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PARTIAL REFLECTION EXPERIMENT AT AHMEDABAD

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ABSTRACT:

The Partial reflection experiment built at PRL., Ahmedabad for studies of the D region of ionosphere basically incorporates a high powered transmitter, a sensitive receiver, a high gain antenna system and data recording facility. The design considerations for building a partial reflection sounding system have been discussed. The design and performance of the individual units have been dealt with in detail. The authors have also outlined the method of deriving electron density of the D-region by means partial reflection technique.

INTRODUCTION :

The D-region of the ionosphere is the ionized part of the middle atmosphere in the altitude region of 50 to 90km. A knowledge of the behaviour of this region is necessary because high frequency radio waves passing through this region get absorbed. The main parameter of interest is the electron density distributions. Amongst various techniques available, partial reflection technique has been used in the last two decades to derive electron density profiles in the height range of 60km to 90km. Partial reflection technique was originally introduced by Gardner and Pawsey (1953) and later modified by several workers. In this technique a high frequency radio wave is transmitted vertically up and the amplitude or phase of the ordinary and extraordinary magnetoionic components of the weakly scattered signals received from the ionosphere are recorded as a function of height. Electron densities are calculated using the difference in absorption between the ordinary and the extra ordinary waves having passed through the D-region i.e. the ratio of the received extraordinary to the ordinary wave amplitudes Ax/Ao. It is not established that in the upper and middle part of the D-region. This method yields reliable results. Information about the dynamics and the meteorology of the D-region can also be obtained by PR technique.

2.0 THEORY:

Partial reflection technique is based on transmission of high powered RF signals in ordinary and extraordinary modes in sequence and reception of amplitudes of partially reflected echo on the two modes as a function of height. The amplitude (Ao & Ax) of partially reflected echos in the ordinary and extra ordinary modes received at the ground is given by

$$A_{x,o} \propto R_{x,o} \times \exp\left[-2 \int_0^h K_{x,o}\, dh\right]$$

where suffixes x and o correspond to extraordinary and ordinary modes of propagation respectively. R is reflection coefficient and K is absorption coefficient. The above formula on simplification, for a differential height in two magnetoionic modes comes out to be

$$\Delta \log (R_x/R_o) - \Delta \log (A_x/A_o) = F.N. \Delta h$$

$$\text{where } N \times F = 2 (K_x - K_o)$$

$$\text{Therefore } N = \frac{\Delta \log (R_x/R_o) - \Delta \log (A_x/A_o)}{F \Delta h}$$

where N is the electron density and F is the differential absorption per km per electron. Shirke and Pradhan (1976) have discussed in detail how the electron density profile can be computed from the observed ratios of the signal amplitudes A_x and A_o from the D region heights. They have also shown that by employing quasi-longitudinal approximation at the low latitude for the sen-wyller (1960) full wave equations, the height variations of the ratio of the reflection coefficients R_x and R_o are very close to the more rigorous evolution by the full wave equations for the radiowave propagation in the D-region at low latitudes. In the quasi longitudinal approximation R_x, R_o and F are independent of the electron density N. At low latitude such as

Ahmedabad differential absorption F is not independent of electron density. One can choose a hypothetical electron density profile and following an iterative procedure of calculations one can derive a unique electron density profile for the given set of observations.

SYSTEM DESIGN:

Partial reflection experiment involves measurement of reflections from D region of the ionosphere. A high power transmitter and an antenna of narrow beam width are used to transmit pulsed RF in both modes of circular polarization and the resulting received echoes are recorded on film. The output of the receiver is inverted during transmission and reception for the second polarization so that the ordinary and extraordinary components can be recorded on the same frame. The receiver output is displayed on a oscilloscope screen, where the horizontal sweep is triggered by the transmitted pulse. A (Robot type) camera photographs the trace which gives amplitude of both modes of reflection and the heights of the reflecting layer. This method of recording enables comparison of amplitudes of both ordinary and extraordinary components at the same height.

3.1 Choice of frequency:

Belrose (1970) has shown that the ratio of reflection coefficient is approximately given by $(w + w_1) / (w - w_1)$, where w is angular operating frequency and w_1 is longitudinal component of electron gyro frequency. The dip angle at Ahmedabad is 33.8° and gyrofrequency is 1.19 MHz. To obtain maximum A_x / A_o the operating frequency close to the gyro frequency is ideal. However the absorption at this frequency would be very high. Therefore a compromise is to be made to cover the height region of interest and low absorption of radio waves. The selected frequency 2.5 MHz yield a maximum A_x / A_o of 1.7. The actual operating frequency used in the present system is 2.523 MHz.

3.2 Path loss calculation:

In order to determine requirements of transmitter output power and receiver sensitivity for accurate measurement of partially reflected echoes following path loss calculations are carried out.

The ratio of received power to transmitted power in free space without any attenuation due to ionospheric absorption etc. can be given by

$$\frac{P_r}{P_t} = \frac{A_r A_t}{d^2 \lambda^2}$$

where P_r = Power of the received signal

P_t = Transmitter output power

A_r, A_t = are the areas of receiving and transmitting antennas respectively.

λ = Wave length in meters

d = Distance in meters

Since output power is dictated by power tubes in output stage, 40 KW of peak pulse power is normally fed to the antenna system by a pair of 4 PR 1000A tubes. In the present case the same antenna system has been used for transmission and reception by means of TR switch network. 30 dipoles are used in rectangular collinear array as shown in Fig.3

$$A_r = A_t = (5\lambda/2)^2$$

Therefore for a signal reflected from a height of 100 KM (d= 200 Km).

$$P_r/P_t = 1.414 \times 10^{-5}$$

So the path loss suffered by the transmitted RF pulse is about 50 db. Loss due to absorption at local noon by the ionosphere for moderate solar activity is about 40 db. The magnitude of partially reflected echoes are normally 50 to 60 db weaker than E region reflection (Belrose et al., 1964). Totalling the above losses (140 to 150 db) if a RF pulse of peak power of 40 KW is radiated, the received partially reflected signal would be between 45 to 140 micro volts across a 50 ohm input impedence. In addition to the above losses, there are system losses between 10 to 20 db as the pulse goes through transmission lines, matching networks, transmit receive switches, phase shifting networks etc. Thus with the marginal system gain, design and installation of each element was made carefully to obtain maximum signal strength.

3.3 Choice of pulse width and repetition rate:

The pulse repetition rate of the system were chosen between 1, 10 and 50 pulses per second so that fading of the echoes could be observed. We have chosen the film speed in the 35 mm camera such that we get 1 record per second. Since both the modes of polarisation were to be recorded on the same film, double pulses, one of each mode were transmitted within 20 ms and received by the system. The processes was repeated every second. Later with the advent of microprocessor technology, it was possible to record data for continuous 5 minutes at the rate of 50 transmitted pulses per sec.

The width of the transmitted pulse determine height resolution. A narrow RF pulse needs wide BW of the receiving amplifiers for faithfull reception. For optimum signal to noise ratio, bandwidth of the receiver is given by BW = 5/2T where T is the width of the rectangular pulse. The transmitter pulse width was adjusted to 25 micro sec in order to achieve a balance between receiver BW and height resolution of the reflected signals. The indetermination, produced by the pulse width, in height is equal to CT/2 where C is the velocity of light and T is the pulse width. For a transmitted pulse of 25 microsec width, the indetermination in height is 3.75 Km. Beam width of the main lobe of the receiving antenna (same as that of the transmitting antenna) is about 19°. Therefore contribution of oblique reflection to the indetermination produced in height for reflection from 80 Km altitude is about 1.1Km. This being smaller than the height of the scattering volume, the indetermination in height is only due to pulse width.

3.4 The block diagram of Partial reflection experiment built at Ahmedabad is shown in Fig.1. The arrangement of the racks housing the transmitter, receiver, data recording system etc. in the experiment room is shown in Fig.2. The programmer unit synthesizes a 300 KHz crystal controlled pulse generator and produces necessary control waveforms and height marker pulse train for the entire system operation with provisions of changing P.R.F. and pulse width. The driver unit comprises of cascaded stages of modulated class C amplifiers with output power capability 5 KW. The amplifier units with their plate and bias power supplies and transistorised RF Xtal controlled excitor units are housed in one rack (L.H.S. rack in Fig.2). The 50 KW final power amplifier with its high voltage power supplies, filament supply and cooling system are housed in the adjacent rack. An electronic transmit-receive switch controlled by the programming unit enables the transmitter final amplifier output and the receiver input to be connected to the antenna system sequentially.

Antenna system comprises of two arrays of 30 dipoles each placed in East-West and North-South direction. The antenna outputs are separately brought to the experiment room by open wire transmission lines terminated on insulators on the top of the fourth rack from left in Fig.2. Matched balloons for the transmission lines, 90^{o} and $0 - 180^{o}$ phase shifting networks for obtaining circular polarisation, electronic transmit-receive switch and the programmer unit are located in the same rack.

The receiv ing and film data recording system are housed in the thrird rack from left in Fig.2. The receiver output is combined with height marker pulses from the programmer unit to facilitate scaling of amplitude of the received echo. An invertor inverts the second received echo in polarity and the composite signal is displayed on the C.R.O triggered by the ground pulse. A 35 mm ROBOT photographic camera with its shutter controlled by programming unit takes the photograph of the composite echo at the rate of one frame per second.

An Intel 8080 microprocessor based data acquisition system stores the amplitude information of the received echo at 10 predetermined heights in RAM memory and subsequently pre-processes the data by averaging. Hard copy of the preprocessed data is made available by teletype machine after about 5 minutes of continuous running of the partial reflection system.

4.0 TRANSMITTER:

4.1 The basic design of the transmitter closely follows the design of an ionospheric sounding transmitter. A modulated RF generator excites the dirver stages which in turn drive the final power amplifier stage. The following requirements were kept in view while designing the transmitter for PR experiment.

1. Output power : 40 KW during pulse
2. Pulse width : 10, 25, 50 and 100 micro seconds.
3. Pulse repetition rates : 1,10 and 50 pps.
4. Center frequency : Tunable from 2 to 3 MHz rang

5. Output impedence : Unbalanced 50 ohms.

6. All transmitter units to be properly shielded to prevent interference to other equipment.

Since the final power out put of 40 KW during pulse cannot be achieved in a single power amplifier stage, the transmitter was designed in two separate units with 5 KW and 40 KW output power capacity. The 5 KW unit is designed as driver amplifier for 40 KW stage, but it can also be used as a stand alone transmitter of 5 KW output capacity during pulse. A transistorised crystal controlled oscillator is used to provide a stable operating frequency of 2.523 MHz. A programmer unit to be discussed later, supplies modulating pulses of 5 volts amplitude and desired duration, usually 25 microsecs to a chain of CIL 622 transistors, which amplify the modulating pulse to -30 volts level and modulate the RF oscillator to generate -30 volts peak RF pulse.

Three power tubes EL 84, BEL 100 and 4PR60B are used in the driver unit having total output power capability of 5 KW peak power. The circuit diagram of 5 KW unit is shown in Fig.3. The first stage, employing EL84 is excited by the modulated RF generator. It is operated in class c region and is capable of during 300 V p to p RF during pulse period to the next stage employing BEL 100. The plate circuit is a parallely tuned LC. An air variable capacitor (10 to 300 PF) provides wide tuning tuning capability. The plate output of EL 84 stage is directly connected to BEL 100 control grid circuit. This stage is also a class c tuned amplifier having parallely tuned place circuit.

Tuning is achieved by air variable 10 - 300 PF capacitor. It delivers 1.6 KV p to p RF pulse to the next driver stage employing 4PR 60 B. The average cathode currents of EL 84 and BEL 100 are monitored by a 1mA/DC ammeter with the help of a 4 pole 2 way switch. The output of EL 84 and BEL 100 are coupled directly to the grids of their successive stages without adopting to impedence matching to the grid circuits, because the problems of additional tuning adjustments and neutralization of a tuned plate tuned grid amplifer more than offsets any advantages of impedence matching. Moreover, by designing all circuits to provide more than adequate drive for the following stages all amplifiers are operated well below their maximum ratings improving the long term life of the system. The 4 PR 60B power amplifier stage has been designed to deliver 5 KW of peak power into a load of 50 ohms during pulse period. It is operated at a plate voltage of 5 KV DC. The control grid bias voltage can be varied from -500 to -700V in order to vary excitation potential to the final stage. The plate tuned circuit makes use of an air cored transformer having 26 turns (12 SWG, 5cm dia) in primary and 7 turns(12 SWG 9cm dia) in the secondary which is tapped suitably to enable link coupling to a 50 ohm coaxial cable. The impedence transformation ratio was determined by measuring with an impedence bridge. An air dielectric variable capacitor 10-300 pf is used for tuning. In all the 3 stages of the 5 KW driver unit a high voltage capacitor is added in series to the variable tuning capacitor to prevent high DC plate voltage from appearing across the plates of air variable capacitors. The chances of spark discharge happening inside the chasis have been minimised in this way. Current indicating meters and insulated knobs connected to the movable plates of the tuning capacitors are mounted on the front panel of the chasis to ensure safety aspects during tuning or other human operations.

4.2 Power supply to 5KW unit:

The circuit diagram of power supplies for plates and the grids of the three stages of 5KW driver unit is shown in Fig.3. A single transformer is used to generate the following supplies.

1) 300V DC 1mA average current for plate supply of EL84 tube and screen grid of BEL100 tube.

2) -100V DC variable 1mA average current for control grid of BEL 100 tube.

3) -700V DC variable 1mA average current for control grid 4PR60B tube.

In the case of 4PR60B tube, a variable 5KW supply is used to supply the plate circuit. Two 3B24W rectifier tubes are used in doubler mode to generate 5KV DC. An auto transformer is used to vary the primary voltage of the transformer supplying 2.75KV AC to the rectifier tubes.

4.3 Final Power Amplifier:

Fig.4 shows the circuit diagram of the final power amplifier employing two 4PR 1000B beam tetrodes in parallel. This circuit alongwith the plate power supply of 16KV variable DC is housed in a separate rack consisting of 5 chases each of

17" x 14" size sufficiently shielded to prevent interference with other equipments. 4PR1000A radial beam pulse tetrodes were chosen for final stage because of their compact size, relatively high pwer gain for high duty factor applications and less stringent cooling requirements. Cooling of the tubes is accomplished by radiation from the plate and by circulation of forced air through the base and around the envelope. The filaments of the tubes are supplied by a transformer. An autotransformer is connected in the primary to enable variation of filament supply slowly from 0 to 8 volts at 20 Amps current. Monitoring of the filament voltage is provided with a panel mounted meter. The tubes are operated at class C condition. Since push pull operation requires balanced feed in the input stage and balanced transformer in the plate circuit, balancing in high power push pull stages is often found problematic and as a result distorted waveshape and high harmonies appear in the load due to improperly balanced networks. Hence in the PR experiment, the tubes were operated in parallel as a single tuned stage. The problems of neutralisation were solved by the physical separation of input connections and output tuned circuits. In order to preserve system shielding short lengths of coaxial cable are used to connect the grids of the final tubes to the front panel input connector. The lengths are much too short to cause any impedence mismatch and do not have sufficient shunt capacitance to affect the tuning of the driver plate circuit. The nominal grid bias of the tube is kept at -500V but some improvement in pulse shape can be realised at the expense of the output power by increasing it to -700 volts. The screen grids are held at 1.6 KV DC. The plate circuit of the final amplifier stage is parallely tuned and transformer coupled to load impedence. Tuning is accomplished by a vacuum variable capacitor of 5 - 300PF 35 KV rating. The air cored transformer offers 40 microhenry in the primary. The secondary winding in series with a radio frequency ammeter is connected to a high voltage unbalanced UHF connector on the front panel and offers 40KW of peak power to aload impedence of 50 ohms. The plate voltage can be varied from a low voltage to 16 KV. Normally the plates are held at 12 to 13 KV with respect to the ground potential. Special attention is paid to provide adequate insulation around high voltage points to prevent corona discharge inside the chasis.

<u>4PR1000A 40 KW class C power amplifier design notes</u>

DC Plate supply voltage Ebb	12,000 volts
DC Screen supply voltage Ec2	1600 volts
DC Control grid bias voltage Ecc	-500 "
RF drive is adjusted so that	
Max inst plate current ib max	2 Amps
Min " " voltage eb min	1600 Volts
Max " grid ec max	350 Volts

The 5 point approximation technique is used to obtain the following parameters for one tube during the pulse.

Dc plate current Ib	2.46 Amps
Peak fundamental RF plate current IP	4.26 Amps
RF power output Po	22.42 KW
Plate dissipation	7.1 KW
Plate circuit efficiency	75.2%
RF plate resistance RL	2.46 Kohms.

For two tubes in parallel, these parameters are:

Ib	4.92 Amps
Ip	8.54 Amps
Po	44.84 Kw
P in	60.04 Kw
RL	1.23 Kohm

Fig.4 shows the circuit diagram of D.C. power sources for the final amplifier stage. An oilcooled step up transformer is used to obtain 7KV A.C. Electronic doubler circuit is made use of to rectify and generate 16KV D.C. Each arm of doubler rectifier consists of twenty four BY127 diodes arranged in series configuration. A resistance of 2M ohm and condensor 0.005 microfarad are connected accross each diode to ensure equal distribution of inverse voltage and to prevent burn out of other diodes in case any particular diode malfunction. The output of the EHT is controlled by a variable autotransformer in the primary circuit. A 500v step up transformer is used to generate -700 VDC for control grid and 1.6 KV DC in doubler mode for screen grid supply of 4PR1000A.

5.0 ELECTRONIC TRANSMIT RECEIVE SWITCH:

The ideal antenna system for use with the partial reflection experiment would employ two separate arrays for transmitting and receiving. However in the present case space was available only for one array. It was therefore necessary to develop a switching network to enable the antenna feedline to be connected to transmitter during the pulse and to the receiver thereafter. The requirements of a usable transmit receive switching system are as follows:-

a) The maximum switching time between transmit and receive modes should be less than 100 microsec, to permit reception of low altitude reflections.

b) The noise generated by the switching system should not degrade the receiving system noise figure.

c) The system should have minimum insertion loss.

d) No appreciable reactive or resistive load should be presented to the transmission line during transmission or reception.

e) The operation of the unit should be very reliable to prevent receiver damage during transmitter pulse.

The conventional vacuum tube TR switch designs as employed in communication system would be unusable for 40 KW power level. The use of quarter wave length transmission was considered for T-R switch application. If one end of a quarter wave length transmission line is connected in parallel with the antenna feed line at the transmitter and the other end of it is connected to the receiver, TR switch action can be realised by shorting the receiver end of transmission line during transmitting pulse. The quarter wave line would then act as an impedence transformer, reflecting a very high impedence across the transmitter output. This design, although suitable in radar installations, has serieous shortcomings for use with ionospheric sounding systems. The physical size of the line, quite large in present application(30 meters) would have to be changed with each change in operating frequency, and the diode and the current required to switch it would have to be excessively large since the RF current at the shorted end of the lime would be over 30 amps. The system adopted in PR experiment, employs a silicon didode in series with the receiver feed line, which is connected in parallel with the antenna feedline. During the transmitter pulse, the diode is reverse biased by a high D.C. voltage. In the receive mode, a current of 25 mA is passed through the diode to switch the diode into a conducting stage. Fig.5 shows the circuitry employed. A series of 6 BY127 diodes have been used. Deach diode has PIV of 1 KV. A didode in reverse biased condition offers a capacitative reactance and leakage of transmitted power to the receiver during transmitted pulse results. Therefore with six diodes in series, capacitative leakage coupling is quite small. A high voltage condensor iosolates the transmitter and the antenna from the DC high voltage source, used to reverse bias the diode. Isolation of the receiver from the DC voltage is obtained by means of a bifilar winding on a torroidal core. In case of a brakedown in the diodes, the torroidal core saturtes and protects the receiver input circuit. However ringing noise generated by high voltage switching through leakage reactance of the diodes appears to be a problem. Efforts have been made to prevent ringing beyond 100 microsec after the end of the transmitter pulse allowing uninterrupted reception of earliest possible echoes arring from low altitudes.

Since the peak to peak amplitude of transmitted pulse o 40KW power at 50 ohms load impedence if 4000V, high voltage to be applied to reverse bias the diodes during transmitting pulse should be higher than 2000v. Allowing a safe margin of 1KV in case of mismatch any where between the final amplifi tuned circuit to the antenna feed points, 3KV was considered to be the minimum required peak value of the TR switch pulse during transmit mode. During the receive mode, 25mA was found to be the optimum current to forward bias the diodes without saturating the torroidal transformer. Fig.5 shows the circuit diagram of the pulse amplifier to generate +3500 volts to -500 volts pulse. A low voltage pulse is amplified in two suc essive pulse amplifier stages. The pulse duration is adjusted to 2 m sec. for reception mode and 18 m sec. for transmission mode. Since no ionospheric echo after 2 m sec is of any interest, high rise time of the pulse from -500 to +3500 volts lev due to 2 M ohm plate resistance of EL504 tube is of no concern. However sharp fall time due to low ON resistance of EL504 during conduction ensures reception of low altitude reflections.

6.0 ANTENNA MATCHING UNIT, PHASE SHIFTER AND POLARISATION SWITCH:

As mentioned earlier, Antenna system comprises of two arrays of 30 dipoles each placed in north sourth and east west direction. Two sets of open wire transmission lines of characteristic impedence 500 ohms run for about 500 meters from the experiment room to the antenna feed points. Circular polarisation is achieved by introducing a phase shift of 180^{o} by a two pole two way switch, as shown in Fig.6. A T section network consisting of two inductive arms and a capacitative leg provide 90^{o} fixed phase shift for our operating frequency in the EW antenna array.

The insertion loss of the phase shifter network amounts to about 2.5 db. In order to compensate for this loss an equivalent resistive network has been added in the NS arm of the antenna. Both the networks have been designed to offer 50 ohm unbalanced characteristic impedence. They are housed in shielded cabinets to prevent leakage coupling.

Since the feed wires for antenna arrays are balanced and offer 500 ohms characteristic impedence the unbalanced networks are matched to the transmission lines by means of two Baluns. Each Balun consists of primary and secondary windings wound on rectangular bakelite former over ferrite slabs. Capacitances added with the windings balance out reactive components.

Tue turnsratio and capacitance values are adjusted by measurement with an impedence bridge at the present operating frequenc The Balun transformer assembly is supported on insullators inside the chasis.

A two pole two way high voltage switch using vacuum sealed reed relays changes phase shift in the transmission line feeding NS antenna array from 90^{o} to 270^{o} on each alternate transmit receive sequence. The sense of polarization can be selected by switching on or off the currents in two solenoids driving the relays. The connections are shown in Fig.6. It was found that 50 pps was the maximum rate of switching possibl with reed switches for chatter free operation. The discharge created due to high voltage, high current switching causes additional noise during reception. Open wire transmission lines using ¼" ACSR conductors with 8" separation are connected by high voltage feed thrus. Two sets of transmission lines extend out of the experiment room with insulator spacers at the distance interval of 10 meters to maintain 8" separation all along their length till the antenna feed points.

7.0 PROGRAMMER UNIT:

The timing and control system is designed to synchronize and control the operation of the various component units of the Partial reflection experiment. A single crystal oscillator of 300 KHz resonating frequency controls the various sequences of operation. A chain of synchronous counters devides the crystal frequency and generates pulses of repetation rate 30 KHz, 1 KHz, 100Hz, 50 Hz, 10 Hz, and 1 Hz. TTL integrated circuits have been used to generate all the control waveforms. The crystal is mounted in an oven which is maintained at constant temperature of $35^{o}c \pm 2^{o}c$. The entire system is wired on a single card and enclosed in a shielded cabinet. The outputs are TTL compatible and brought out on the front panel. The schematic block diagram of the programmer unit is shown in Fig.7. The different functions of the unit are described below:

1) The transmitter is modulated by a composite double pulse with 20 m sec separation. They are derived from 50Hz output of the counters. An option of changing modulating pulse rate is provided. In the case of fast data recording system, 50 Hz repetation rate of modulating pulses is used. The composite double pulse can be also repeated at 10 and 1 Hz rate. In the case of photographic data recording 1 Hz operation is required. The modulating pulse width can be varied between 10 to 100 microsec by means of a monostable multivibrator however normally 25 microsec fixed pulse width is used. The monitoring oscilloscope is triggered externally by the same pulse train.

2) The transmit receive switch is provided with a pulse train of 2 m sec duration for reception, delayed by

about 100 micro secs with respect to the transmitter modulating pulse.

3) In order to diplay the received echoes for both the ordinary and extra ordinary mode of polarization simultaneously on the CRO screen, the receiver output for the second transmitted pulse is inverted in polarity. Since the CRO is triggered externally by each transmitter modulating pulse, the ordinary component of received echoe appears over the inverted extra ordinary component on the oscilloscope screen. This arrangement facilitates scaling of the photographic record. Pulse train required to invert receiver output is generated as shown in Fig.7.

4) Height marker pulse train is generated from 30 KHz and 6 KHz. 5 Km markers, generated from 30 KHz have 1 microsec width and 25 Km markers, generated from 6 KHz have 3 microsec width. The height marker pulses are analog added with the receiver output so that narrow thin pulses rise over the ionospheric echoes without distorting the echo structure.

5) The composite echo signal is photographed in 1 Hz operation. The camera shutter is opened 200 m sec. before the transmitting pulse and it is held open for 700 m sec. As the shutter is released, film advance mechanism is actuated for 300 m sec. The sequence of operation is shown in Fig.14.

6) In order to switch the antenna polarization from ordinary to extra-ordinary mode, a 400 m sec wide pulse is generated and fed to the solenoid switching circuit in the polarization control switch. However, since the performance of the switch for 50 Hz operation is not satisfactory, this pulse train is used only for 1 Hz operation.

8.0 RECEIVER:

In case of Partial reflection the echoes received are not only weak in amplitude compared to E-region reflections, but also vary considerably with change of altitude and time of the day. So a sensitive receiver with large dynamic change is required for PR experiment. The bandwidth of the receiver should be large enough to preserve the amplitude and position (altitude) information of the narrow r.f. pulse. For optimum signal to noise ratio, the bandwidth of the receiver is given by BW = 5/2T where T is the pulse duration. So for 25 micro-sec pulse width of PR transmitter, receiver bandwidth should be 100 KHz. It was found experimentally, that the echoe received by the antenna system varied from few micro volts to about 100 micro volts for most of the time and altitudes. Therefore the receiver gain should be about 100 db with 1 atleast 20 db dynamic range. But if the E region echoe is to be recorded simultaneously with the weak partial reflections, the dynamic range of the receiver requires to be 60 db. However large dynamic range is not as difficult a proposition as large bandwidth of 100 KHz is for design of a receiver with operatin centre frequency of 2.523 MHz. Conventional intermediate frequency of 455 KHz would yield about 30 KHz bandwidth in a high gain superheterodyne receiver. Since the operating frequency of the transmitter is kept fixed at 2.523 MHz, I.F. amplifier were deisgned for the same centre frequency. Thus the necessity of providing variable local oscillator and mixer was eliminated. The circuit diagram of the receiver used in PR experiment is shown in Fig.8.

The receiver utilises a dual insulated gate mosfet 3N187 in the input stage to have higher isolation between input and output and convenient AGC control. It is used as a tuned amplifier with a high Q transformer coupled tuned circuit. Two more tuned amplifiers and a detector-amplifier stage are built with CIL931 transistors. The tuned circuit employ variable ceramic trimmers for better stability and high Q coils would around low permeability torroidal cores. With the use of torridal coils, problems of interstage separations are eliminated. The transistors are biased for 15 volts DC power supply operation. Total gain of the receiver is 100 db and dynamic range of operation is found to be 60 db. A gain control is provided in the AGC circuit to decrease total gain and increase stability if the need arises. 3 db bandwidth of the receiver is 85 KHz. It is possible to increase bw to 100 KHz at the cost of reduction of gain. The receiver wired on a 10 cm x 10 cm card is enclosed in compact 4" x 4" x 1" copper box. Two bnc connectors and a 9 pin cannon type connector provide the input, output and power supply connections.

ANTENNA:

A large antenna system is required to receive the weak partially reflected echoe signals. One way to increase signal strength would be to increase the power output of the transmitter. Doubling of the power output of the transmitter increases the signal to noise ratio of 3 db only. So by multiplying the output stages of the transmitter to the extent final output power is increased by 20 db, about 4 megawatts of power have to be radiated. It is more economical to have a high gain narrow beam antenna to achieve the same signal to noise ratio. However construction of large gain (20 db) antenna for an operating frequency of 2.523 MHz, requires large area and long lengths of feeder line.

In the ideal case, PR experiment should have separate antennas for transmission and reception. But with the available land and economic reasons only one antenna system was constructed. The present antenna system consists of 60 half wavelength dipoles in a rectangular colinear array. With 5 dipoles in each line, 30 dipoles are erected in six lines. Spacing between the lines is one half wavelength. All 30 dipoles are fed in phase. Another 30 dipoles at right angles to the above are also fed in phase, but shifted with respect to the first set of 90° or 270° to achieve right or left circular polarization. The antenna arrangement is shown in Fig.9. The antenna structure is supported on 36 poles made of galvanised iron pipes standing 70 to 90 feet above the ground. These supporting poles are arranged in north-south and east-west direction in the form of a square of 6 x 6 with 60 meters spacing between the adjacent poles. The dipole elements are made of aluminium conductors reinforced with steel, commercially known as squirrel ACSR conductors. Wire diameter is quarter inch. Between two successive dipoles of 60 meters length, a non-radiating length of 60 meters of the same conductor has been added in a folded loop. Since alternate half wavelengths are folded, the radiating dipole elements have current distribution in the same sense. Since the total length of any line is $5/2\lambda$, feed point is fixed between $3/2\lambda$ and 1λ. In order to feed all the six lines of NS or EW array in the same phase, the feed lines connecting two successive lines are interchanged. The feeder wire is made of same conductor with 8" separation and matches the 500 ohm impedence of the antenna. Two separate transmission lines have been used for feeding the N-S and E-W arrays. All along the length of about 500 meters of the open wire transmission lines, PVC spacers have been used at frequent intervals (about 5 meters) to maintain a constant separation of 8" between the wires. Calculated antenna gain with 30 dipoles in NS direction and 30 dipoles in the EW direction is 19 db. The calculated 3 db beam width of these arrays is 18 degrees. The directivity is an important factor to avoid strong contributions of oblique reflections to the received signal. Assuming all the power is uniformly distributed over the main lobe of the antenna the reflections received for a height of 80 Km will be produced by a volume with an average width of 2 x 80 x tan(18/2) = 26 Km and height of $3 \times 10^5 \times 25 \times 10^{-6} / 2 = 3.75$ Km. The indetermination in height produced by the finite angle of radiation of the antenna is 80(1-cos (18/2) = 1.1 Km, therefore it is small compared to the height of the scattering volume i.e. 3.75 Km. Hence indetermination in height depends only on the width of the transmitted pulse. An antenna lobe of 18°, in this case is enough for partial reflection measurements and keeps contribution of oblique reflections at a low level.

10.0 DISPLAY AND RECORDING SYSTEM:

10.1 Photographic recording:

As indicated earlier, the receiver output is displayed on the oscilloscope in the amplitude scan mode in the following sequence. The oscilloscope is triggered externally by the modulating pulse stream with the time base fixed at 0.1 m sec/cm. With 10 cms width of the CRO screen echoes received from altitudes upto 150 Km can be displayed. The first pulse of the double pulse train is transmitted and echoes are received in the right circular polarisation. The received echoes with 5 and 25 Km height marker pulses are displayed in the CRO screen with reference to the transmitted pulse. After 20 m sec the second pulse is transmitted with left circular polarisation and received echoes are inverted in polarity. The second pulse and received echoes with height marker pulse train appear inverted just below the first pulse sequence, so as to match the altitude of the received signals. Since the receiver is connected to the antenna for 2 m sec from the transmitted pulse with the help of TR switch, the entire sequence is covered in 22 m sec. The displayed signal is photographed on a single photoframe. For photographic recording the pulse repetation rate is fixed at 1 double pulse per sec.

A 'Robot autorecorder' camera has been used to take pictures of 25 x 35 mm size. The shutter operation can be controlled externally by means of a relay. The film is advanced automatically after each exposure in about 300 m sec. time. It is capable of recording two frames in one sec. But it is operated on 1 frame/sec rate. A watch and a frame counter provided in one corner of the frame helps recording of time and identification of the frame on the film. The camera is actuated by a timing circuit built in the programmer unit. In this method of recording on photographic film, since the two transmitter pulses for each sense of polarisation are separated only by 20 m sec and recording can be continued every second, a permanent copy of amplitude information of reflections from all the relevant altitudes is obtained within close interval of time.

10.2 Paper chart recording:

In this system, 50 Hz operation of transmitter modulating pulse rate is chosen. A box car integrator is connected directly to the receiver output. The receiver output is integrated for all the altitudes by a slowly scanning gate and recorded on a paper chart recorder. The transmitter and receiver operate first on the right circular polarisation for about 5 minutes and the output of the box car integrator is recorded till the end of the E-region reflection. The process is repeated for next 5 minutes after switching to left circular polarisation. In the process of intgration noise gets averaged to a low value while the reflected signals add up in amplitude. Although signal to noise ratio improves considerably in this method, assumption is made that ionospheric conditions do not change for a long time of recording which is of the order of 10 minutes. Therefore results obtained from this mode of recording are not quite reliable.

MICROPROCESSOR BASED DATA ACQUISITION SYSTEM:

In the case of photographic film recording, the amplitudes of ordinary extraordinary components of the reflected signal (A_o and A_x) are scaled from the film after development and enlargement. This process of recording and scaling involves considerable time since human operations are involved. If the receiver output is converted into a digital signal of 8 bits with a fast linear A to D converter, accuracy of measurement improves to 0.4%, while in case of film reading, accuracy can be 1% at the best. Therefore if the amplitudes of the reflected signals A_x and A_o are digitised and printed, in addition to saving in time and recurring cost of the film, accuracy of measurement improves. The system employed in the present case is described below.

For every transmitted pulse reflections from 7o to 100 Kms altitudes appear for 200 micro sec after in initial delay of 466.66 microsec with respect to the transmitted pulse. A narrow gate of 1 microsec is used as start convert pulse for the A to D converter (ADC EH-8 B1) which has total conversion time of 4 microsec(Fig.11). After a predetermined fixed delay with respect to the transmitted pulse, a start convert pulse triggers the A to D converter which is connected to the receiver output. It produces 8 bits corresponding to the amplitude of the received echo for a predetermined altitude. After 20 m sec., as the next pulse is transmitted, the gate pulse is shifted in time by 200 micro sec. The digitised information now corresponds to an altitude 3 Km above the first one. 10 such gate pulses are used with 200 micro sec. time duration between each. Thus in 200 m sec 10 different gate pulses cover a total height of 30 Kms. In one second the process is repeated 5 times. After one second polarisation is changed and the sequence is continued. So in each second 30 Kms of the ionosphere is scanned 5 times at the interval of 3 kms in the same sense of polarisation. The schematic diagram for generation of fixed delay and the sampling gate pulse is shown in Fig.12. TTL counters and flipflops have been used to generate 10 sampling pulses of 1 micro sec width in a sequence discussed above. The 50 KHz and 50 Hz pulse trains are derived from the crystal controlled programmer unit described before. The initial delay generation can be software controlled by a microprocessor, discussed below, with the help of a presettable counter 74177 and a 4 bit latch 7475. A programmable read only memory (74188) has been used to store the height values with changes of the initial delay.

An Intel 8080 based microcomputer of the type Intel MCS80 with 16 K Random acess memory(RAM), fabricated in the electronics laboratory is used for data acquisition, preprocessing of data and printing out amplitude information of the gated echoes with the help of a Teletype ASR 33 machine. As mentioned earlier the A-D converter produces 50 8bit amplitude information is one second. A 8255A programmable peripheral interface is used to provide 3 8bits parallel I/O ports. The A-D converter output lines are connected to the A port of 8255. After completion of conversion the A-D converter acknowledges the status by a End of Conversion(EOC) level change. The 'C' port inputs the EOC status. The microprocessor waits till the occurrence of EOC state change and the 8 bit word output of the A-D converter is inputed via the A port and stored in the RAM memory sequentially. The initial delay between the transmitted pulse and the first gate pulse can be adjusted by the 'C' port of 8255. The 'B' port is used to input the height values selected. Since 50 reflection amplitudes are digitised in one sec. 300 x 50 = 15000 words (8 bits) are stored in the RAM memory in five minutes.

In the case of photographic recording, only one double pulse is transmitted in one sec and any noise signal present in the reflected echoes is also recorded on the film. In the case of microprocessor based data recording, five consecutive reflection values for a particular amplitude in one sec are added and average value is printed. After 5 minutes of data acquisition, the microprocessor works on preprocessing and printing mode. The amplitude information after averaging for one sec for all the ten predetermined altitudes is converted to ASCII characters from binary form and printed serially in 110 band rate by a teletype machine ASR33 with the help of 8251 a programmable communication interface used as a serial I/O port to 8080 microprocessor.

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REFERENCES:

1. Gardner, F.F. and Pawsey J.L., J. Atmos. Terr. Phys., 3, 321(1953).

2. Shirke, J.S. and Pradhan S.N., Indian Journal of Radio and Space Physics, 5, June 1976, 162-166.

3. Sen, H.K., and Wyller A.A., J. Geophys. Res., 65, 3931(1960)

4. Belrose, J.S., and Burke J.M., J. Geophys. Res., 69, 2799(1964).

5. Belrose, J.S., J. Atmos. Terr. Phys. 32, 567(1970).

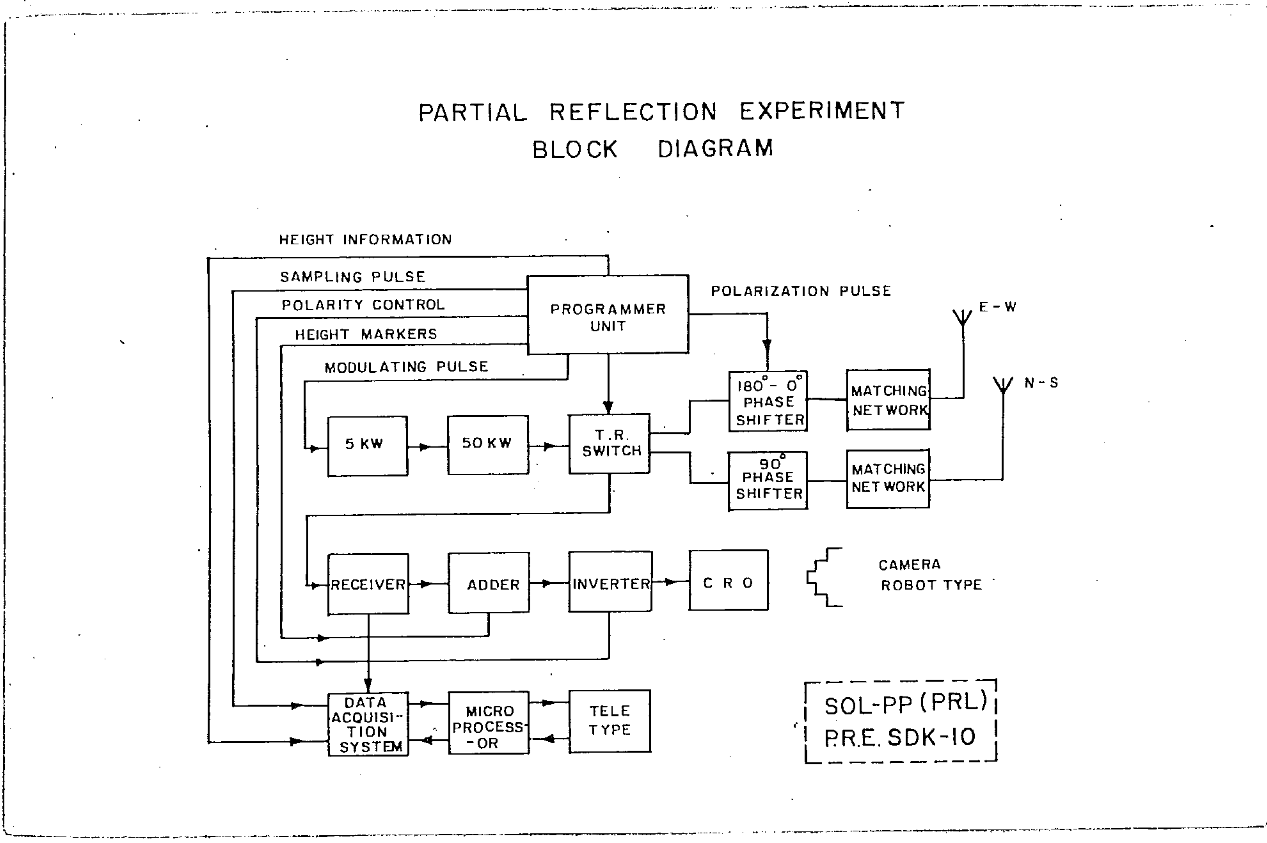


Fig.1 : Block diagram of Partial reflection experimental set up.

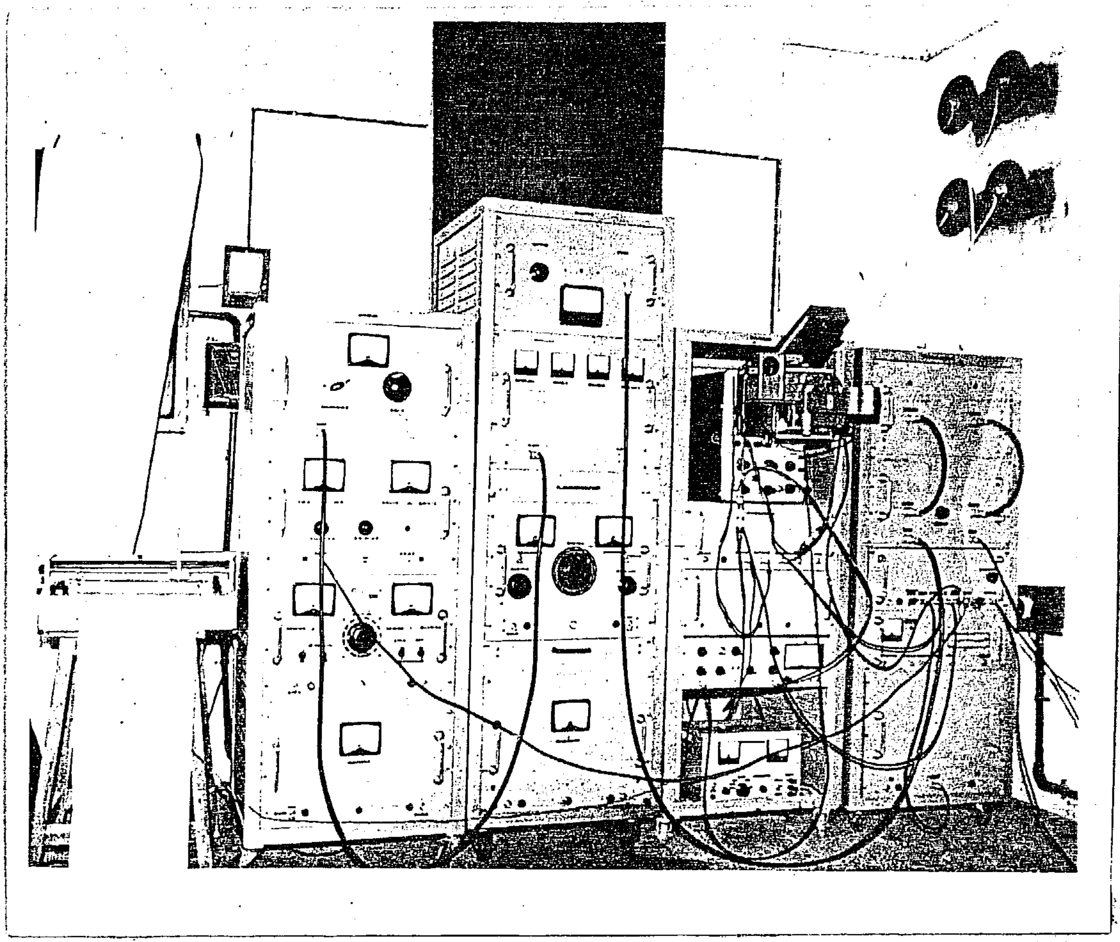


Fig.2 : Partial Reflection Equipment at AHMEDABAD

CIRCUIT DIAGRAM OF 5 K.W. EXCITER

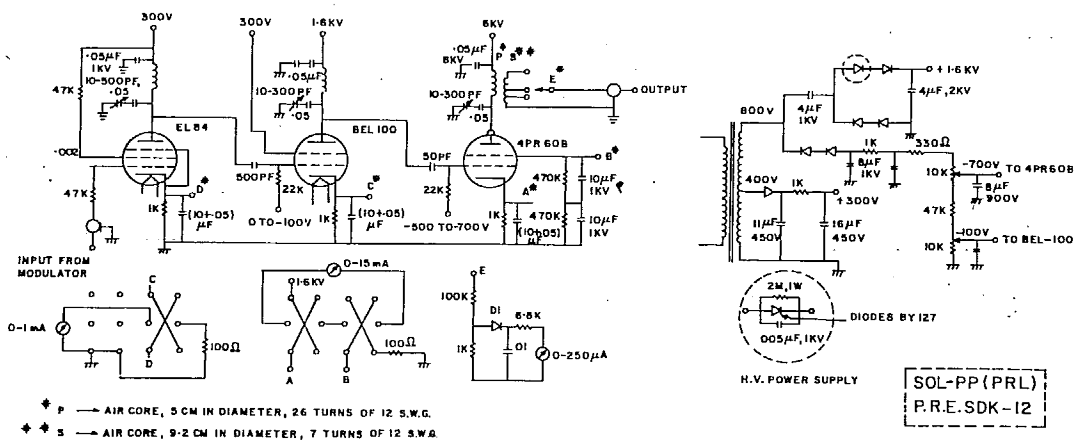


Fig.3 : Circuit diagram of Transmitter 5 KW unit.

CIRCUIT DIAGRAM OF 50 K.W. POWER AMPLIFIER

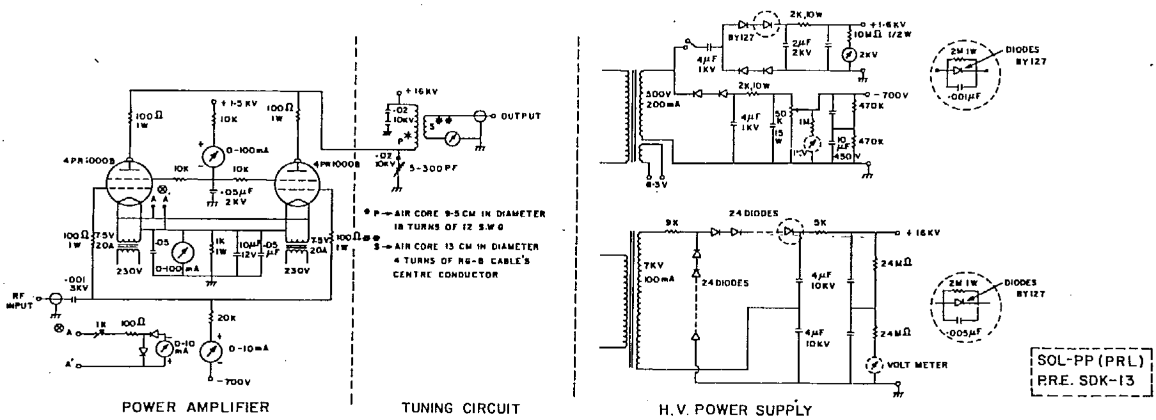


Fig.4 : Circuit diagram of 50 KW power amplifier

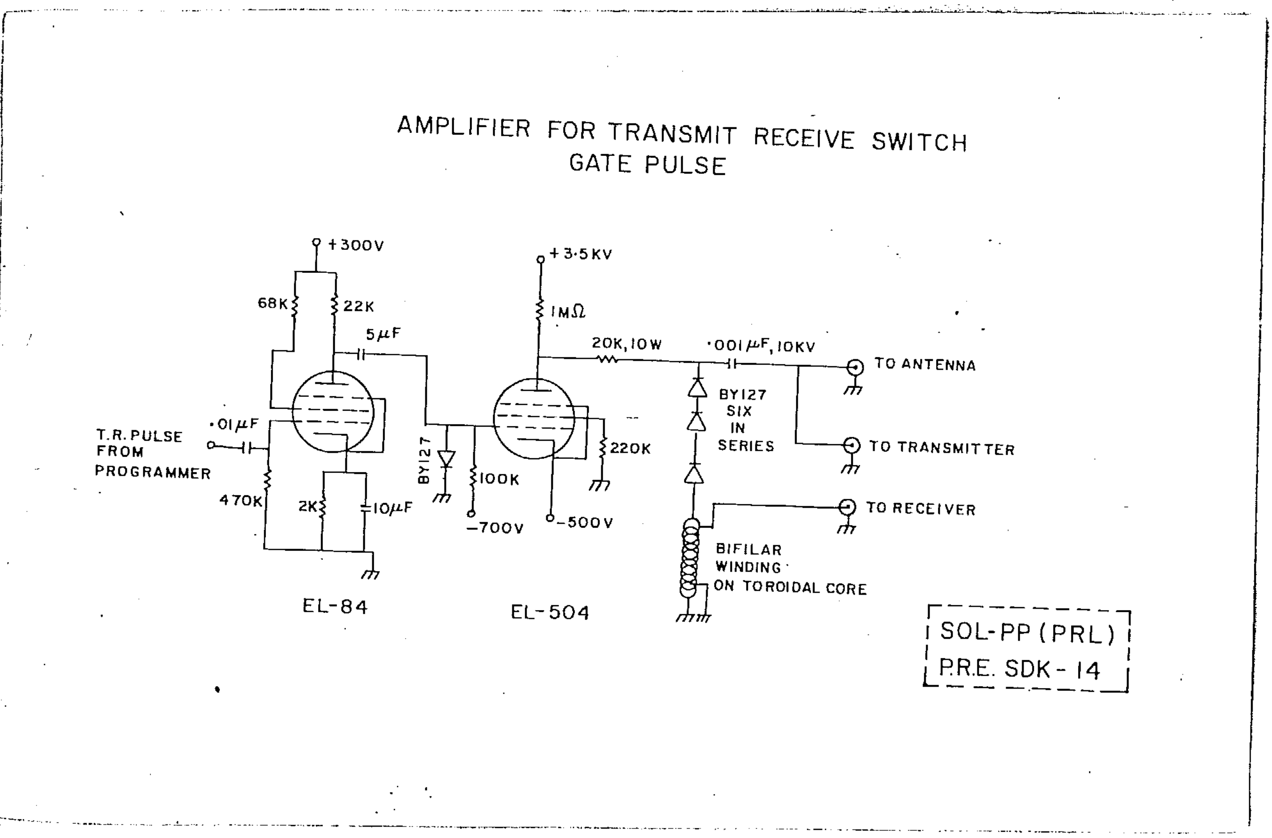


Fig.5 : . Circuit diagram of transmit receive switch.

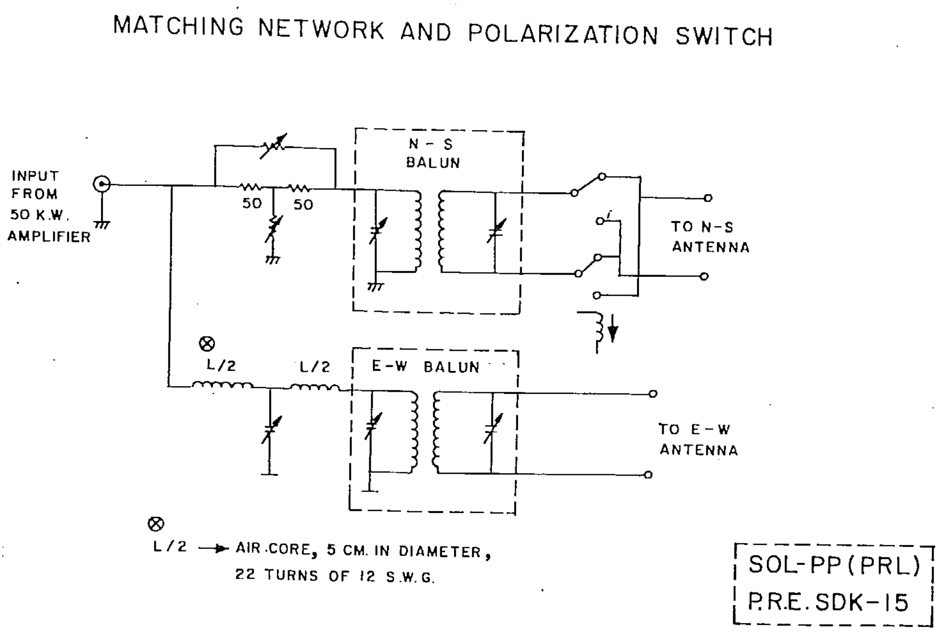


Fig.6 : Matching network, Phase shifter and polarisation switch.

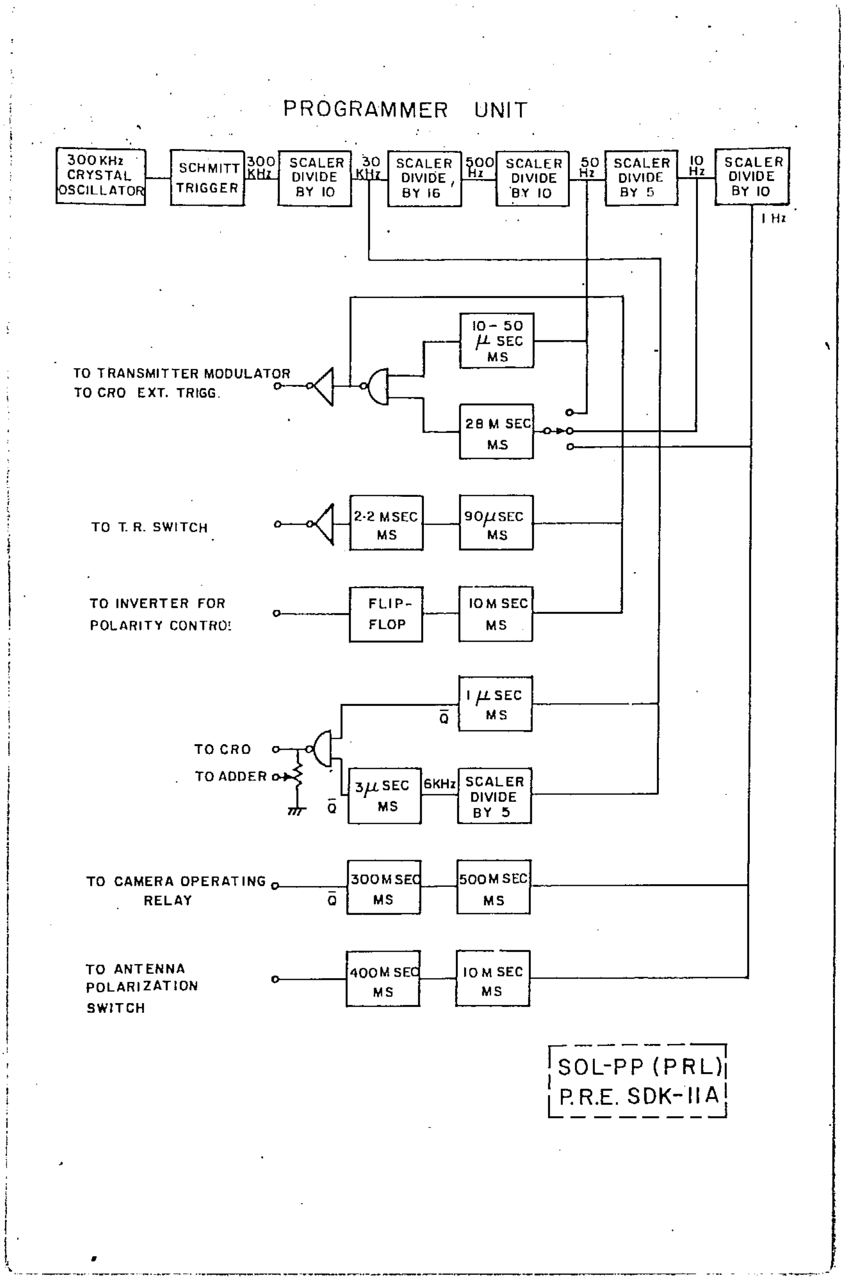


Fig.7 : Programmer unit

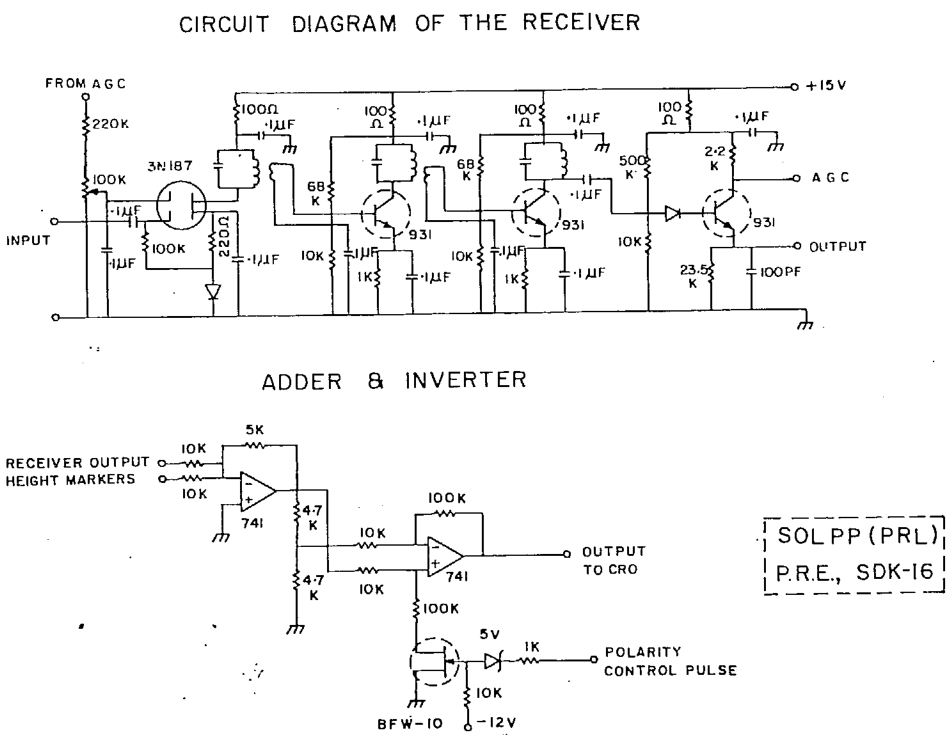


Fig.8 : Circuit diagram of the receiver

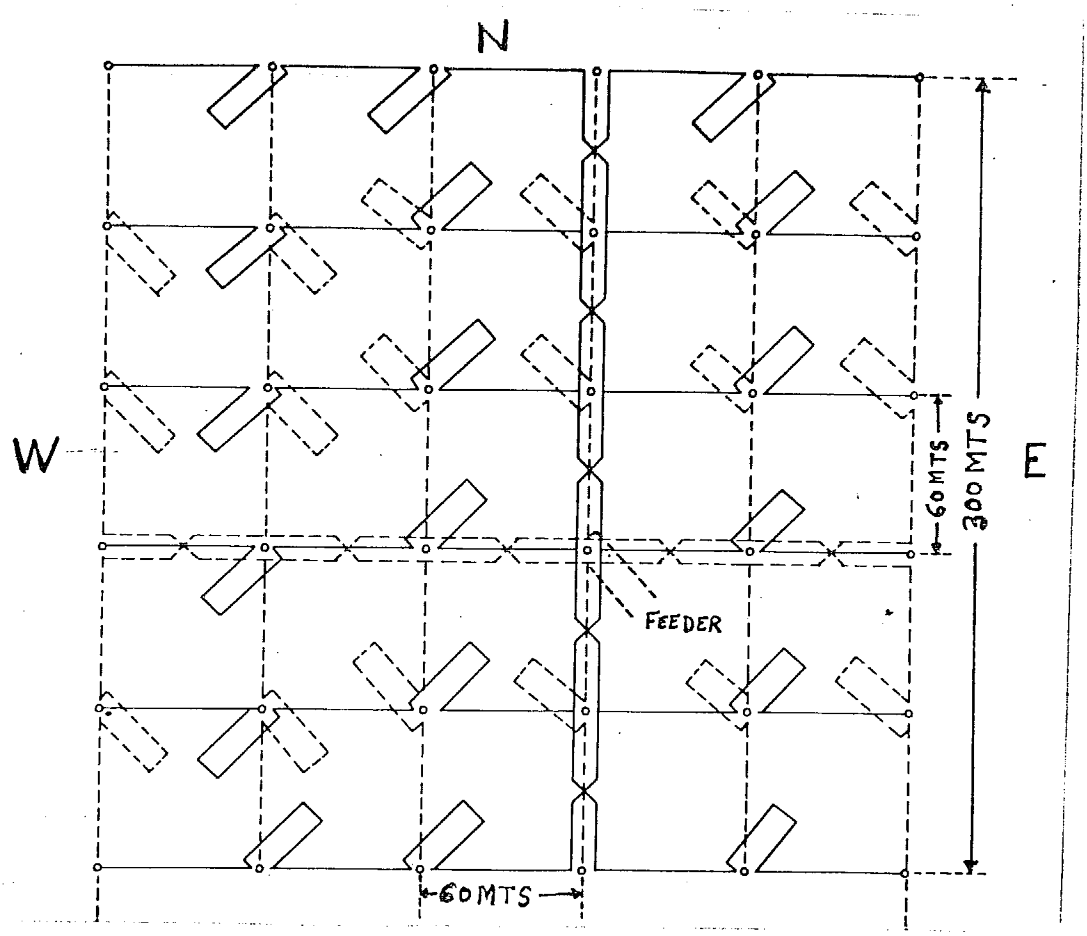
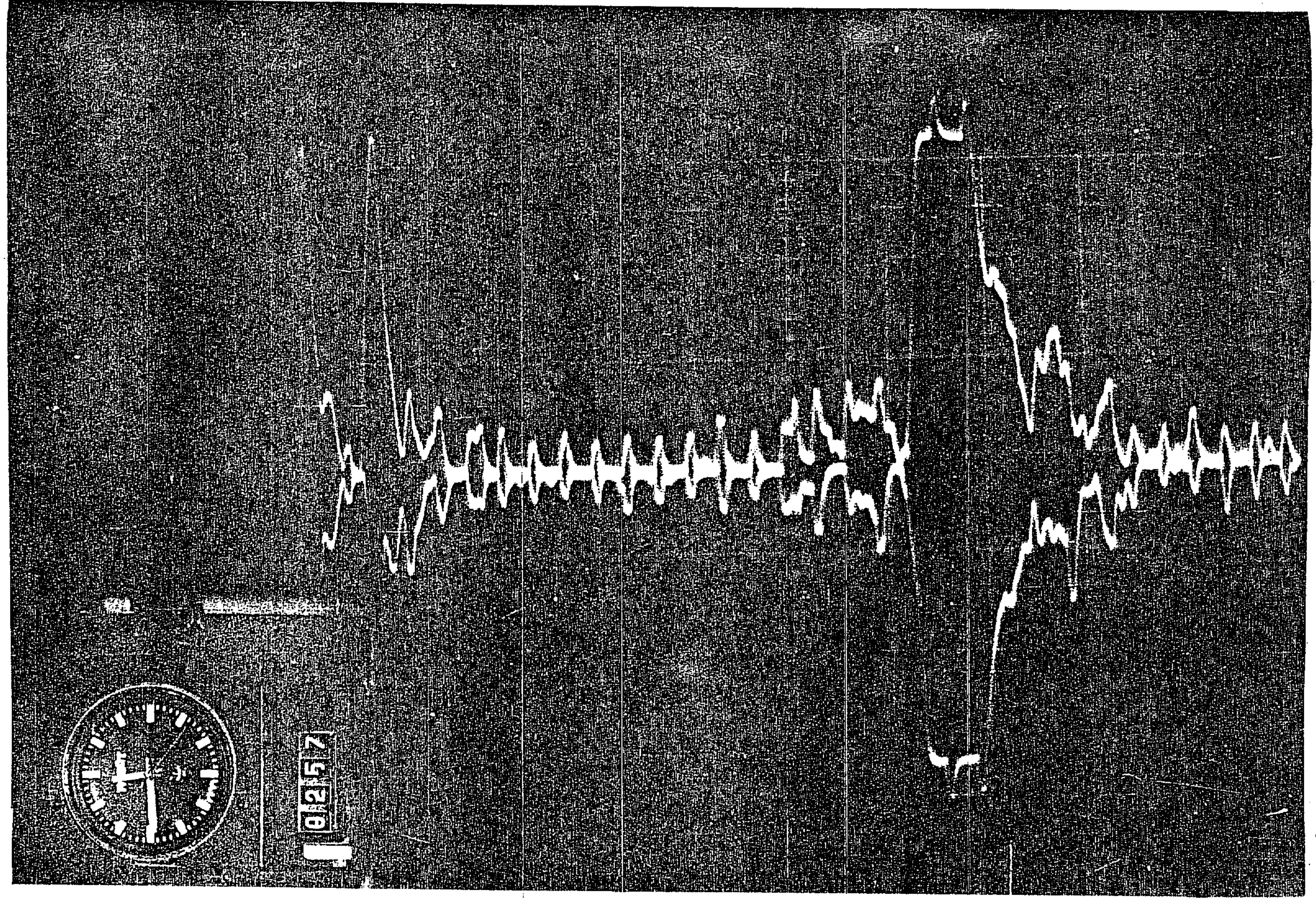


Fig.9 : Antenna system



A typical partial reflection record. The trace on the top side corresponds to ordinary mode and the bottom trace extra-ordinary mode.

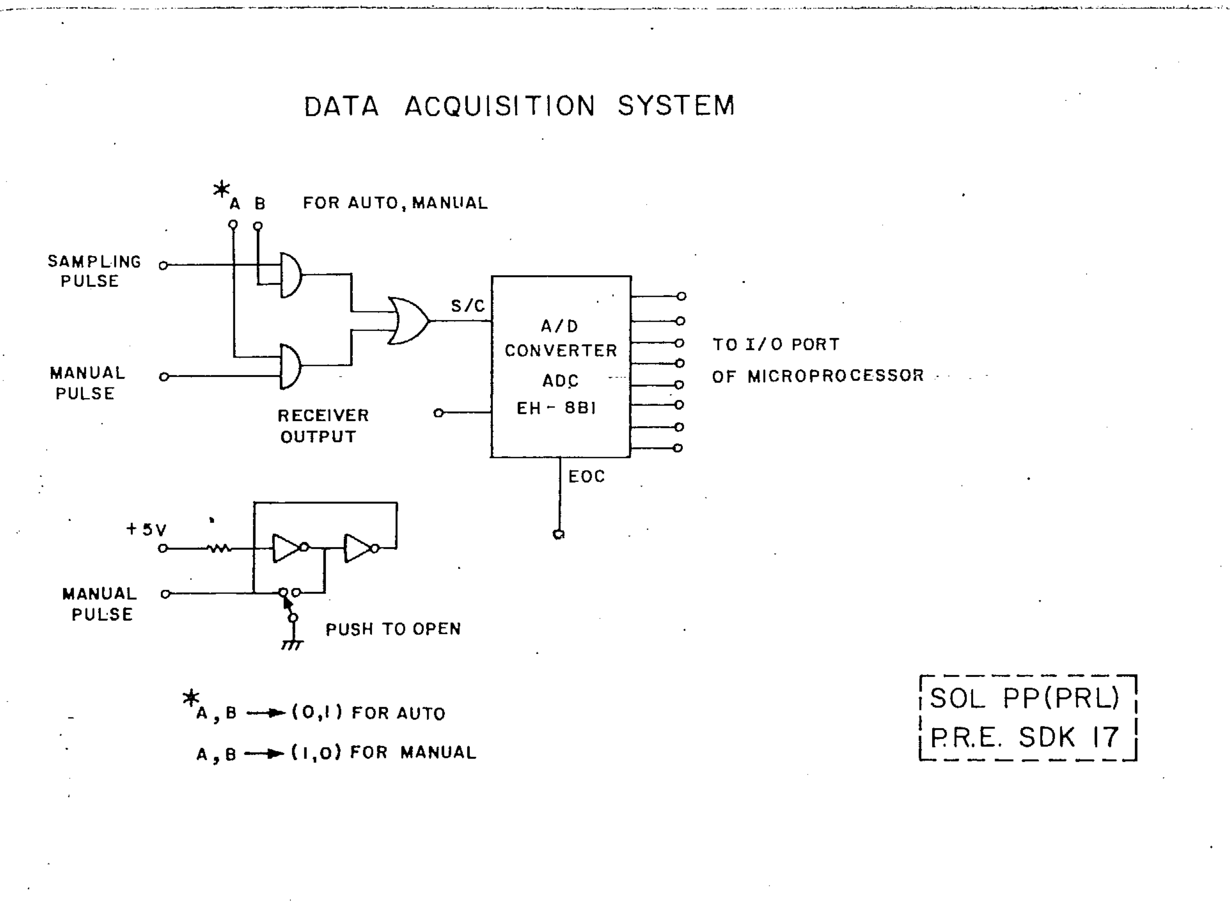


Fig. 11 : Data acquisition system

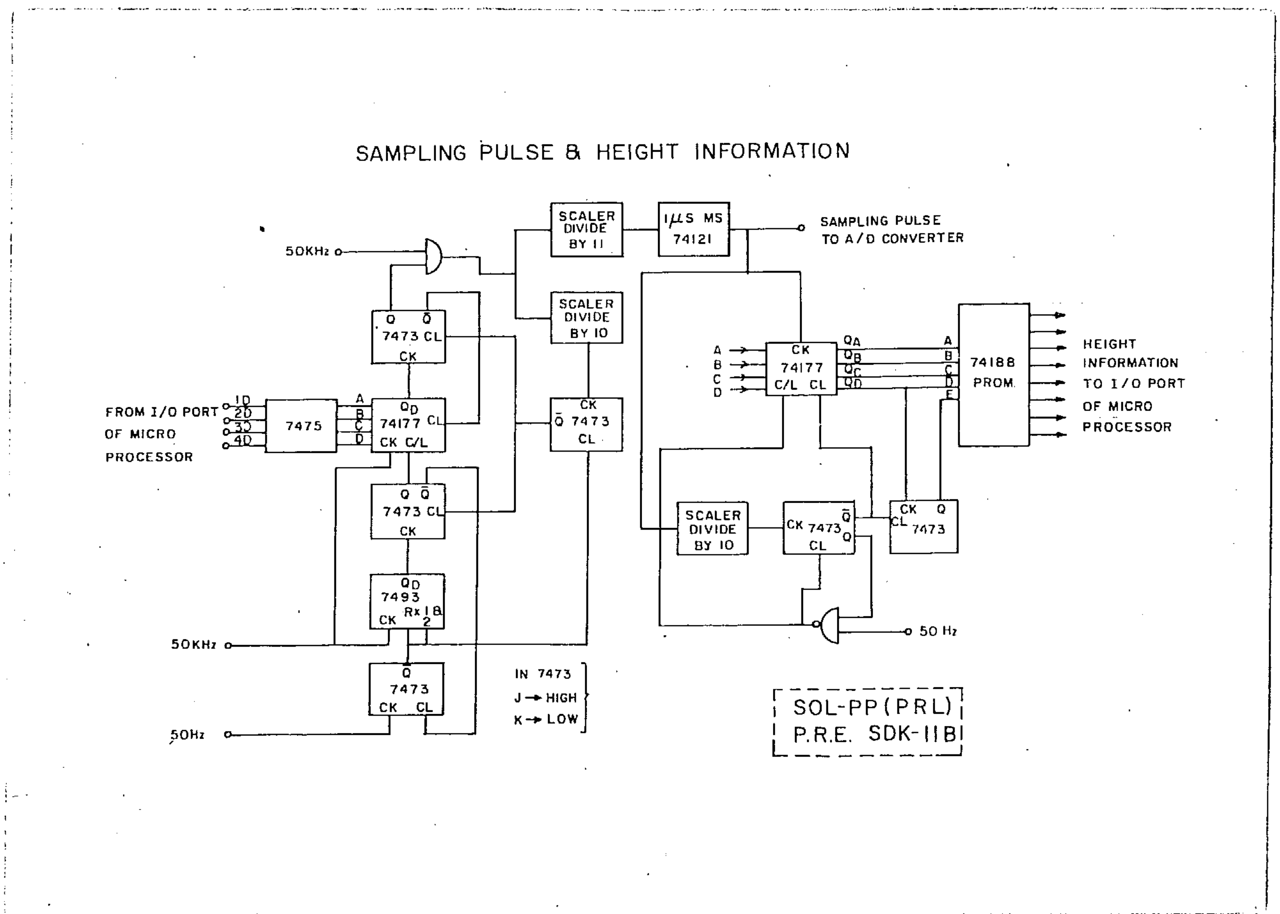
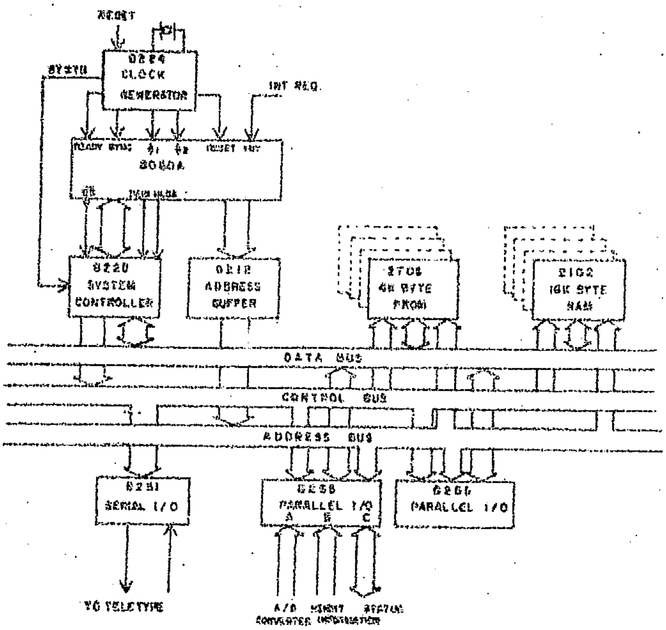


Fig.12 : Sampling pulse and height information.

MCS 80 MICROCOMPUTOR



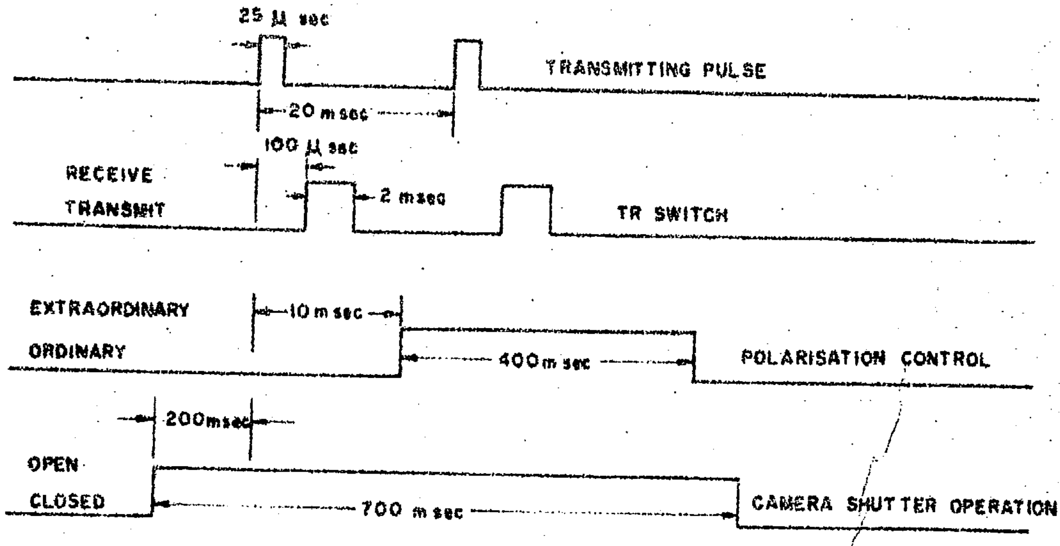


FIG.-14. SEQUENCE OF OPERATION