MHz, figure 11 has been derived. The figure shows how the angular

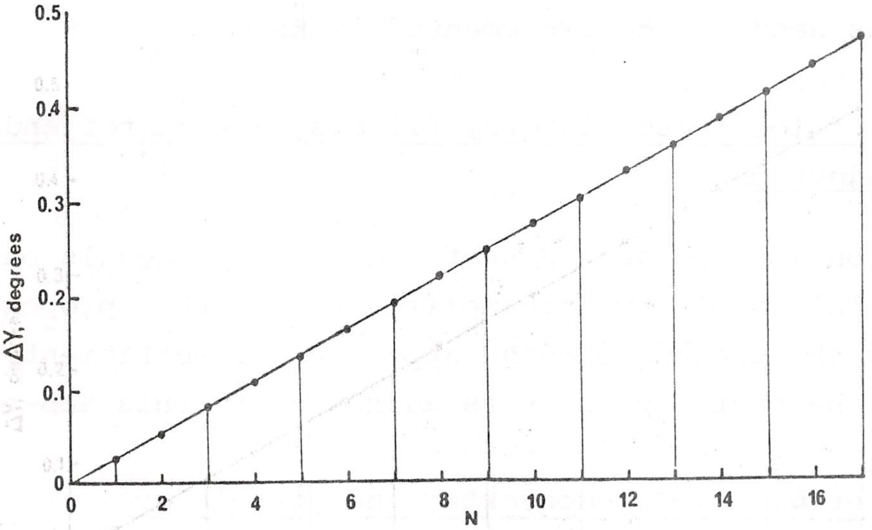


Figure 11 Variation in $\Delta\gamma = \gamma_{221.6} - \gamma_{226.4}$ as function of N.

spacing of the beams, computed for the maximum and minimum frequences, varies for varying values of N. The maximum deviation is less than the beamwidth, and therefore considered to be insignificant for most purposes.

6. REAL TIME COMMAND STRUCTURE FOR VHF

It is evident that parts of the present EROS command hierarchy will have to be modified to accommodate VHF-operations. Here we summarily examine the various parts of the system with the view of indicating where changes are required.

6.1 Operation of Switch-yard and coaxial switches following the preamplifiers

The switch-yard is operated manually, either locally or remotely from the control room. If it is acceptable that also the coaxial switches are set manually, these switching functions need not be implemented in EROS.

6.2 Setting of local oscillators, filters, attenuator and noise injection

In section 3 we suggested that the control signals be fed in parallel to the two preamplifiers. If this proposal is endorsed the present command apparatus is sufficient for setting the system parameters addressed in this sub-section.

6.3 Radar controller, A/D-converter and correlator

The phase flipping required for Faraday rotation experiments is already incorporated in TARLAN. With the same programme applied to both systems in dual-beam experiments, having one A/D-converter and one correlator, we cannot see that any modifications of the EROS or TARLAN instructions sets are necessary to control the units mentioned above.

<u>If a new correlator construction should be accepted, the correlator command structure might have to be completely redesigned</u>.

6.4 Antenna handling

The real time operating system must be capable of:

(i) Distinguishing between the two modes of operation, (designated I and II).

(ii) Assigning phasing angles. Note that for mode II different phasing angles are possible for the two antenna halves.

(iii) Moving the two antenna halves separately during experiments in mode II.

As noticed in the preceding chapter the present EROS commands for antenna pointing are inadequate. Accepting the procedure outlined in that chapter, they may all be replaced by a command POINT-ANTENNA $\langle \beta \rangle$

6.5 Tape handling/RT graph

For the data analysis it will be necessary to modify the parameter block to include the phasing angle(s) and the mechanical steering angle(s) of the antenna(s). The header should also be prepared to accommodate the beam azimuths and elevations for both antennas in dual-beam experiments.

Otherwise it seems that the present tape handling-system and RT graphs-display are cabable of handling the data acquisition also at VHF.

6.6 General comments

It will be a task for the EISCAT programmers to hammer out the details of the EROS-system to handle the VHF-operations. In the present EROS version several command sections are optional, intended to work equally well both for UHF and VHF. A major decision will be whether it is worthwhile to continue this philosophy or whether the changes required justify an entirely new and separate version of EROS.

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