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STANDARD TIME AND FREQUENCY SIGNAL DISSEMINATION
SERVICE VIA INDIAN DOMESTIC SATELLITE INSAT-1B

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ABSTRACT

INSAT-1B is a multipurpose Indian Domestic Satellite parked on the equator at 74°E. It has twelve transponders in C-Band and two in C/S Band. One of the narrowband injected carriers in one C/S band transponder is dedicated for Standard Time and Frequency Signal (STFS) dissemination. The uplink frequency of this channel is 5899.675 MHz and downlink is 2599.675 MHz. The permissible RF bandwidth is 160 KHz and audio bandwidth 10 KHz. The STFS used, consists of a train of 5 KHz bursts which is frequency modulated on the carrier. The coded information on the IST clock and satellite position is transmitted by binary modulation of the width of 5 KHz packets. The satellite position coordinates are updated every 10 minutes to take care of the propagation delay corrections. The STFS format generator driven by Cesium frequency standard is interfaced with the INSAT earth station uplink channel. The receiving setup consists of an 8-foot chicken mesh antenna, front-end converter, FM demodulator, and a microprocessor controlled signal decoder. The decoder not only extracts the coded information of IST and the satellite position coordinates but also makes measurements of the time interval between the received signal and a local 1 pps.

Preliminary investigations on the performance of this dissemination scheme were carried out by receiving the signal at the Earth Station site. These measurements indicate the time transfer capability with a precision of better than 1 microsecond and accuracy of better than 20 microseconds. The inaccuracy comes mainly because of the uncertainty in the satellite position prediction.

1. INTRODUCTION

Dissemination of standard time and frequency is an aspect which engages major attention of the Time and Frequency group at NPL. This is mainly because of the vastness of our country spanning six million square kilometers. The high frequency time broadcast of NPL under the call sign ATA has been in operation for about 30 years now and has been widely used. However, due to the inherent limitations of the HF technique and due to an evergrowing demand of accuracy and reliability from several user organizations, the ATA service is

unable to fully meet the requirements. With this in view, a survey was conducted in 1981 through questionnaires. One of the interesting findings of this survey was that if a Standard Time and Frequency Signal (STFS) service was given via the Indian domestic satellite INSAT, then there would be many user organizations willing to make use of it. With this in mind, such an STFS service was conceived. The scheme was to be in principle similar to the GOES satellite dissemination service in the United States (ref. 1). Basically in a one-way broadcast mode, it would consist of transmitting binary coded time signals containing information on time of day in Indian Standard Time (IST) and the satellite position coordinates updated every 10 minutes. At the receiver's end, this coded signal would be received using small and relatively inexpensive Direct Reception Set (DRS) and decoded to recover and display directly the IST and the satellite position coordinates. The jitter in the received signal; i.e., the precision of synchronization is estimated to be of the order of 1-2 μsecs. There would be a delay in the received time signal of about quarter of a second in propagating over the transmitter-satellite-receiver path. This delay could be accounted for by an accurate knowledge of the locations of the transmitting earth station and the receiver along with the satellite position coordinates which are sent along with the signal.

After considerable deliberations and on final recommendations of a committee (which included several Time and Frequency user agencies), a narrowband channel of radio networking (RN) type on INSAT was allocated for this purpose on an experimental basis in 1983. However, actual experimental work using this channel could not be started till much later because of the non-availability of suitable interfacing equipments at the earth station. Over the last four years, four phases of experiments have been performed in order to optimize the STFS format and the signal encoding and decoding instruments. The results of these experiments have been described elsewhere (ref. 2-5) and will not be discussed here. In the present paper, we shall discuss the present status of the INSAT STFS service which has become operational since March 1987.

2. SIGNAL FORMAT

INSAT-1B is a multipurpose domestic satellite providing domestic telecommunication, meteorological, direct TV broadcasting, radio networking, disaster warning and standard time and frequency services. It has twelve 36 MHz wide telecommunication transponders in the C-Band (6/4 GHz) and two 36 MHz wide direct TV broadcast transponders in the C/S Band (6/2.5 GHz). The C/S transponder frequency allocation details are shown in Figure 1. In each transponder, in addition to a 30 MHz TV channel, there are five injected carrier narrowband channels, which provide different services as indicated. Each of these channels (known as RN channels) is allowed an r.f. bandwidth of 160 KHz. The modulation on these injected carrier channels is FM with a baseband audio bandwidth of 10 KHz.

The STFS that is presently adopted is being given on RN 5 channel of transponder 2 of C/S and is shown in Figure 2. This consists of packets of 5 KHz sinusoids occurring at the rate of 100 per second. The start of each packet is a positive zero crossing of 5 KHz and occurs at 0,10,20 ... msec from the 1 pps. The packet width is binary modulated being 2.5 msec or 7.5 msec

depending on whether it is carrying a 'Zero' or 'One' bit information. The sequence of bits is as follows:

(a) The packet whose start coincides with UTC 1 pps is designated as 00th bit. The 0th and the 1st bits have a value 'Zero' for all seconds except the minute mark; i.e., 00th second when they have a value 'One'.

(b) The 2nd and 3rd bits are always 'Zero'.

(c) The subsequent eight bits; i.e., 4th to 11th, carry one data byte in BCD Code.

(d) The 12th through 91st bits are always 'One'.

(e) The remaining eight bits; i.e., 92nd to 99th, carry the binary byte 10101010 (AA_{HEX}). This code serves as a preamble byte, immediately following which is the (1 pps mark; i.e., the start of the 0th bit).

It is thus clear that data is transmitted at the rate of 1 byte per second. The sequence of data transmission is as follows:

(a) The 00th second carries no data.

(b) The first two seconds carry the IST hour and minute information (1 byte each).

(c) The following 12 seconds carry the three satellite coordinates, each 8 digits long (4 bytes each).

The satellite coordinates are defined as S_x, S_y, S_z in a geocentric reference frame with x-axis along Greenwich meridian, y-axis along 90°E both in the equatorial plane and Z-axis along the geographical north. These are computed every ten minutes from the six osculating orbital parameters of the satellite orbit. These parameters are obtained once in roughly 4-7 days from the Master Control Facility (MCF) at Hassan.

The complete sequence of data is repeated three more times during the remaining three quarters of the minute. A fresh data set starts at the beginning of the next minute. The satellite coordinates are updated every 10 minutes.

3. TRANSMITTING SET-UP

The entire transmission equipment is kept at the Delhi Earth Station (DES) at Sikandarabad situated 70 Kms eastward from Delhi. This set up is shown in the block diagram of Figure 3. It consists of the STFS format generator which takes its inputs 1 MHz and 1 pps from a cesium clock, kept synchronized to Indian Standard Time. The clock synchronization is checked every 20-25 days with the help of a portable clock from NPL. The STFS format generator also takes inputs of the satellite coordinates S_x, S_y, S_z every ten minutes from a small computer which is fed with the six orbital parameters. The STFS so generated is an audio signal which frequency modulates an IF carrier of 54.675 MHz. The audio level is adjusted to give a peak deviation in the

carrier of ±50 KHz and the IF output level is adjusted to 0 dBm. The modulated IF outputs of the remaining four RN channels and one TV channel are added linearly to this output in the combiner. The composite IF at 70 ±20 MHz is uptranslated to 6 GHz and amplified in a high power amplifier before feeding it to an 11.8 meter parabolic dish antenna. The uplink E.I.R.p. is 60.4 dBW.

A somewhat detailed block diagram of the STFS format generator is shown in Figure 4. The heart of this unit is a digital 5 KHz sinewave synthesizer which operates in the following way. The 1 MHz from the Cesium clock is divided down to 200 KHz which provides the clock pulses. This is fed to a 40:1 divider whose BCD outputs are connected to the address ports of an EPROM containing the look-up table of a sinewave in 40 equal steps. The data output of the EPROM is connected to a D/A converter. Thus, with the succession of clock pulses, the output of the D/A converter follows a sinewave which has discrete steps at intervals of 5 μsec. These steps, however, are close enough to get smoothened in subsequent stages of low pass filtering. The 40:1 divider stage is enabled by a gate width logic which enables the 5 KHz generation of 2.5 or 7.5 msec duration, respectively, depending on whether it is a '0' or '1' bit on command from the SOD line of the microprocessor. The divider chains are all reset with 1 pps from the cesium, thus synchronizing the positive zero crossing of the 5 KHz with it.

Binary encoding of the signal is controlled by an 8-bit microprocessor (INTEL 8085) card containing 2K RAM, 2K ROM and 8255 parallel I/O interface. The microprocessor is run in an interrupt driven mode by a 1 pps from the cesium clock and a 100 pps from the divider chain. The basic functions performed by the μp card can be summarized as follows:

(a) The 1 pps driven interrupt program runs a software clock which can be set to IST by a command thumbwheel. The real time parameters are then coded along with the signal.

(b) The satellite coordinate data for 24 hours, which is converted into bit parallel byte serial form by an interface card is stored in the system RAM. These are then used for real time signal coding.

(c) The IST clock, the current values of the transmitted satellite coordinates and the complete set of satellite coordinates for 24 hours can be visually displayed by appropriate thumbwheel commands. This is done by the μp by outputting the relevant data to a display card with seven segment displays.

In the event of a power failure, the μp Card is powered by batteries so that the clock is not disturbed.

4. RECEIVING SET UP

The receiving set up is shown schematically in Figure 5. At the user's end, the STFS is received in the S-Band at 2599.675 MHz. The complete set up of a narrowband FM receiver along with an 8-foot chicken mesh antenna and a front-end converter is available commercially in India. This is a quartz controlled fixed frequency receiver with excellent low drift of L.O. The

front-end converter uses a low noise amplifier (LNA) with 1.5 dB noise figure, giving an overall carrier to noise ration of 11.7 dB. The demodulated output of the receiver is the coded STFS in the form of 5 KHz bursts. This signal is to be decoded to identify the 1 pps mark and extract time of day and satellite coordinates. An 8-bit microprocessor (INTEL 8085) controlled decoder has been designed at NPL for this purpose. The know-how for the manufacture of the decoder has not yet been passed on to any commercial firm. At present, we are in the process of developing five prototype units for ERTL Laboratories of the Department of Electronics, Government of India. This has been taken up as a pilot project which will be followed shortly by a know-how transfer to a commercial firm. The basic functioning of the signal decoder is shown in Figure 6. The first step in the signal conditioning is to convert the sinewave packets into pulses (a) of the same width (2.5 msec or 7.5 msec) using a retriggerable monoshot and (b) thin pulses of 20 µsec at the leading edge of the 5 KHz packet. The pulses (b), occurring at 100 pps, drive an interrupt program of the µp which continuously monitors the width of the pulses (a) at the SID line (i.e., bit status) and tests the latest 8 bits received. On receiving the preamble byte AA (10101010), a command is issued to gate out the immediately following pulse (b) which is the received 1 pps marker. This is, however, only a rough detection of 1 pps mark, having a jitter of few microseconds and an uncertain delay depending on the level setting of the zero crossing detector. The accurate 1 pps detection is achieved using a Digital Phase Lock Loop (DPLL) in the following way. The 5 MHz from a local frequency standard is divided down to 5 KHz which is then phase compared with the received 5 KHz packets of the STFS. This phase error is used to advance or retard the phase of the local 5 KHz in digital increments of 0.2 µsec by adding an extra pulse or deleting a pulse of the 5 MHz input to the divider. This process continues until the phase error vanishes and the locally generated 5 KHz is locked to the received STFS. This 5 KHz is then further divided down to 1 pps and the divider chain is reset by the roughly detected 1 pps which was gated out previously. The 1 pps so obtained is in precise synchronism with that of the received signal. It is used for two purposes: (a) for driving an interrupt subroutine which runs a software clock, collecting one received data byte each second, detecting the minute mark, testing the consistency of the received data over last minute interval during the minute mark and finally updating the software clock by the received time of the day information and storing the satellite coordinates once every ten minutes in the system RAM; (b) as a stop pulse in a time interval counter which is started by a 1 pps from the local time standard. The time interval counter is interrogated by the µp once each second and measured value of this time interval averaged over 10 seconds is stored in the RAM once every 10 minutes. The µp outputs the clock, satellite coordinates and the time interval measurements data onto a display card on thumbwheel command for a visual front panel display. The output is also given in the serial form at a baud rate of 300 in RS232C protocol for a printer.

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental results described here are measurements made by receiving the signal back at the Delhi Earth Station. The same cesium clock was used for both the transmitting STFS generator and the receiving decoder. Thus, the received time interval measurements were exactly equal to the sum of the

propagation delay of the signal over the transmitter-satellite-receiver path and the instrument delay of the transmit and receive chain. Typical sets of measurements are shown in Figures 7(a) and 8(a). The following features have been observed in the data.

(a) The jitter in the received 1 pps from the decoder is better than 1 μsec over a short time scale of several minutes. This is better than the antici-pated 1-2 μsec jitter while conceiving the STFS scheme.

(b) The combined delay of the signal through the transmit equipment and the receive chain is 25 μs ±1 μs. This was measured by looping back the trans-mitted IF carrier at 54.675 MHz and feeding it to the input of the receiver after suitable attenuation. The measurement thus made assumed that in the high frequency portions of the link, the delay is negligible. In all, six different receivers tested in arriving at the above figure of the delay which is remarkably consistent. In addition, the long-term stability of the re-ceiver delay was tested using a single receiver and was found to be constant to better than a microsecond over the measurement period of a few days. The delay variation was better than a microsecond with respect to signal strength variation over 20 dB.

(c) The received 1 pps undergoes diurnal variation in delay due to satellite wobble. The total diurnal excursions in the delay amount, in typical cases, to about 200-300 μsec centered about a mean value of 244780 μsec. This mean value corresponds to the total propagation delay over this path assuming that the satellite is perfectly geostationary at 74°E. This means that even if no corrections were applied for satellite wobble by making use of the satellite coordinates transmitted and only a fixed delay was incorporated corresponding to this mean value, then time synchronization could be achieved with an un-certainity of about ±150 μsec in the worst case. For a better time synchron-ization, the current values of the satellite coordinates can be made use of to compute the actual propagation delay in real time. This computation is discussed in the next section in greater detail. In the present work, such computations were made and the computed values of the propagation delay com-pared with the observations. It was observed that there were still residual departures as shown in Figures 7(b) and 8(b), which in the worst case, could be as high as 20 μsec. In Figure 7(b), we observed a positive bias in the residuals, but this goes on both sides of zero in Figure 8(b). On some occasions, we even have a negative bias. Thus, the limit of the absolute accuracy of time synchronization using this system at present is about ±20 μsec, even after taking account of the propagation delay.

6. COMPUTATION OF THE PROPAGATION DELAY

For computation of the propagation delay, use is made of a simple geocentric rectangular cartesian coordinate system, X, Y, Z, as described in section 2.

The coordinates of the transmitter and the receiver sites in this system are defined as:

$$X = (H + h) \cos \theta_S \cos \emptyset_S$$

$$Y = (H + h) \cos \theta_S \sin \emptyset_S$$

$$Z = [(1-f^2) H + h] \sin \theta_S$$

where

$$H = R_E [1 - \sin^2 \theta_S (2f-f^2)]^{1/2}$$

θ_S, $\emptyset_S$ are the latitude and longitude of the site.

h is the height of the site above the mean sea level.

R_E is the Equatorial radius of the earth.

f is the oblateness of the Earth (1/298.257)

Satellite coordinates S_X, S_y, S_z are supplied along with the coded STFS. Using the above definitions, the propagation delay can be written as

$$T_p = \frac{[\Sigma_{i=x, y, z} (S_i - T_i)^2]^{1/2} + [\Sigma_{i=x, y, z} (S_i - R_i)^2]^{1/2}}{299.7925} \text{ msec}$$

The satellite position coordinates are in the same coordinate system as the transmitter and receiver. The computations are performed at the transmitting site for the coordinates every ten minutes using a small computer. Main assumption in the computation is that the orbit is a Keplerian orbit defined by six orbital elements (ref. 6).

a = semi-major axis

e = eccentricity

i = orbit inclination

Ω = right ascension of the ascending node

W = argument of the perigee

M = mean anomaly

Using the six elements, the satellite position coordinates are described by:

$$S_X = \gamma [(\cos(W+f)\cos(\Omega-\emptyset)-\cos i \sin(W+f)\sin(\Omega-\emptyset)]$$

$$S_y = \gamma [(\cos(W+f)\sin(\Omega-\emptyset)+\cos i \sin(w+f)\cos(\Omega-\emptyset)]$$

$$S_z = \gamma \sin i \sin (w + f)$$

where $\quad \gamma = \dfrac{a(1-e^2)}{1+e \cos f}$: is the geocentric distance of the satellite.

f = (M-2e \sin M) is the true anomaly

387

$$\emptyset = 99.79098 + 0.985647335D + (15.0411069/360)T$$
is the Greenwich sidereal angle

D = Day number starting from 0000UTC on 1.1.1900

T = time in UTC in hours.

A set of values of the six orbital elements for a certain time and data is supplied to us by the MCF Hassan once every 4-7 days. These are based on the satellite ranging every 3 hours by them for three previous days. One such set of values so obtained is used to compute the satellite position for the next 4-7 days until a fresh value is obtained. While normally such a procedure gives acceptable propagation delay computation results, there are occasionally problems for a couple of days every 2-3 months, when satellite maneuvers are performed.

7. SUMMARY AND CONCLUSION

In conclusion, the status of STFS service at present via INSAT 1B can be summarized as follows:

The STFS broadcast is given round the clock (excepting during satellite eclipse periods) on an RN channel with a downlink frequency of 2599.675 MHz. This carrier is frequency modulated with the coded audio STFS with a peak deviation of ± 50 KHz. The audio STFS consists of packets of 5 KHz sinusoids occurring every 10 msec, the packet width being binary modulated to carry information on time of day in IST and the satellite position coordinates. The entire transmitting setup is situated at the INSAT earth station at Sikandarabad (Lat. 28°-28'-52.6", Long. 77°-42'-31.7") and is synchronized to time standard at NPL. The satellite coordinates are computed from the six orbital parameters defining the Keplerian orbit of the satellite received from the MCF at Hassan once every 4-7 days. A fresh value of the coordinates is transmitted every 10 minutes.

The STFS broadcast can be received using 8-foot chicken mesh antenna with an LNA and down converter mounted at its feed point, whose IF output is fed to a fixed frequency FM demodulator. The demodulated STFS can be decoded using a microprocessor based decoder which uses as its input a 5 MHz and 1 pps from a local clock.

There are two levels at which the decoder can be used. First, for such users who do not require time synchronization accuracies of better than about ± 200 µsec, it is not required to account for the path delay variations due to satellite wobble. One needs only to compute one value of the path delay assuming that the satellite is ideally geostationary at 74°E and advance the received 1 pps by this amount. Secondly, for users who require better time synchronization accuracies of the order of ± 20 µsec, one needs in addition to make use of the satellite position coordinates to compute actual values of the path delay at 10 minute intervals. These computations as described in section 6 can be made by using a programmable calculator or a small computer and the received 1 pps advanced by this amount using a programmable delay generator.

The present STFS service as has been described in the introduction has become regularly operational since March 1987. The use of this service is still extremely limited due primarily to lack of awareness and availability of suitable receiving and decoding equipments in the market. We at NPL are in the process of creating awareness among users, by sending information circulars to as many user institutions and universities as we know. Out of the several institutions that have shown interest are the ERTLs of Department of Electronics for the frequency calibration; Radio Astronomy Centre, Ooty; Organizations under ISRO at MCF Hassan and Sriharikota; Television Centres; Central Electricity Authority for time synchronization in the power network and India Meteorological Department for time synchronization of their seismological recordings.

The S-Band receiving equipment is already being commercially manufactured in India. The design of the STFS decoder as discussed in section 4 has been finalized at NPL and a prototype unit is in operation continuously for the last several months. This know-how will be transferred to a commercial firm shortly.

The future plan of work at NPL is along two lines:

(a) The computation of the path delay of the received signal is at present being done manually using a programmable calculator. This is a distinct disadvantage because for a real-time time synchronization, it requires considerable amount of operator involvement. We have plans to use the microprocessor in the decoder itself to do the computation of the path delay and apply this correction on-line to the received 1 pps.

(b) It is clear from the results discussed in section 5 that the inaccuracy in time synchronization of up to ±20 µsec arises primarily due to the computation of the path delay as the jitter in the received signal is less than 1 µsec. The inaccuracy of the path delay and its variation comes due to uncertainty in accurate satellite position computations, which as discussed in section 6, assumes a simple Keplerian orbit for the satellite. This is obviously an oversimplification of the situation. There are considerable amount of perturbations to the orbit due to gravitational attractions of the Sun and the Moon and solar radiation pressure. In order to improve the quality of satellite coordinate predictions, these factors have to be taken into account. This we plan to do in future using a more elaborate computer program.

8. ACKNOWLEDGEMENT

9. REFERENCES

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2-5. STFS dissemination via INSAT 1B, Research reports of Time and Frequency Section, NPL, New Delhi, 1983-1987.

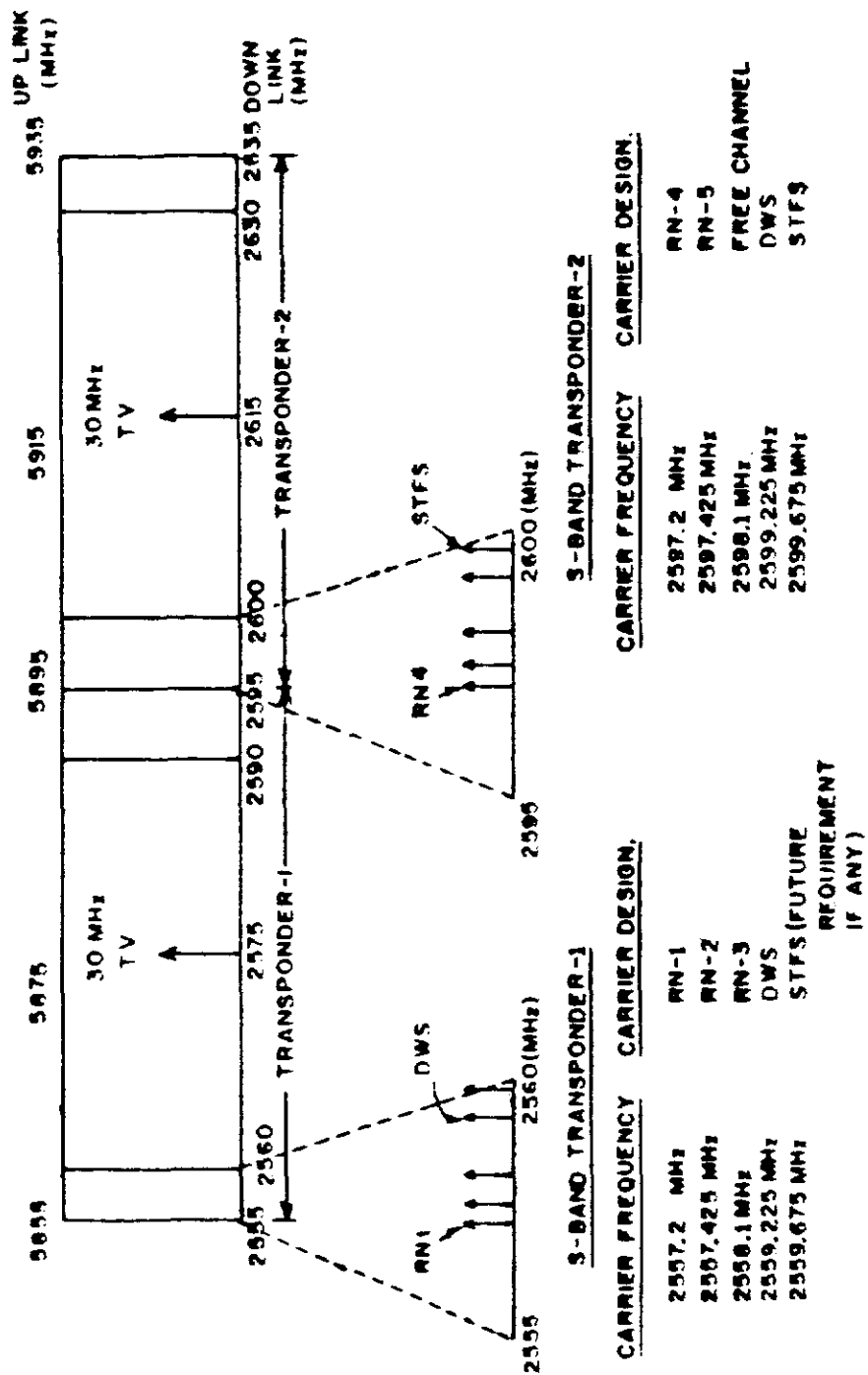6.   Introduction to geostationary orbits - E. Mattias Soop, E.S.A. SP - 1053, 1983.

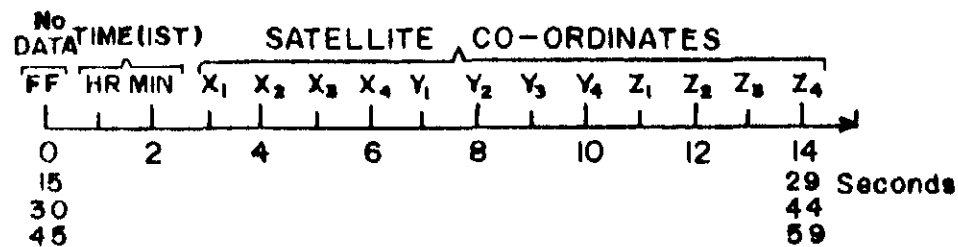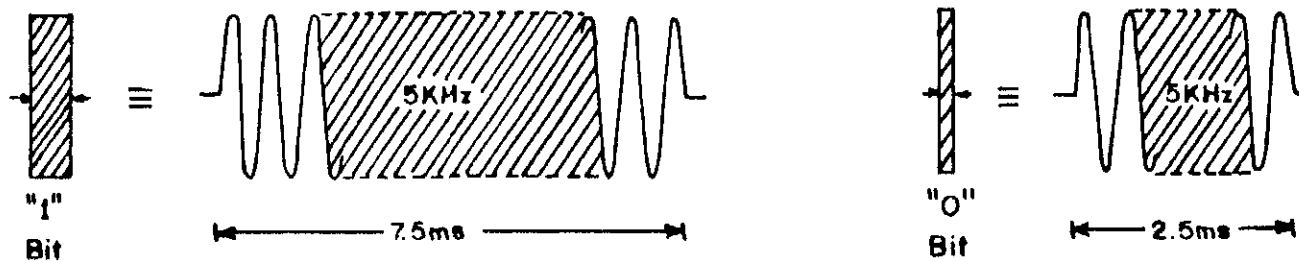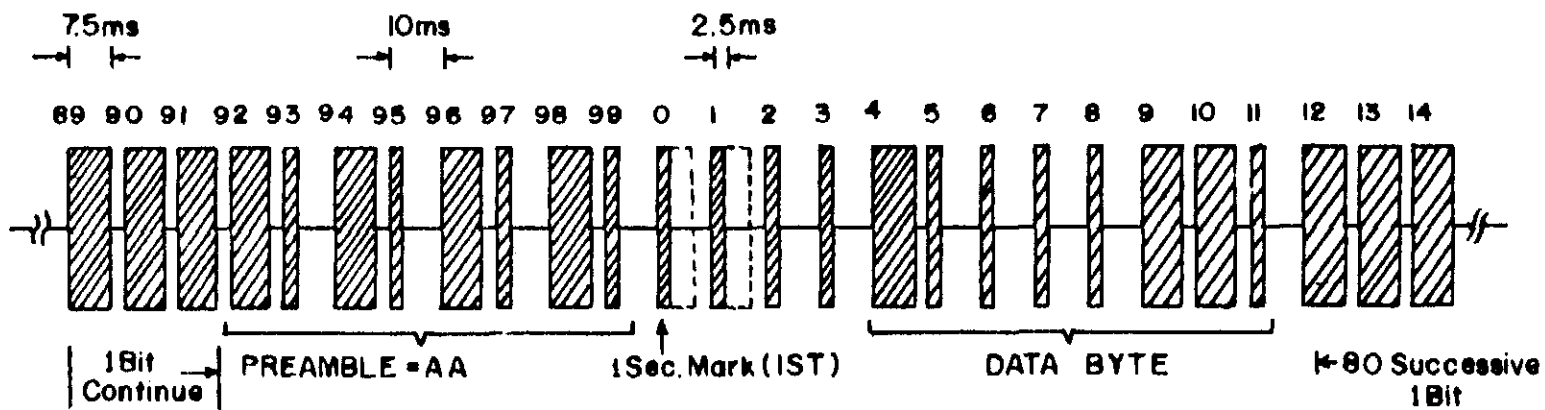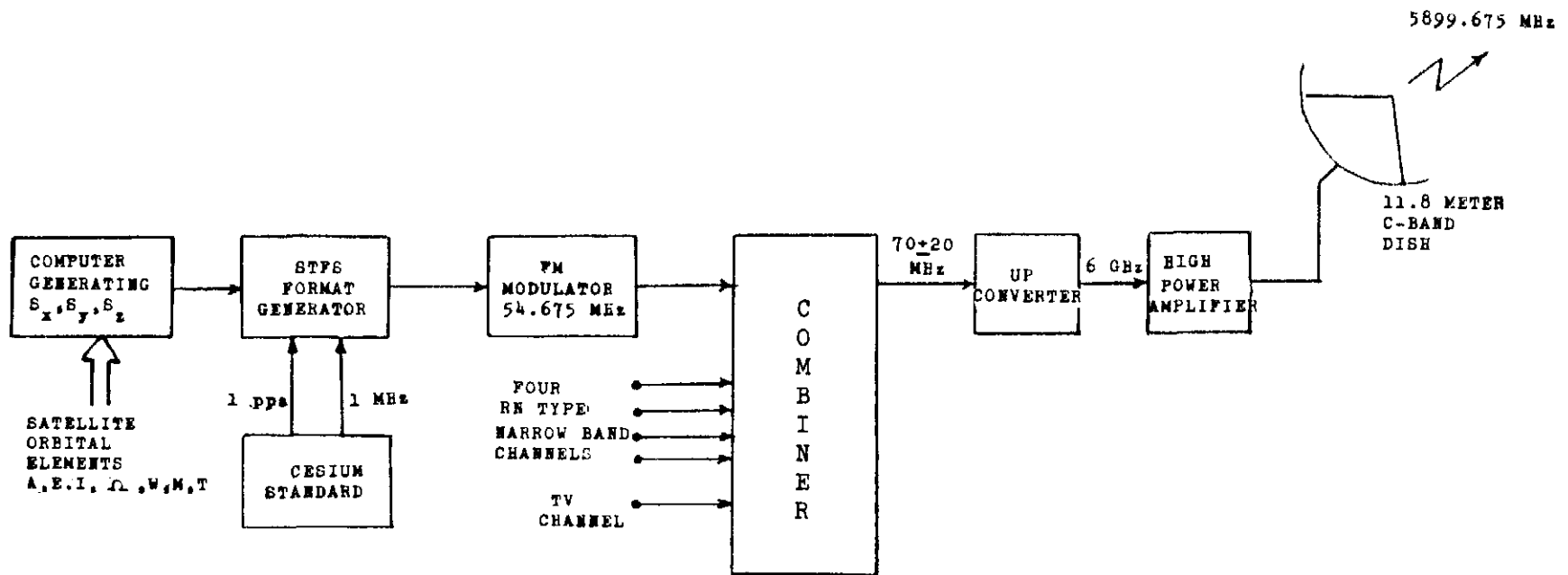Figure 1. C/S Transponder Channel Allocation Chart

Figure 2. Format of STFS Broadcast

5899.675 MHz

11.8 METER
C-BAND
DISH

| COMPUTER GENERATING S_x, S_y, S_z | STFS FORMAT GENERATOR | FM MODULATOR 54.675 MHz |

SATELLITE ORBITAL ELEMENTS A,E.I, Ω ,W,M,T

1 .pps   1 MHz

CESIUM STANDARD

FOUR RF TYPE NARROW BAND CHANNELS

TV CHANNEL

C O M B I N E R

70±20 MHz

UP CONVERTER

6 GHz

HIGH POWER AMPLIFIER

Figure 3.   Block Diagram of the Transmitting Setup
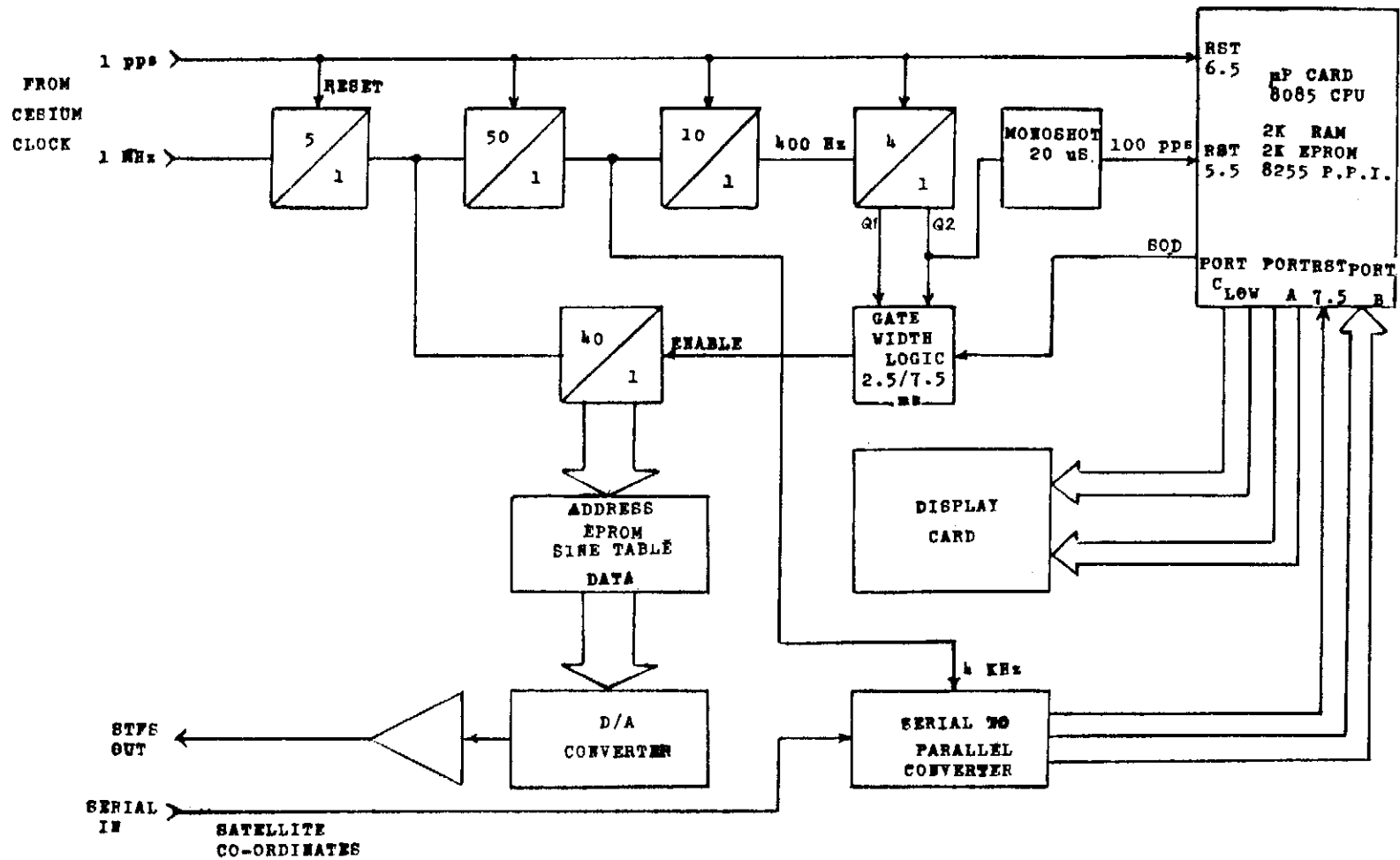
Figure 4.   Block Diagram of the STFS Format Generator

2599.675 MHz

8' CHICKEN MESH
ANTENNA

LOW
NOISE
AMPLIFIER

AMPLIFIER
54.675 MHz

LOCAL
OSCILLATOR

2545 MHz

ANTENNA MOUNTED FRONT END

F M
RECEIVER

DEMOD

STFS

STFS
DECODER

1 pps

5 MHz   1 pps
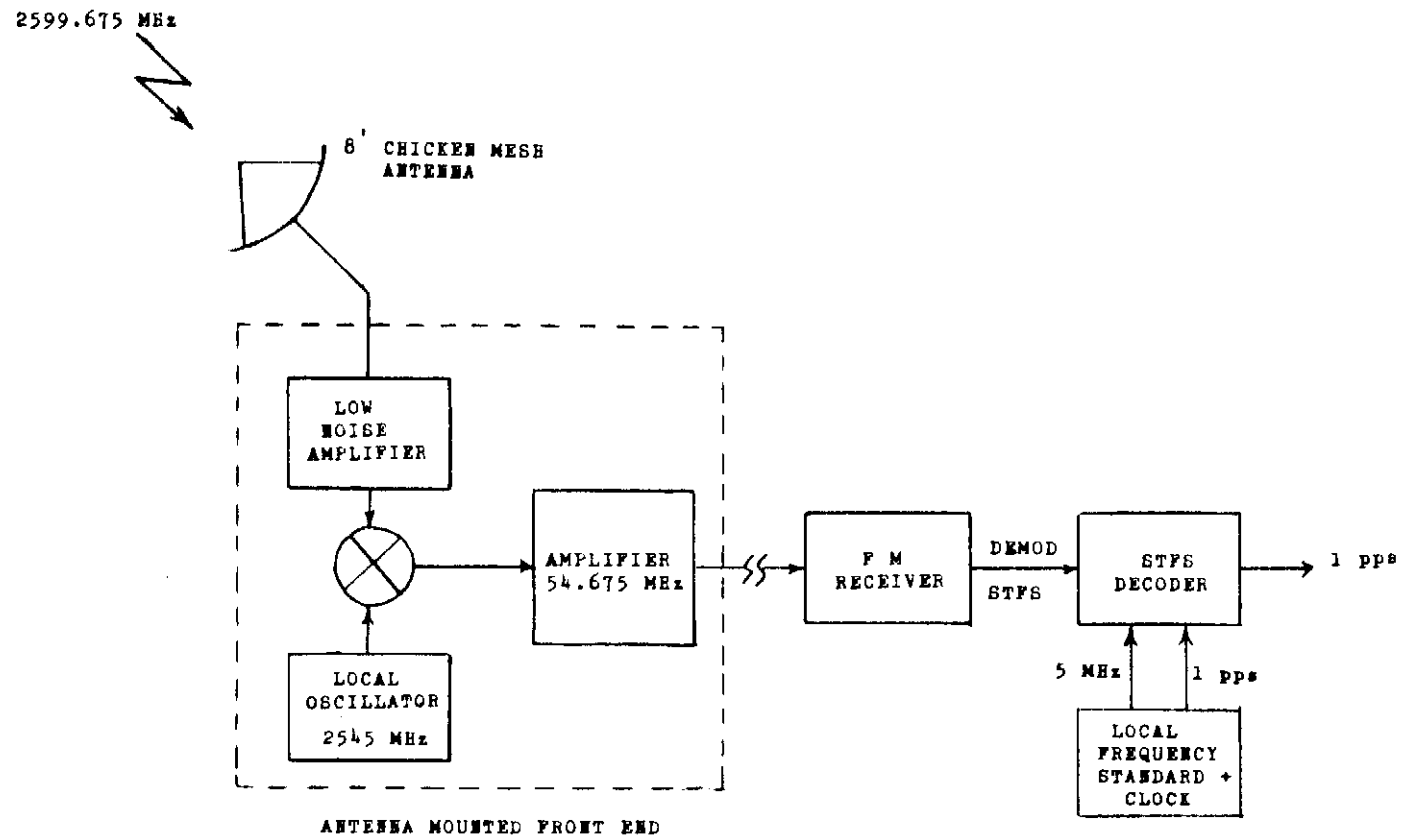
LOCAL
FREQUENCY
STANDARD +
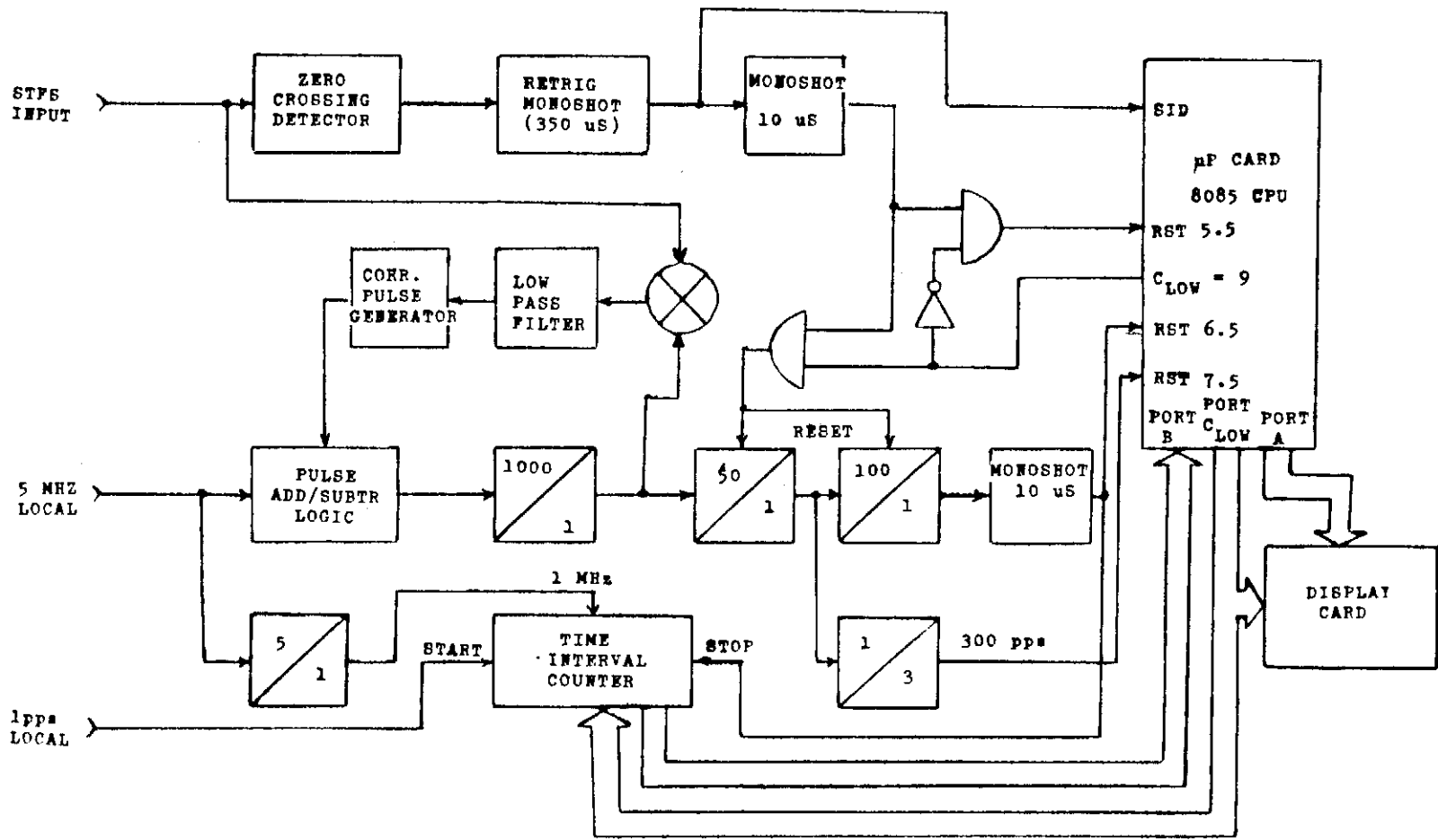CLOCK

Figure 5.   Block Diagram of the Receiving Setup

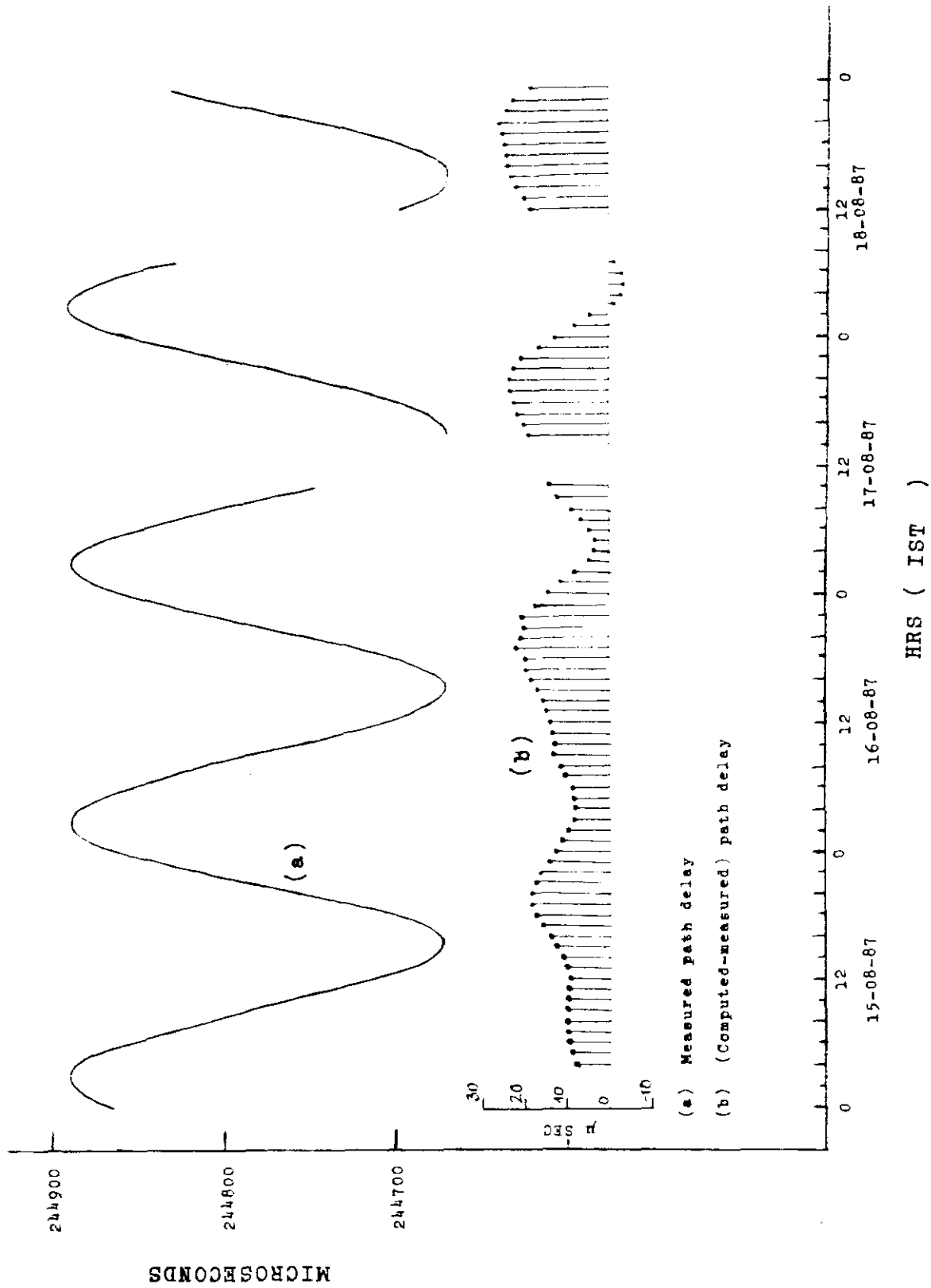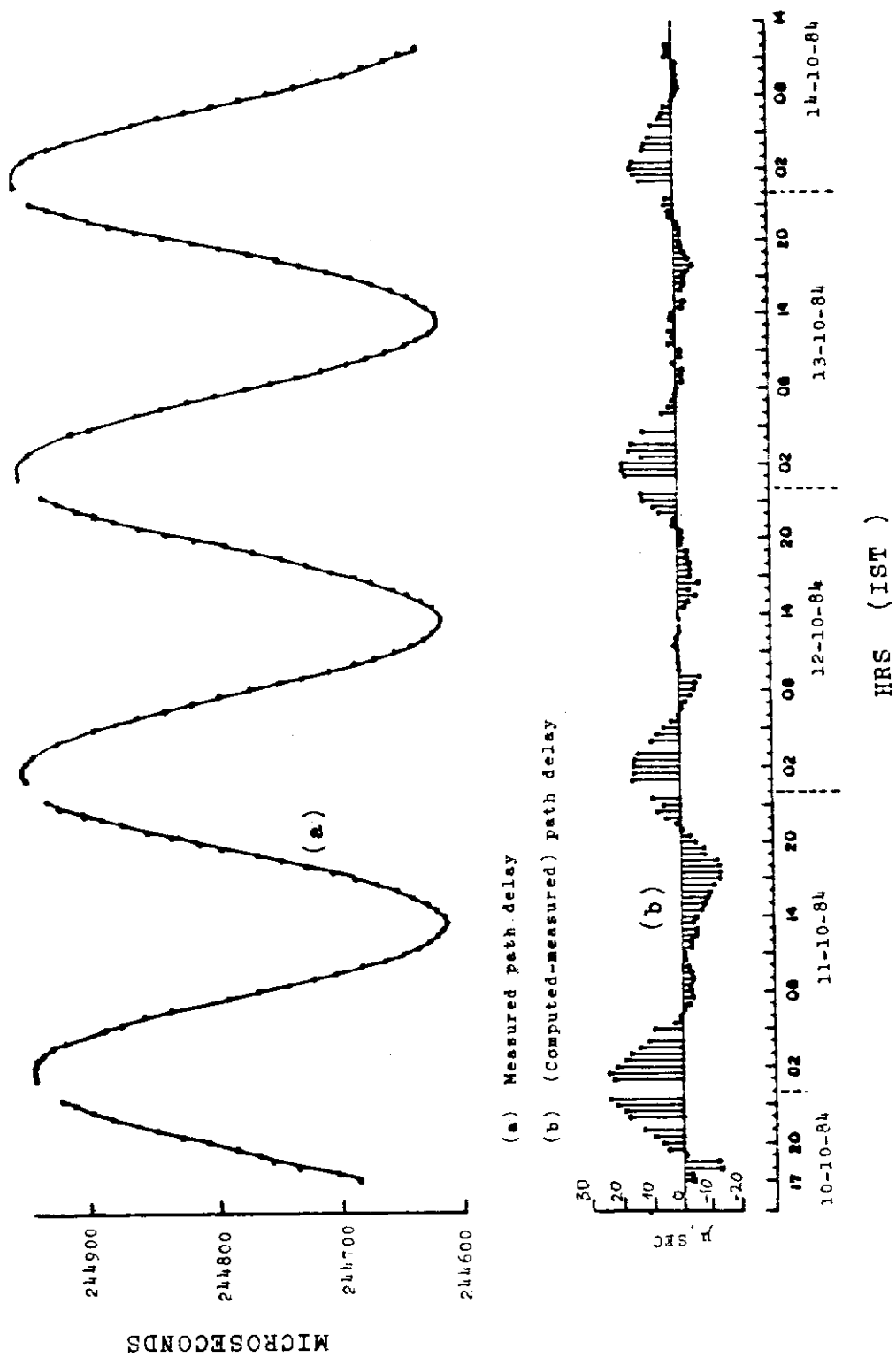Figure 6. Block Diagram of the STFS Decoder

Figure 7. Data for August 15 - 18, 1987

Figure 8. Data for October 10 - 14, 1984

398