PRL
Technical Note

TN-77-04

VHF TELEMETRY AND DATA PROCESSING SYSTEM FOR SOLRAD 11 SATELLITE SIGNALS

D.V.Subhedar, R.Sharma, A.K.Goyal &
P.Sharma

Physical Research Laboratory
Ahmedabad 380 009, India.

CONTENTS

VHF TELEMETRY AND DATA PROCESSING SYSTEM FOR SOLRAD-11 SATELLITE SIGNALS

D.V. Subhedar, R. Sharma, A.K.Goyal and P. Sharma

Physical Research Laboratory
Navrangpura, Ahmedabad-380 009
India

ABSTRACT :

An experimental set up to receive, record and decode the telemetry signals from Solrad 11A and B satellites is described. Most of the equipments used in the set up have been designed and fabricated at Physical Research Laboratory with mostly indigenously available components. The system consists of a short backfire (SBF) antenna and its associated drive and remote control unit, PM receiver, analog tape recorder, PCM bit synchronizer, Viterbi decoder, PCM decommutator, time decoding and formatting unit, digital tape recorder and microprocessor. Solrad 11 satellites have been successfully tracked using the SBF antenna, designed and fabricated for the first time in the country. The necessary software to retrieve the data of the scientific experiments on board Solrad 11 satellites has been developed and the data counts have been obtained for a number of experiments. Calibration curves have been received for five of the experiments measuring solar X ray fluxes and absolute flux values for these experiments have been obtained.

-more-

Although, the experimental set up has been designed for tracking Solrad 11 satellites, it can be used for tracking any other high orbiting low inclination satellite transmitting in the VHF band 135 - 140 MHz.

1. Introduction :

Two identical satellites Solrad 11 A and 11 B carrying exactly identical experiments to monitor electromagnetic as well as particle radiations from the sun were launched by the Naval Research Laboratory (NRL), Washington, USA in March 1976. The two satellites are nearly 180^{0} out of phase in a nearly circular orbit of 20 earth radii, their orbital period being about 5.1 days. The details of the physical, orbital and telemetry specifications of Solrad 11 satellites are given in Appendix-1.

The motivation for obtaining the data from Solrad 11 satellites at PRL was two-fold. First, the Solar and Planetary Physics Group at PRL is engaged in the experimental as well as theoretical study of the earth's ionosphere. The knowledge of the real time measurement of the solar ionizing radiation is essential to arrive at a realistic model of the earth's ionosphere. Secondly, the study of solar electromagnetic and particle emissions would enable us to understand the plasma processes in the sun's atmosphere.

-more-

Another important consideration for recording Solrad 11 data at Ahmedabad ($23^{\circ}.0$ N lat., $72^{\circ}.6$ E long.) is its geographic location. Being in the opposite hemisphere of Blossom point, Maryland, USA ($38^{\circ}.4$ N lat., $77^{\circ}.1$ W long.), the tracking station of NRL, any one of the two satellites would be in the radio visibility of Ahmedabad when it goes below the horizon of Blossom point. Therefore the data obtained at Ahmedabad would be complementary in nature to those obtained at Blossom point.

On the basis of above considerations, it was planned to track the Solrad 11 satellites from the telemetry station at PRL. The goal was to be ready with the receiving and decoding system by the time the satellites were up in the orbit. The system for tracking the satellite at PRL was ready by December 1976 but unfortunately excessive heating of both the satellites due to some malfunction in their transmitters compelled switching off the transmitters onboard the satellites while they were about to leave the horizon of Blossom point during each pass. The temperature onboard Solrad 11A reduced to tolerable limits towards the middle of April 1977 and its transmitter was left 'on' continuously effective from April 26, 1977. About 25 passes were recorded between April 26 - June 12, 1977. On June 12, 1977, something went wrong onboard Solrad 11A due to which the PCM biphase data (containing the data of the scientific experiments) was missing in the received telemetry. -more-

Solrad 11B passes were scheduled for Ahmedabad from July 30, 1977 onwards at our request. A number of passes of Solrad 11B were recorded between July 30 - October 15, 1977. However, in none of these passes the data were of good quality. This fact was communicated to NRL. A message was received from NRL on November 9, 1977 that Solrad B will be turned off until March 1978 when it is about to leave the Blossom Point horizon during each pass because of temperature rise onboard Solrad 11B due to minimum sun-earth distance during winter.

2. Scientific Experiments :

There were twenty five experiments on board each one of the Solrad satellites out of which one (No.24, measuring non-solar X-ray background) failed on both the satellites. The twentyfour experiments measure the X-ray, gamma ray, extreme ultraviolet (EUV) and ultraviolet (UV) radiations as well as the electrons, protons and alpha particles emitted by the sun. The details of the experiments are given in Appendix-2. The X-rays being measured are hard (3-150 keV energy range) as well as soft (1-60 Å) in various energy bands. The intensity of X-ray line emissions at 9.2 Å and 8.4 Å (Mg XI and XII lines respectively) and their polarization are also measured. The EUV and UV fluxes in the wavelength range 170-1800 Å are measured in various bands. The particle emissions being measured are the solar wind electrons in the

-more-

energy range 0.2 - 4 KeV and also energetic electrons in the energy range 0.01 - 1.5 MeV emitted during solar flares. The protons being monitored are the solar protons and alpha particles in the energy range 1-100 MeV, antisolar protons having energy above 10 meV and omnidirectional protons having energy in the range 0.02 -460 MeV. The experiments measuring the solar and antisolar protons are mounted on the face of the satellite looking towards the sun and opposite to the sun respectively, whereas the experiments measuring the omni-directional protons are mounted on the periphery of the cylindrical surface of the satellite. The experiments measuring the X-ray, EUV and UV emissions from the sun are mounted on the surface of the cylinder facing the sun.

3. Importance of Solar Flux Measurements :

The importance of the measurement of solar X-ray and ultraviolet emissions lies in the fact that these radiations (below about 1300 Å wavelength) are responsible for producing various ionospheric layers (D, E and F) in the earth's upper atmosphere. Knowing the actual solar flux in different wavelength ranges it is possible to calculate the exact amount of ionization produced in various ionospheric layers. This would be useful in understanding many of the puzzling features of the behaviour of the ionospheric layers during quiet as well as disturbed periods.

-more-

The energetic electrons and protons coming out of the sun enter the earth's magnetospheric cavity on certain occasions thereby giving rise to magnetospheric sub-storms. The occurrence of weather disturbances at high latitudes is shown to be correlated with magnetospheric substorms. Recent hypothesis put forward by Cole (1) ascribes the sun-weather relationship phenomena to some kind of interplay between the processes giving rise to the electromagnetic and particle emissions in the sun's corona. The data obtained from Solrad 11 satellites may be helpful in testing this hypothesis. The entry of the energetic particles in the high latitude ionosphere gives rise to phenomena like auroral displays and polar cap absorption (PCA) events. The PCA events at times can cause total radio communication blackouts at high latitudes. Thus the study of charged particles emitted by the sun is important in order to understand and possibly predict the weather disturbances and radio communication blackout phenomena on the earth.

The continuous measurement of the solar X-ray flux by Solrad 11 satellites can be used for predicting the solar flares on a short term basis. In this connection it is important to mention here that regular observations of the solar flux in the radio as well as visible region are being made in India. The radio observations at 10.7cm wavelength are made by the radiometer at the Space Applications Centre, Ahmedabad, which is being operated by PRL. The observations

-more-

of the sun in the visible region are made from Vedhshala Solar Observatory, Udaipur and Indian Institute of Astrophysics, Kodaikanal. With the help of Solrad 11 X-ray data, it would be possible to predict a solar flare event 10-15 minutes in advance and the sun can be monitored simultaneously in X-ray, visible as well as radio frequency region of the spectrum. Such a multipronged attack on the solar flare problem would lead to significant advances in our knowledge of the complex relationships in solar and planetary physics. The prediction of solar flare event is important because of its effects on the lowermost (D) region of the earth's ionosphere. The increase in the X-ray flux emitted by the sun produces excess ionization in the D region which is turn causes severe attenuation of high frequency radio waves, occasionally producing total radio communication blackout on a global scale.

4. Experimental Set-up at PRL :

Fig.1 gives the block diagram of the overall telemetry set up used for data acquisition/recording/decoding the Solrad 11 data at the telemetry station of PRL. The system comprises short backfire (SBF) antenna, polarization switch, preamplifier, drive and the remote control unit for SBF antenna, PM receiver, analog tape recorder, bit synchronizer, viterbi decoder, PCM decommutator, digital tape recorder, and microprocessor.

-more-

4.1 Short Backfire (SBF) Antenna :

The link calculations (Appendix 3) show that in order to obtain a desirable S/N (of 6 db) of the Solrad 11 telemetry signal, the antenna gain should be 24 dBI.

In order to track the Solrad 11 A and B satellites, the main electrical requirements of the antenna were specified as follows :

Frequency range :	136 - 138 MHz
Gain :	24 dBI
Polarization :	Right circular and left circular
Half power beam width :	10^{o} (approx.)

The following different antennas, and feed systems were considered for this purpose :

1. Parabolic dish
2. Dipole array
3. Yagi array
4. Backfire Yagis of different lengths
5. Short backfire array

If one considers the parabolic dish antenna, to get the required gain of 24 dBI, an effective area of 95 m^2 is required. Assuming an efficiency of 60%, parabolic dish of 14.2 m diameter is required. Simple half-wave dipoles as feed elements with a plane reflector were also considered.

-more-

The number of dipoles required to give 24 dBI gain is 128 taking feeder and connector losses into consideration. The area of such dipole array would be 8.5 λ x 8.5 λ which makes its cost prohibitively high if it is to be steerable. A cluster of 32 Yagis of each 1.5 λ boom length are needed to give 24 dBI gain and the area becomes 8 λ x 8 λ which is also costly in order to make it steerable.

The concept of high gain "backfire" antenna as reported by Ehrenspeck (2,3) was evolved in order to reduce the overall number and length of the feed elements. A backfire antenna is an ordinary slow wave antenna, e.g. Yagi antenna, terminated by a large reflecting plane and the slow wave (or surface wave) reflector normal to its axis. The reflector backfires the wave in the slow-wave structure, thus causing the electromagnetic radiation to travel along the physical length of the structure. The backfire antennas are well suited in the gain range of 15 to 30 dB, combining structural advantage of a single endfire with a high gain of a reflector antenna. Its reflectors are planar and are simpler than paraboloidal reflector in construction.

The maximum gain of the backfire Yagi antenna is proportional to its length provided the phase velocity is adjusted to it's optimum value through proper choice of spacing of the directors. The optimum value is very nearly the same as an ordinary endfire antenna that is twice as long.

-more-

Zuker (4)has given a qualitative approach to its design, which shows that a stacked reflector has to be used to get the optimum gain from the single backfire Yagi antenna. Dod and Ehrenspeck (5) have reported a single 4λ long Yagi with 23.5 dB gain. The overall size of 4λ long Yagi with the larger stacked reflector (dia. 6.15m) at the required frequency of 136.5 MHz becomes comparable to the dimensions of a paraboloid with additional disadvantage of a long feed. The Yagi arrays of different lengths (i.e. 1.5 λ, 2 λ, 3 λ) were considered.

The short backfire antenna (SBF) (Ref.6,7) as an element for the array to get the desired gain has a definite advantage of reducing the overall length i.e. reduction upto one-tenth compared to a Yagi array (Ref.6) for similar performance. Secondly the radiating aperture of SBF antenna element is much wider than that of usual dipole fed reflector with additional advantage of extremely weak side and back lobes. Table-1 gives a comparative idea of different types of antennas considered and their dimensions in terms of λ.

4.1.1 Short Backfire Principle and Structure of a Single Element :

The short backfire antenna can be thought of as a backfire antenna of 0.5λ length with additional peripheral 0.5λ rim around the surface wave reflector. Such a system is characterised by multiple reflections of electromagnetic

-more-

waves and radiation occurs beyond the smaller of the two reflectors. The two reflectors of the short backfire antenna (M and R ; being the larger and the smaller reflector respectively as shown in Fig.2) differ radically in area. The inclusion of the peripheral rim reduces, (a) the backward and side lobes and (b) increases the directivity of the antenna because of the additional contribution from the edge(E)of the rim in front of surface wave reflector.(Ref.8).

The short backfire antenna is so compact that practically all the energy radiated into the cavity is intercepted by reflectors M and R, over distance of 0.5 λ. A slow wave structure would be of no help in trapping the energy and is therefore not used.

It appears from Table-1 that there are two choices: (i) 16 element backfire Yagi array of 1.5 λ length and (ii) the sixteen element short backfire array. The base area occupied by these two configurations is nearly equal but in the case of SBF the height is reduced to one-third though a peripheral rim of $\lambda/2$ length is required. It was estimated that the cost of supporting structure suitable for $\lambda/2$ length would be lower than that of the longer elements in spite of the additional peripheral rim. The final choice was 16-element SBF which turned out to be the cheapest with increased reliability due to the smaller number of feed elements.

-more-

4.1.2 Structure of a Single Element used as the Basic Element:

Since no data about relevant dipoles and feeder system to be used with SBF are available in literature it was decided to make one single element at 136.5 MHz to carry-out the required measurement. This SBF element was optimized (Ref.8) in regard to its gain, side lobe suppression and front-to-back ratio. The SBF element was used for most of the experimental studies. Fig. 2 shows the sketch of 136.5 MHz antenna in which 3/16" expanded aluminium is used for reflectors and the peripheral rim.

The diameter of the larger reflector (M) is 2.35 λ and the smaller reflector (R) is a circular dish made of expanded aluminium mesh of 0.5 λ in diameter spaced 0.5 λ from the larger reflector. It offers the advantage of being sensitive to the polarisation of the feed, which may be polarised linear, right circular or left circular. The width of the peripheral rim surrounding reflector M is 0.57 λ. Two crossed dipoles are used as feed elements and the input is matched to 50 ohm by using a quarter wave matching section of air coaxial line. The gain of the SBF antenna has been found to be 17 dB over a dipole ; voltage standing wave ratio (VSWR) being of the order of 1.1.

-more-

4.1.3 General description of the 16-element SBF Array and the Feed Arrangement :

The dimensions of the sixteen element SBF array chosen are consistent with the single element except for the spacing which has been made adjustable in this case. Fig.3 shows an artist's view of the telemetry antenna. A sketch of the array is shown in Fig.4. The sixteen elements are divided in four quadrants. The four element of one quadrant are combined by a four-way co-axial power divider, thus the two crossed dipoles V and H of the quadrant are combined separately by two four way power dividers. The vertical and horizontal outputs of the four individual quadrants are further combined by two four-way power dividers. Thus all the vertical and horizontal dipoles appear in phase at the output points, where they are fed to a polarisation switch to get the desired polarisation.

4.1.4 Two way and Four way Power Dividers :

Fig.5 (a,b) shows the sketch of the four way and two way power dividers. Air co-axial lines are made of 22 mm brass tube and rod. Impedance and phase measurements were carried out using RX Meter Model HP 250 B, and Vector Voltmeter HP 8505 and GR Admittance Bridge GR 1602 B.

4.1.5 Experimental Measurements :

Impedance measurements are carried out on all the sixteen elements by using the RX Meter. The dipoles are

-more-

tuned to the desired frequency by adjusting their length. The input impedance is adjusted to 50 ohm by varying the diameter of the inner rod of the quarter wave matching section of the air co-axial line. The values of impedance are shown in Table-2. VSWR measurements were performed on all individual elements, individual quadrants and the final output points for vertical and horizontal feeds separately. Fig.6 (a) gives the VSWR of a typical element versus frequency and Fig.6 (b) gives the same for the combination of four elements. Fig.7 gives the final (16 element array) output VSWR of V and H separately. The gain of the antenna was found to be 22.5 dB (i.e. 25.5 dBI) with respect to a standard dipole.

Individual cross polarized component was measured by transmitting signal from vertical antenna and received by horizontal antenna and was found to be 30 db below the vertical polarization.

4.1.6 Solar Transit through the SBF :

Fig.8 (a) shows the transit of the Sun on a quiet day and Fig.8(b) on a noisy day at 140 MHz. The X axis in this figure represents time in terms of degrees (1 hr = 15^{o}). The half power beam width is seen to be about 10^{o}.

4.2 Polarization Switch at 136.5 MHz :

A polarization switch at 136.5 MHz is used with the 16 element short backfire antenna for the Solrad 11 satellites. It is well known that a pair of crossed -more-dipoles can be used to determine the complete polarization. The conditions for the two circular components of polarization (right and left handed) are achieved by adding the signals from the two dipoles together through lengths of transmission line that introduces a path difference of $\pm\lambda/4$ where λ is the wavelength.

4.2.1 The Principle of Operation :

The polarization makes uses of the properties of $\lambda/4$ length of co-axial transmission line connected between the points 1, 2,......7, as shown in Fig.9. It is used to route r.f. signals through the network in various ways. Use is made of the property that the impedance of a low loss transmission line appears very high at a point $\lambda/4$ away from a very low impedance point and vice versa. The r.f. switches A and B are connected so that one is conducting and the other is non-conducting. Hence the impedance shunted across the junction 3 is high when that across junction 4 is low, thus allowing signals to pass freely along the arm A (1-3-5) but with high attenuation through arm B (2-4-5). Similarly, reversing the connections renders arm B conducting and arm A non-conducting.

The receiver input is thus effectively connected through $\lambda/2$ path to either point 1 or 2 depending on the switch position. The cross dipoles V and H are connected to the junction points 1 and 2 respectively -morevia switches through paths having path difference of either zero or $\lambda/4$. Thus the combination accepts left handed or right handed circular polarization according to the setting of the r.f. switches A and B.

4.2.2 Construction and performance of the Slab Line Polarization Switch :

Fig.10 shows the sketch of the polarization swtich using slab line construction at 136.5 MHz. The slab line construction is used to reduce the insertion loss. An aluminium sheet of 1/8" thickness is used as ground plane and copper rods of 9.5 mm diameter as the central conductors. Input and output impedance measurements were carried out at different ports. V and H are the input ports and O is the output port. S_1 and S_2 are the switched ports which offer high and low impedance to the conducting and non-conducting arms depending on the r.f. switch condition.

The switches select the type of polarization. Fast operation is not required here and the switches are manually controlled from the control panel located inside the telemetry building. The final switch assembly must be accurately balanced for phase and amplitude. Considerable care is taken to ensure correct impedance of $\lambda/4$ sections of cable to avoid magnification of the termination errors. The measured characteristics of the polarization switch are shown in Table-3.

-more-

4.3 Drive and the Remote Control Unit for the SBF Antenna :

The SBF antenna is mounted on an equatorial mount using two North-South aligned towers of 10.5 m and 7.5 m in height respectively. The distance between the two towers is 6 m from centre to centre. The antenna, a square bowl of 12.5 m x 12.5 m x 1.25 m and weighing approximately 9 tonnes (metric) is remote controlled to facilitate Solrad satellite data receiption at the telemetry building, approximately 50 m away from the antenna. In the hour angle mode the antenna can be moved from -90° to $+90^{\circ}$ through zenith (0°), where as the antenna movements in the declination are restricted from $+5^{\circ}$ (N) to -49° (S) through the zenith (0°). The range of declination mentioned above was enough to track Solrad 11 satellites (having orbital inclination of about 26°) at Ahmedabad (Geog. lat. 23°N), where the range of declination encountered would be from $+3^{\circ}$ to -49°. Four limit switches are provided to protect the antenna and the structure from being damaged while antenna reaches its extreme designed position.

The hour angle drive is provided by a 2 horse power, (h.p) 1440 rpm motor through two gear boxes with a total gearing ratio of 24000. This gives an hour angle speed to

-more-

the antenna of 0.36^{o} S^{-1}. By using Kopp's Variator, the antenna speed in hour angle is made remote variable from 0.06^{o} S^{-1} to 0.6^{o} S^{-1}. This enables slow tracking and fast return. The declination drive consists of a geared motor of one h.p. and 36 rpm, at the output. This motor drives a 2.4 m threaded shaft with 3 thread per inch (TPI) through a nut, thus providing an approximate antenna speed of 0.1^{o} S^{-1} in declination.

Schematic block diagram of the remote control unit is shown in Fig.11 . This unit provides the digital displays of the antenna positions which are directly calibrated in degrees. Multiturn servograde potentiometers are used for position encoding. Precision comparators with presettable deadbands, and other electronics enable the unit to be operated in either of the two modes, viz. manual or preset. In the manual mode one can move the antenna to a desired position by keeping track of the angles indicated, whereas in the preset mode, the antenna positions are presettable on reference indicators and the antenna automatically moves to the pre-set positions (within $\pm 0.2^{o}$). Pre-set mode provides an easy interface for a pre-programmed tracking.

-more-

When the antenna reaches one of the extreme designed positions, a limit switch operates to prevent it from moving further. At this point on the front pannel also a visual indication is provided to the operator as a precautionary measure.

4.4 PM Demodulation and Analog Recording:

Right or left circularly polarized signals from the SBF antenna through polarization switch are amplified by the low noise preamplifier fabricated in the laboratory. Design specifications of 35 db gain and 3 db noise figure were used, on the basis of expected losses for the cable length used and the tolerable signal to noise ratio at the input of PM Receiver required for locking. Preamplifier is directly connected to the polarization switch on the top of antenna. The cable between preamplifier and receiver is 150 feet long and its antenuation is about 5 db.

Microdyne PM receiver used for the programme is modular in construction. The RF tuner has about 6 db noise figure and can be tuned to any frequency in the band of 105-150 MHz by choosing a suitable crystal in the first local oscillator. First I.F. of 50 MHz is amplified and mixed with second L.O. of 60 MHz which is a VCO. The third I.F. of 10MHz thus generated is amplified by an IF amplifier module of 10 KHz bandwidth. Module of 1 KHz bandwidth will increase the

-more-

sensitivity of receiver by reducing the system noise without affecting the shape of PCM signals appreciably. However, at present the Microdyne Corporation (U.S.A.) does not manufacture modules of less than 10 KHz bandwidth. A development project has been undertaken in the laboratory to build a mixer and an IF amplifier of 1 KHz bandwidth, compatible with the existing receiver.

The 10 MHz third IF is fed to a phase lock demodulator where it is phase compared with a 10 MHz crystal. Phase detector output is amplified by the video amplifier. The video bandwidth is selected from the front panel (6.25 KHz). Phase detector output is also passed through a low pass filter and controls the 60 MHz VCO (second L.O.). The loop bandwidth can be selected from front panel. To start with 100 Hz loop bandwidth is selected for signal locking. For reception of 204.8 Hz data rate, loop bandwidth of 10 Hz is desirable and the same is used. Receiver lock condition is indicated by the LOCK lamp on the front panel. AGC time constant can also be set from the front panel. Loss or absence of carrier is denoted by a lamp. Approximate signal strength available at the input of the receiver is also indicated by a meter. The video output from the receiver is directly recorded on the analog tape recorder (REVOX A77) driven at a speed of 3.75 ips.

-more-

4.5 PCM Decoding and generating Computer Compatible Digital Tapes:

The PCM decoding equipment used for Solrad 11 Satellites consists of a PCM Bit Synchronizer, Viterbi decoder, PCM decommutator and Interface with PERTEC digital tape recorder. The Bit Synchronizer, Decommutator and Interface with PERTEC were developed and fabricated in the laboratory. The interface between PDP11V03 micprocessor and the PERTEC is being developed for transferring satellite ephemeris information computed with the help of orbital elements at regular intervals. Each of the units is described in this article. The circuits were ready before the satellite signals were received in the telemetry station. Fortunately, a replica of convolutional encoder on board the SOLRAD 11 satellites is available as a module in Viterbi decoder LV 7015. The Solrad 11 PCM data was simulated with same bit rate word rate, frame rate and frame synchronization pattern (1101 0111 0101). In between two sync patterns a PRBS (pseudo random bit sequence) of 372 bit length was introduced. This composite signal was convolutionally encoded and was frequency modulated on 136.65 MHz. The RF signal thus generated was transmitted by a whip antenna and was received on the SBF array antenna built for SOLRAD programme. The PM receiver (MICRODYNE 1100 AR) demodulated the signal which was used for PCM decoding. By controlling the transmitted signal power, change in the signal to (receiver) noise ratio was

-more-

simulated and the performance of PCM decoding equipment, i.e. the duration for which Decommutator continuously remains in lock was extensively tested. For the signal to noise ratio of 6 db, which is expected in actual conditions, the Decommutator hardly went to CHECK mode from LOCK mode over a period of 12 hours of continuous testing.

4.5.1 <u>PCM Bit Synchronizer:</u>

The phase demodulated output from the PM receiver (raw PCM signal) is recorded on the analog tape recorder alongwith NASA 36 bit time code modulated on 1 KHz on two channels separately.

At a later time the tape is replayed and the video signal is fed to the bit synchronizer for PCM decoding. The bit synchronizer cleans, reshapes and quantizes the signal for Viterbi decoder (LV 7015, Linkabit Corporation, USA) where the convolutionally encoded signal is decoded. The Viterbi decoder requires clock synchronized with the data at its input. This clock is regenerated in the Bit Synchronizer (Fig.12).

The video signal from receiver or analog tape recorder is of 204.8 Hz frequency and is biphase modulated. The clock is hidden in the data and has to be 'extracted' from the data signal in the presence of noise. For this, phase lock loop NE 565 (Signetics) IC has been used. By adjusting

-more-

thresholds on comparator chips hard quantized data (sign bit) or 3 bit soft quantized data (1 sign bit and two magnitude bits) is obtained. Selection of quantization data is controlled by the HARD/SOFT switch on the Viterbi decoder panel. The threshold voltages on the comparators are adjusted by assessing the noise on the channel, as required by the Viterbi decoder.

The loop bandwidth in the phase lock loop circuit is adjusted to 10 Hz. This is sufficiently high to take care of tape speed fluctuations and fairly low enough to keep data waveform distortions to a minimum.

At the front end a prefilter band limits the signal and keeps the noise level adequately low. Great care had to be taken in order to make the filter phase compensated.

The biphase ambiguity introduced by the bit synchronizer (bit 0 detected as 1 and vice versa) cannot be resolved by the viterbi decoder. In order to resolve this ambiguity inverted data output terminal is also available on the bit synchronizer. Proper output is selected after keeping track of all the inverting amplifying stages before the comparator circuit.

4.5.2 Viterbi Decoder:

Data from Bit synchronizer is fed to the Viterbi Decoder (LV 7015, Linkabit Corporation, USA) at 204.8 bps rate alongwith the synchronized clock derived in bit synchronizer. This is very essential unit in the decoding chain

-more-

as the corresponding convolutional encoder is on board the Solrad 11 satellites. Without this the decoding will be absolutely meaningless. The specifications of the Viterbi Decoder are given in Appendix 4. Theory of its operation, in brief, is as follows.

The state of a convolutional encoder having constraint length K (7 in the present case) is defined as the contents of first K-1 stages of the encoder shift register. Letting x represent a K-2 bit sequence, the states of the encoder, can be represented as x0, x1, 0x, 1x. The encoder state changes from x1 to jx when the encoder input is j. The transition from state xi to jx requires that the encoder shift register contents be jxi.

The operation of the decoder requires that a maximum likelihood decision be made as to whether state jx was entered from state x0 or x1. Thus during each bit time 2^{K-1} pairwise decisions must be made. The results of these decisions are stored forming 2^{K-1} paths. Associated with each of these paths is a path metric, or state metric, which is a measure of distance between the path and the received channel symbols. In LV 7015 the path length of 32 has been chosen which is more than four times the constraint length K (= 7). During each bit time 64 pairwise decisions are made, the path with minimum metric is determined and the oldest bit on that path is the decoded information bit.

-more-

The convolutional encoder on board the Solrad 11 satellite operates in the serial BPSK mode. Information bits input to the encoder generate two code (parity) symbol streams P1 and P2. These two symbol streams are interlaced into single serial stream output at the 2R (204.8 bps) rate. The Viterbi Decoder resolves the two state ambiguity by a process of 'node synchronization' and produces two streams P1 and P2. When the decoder is operating with incorrect node synchronization, and the data source is random, the received symbols are random and result in high correction rate i.e. the rate at which static metric increases. At this stage assumed node synchronization is changed, and proper bit train appears at the output. Proper bit train starts appearing after about 350 bits for hard quantization mode (150 bits for soft quantized mode) for decoder output error rate of 10^{-1}. After that error rate diminishes with time.

4.5.3 The PCM Decommutator

The train of bits from Viterbi decoder is passed through PCM decommutator specially built to suit Solrad 11 format requirements. Initially it was proposed that the efforts should yield versatile PCM decommutator or frame synchronizer useful for any other satellite having different frame sync pattern and different bit patterns as well. But the fact that the Solrad 11 data has to be recorded, almost round the clock,

-more-

on the computer compatible tape recorder in a special format for useful data exchange with Naval Research Laboratory, U.S.A. was more important. In this format time (U.T.) satellite ephemeris information and information of quality of signal for PCM decoding is to be multiplexed with satellite signal for each of record (2082 bytes) at regular intervals for computer analysis. Hence it was decided to opt for dedicated decoding equipment for Solrad 11 programme.

The current trend in this field is to slave a mini computer for frame synchronization purpose. The minicomputer searches for frame synchronization pattern and directly records the PCM words on digital tape recorder attached to it as a standard peripheral.

The digital tape thus prepared can subsequently be processed on a big computer. In the case of Solrad 11 data the minicomputer will have to do a dual job of frame synchronization as well as computation of ephemeris starting from the orbital elements. It was estimated that considerable time and efforts would be needed to develop the necessary software for the above purpose and therefore the above scheme was discarded. Also it was argued that in order to have spare sets of decoding equipments it is worthwhile to go for decommutator with hardware rather than completely rely on one minicomputer which has to be tied round the clock.

Once it was decided to go for decommutator with hardware, various philosophies were studied and finally the one described below was adopted (Fig.13). A schematic diagram of the PCM Decommutator is shown in Fig.14.

The decommutator works in one of the four modes at any given time. The four modes SEARCH, VARIFY, LOCK and CHECK are automatically selected depending upon quality of the incoming signal. All the modes are displayed by the lamps on front panel. The front end circuitry uses a 12 bit shift register which gives a one bit pulse when 12 consecutive bits form a frame synchronization pattern. Until that time the decommutator remains in SEARCH mode which is indicated by glowing of the SEARCH lamp on the front panel. After detection of first frame sync pattern the VARIFY lamp on front panel starts glowing. The one bit pulse triggers a circuitry which blocks data pulses going to the shift register by closing a gate. The gate is opened only when the next frame sync pattern is expected to arrive i.e. after 384 - 12 = 372 bits. Thus each such pulse corresponds to one frame sync pulse. It is likely that the circuit may be falsely triggered by any twelve consecutive bits in the data, forming exactly the frame sync pattern. The probability is 1 in 2^{12}. But the probability decreases exponentially for the same bits forming frame sync pattern at exactly the frame rate. An operator

-more-

with his own judgement sets a number from 0 to 9 on the front panel thumb wheel switch (LOCK range). For example, if number 7 is set on this switch, the circuit will examine for seven successive frames for sync pattern and if all of them detect it, the decommutator goes to LOCK mode. If for a single frame in between, the sync pattern does not appear the decommutator immediately goes to SEARCH mode till it detects the next sync pattern. This continues till 7 consecutive frame sync patterns are detected. As long as the decommutator remains in LOCK mode it is assured that all the frames have proper sync pattern in the beginning. During the LOCK mode, if for a while the channel noise increases and consequently sync pattern is lost, the equipment goes to CHECK mode. Here again the operator can set a number from 0 to 9 on a front panel thumb wheel switch (CHECK range). Here the logic used is opposite to that used in LOCK mode. For example, if a number 5 is set, the decommutator goes to SEARCH mode if for five consecutive frames sync pattern does not appear. Otherwise it comes back to the LOCK mode.

In all the modes serial to parallel conversion is continuous. Thus decommutator gives 12 bit output on 12 parallel lines. The words are aligned only if proper sync pattern is detected. The word following the frame sync pattern gives a 10 bit binary frame counter which is incremented for each transmitted frame. The remaining two bits give the information regarding the type of data format selected on board the satellite. This word is displayed

-more-

on the front panel by means of 10 light emitting diodes (LED'S). Operator can monitor this counter which increments at every 3.75 seconds. All the 10 LED'S go through a cycle which lasts exactly for 64 minutes.

Alongwith the 12 bits of data, 4 bits for signal quality are added to produce two 8 bit characters compatible to CCT, as follows.

0 L S 0 1 2 3 4	5 6 7 8 9 10 11 12
First Character	Second Character

In the word consisting of 12 bits, bit No.1 is transmitted first from the satellite. The bit L is high (logic 1) if the decommutator is in LOCK mode. The bit S goes high if the word corresponds to frame sync pattern. Thus for each satellite data word there are two consecutive characters in the record, on the digital tape recorder. For a two minute telemetry cycle there will be 2048 characters. The remaining 34 characters are reserved for ephemeris and time information, thus making a record of 2082 characters.

To detect frame sync pattern, the maximum resemblence technique is deliberately avoided. In this technique, if frame sync pattern does not appear because of high channel noise, the pattern which resembles most with frame sync and repeats at frame rate is declared as correct pattern. This is suitable only when the words are designated to give quantized output of some physical parameter. Any noise fluctuations of the data can be rejected in analysis.

-more-

But in case of Solrad 11 data all the experiments generally do not follow the same bit position pattern as far as intensity, range, power supply status, detector selection and satellite 'health' information are concerned. Therefore, when decommutator is not in LOCK mode for a considerable time, no useful information can be obtained as statistically the channel noise is equally distributed over all the bits. In the present case, it is left to the user to decide whether he can accept the data for analysis or not if decommutator is not in LOCK mode for a long time.

4.5.4 Time Decoding and Formatting

Alongwith the raw PCM data received from satellites, the NASA 36 bit time code is also recorded on the other channel of REVOX tape recorder. This is basically a 100 pps PCM signal (PDM) amplitude modulated (75 to 85%) on 1 KHz sine wave. A logic 1 is denoted by 6 ms 'on' pulse and logic 0 is denoted by a 2 ms 'on' pulse, the period in both cases being 10 ms. When tape is replayed, for a logic zero, 2 cycles of 1 KHz appear with 100% amplitude with a gap of 8 cycles below 25% level. The figures are 6 cycles and 4 cycles for logic 1. During one second, 9 digits for time (3 for days, 2 for hours, 2 for minutes and 2 for seconds) are multiplexed with one reference marker (111110), nine index - 0.1 sec. - markers (000001). The digits are expressed in BCD.

-more-

The time decoding circuit (Fig. 15) searches for reference marker and detects 36 bits for the 9 digits and latches them on a 36 bit latch. On the latch, bits are updated as and when they change.

The 1 KHz sine wave derived from the clock is connected to a phase lock loop chip NE 565 with VCO centre frequency of 10 KHz. This 10 KHz frequency is counted on a 16 bit binary counter. 1 PPS reference marker resets this counter as and when it is detected. At every two minutes (i.e. period of a telemetry cycle), 16 bits from counter and decoded time from the 36 bit latch is sampled. The BCD outputs for days, hours, minutes and seconds are converted to binary form (9 bits for days, 5 for hours, 8 for minutes and 8 for seconds) to suit the standard recording format of time characters in the 2082 byte long record. The data decoding is done only off line at present and hence NASA 36 bit/1 KHz time clock has to be recorded alongwith the satellite data.

4.6 Microprocessor PDP11V03

For the Solrad 11 satellite data processing, it was first thought to use the microprocessor as PCM decommutator (or frame synchronizer). Since it is also to be used for satellite ephemeris calculations, this idea was dispensed with and a hardware decommutator was fabricated. The PDP11V03 has a KD11-F CPU and 12K of dynamic MOS-RAM for computation use. It is attached with LA36, DEC-writer as console device.

-more-

Software FORTRAN-compiler has been provided on system dis-kett (floppy disk). At a time two disketts can be used as there are two disk driving units.

On receiving the 'orbital elements' from Naval Research Laboratory every week, the satellite orbit can be predicted for next few days by solving Kepler's equation of motion for orbiting bodies. The 6 orbital elements define the satellite's orbit parameters at a given time, as follows:

1. Right ascention of the ascending node (longitude of the point where the satellite crosses the equator and goes northward from the vernal equinox direction).

2. Inclination (of the orbital plane with respect to the equatorial plane).
3. Argument of perigee (angular distance of the perigee point of the orbit from the ascending node along the orbit of the satellite).
4. Semi major axis.
5. Eccentricity.
6. Mean Anomaly (M, defined as the angle swept by the radius vector in the interval $(t - T)$ where t is the time at any instant and T is the time of perigee passage. Thus, $M = n(t-T)$ where 'n' denotes the mean angular velocity given by $n = 2\pi/\text{period}$).

After solving the Kepler's equation of motion, the orbit is corrected for gravitational effects of sun and moon depending upon their position with respect to the satellite's position along the orbit.

According to the accepted NRL format (Fig.16), the satellite position information is calculated every two minutes in the form of geocentric coordinates (x, y, z) and their time derivatives ($\dot{x}$, $\dot{y}$, $\dot{z}$). x, y, and z are calculated in decimetres and each of them occupies four - 8 bit characters, whereas $\dot{x}$, $\dot{y}$ and $\dot{z}$ are calculated in ms^{-1} multiplied by 10^4. These also occupy 4 characters each. Thus satellite ephemeris information occupies 24 characters in a 2082 byte length record corresponding to two minute telemetry cycle. The computer program for this purpose consists of one main programme and 22 subroutines and all are written in FORTRAN language. The test as well as compiled output is stored on the diskett (capacity 256 K bytes). Efforts are underway to accommodate the full programme in the limited 12 K memory and with the limitation of 2 min computation time, as the information has to be updated every two minutes. Also essential is to connect the microprocessor to PERTEC digital tape recorder, for transfering the computed satellite position coordinates, through interface being developed in the Laboratory for this purpose.

Presently only the satellite PCM data and time information is being transferred to digital tape recorder through interface and the ephemeris information is computed in IBM 360/44 computer as and when necessary.

-more-

In addition to this development work, this microprocessor is being used for software development in both FORTRAN as well as assembly language (MACRO). All the programmes developed so far have been stored on the diskette. The most important amongst these are:

i) Programme for computation of antenna look angles (predicted) for tracking the Solrad 11 satellites on the basis of orbital elements' information.

ii) Generation of PRBS (pseudo random bit sequence) of $(2^{12}-1)$ bit length for simulating Solrad 11 PCM signals.

iii) Synthesis of convolutional encoder circuit with knowledge of response at the output for known input sequence.

iv) Design of active filters.

5. Solrad Telemetry and Retrieval of the Scientific Data from the Digital Tapes

Each Solrad 11 satellite transmits real time telemetry link, transmission frequencies being 137.44 MHz and 136.53 MHz for the satellites A and B respectively, carrying all experiment and house keeping data. There are five formats; each format consisting of 32 frames containing 32 twelve bit words per frame. The information rate is 102.4 bits per second. Therefore, it takes 3.75 seconds to transmit each frame and two minutes to transmit a complete format. Format one is the normally selected format because it

-more-

contains data from all experiments (except 18, 19 and 25), complete experiment status and house keeping information and spacecraft house keeping information. Analog data from experiments and monitors is converted to digital form, in most cases to 8 digital bits. The eight bit analog-to-digital data is transmitted most significant bit (MSB) first using the first eight transmitted bits of the twelve bit telemetry. The last four transmitted bits sometimes contain status and house keeping information and sometimes are blank.

For some of the experiments, the analog data is converted to 12 digital bits, occupying an entire twelve bit telemetry word and transmitted MSB first. Digital data from some experiments is encoded by letting the telemetry words carry the output of linear accumulators which also is transmitted MSB first. However, digital data from most of the experiments is encoded by letting the telemetry words carry the output of a 12 bit floating point accumulator (FPA) in the form of a 4 bit exponent and 8 bit mantissa. If the values of the exponent and the mantissa are denoted by E and T respectively, the decimal value of the count C is given by

$$C = (T + 255)\ 2^{E} - 255$$

If T = 0 and E = 0, the following formula is used.

$$C = 511 \cdot 2^{E-1} - 255$$

The exponent and the mantissa are transmitted using the first four and the last 8 bits of the 12 bit telemetry word, both MSB first.

-more-

Four bits O, L, S, O are added to each of the 12 bit telemetry word in the PCM decoding equipment where L and S denote the status of the locking of the equipment ('1' if locked and '0' if unlocked) and the presence of the sync ('1' if present and '0' if absent). Thus, each telemetry word becomes 16 bits, the first four being those added in the PCM decoding equipment, which is equivalent to two words of 8 bits each of IBM 360/44. Each telemetry cycle of 2 min duration has thus 32 x 32 x 2 = 2048 bytes of eight bit each. In the standard NRL format, 34 bytes having 16 bits each are added in the beginning of each telemetry frame to incorporate the real time of the data and the ephemeris of the satellite at the time when the data was obtained. This information is generated by the microprocessor and transferred to the digital tape at each 2 min interval before a telemetry cycle commences.

As already mentioned above, the telemetry of either Solrad 11 satellites contains the data of various experiments as well as the experiment status and house keeping, e.g. on/off state of the experiment, range, mode automatic/manual, calibration on/off, etc. If the telemetry data is clean, the sixteen bits of the first word of each of the frames as read on the digital tape will be:

Lock, Sync	Sync Pattern		
0110	1101	0111	0101
I byte		II byte	

—more—

The decimal values of the two bytes (of 8 bit each) of the above words are 109 and 117 respectively. These bit patterns repeat after each 32 words (i.e. 64 bytes) of a frame and therefore enable one to determine the quality of the data. If the values of two successive bytes are 109 and 117 respectively, it shows the first word of some particular frame in a telemetry cycle (consisting of 32 frames numbered from 0 to 31). The frame identification is contained in a 10 bit frame counter, bits 7-16 of word 1 of every frame in every format, which increments by 1 in successive frames of a telemetry cycle. The frame count is 0 when the bits 12-16 are all in zero state. Satellite clock (giving relative time) appears in the data as a 24 bit counter in words 18 and 19 (bits 5-16 in each) of frames 6, 14, 22 and 30 in format 1. Thus after each eighth frame, the time increments by 30 seconds, which could go upto a maximum of 16 million seconds (i.e. 400 days). The information on the words and the particular bits in which the data of various experiments is contained has been provided by NRL. Computer programmes have been developed to identify the data words in the appropriate frames in the given format and the counts are plotted against time by the IBM Plotter. Figs. 17-19 show the plots of counts versus time for 6 of the experiments on Solrad 11A on May 10, 1977 from 10:54 UT to about 12:09 UT. Calibration curves have been received from NRL for five of the X-ray experiments

-more-

(No.4, 5, 6, 12 and 13) on board Solrad 11A/B satellite. For these experiments, the Solrad 11 telemetered digital count (C) is converted to energy flux (F) by using the conversion equation

$$F = A(C-b)$$

where coefficients A are based on laboratory measurements of detector efficiency and assume a gray body solar emission spectrum. The coefficients b are based on laboratory measurements of amplifier performance and in-fight calibrations. The coefficients A and b for different experiments have been provided by NRL for the two detectors (A and B) for different ranges (1-4).

Fig.20 shows the energy flux of the solar X-rays obtained from experiments 4, 5, 6 and 13 on May 10, 1977 (Experiment 12 shows abnormally low data count and hence is not plotted). The solar X-ray flux is seen to be nearly constant thereby revealing absence of any significant activity on the sun for the time interval shown.

6. Conclusions:

The system planning, design and development of the sub-systems, namely, SBF antenna, polarization switch, pre-amplifier, remote control unit for SBF antenna, PCM bit synchronizer, decommutator and time decoding unit, was carried out. For maintaining the performance of entire set-up and sub-systems, Solrad 11 signals were simulated and transmitted from the telemetry building. Before each pass of Solrad 11 was recorded, the overall system performance was tested by monitoring these simulated PCM signals. The Solrad 11 satellites were successfully tracked, and the data were recorded, decoded and put on to IBM computer compatible digital tape. The software to retrieve the data of the scientific experiment has been developed and computer plots of variation of counts for a number of experiments have been obtained. Calibration curves for some of the experiments have recently been received from NRL and the corresponding absolute solar fluxes have been calculated. It is hoped that the Solrad 11 data recording will be resumed after the satellites are put on after March 1978.

Acknowledgements:

We thank Professor K.R.Ramanathan, Professor D.Lal, and Professor S.P.Pandya for the support and their encouragement to this project. We express our sincere thanks to Professors R.Raghavarao, J.S.Shirke, R.V.Bhonsle, R.P.Kane, R.G.Rastogi, Dr.M.R.Deshpande and Dr.J.A.Klobuchar for coordination, help and advice during the course of the work. We acknowledge the cooperation and help of all the members of Solar and Planetary Physics Area of PRL.

We appreciate the help of Drs. R.W.Kreplin, D.M.Horan and A.J.Martin of Naval Research Laboratory, USA in arranging for allotting us the satellite passes, for providing the

-more-

details of the telemetry format, calibrations of experiments and software for generating the satellite ephemeris. One of us (D.V.S.) gratefully acknowledges the hospitality at NRL when he visited USA for studying the Solrad Telemetry System.

We sincerely thank Mr.N.M.Patel, Mr.B.L.Panchal and the staff of the Workshops and the Engineering Services without whose active support, it would have been impossible to carry out this work. The help of M/s. P.Venat, Bansidhar, N.M.Vadher, N.K.Modi, K.D.Patel, S.V.Kasture, V.K.Parmar, K.V.Pandya, N.Dutt and other members of the telemetry group is acknowledged. The help of Dr. Dinesh Patel and Mr.P.S.Shah for data processing on computer is appreciated. We thank Mr.S.P. Satija and Mr.S.K.Shah for help in developing computer programmes for generating look angles as well as for retrieving the data of the scientific experiments from the Solrad 11 telemetry. We thank Mr.H.S.Mazumdar and Mr.P.P.Kale and his group at Space Applications Centre, Ahmedabad for helpful discussions during the initial phase of the Solrad 11 programme.

Our special thanks are due to Prof.R.V.Bhonsle for suggesting the preparation of this report and for critically going through the manuscript.

References:

1. K.D.COLE, Nature 260 (1974), 229.
2. H.W.EHRENSPECK, Proc. IRE, 48 (1969), 109.

-more-

3. H.W.EHRENSPECK, Proc. IEEE 53 (1965), 639.

4. F.J.ZUCKER, Proc. IEEE, 53 (1965), 746.

5. L.R.DOD and H.W.EHRENSPECK, in Antennas and Propagation Year Book (1969), Douglas Communications Inc., New York.

6. H.W.EHRENSPECK, Proc. IEEE, 53 (1965), 1138.

7. H.W.EHRENSPECK and J.A.STORM, USAF Cambridge Res. Lab., Bedford, Mass. Rep. AFCRL-71-0234 (1971).

8. H.W.EHRENSPECK, IEEE Transactions on Antennas and Propagation, AP-22 No.2 (1974), 329.

APPENDIX - 1

PHYSICAL, ORBITAL AND TELEMETRY SPECIFICATIONS OF SOLRAD-11 SATELLITES

Shape	:	Cylindrical
Diameter	:	1.4 m.
Height	:	0.4 m
Weight	:	182 Kg (approx.)
Spin period	:	4 sec. (approx.)
Inclination	:	26° (approx.)
Semi-major axis	:	125,000 Kms (approx.)
Period	:	122 hours (approx.)
Transmission frequency	:	136.53 MHz (Solrad 11 B)
		137.44 MHz (Solrad 11 A)
Transmission Power	:	5 watt (37 dbm)
Type of signal	:	PCM (Bi-phase)/PM
Transmission rate	:	204.8 bits/sec. convolutionally encoded
Information rate	:	102.4 bits/sec.

APPENDIX - 2

THE EXPERIMENT COMPLEMENT ON SOLRAD 11

Exp. No.	Sponsor	Type of Measurement	Range
1.	NRL	X-rays	15 - 150 KeV (4 bands)
2.	NRL	X-rays	3 - 60 KeV (4 bands)
3.	NRL	X-ray lines of Mg XI and XII ions	9.2 & 8.4 Å
4.	NRL	X-rays	1 - 8 Å
5.	NRL	X-rays	8 - 16 Å
6.	NRL	X-rays	44 - 60 Å
7.	NRL	Extreme UV	170 - 1050 Å (3 bands)
8.	NRL	Lyman Alpha	1080 - 1350 Å
9.	NRL/Johns Hopkins	UV spectra	1175 - 1800 Å
10.	NRL	X-ray polarization	10-22 KeV & 22-60 KeV
11.	NRL	X-ray polarization	2.8 Å
12.	NRL	X-ray	0.5 - 3 Å
13.	NRL	X-ray	2 - 10 Å
14.	NRL/Aerospace	Solar protons	2 - 10 MeV
15.	NRL/MIT	Solar wind electrons	0.2 - 4.5 KeV
16.	NRL	Auroral X-ray	1 - 8 Å
17.	NRL/Aerospace	Omnidirectional protons	0.02 - 460 MeV
18.	NRL	Interplanetary EUV	1180 - 1500 Å (2 bands)
19.	NRL	Interplanetary EUV	170 - 800 Å (3 bands)
20.	AFCRL	Alpha particles and protons	1 - 100 MeV
21.	AFCRL	Low energy protons	0.1 - 6 MeV
22.	NRL/Aerospace	Solar flare electrons	0.01 - 1.5 MeV
23.	NRL/Aerospace	Antisolar protons	Above 10 MeV
24.	NRL	Nonsolar X-ray background	0.6 - 25 Å
25.	Sandia Laboratories	Gamma ray burst	0.2 - 2 MeV

NRL : Naval Research Laboratory, U.S.A.
MIT : Massachusetts Institute of Technology, U.S.A.
AFCRL : Air Force Cambridge Research Laboratories, U.S.A.

APPENDIX - 3

LINK CALCULATIONS FOR SOLRAD 11 TELEMETRY

1) Total Noise factor for Receiving System.

Let,

NF1 = Noise factor of preamplifier = 2 (= 3 db)
G1 = Gain of preamplifier = 3000 (= 35 db)

NF2 = Noise factor for cable, equivalent to cable losses = 3 (= 5 db).
G2 = Cable lossess = 3 (= 5 db).

NF3 = Noise factor of the receiver = 4 (= 6 db).

$\therefore$ Total Noise Factor,

$$N.F. = NF1 + \frac{NF2 - 1}{G1} + \frac{NF3 - 1}{G1 . G2}$$

$$= 2 + \frac{3 - 1}{3000} + \frac{4 - 1}{(3000\ (3)^{-1}}$$

$$\cong 2 = 3 \text{ db.}$$

2) Equivalent Noise Temperature at input of preamplifier.

Teqvt = Tamb. (NF - 1) + Tgal

Where Tgal is the antenna noise temperature for the galactic noise received by the antenna in the frequency band of interest and is taken to be 1000° K.

$\therefore$ Teqvt. = 300 (2 - 1) + 1000 = 1300° K.

3) Equivalent Noise power at the input,

Ni = (K) (T equivalent) (B)

Where K is Boltzmann constant and B is the receiver bandwidth (= 10 KHz)

-more-

APPENDIX - 3
(contd.)

$\therefore$ Ni = (K) (T equivalent) (B)

$= 1.38 \times 10^{-23} \times 1300 \times 10^{4}$

$= 2 \times 10^{-16}$ watt

$= 2 \times 10^{-13}$ m watt.

$= -127$ dbm.

4) Effective isotropic radiated power (EIRP) from satellite = 37 dbm.

Path losses for height of 120,000 KM. = -177 db.

Average ionospheric and other losses = 6 db.

Antenna gain = 25 db.

$\therefore$ Carrier power at the input of receiving system is = -121 dbm.

5) $\therefore$ Carrier to Noise ratio at the input of the receiving system = +6 db. This is adequate for the locking of phase lock demodulators in the receivers used.

APPENDIX - 4

CONVOLUTIONAL ENCODER - VITERBI DECODER LV 7015
(LINKABIT CORPORATION)

Characteristics:

Constraint Length	:	7
Rate	:	1/2
Maximum data rate	:	100 K bits/sec. (200 K code symbols/sec.)
Coding gain	:	5 db for soft quantization 3 db for hard quantization for 10^{-5} bit error rate.
Expected number of bits for resynchronization after synchronization loss	:	$<$ 350 bits for hard quantization and $<$ 150 bits for soft quantization for decoder output error rates $< 10^{-1}$
Encoding Decoding delay	:	38 bits

TABLE - 1

COMPARISON OF THE PARAMETERS OF DIFFERENT TYPES OF ANTENNAS

Sr. No.	Type of Antenna	No. of elements	Gain	Base Dimension	Vertical Dimension	Remarks
1.	Parabolic antenna	1	24 dB	47 ft.		
2.	$\lambda/2$ dipoles	128	25 dB	$8.5\lambda \times 8.5\lambda$	0.25λ	
3.	Yagis	32	25 dB	$8\lambda \times 8\lambda$	1.5λ	
4.	Backfire Yagi					
	a) 1.0λ	16	23.5 dB	$(4\lambda)^2$	1.0λ	
	b) 1.5λ	16	25.2 dB	$(6\lambda)^2$	1.5λ	
	c) 2λ	8	24.3 dB	$(6\lambda)^2$	2λ	
	d) 3λ	4	24.2 dB	$(6\lambda)^2$	3λ	length becomes too large
	e) 4λ	4	25.4 dB	$(8\lambda)^2$	4λ	
5.	Short backfire array	16	25.0 dB	$(5.6\lambda)^2$	0.5λ	
6.	Single backfire Yagi with stacked reflector	1	23.5 dB	6.15λ dia.	4λ	

TABLE - 2

IMPEDANCE VALUES OF INDIVIDUAL V AND H ELEMENTS OF SBF ANTENNA

Element No.	V-element Ohms	H-element Ohms
1	50 + j1.494	47 + j1.8
2	51.31 - j2.34	46.6 + j4.31
3	50.9 + j1.125	53.259 + j6.26
4	46.598 + j1.073	46.99 - j0.186
5	52.97 - j1.115	56.74 + j3.8
6	50.19 - j6.39	51.95 - j1.66
7	53.74 - j3.67	50.69 + j8.13
8	53.84 - j2.90	51.84 + j2.75
9	51.94 + j1.74	46.69 + j10.35
10	49.89 + j2.32	53.85 + j2.74
11	54.99 - j0.51	50 + j0
12	56.99 + j0.279	55.97 - j8.20
13	55.86 - j2.43	59.02 + j7.6
14	53.89 - j2.44	54.68 + j4.13
15	56.98 - j0.81	51.35 - j2.76
16	51.76 + j8.87	49.98 + j0.87

TABLE - 3

THE CHARACTERISTICS OF THE POLARIZATION SWITCH

Input impedance at port V	:	58 + j3 ohms
Input impedance at port H	:	48 + j0 ohms
Impedance at the output port O	:	44 + j6 ohms
Insertion loss	:	$\leq$ 0.7 dB
VSWR at the input/output ports	:	$\leq$ 1.1
'Cross-talk' due to polarization switch	:	20 dB down

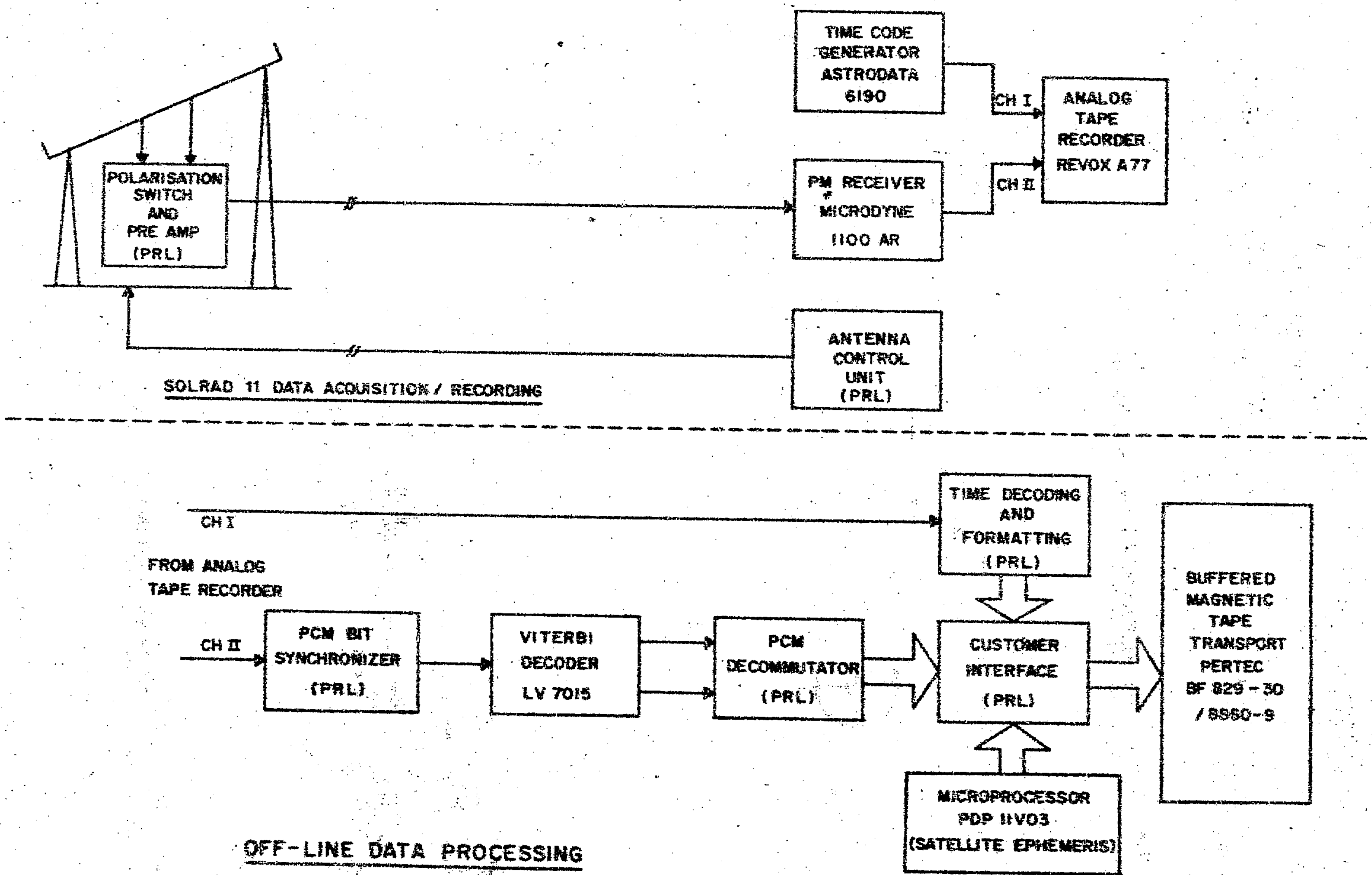


Fig.1 : Block diagram of telemetry set-up for Solrad 11.

SINGLE ELEMENT SHORT BACK FIRE ANTENNA

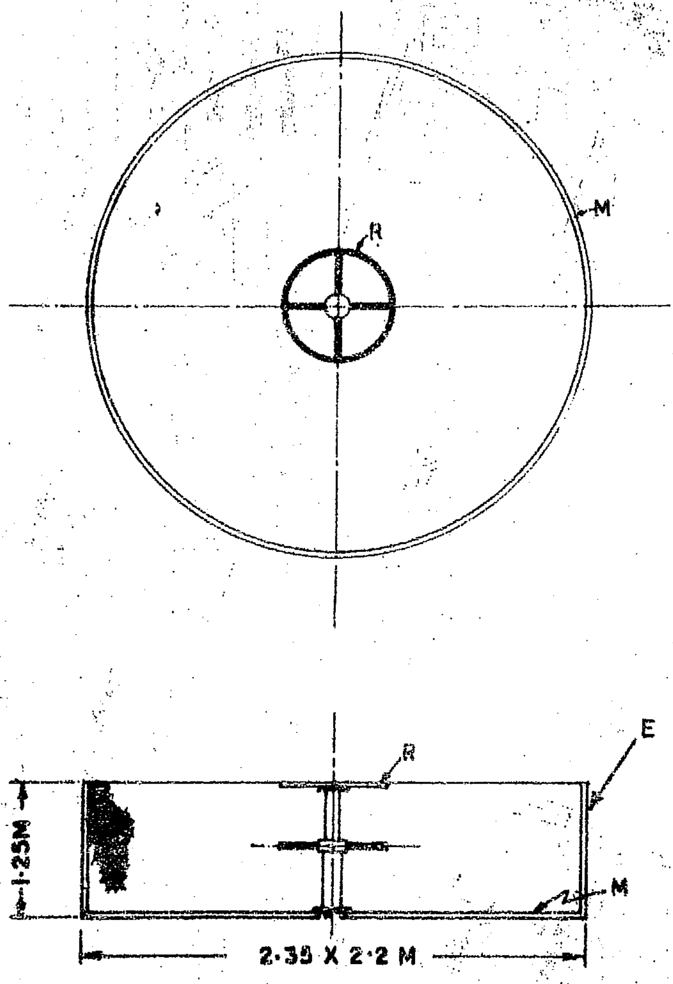
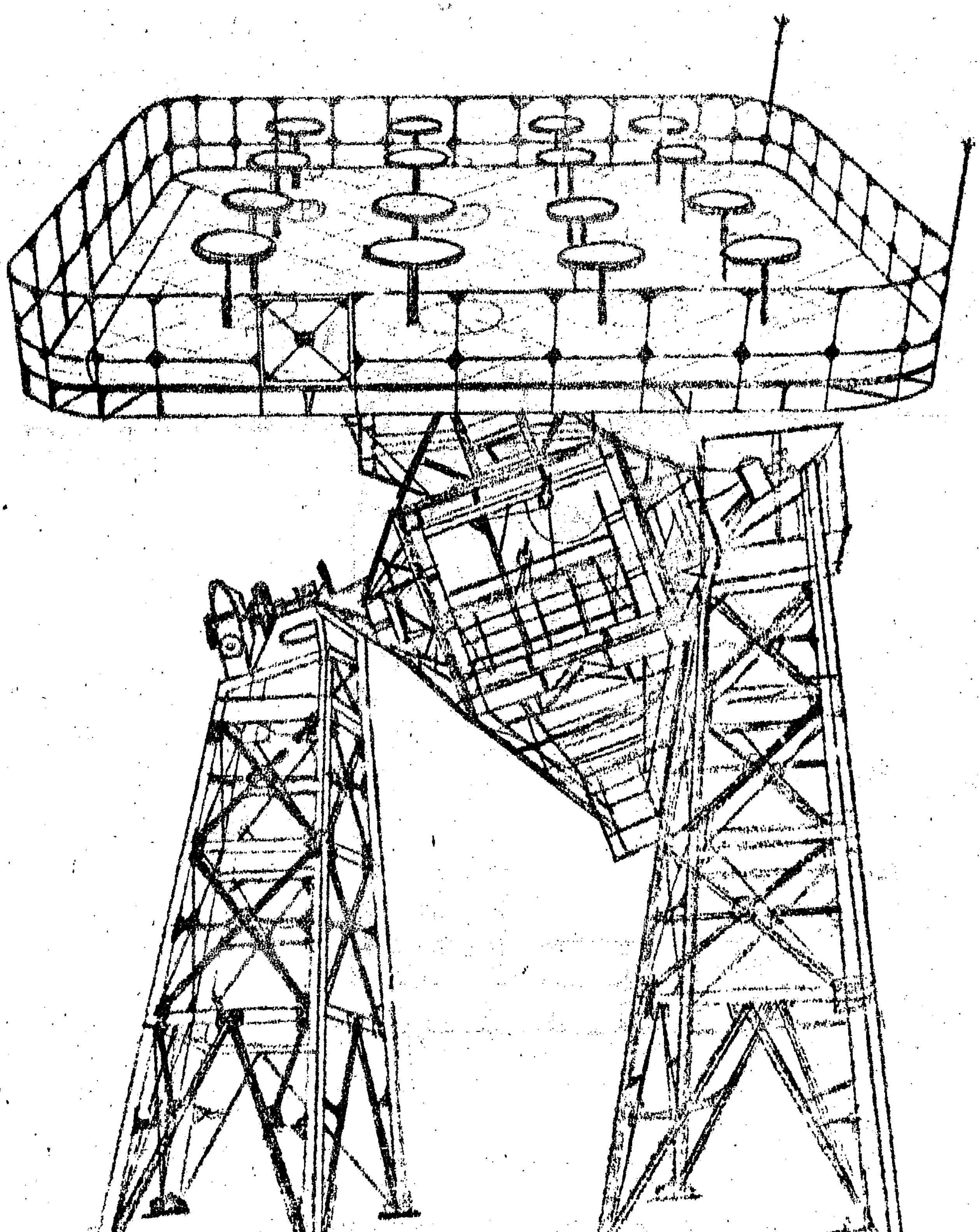


Fig.2 : Sketch of 136.5 MHz antenna



THE SHORT BACKFIRE ANTENNA

Fig.3 : Artist's view of the SBF antenna.

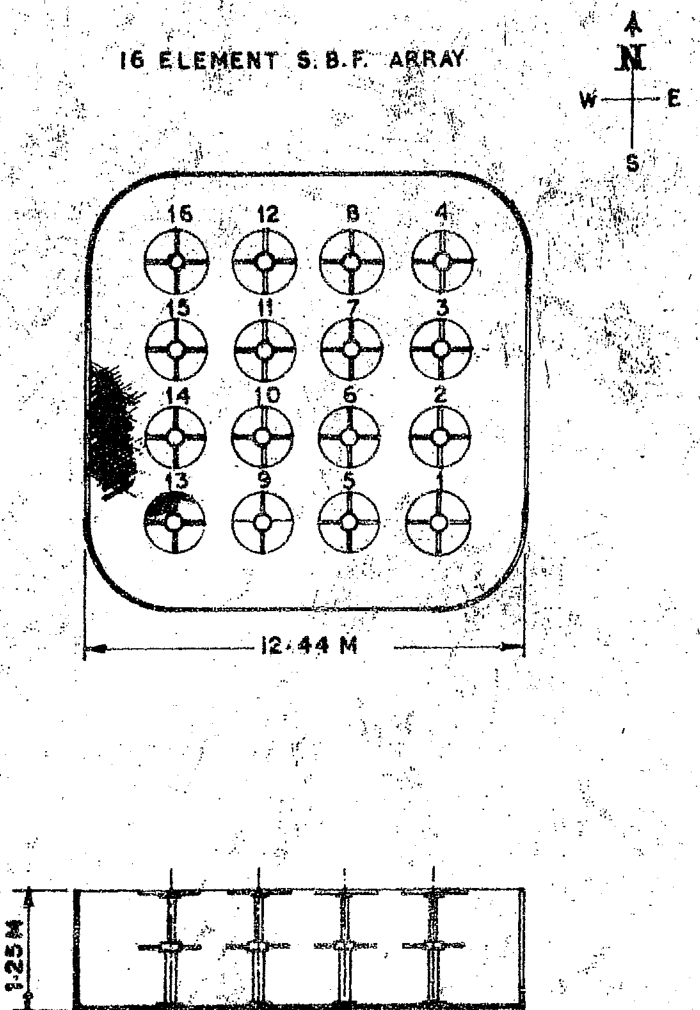


Fig.4 : A sketch of 16 element SBF array.

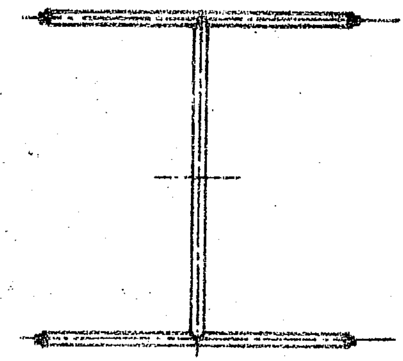


FIG. a

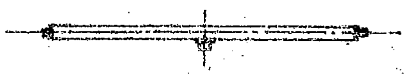
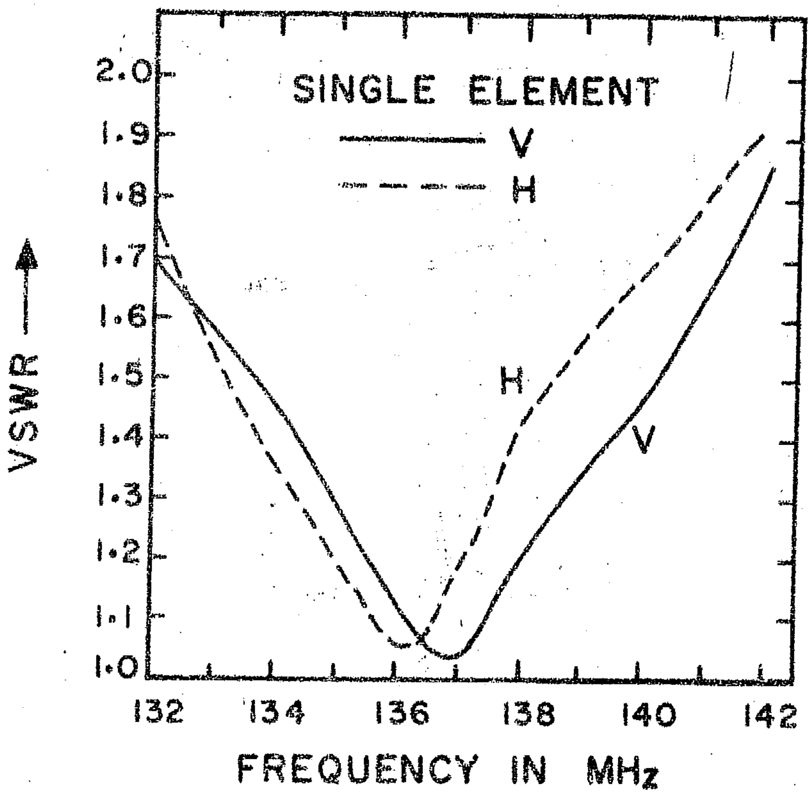


FIG. b

a: FOUR WAY POWER DIVIDER

b: TWO WAY POWER DIVIDER

Fig.5 : A sketch of (a) four way power divider and (b) two way power divider.



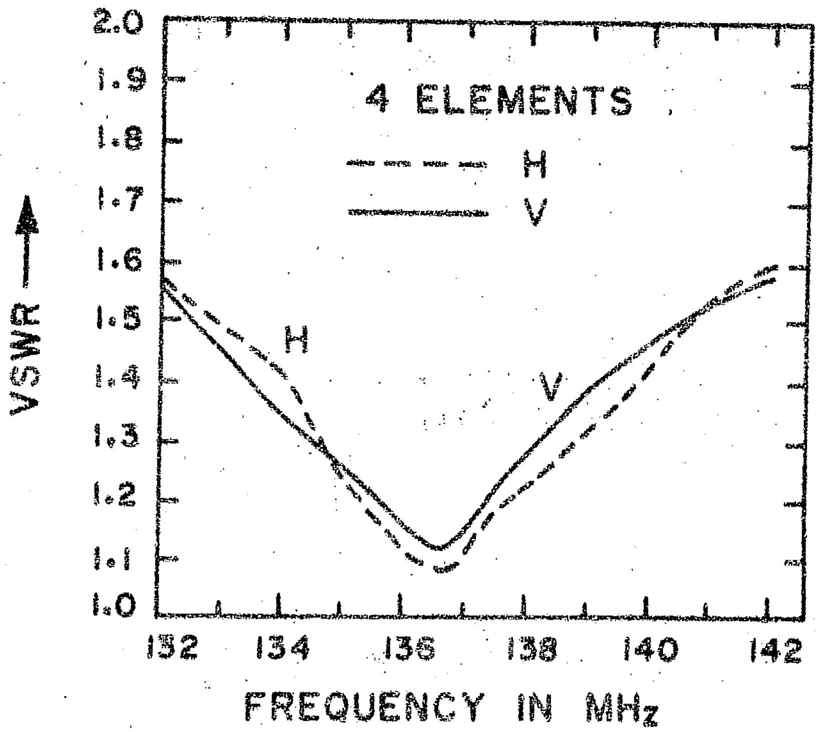


Fig.6 : VSWR versus frequency curves for (a) a single element and (b) combination of four elements.

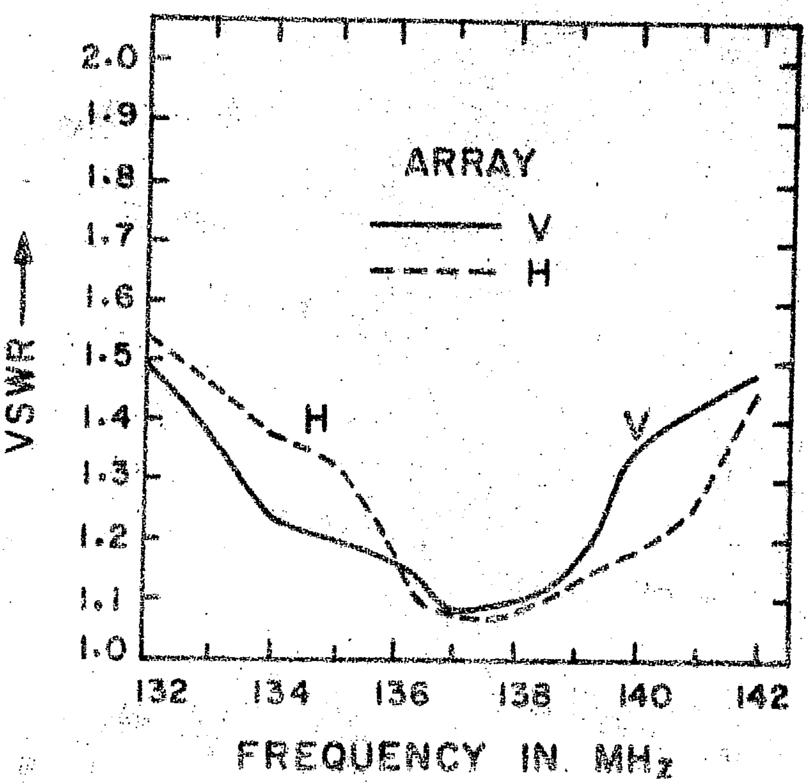
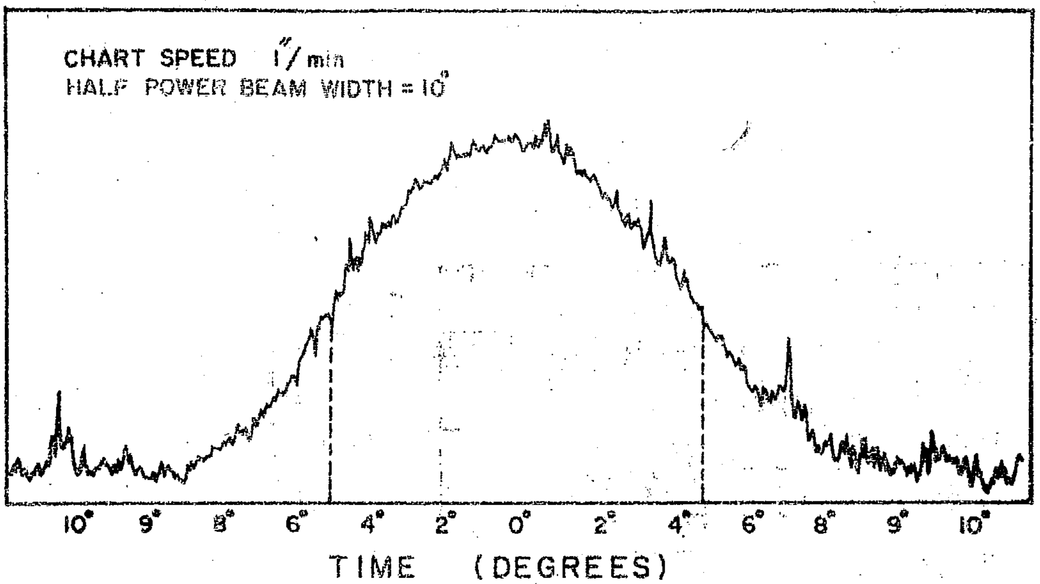


Fig.7 : VSWR versus frequency curves for the 16 element array.

TRANSIT OF THE SUN THROUGH THE SBF ANTENNA BEAM



TRANSIT OF THE SUN THROUGH THE SBF ANTENNA BEAM

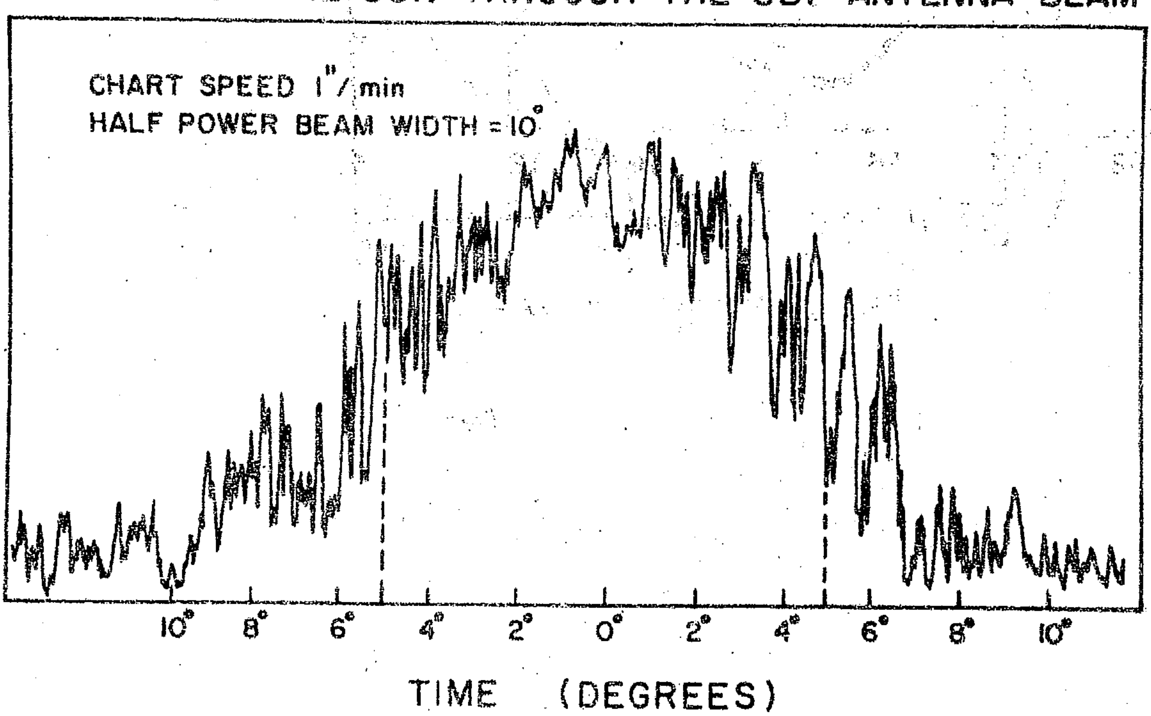


Fig.8 : Solar transit at 140 MHz (a) on a quiet day and (b) on a noisy day.

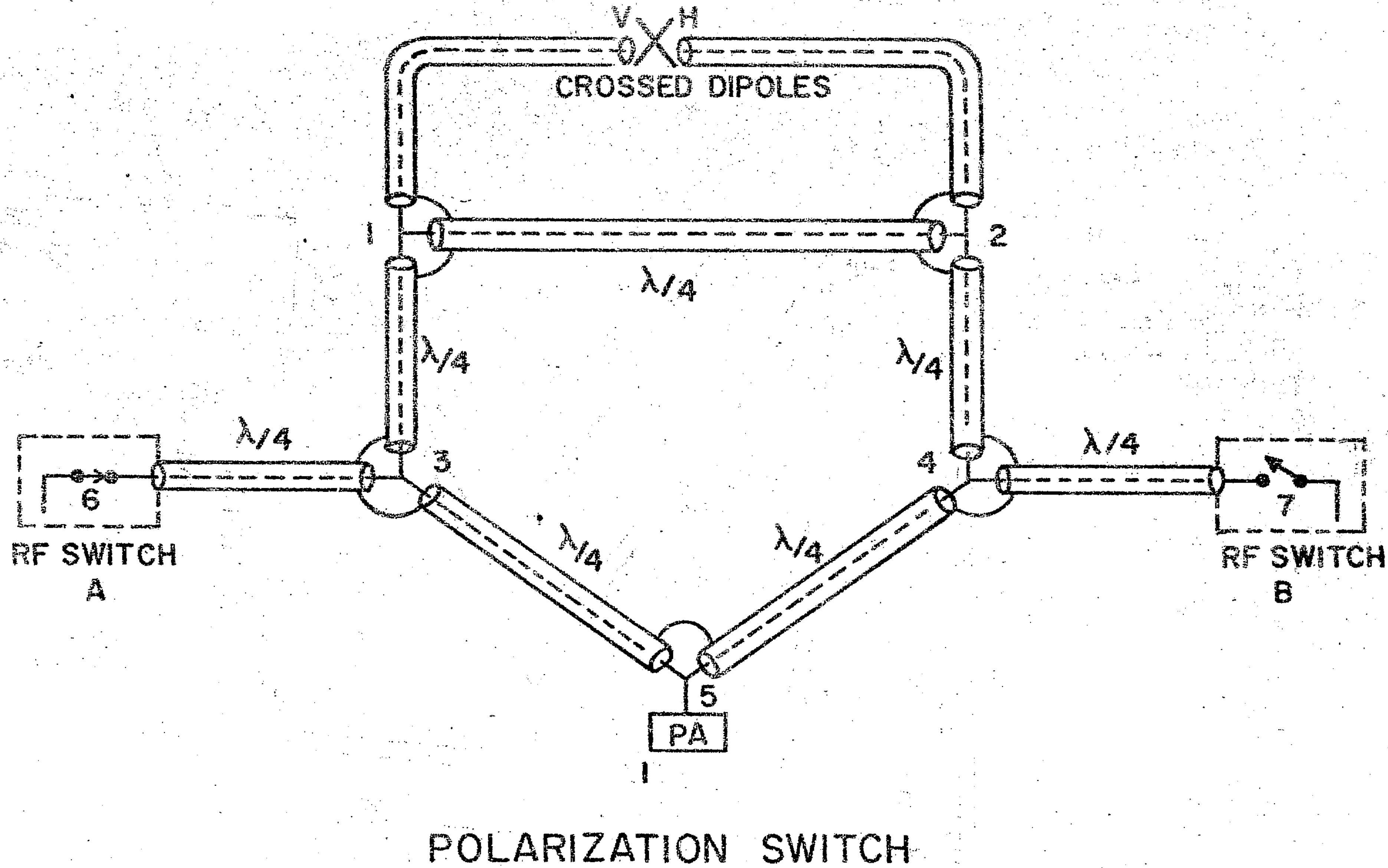
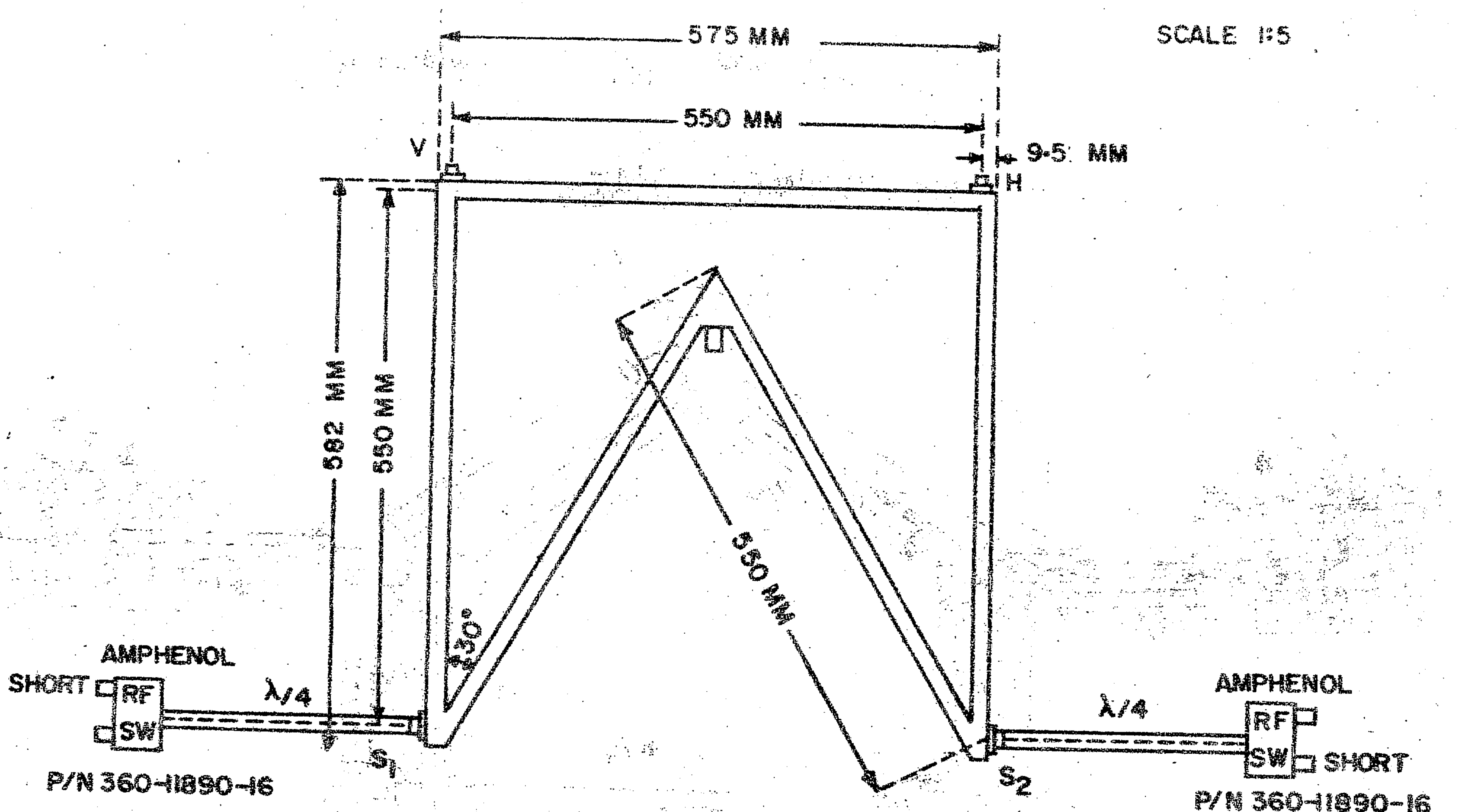
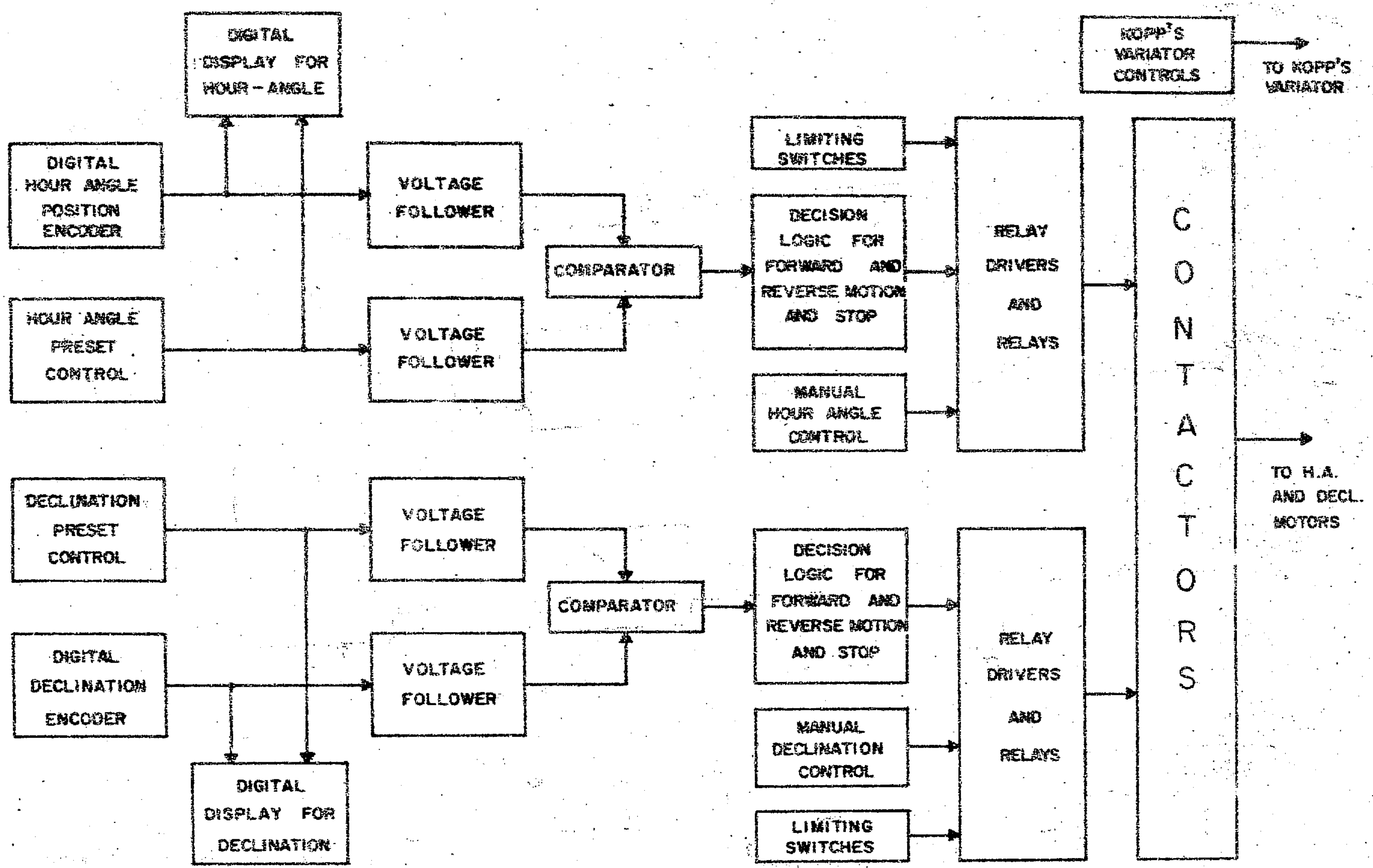


Fig.9 : Principle of polarization switch.



POLARIZATION SWITCH

Fig.10 : Sketch of polarization switch.



CONTROL UNIT FOR SBF ANTENNA

Fig.11 : Block diagram of antenna control unit.

PCM BIT SYNCHRONIZER (SCHEMATIC)

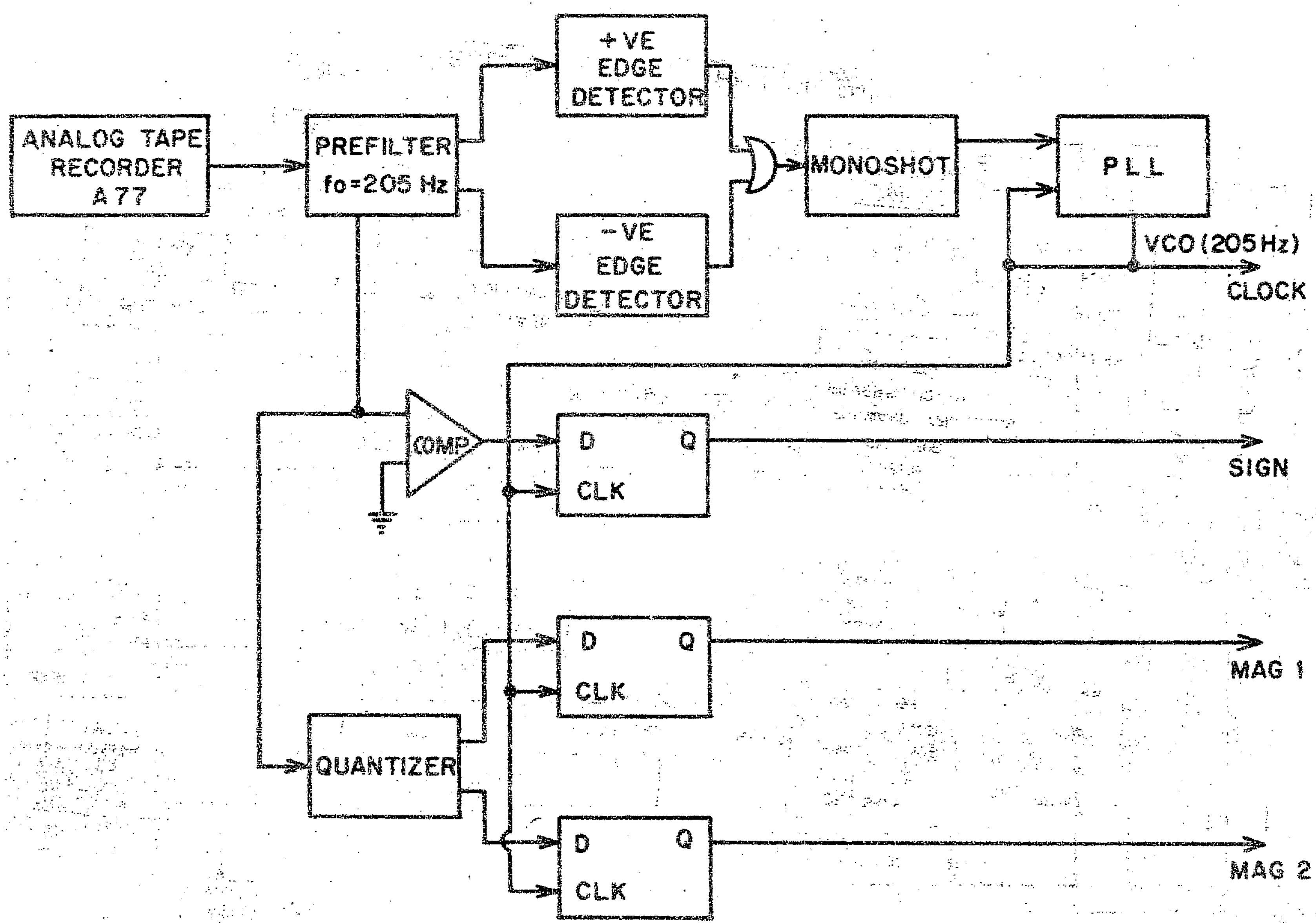
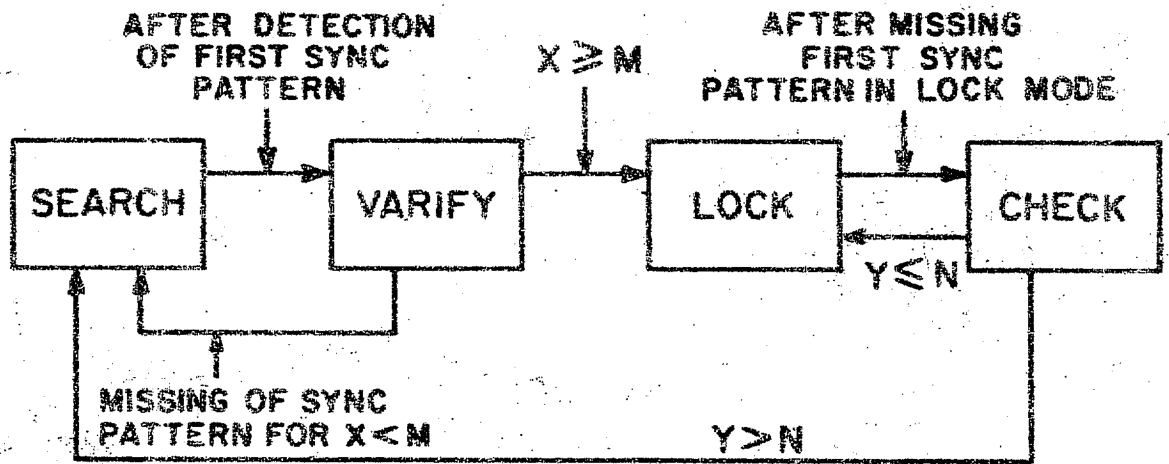


Fig.12 : Schematic diagram of PCM bit synchronizer.

DESIGN PHILOSOPHY OF PCM DECOMMUTATOR



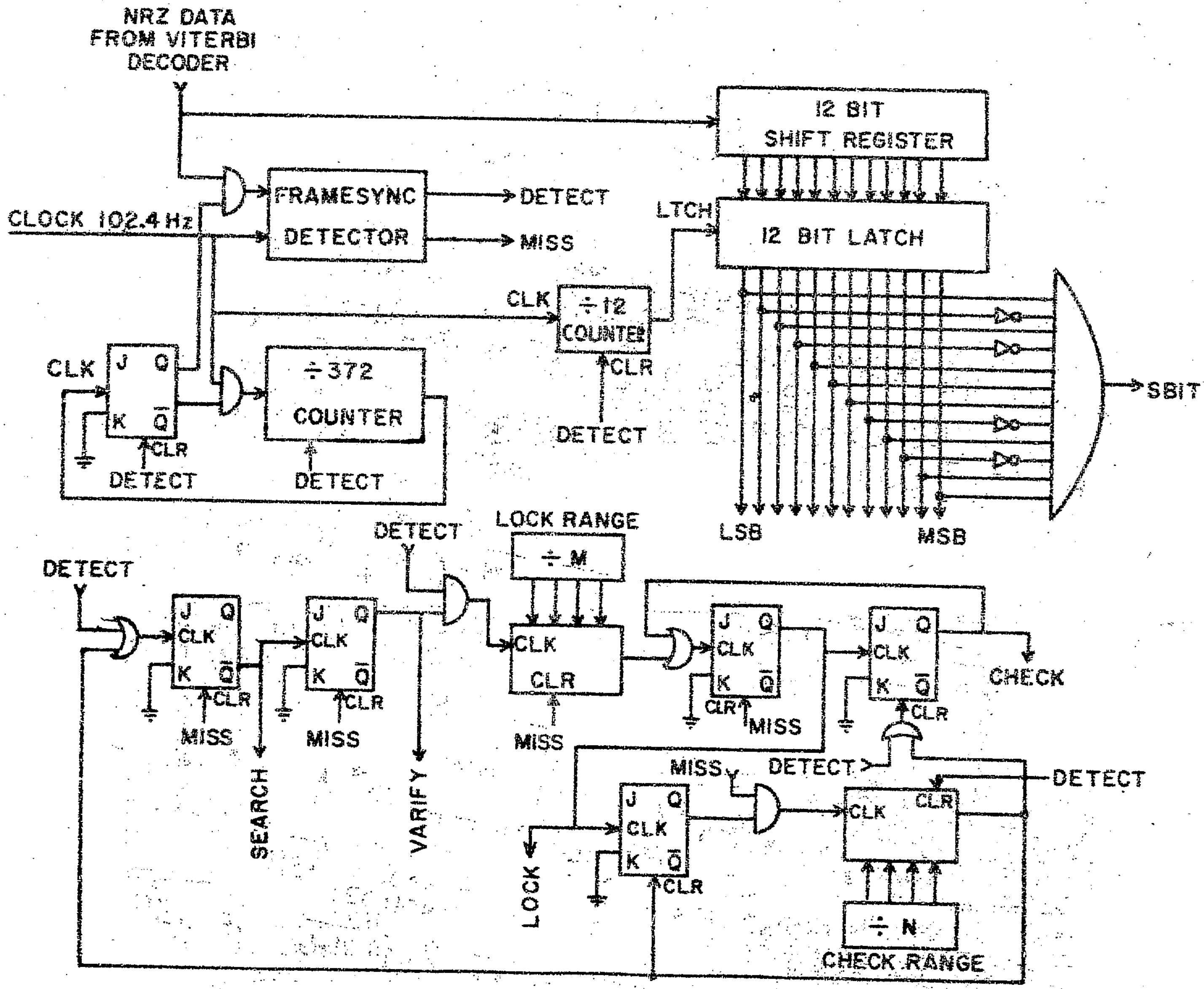
M : LOCK RANGE

N : CHECK RANGE

X : NUMBER OF SUCCESSIVE FRAMES FOR WHICH SYNC PATTERN IS DETECTED

Y : NUMBER OF SUCCESSIVE FRAMES FOR WHICH SYNC PATTERN IS MISSED

Fig.13 : Design philosophy of PCM decommutator.



PCM DECOMMUTATOR (SCHEMATIC)

Fig.14 : Schematic diagram of PCM decommutator.

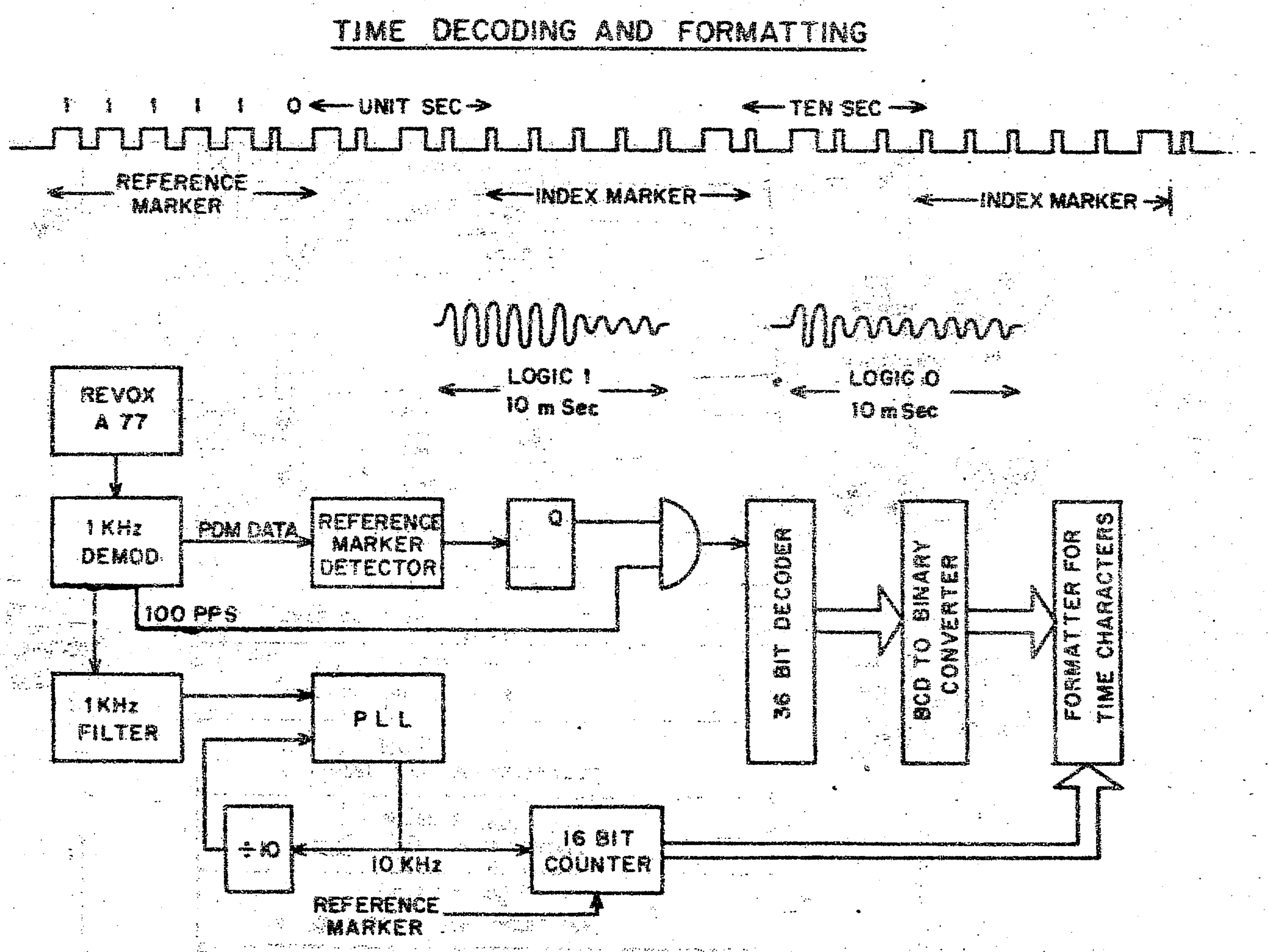


Fig.15 : Block diagram of time decoding and formatting.

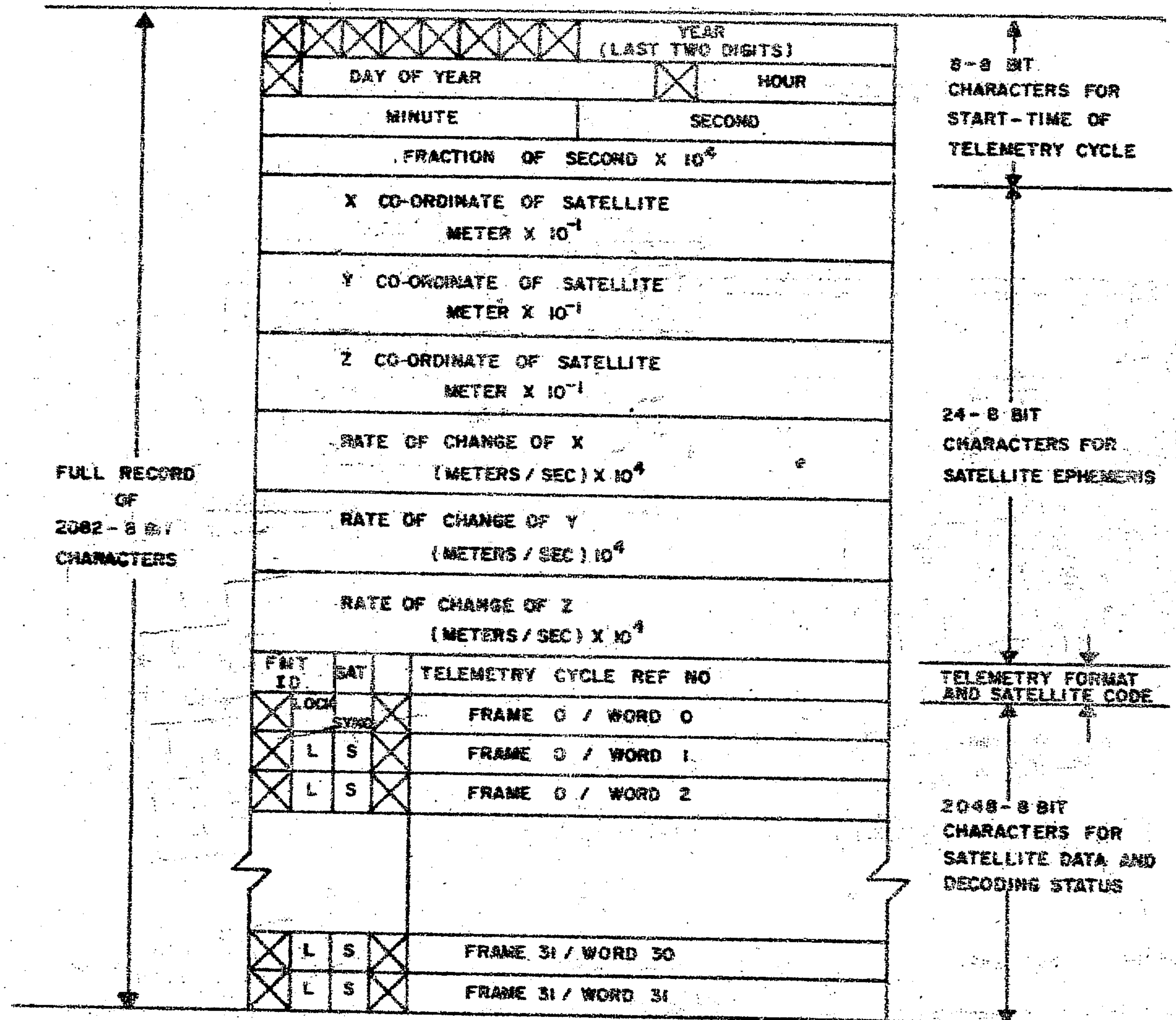


Fig.16 : Standard format of one telemetry record on a digital tape.

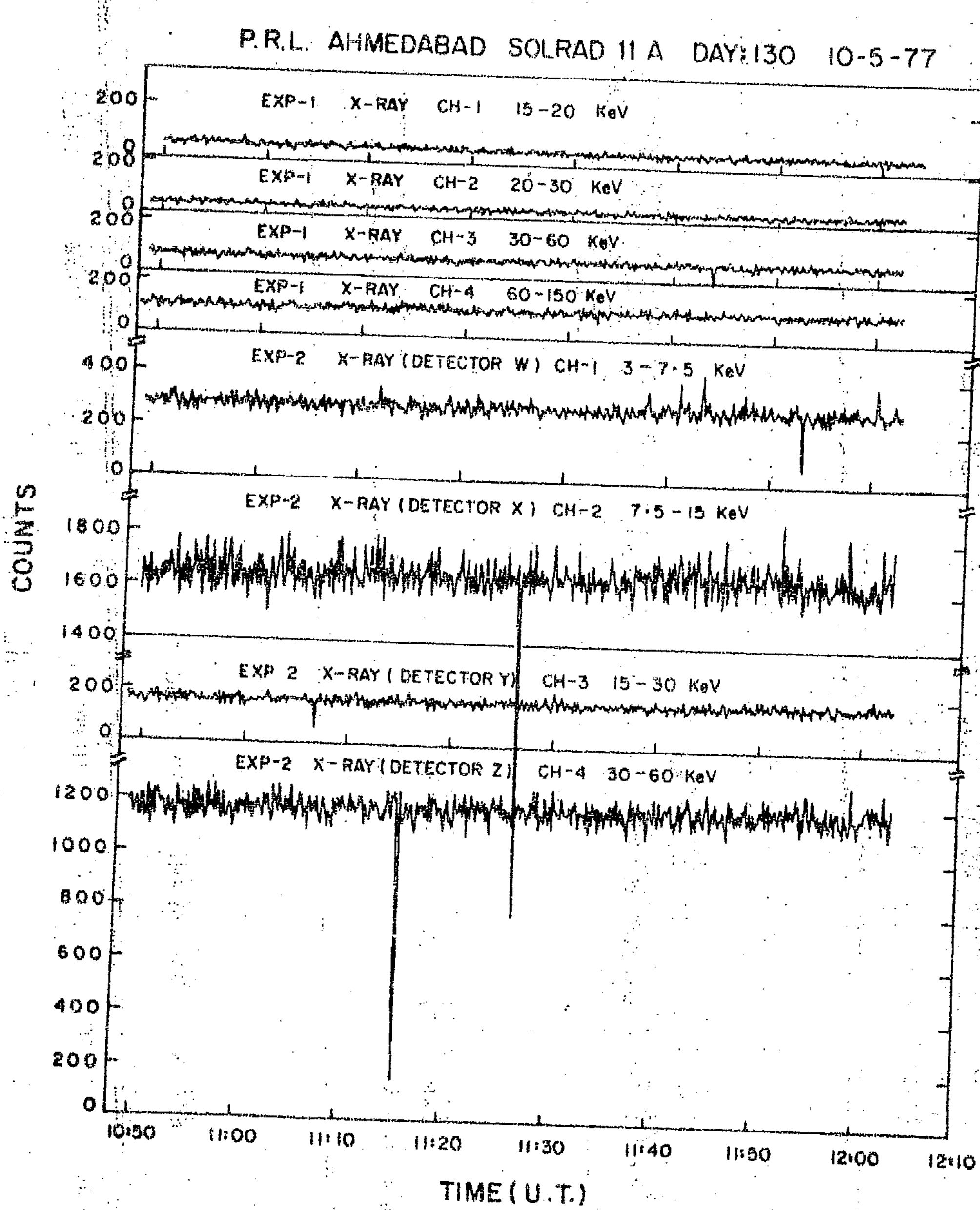


Fig.17 : Telemetered counts for different channels of Exp.1 and 2.

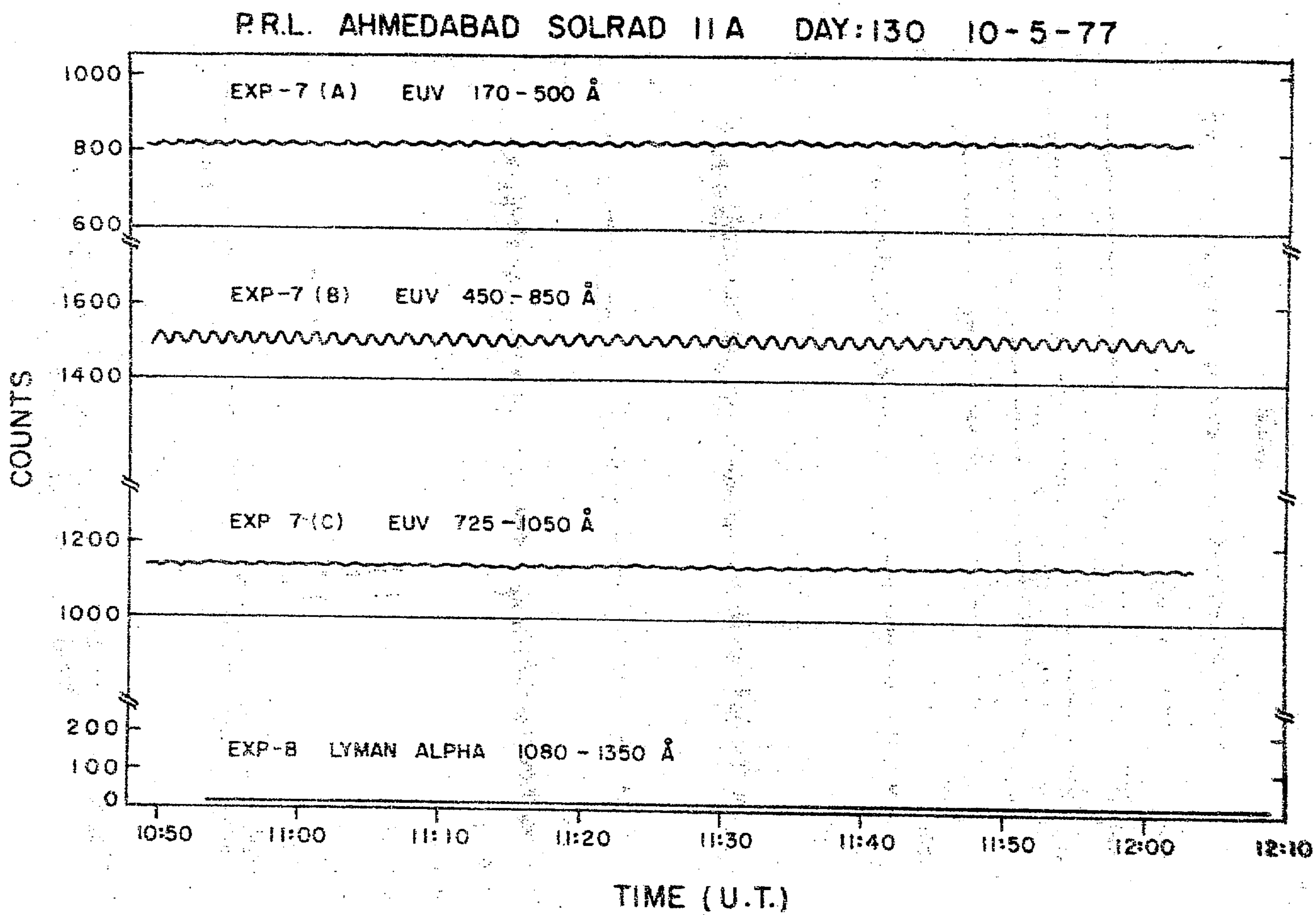


Fig.18 : Same as in Fig.17 for Exp.7 and 8.

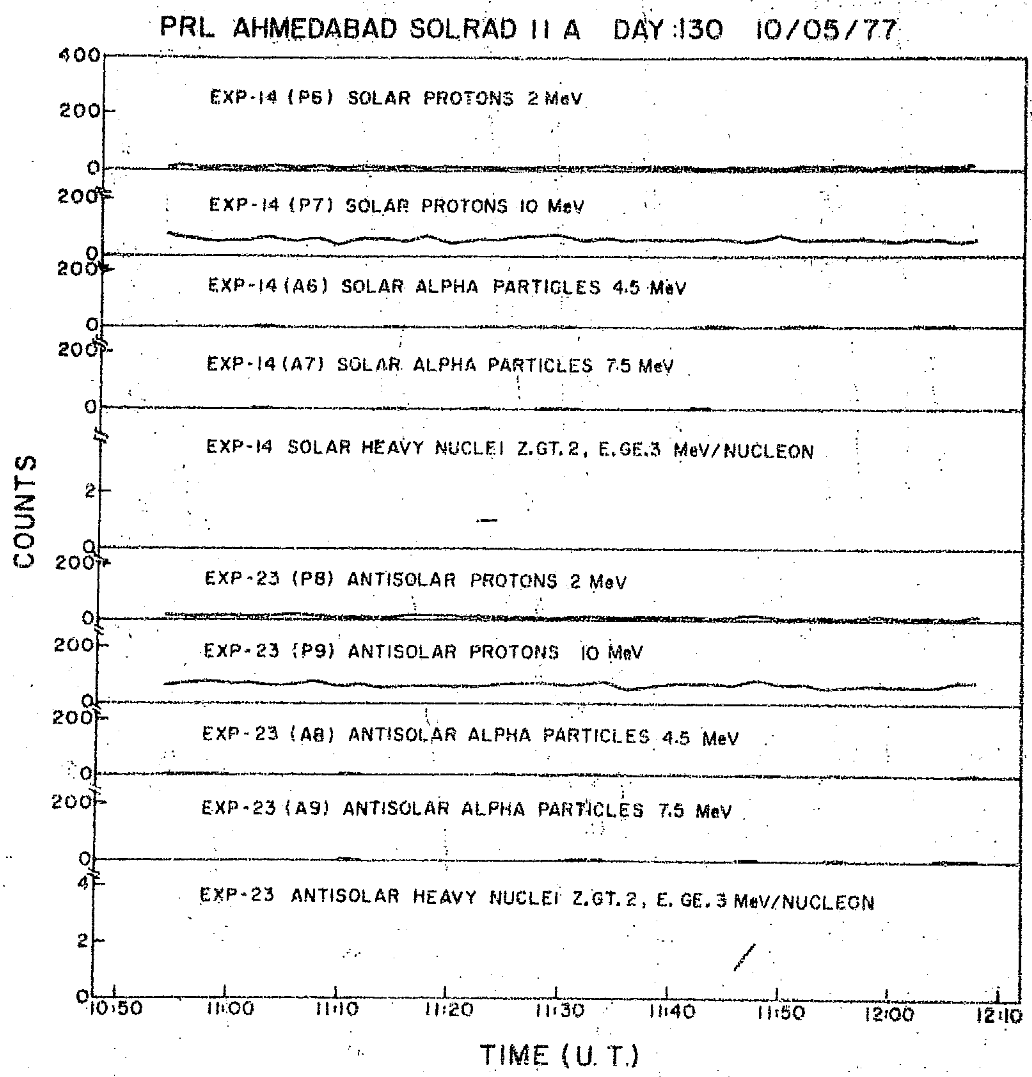


Fig.19 : Same as in Fig.17 for Exp.14 and 23.

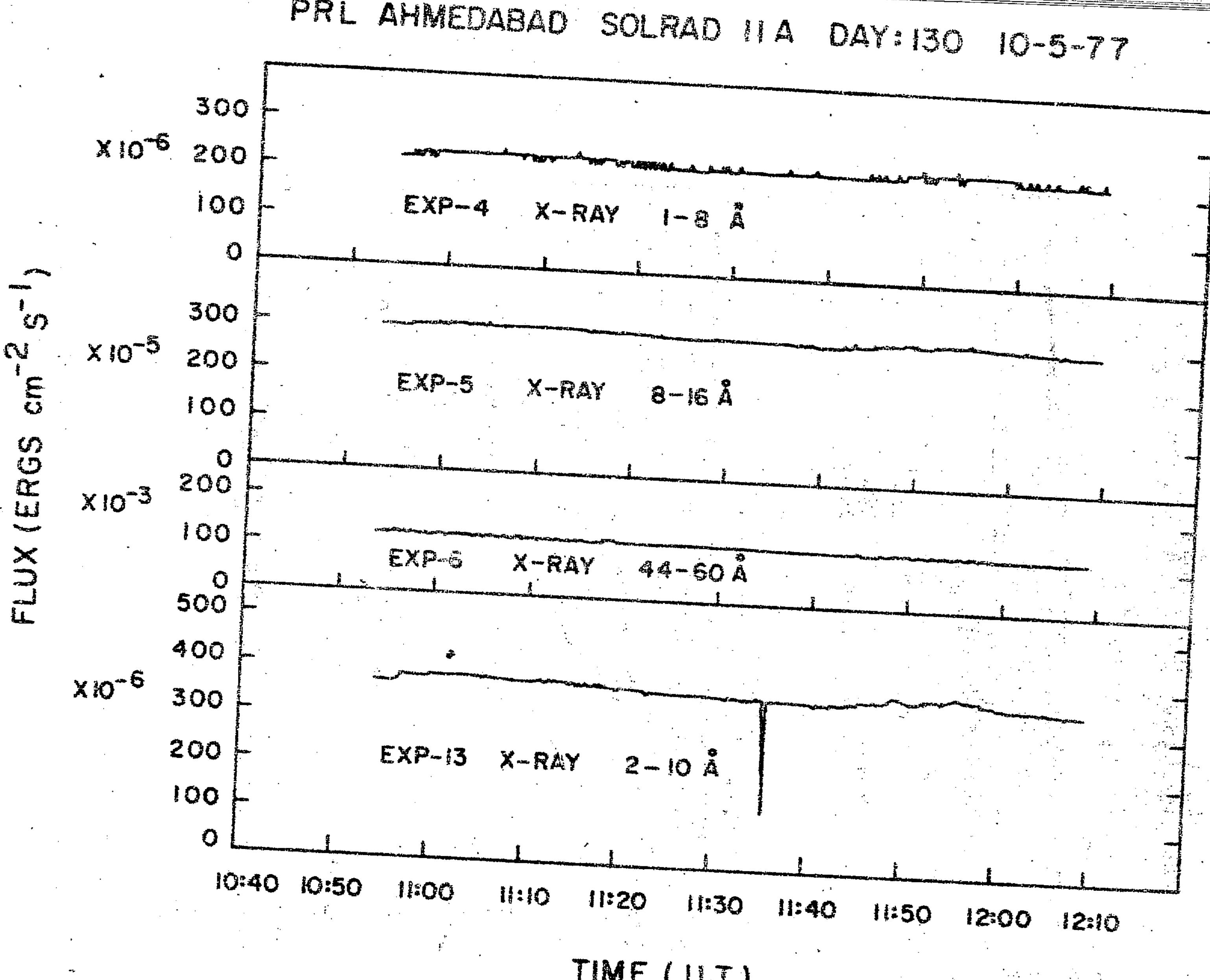


Fig.20 : Energy flux of X rays in various bands obtained from Exp.4, 5, 6 and 13.