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A Digital Processor for Atmosphere Telemetry Data

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ABSTRACT

Upper air primary meteorological data (pressure, humidity and temperature)and other derived data (namely air density, sound speed..etc) are important for aviation , marine , science , agriculture ,military operations and industry. Primary information are measured by sensors within radiosonde carried by balloon or special tailored rockets. Collected data are multiplexed in time division multiplex format (TDM) whose basic slot time is about one second and frame time is 8-10 seconds. Each slot contains a signal whose frequency or code sequence usually represents the respective sensor information: pressure , temperature and humidity. Other information relevant to calibration and synchronization may also be included. The TDM packet is then used to frequency modulate (FM) a carrier at either of two frequencies that are allocated to meteo telemetry data :400 MHz(±10 MHz) or 1680 MHz. This signal is received by a ground station where it is processed so as to extract the actual temperature ,pressure and humidity and present their behavior as function of altitude over the ground. Further data processing so as to format the meteo data in a prescribed report format may be requested. Extraction of real meteo data would necessitate frame synchronization of the received signal packets in order to demultiplex the signals and deliver their actual variation with height as well as local time. This task is usually partitioned between a reception segment and a processing segment. .Such a processing segment has to perform the following functions :

-Frame and clock"slot" synchronization.
-Data extraction within each slot.
-Filtering and "local" or short-term data smoothing.
-Measurand-to-physical data conversion.
-"Global" or long-term data smoothing to yield the required data profile with altitude and even graphical display.
-Derivation of the required end-user meteo reports and data logger functions.

The present work is devoted to the processing function of the system. Most of the above mentioned functions :acquisition, synchronization , filtering,data extraction are considered . Examples of graphical displays for real data are presented .

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KEY WORDS :Atmosphere pressure ,temperature ,humidity ,FM, median filter ,synchronization , frequency measurement.

I.Introduction

Local weather forecast and tactical defense applications need upper-air data up to an altitude of 20 Km.Radiosondes are an important component of test systems used on military test ranges to acquire atmospheric data. The parameters are wind speed and direction along with atmospheric pressure, air temperature and humidity (PTU). For measuring these parameters, a low-cost,light-weight sensor package along with support electronic circuitry are used. This package is carried aloft by a helium (hydrogen) filled balloon, measuring the atmosphere parameters as it ascends and transmitting the data to a ground station. As to wind parameters ,there are, in fact ,several methods for windfinding. Radar-based systems are quite expensive, heavy and difficult to maintain in the field. Technical complexity can lead to low reliability and high maintenance costs. Moreover ,in operation radar is not passive, it transmits electromagnetic energy with its consequences of powering and ease of location by enemy.

Passive systems based on VLF-NAVAID (Communications VLF, OMEGA and ALPHA), Cross-Chain LORAN-C or GPS (Global Positioning System)[1] are well suited for field use, but are dependent on the availability of navigation networks or satellites. Another low cost, passive but independent system ,is using the radio direction finding principle known as radiotheodolite. The radiotheodolite measures azimuth and elevation angles to the radiosonde. PTU data from the radiosonde provides the third parameter, height, for wind calculation.

Commercial radiosondes are heavily using the meteorologicalband (400 - 406 MHz) . Typical radiosondes require 500 KHz for the signal and an additional 500 KHz to allow for frequency drift of low-cost (non-crystal controlled) radio transmitters. In many locations a number of radiosondes can be detected at any one time as a receiver is tuned over the 400 to 406 MHz band especially in Európe where many countries are using this band within a relatively small (for radio telemetry) geographic area There is a significant problem of transmitter drift and frequency interference that deteriorate transmission of the collected data .

As to the collected data ,they are generally multiplexed in time division multiplex format (TDM) and then used to frequency (FM) modulate a carrier.The TDM packet basic slot time may reach about one second and frame time to about 10 seconds. Each slot contains a signal that represents the respective sensor information :pressure ,humidity, temperature as well as other information relevant to calibration and synchronization . Two approaches are adopted for inclusion of sensor information :digital and analog .The former class uses biphase encoded digital data that include the sensor information with near-the-sensor processing and this is exemplified with GPsonde and MarkII MICROSONDE . Near-the-sensor processing relies generally upon measuring the frequency of an RC oscillator that incorporates sensors in its circuitry and thus makes measurand -to-physical data conversion

before transmitting the data to the ground station.
The second class uses a signal whose frequency represents the respective sensor information and this is exemplified by VIZ and VAISALA analog radiosondes .
Mark II MICROSONDE samples the data every 1.2 second during flight. Data is transmitted (with repeat)at rate of 400 baud(1000 baud for GPsonde) biphase digital stream with cyclic redundancy check (CRC) error correction information. The microprocessor in the radiosonde adds the pressure ,temperature and humidity and transmits their sum for error checking. The ability to transmit and receive data without error makes it unnecessary to smooth or filter the data .
The periodically transmitted data contains :
-Synchronization preamble in form of periodic or Barker code is sent at the beginning of each transmission.
-Radiosonde serial number where the receiver spots upon as authentication aid and helps locking upon.
-Calibration data.
-Meteorological sensor information (pressure ,temperature and humidity)
-Navigation aid signals in certain versions
Upon reception of radiosonde signal ,the baseband signal processing includes clock and frame synchronization as well as data demultiplexing.Clock and frame synchronization for such type of signals (used also with satellites like ARGOS and SARGOS)is studied in [2,3] and will not be followed here .
The analog radiosondes (exemplified by two of the worldly known system VIZ and VAISALA that are considered in this work) have the typical signal formats given in Fig.1. The VIZ system has a frame time of about 8 seconds divided into 8 slots where the pressure is transmitted periodically once each 2 seconds ,the temperature each 4 seconds and the humidity once per 8 seconds. A reference signal is also transmitted once per frame ;i.e once per 8 seconds and the reference signal frequency is higher than other sensor frequencies .The pressure is indicated by the succession of either of 4 fixed frequencies while both temperature and humidity are indicated by a varying frequency according to the current value of the thermistor or hygristor resistances respectively.
As to VAISALA system, a frame time of either 1.2 or 1.8 seconds divided into 6 slots is used .Each parameter is transmitted periodically once per frame .Pressure ,air temperature,humidity and internal temperature of pressure capsule are transmitted. Moreover ,two reference signals are transmitted within the frame for synchronization and calibration purposes.
Extraction of the required information in such meteo system can be formulated as frequency measurement problem complicated by gating within each time slot and by being low frequencies contaminated by shot or impulse noise induced due to the used demodulation system. Frame synchronization as well as time slot synchronization has to be implemented .Conversion of measurand-to-physical quantities has to be done along with other end user requirements. A functional system sketching may be seen in Fig.2.
In the following , the FM discriminator-induced noise spikes (impulses) are considered in section II. Section III considers the problem of low frequency measurement and synchronization.

Median filtering and data smoothing are discussed in section IV. Data processor hard-and software for acquisition and processing are considered in section V. Finally, conclusions and future work are given .

II FM Discriminator-Induced Noise Spikes / Impulses

The considered meteo telemetry systems are essentially FM systems that are usually demodulated by FM discriminators. such discriminators are known to suffer threshold region [4] or breaking region [5]. In such region ,the discriminator output contains impulses or spikes .This tends to occur even when the noise power is 10-15 dB below the carrier power and multiplies as the carrier- to-noise ratio lowers down. The onset of the impulses or spikes is highlighted in the following.

Fig.3.depicts the phasor diagram for the carrier signal and narrow-band represented noise n(t). When n(t) becomes comparable to the carrier amplitude A ,the locus of the resultant R(t) may encircle the origin and hence the $\vartheta(t)$ jumps by 2π during short time interval. As the discriminator output is given by ($d\vartheta/dt$), a spike or an impulse with intensity 2π is generated. and may be observed using an oscilloscope at the discriminator output.

In the present application ,the frequency of occurrence of such spikes as well as their duration are of importance. In order to relate the mean time between spikes and their average number per unit time as well as the spike duration to the system parameters ,let us consider Fig.4.

First of all,the spike duration can be estimated as 2/BW which ranges to 4-10 μsec for typical meteo telemetry system where bandwidth BWranges to 200-500 kHz. BW is 2B for input filter and f_M for the output filter.

As to the mean time (T_s)between spikes (as the origin is encircled), calculations under gaussian assumption of noise and unmodulated carrier are found to yield [4] :

$$T_s = (2\sqrt{3}) / B \; \mathrm{erfc}((f_m/B)(S/N_m)) \qquad (1)$$

and average number N_s per unit time is $1/T_s$.

where S and N_m stand for signal and noise powers respectively.

It was found that this number of spikes increases ,unfortunately, in the presence of modulation by an amount δN given by :

$$\delta N = |\delta f| \exp(-(f_m/B)(S/N_m)) \qquad (2)$$

Moreover,δN dominates ($\delta N \gg N_s$) near and below the threshold.

The importance of spikes in meteo telemetry systems comes out of the fact that the required information are imbedded as frequency ; i.e. the measured frequency is what the system searches about. In other words, each spike-specially when frequency measurement by counting shaped impulses - would generate a countable pulse and thus an immediate change of the measured frequency occurs practically on linear basis. This means that the measured quantity is subjected to noise of impulsive nature as the counting over the given interval accumulates the number of spikes without any filtering or smoothing effect. Consequently , a "nonlinear" filtering technique is required . This is the reason for proposing to apply a median filtering algorithm in the class of meteo telemetry systems that rely upon frequency measurement for their functioning .

III.Frequency Measurement and Frame Synchronization

As the required information in the above class of meteo systems is embedded in the form of frequency modulation ,a technique for frequency measurement should be adopted. Such technique should allow the extraction of required information as well as the solution of the synchronization problem to allow for data demultiplexing.

There are several methods for frequency measurement :

-Spectral methods based upon a bank of narrow band filters and detection or equivalently upon fast Fourier transform (FFT) of the signal under consideration.

-Correlation methods based upon correlating the signal with a locally generated signal as in Lissajous figures generation or with a phase locked loop so as to find the frequency.

-Frequency-to-voltage conversion based upon shaping the signal in the form of fixed duration pulses and integrating (or low pass filtering) the shaped signal.

-Counting methods including period measurement.This method relies upon counting the number of signal periods in a given time interval (gate) or using the signal as a gate and counting the number of a known signal periods within the signal period; i.e period measurement.

This last class has several advantages among them are the digital implementability and liability to automatic evaluation and decision about the signal frequency .This method will be considered for both signal frequency measurement and synchronization.

3.1.Principle of Low Frequency Measurement

The counting method shown in Fig.7 requires for implementation two signals :the gate and the signal whose number of cycles within the gate time ar to be counted within each slot duration for the respective parameters .The gate duration is chosen on decadic bases for frequency measurement . As the measured frequencies get lower ,the gate time should get longer to keep the measurement accuracy reasonable. Frequency multiplication is sometimes used to improve the measurement accuracy [6]. A better approach is to measure the signal period ;i.e. the gate is formed by the unknown signal and a known frequency is measured within the gate duration ,hence the signal frequency is deduced within each slot duration .Period measurement is a part of Fig.5. Accumulation of several measured values is sometimes considered for improving the measurement accuracy. In Fig.7 ,a dual-port RAM store of the measured frequency data is used for further access by the computer .Address is generated by a counting function clocked from the slot clock .The used RAM may be selected to suffice for a part or to the whole sounding session.

In the cases where the slot time is different from 1 second a scale factor is to be considered if absolute frequency value is required .As normalized frequency is used (see section 4), there is no need for such scale factor in this work .

3.2.Synchronization

As the frequency measurement requires a time interval during which a number of signal cycles are counted ,a delay (with gate duration) is imposed and it is larger the lower the measured frequency .To reduce such delay ,period measurement is adopted in the following(as the maximum delay before decision is just one signal period)
Successive signal periods are measured by either of the two counter and the latched value is outputted by the digital-to-analog converter as given in Fig.5. Ideal operation of such system would yield at the D/A output a replica for the signals given in Fig.1.except for certain delays. Hence ,from Fig.1,the frame sync signal is obtained by thresholding to get the minimum period (maximum frequency). An equivalent implementation could be based upon replacing the D/A and its subsequent threshold device by a magnitude comparator whose single threshold is sufficient for frame sync. This frame sync signal could be used in a digital PLL [2] with an in-the-loop divider with division ratio equal to the number of per frame slots. A separate module for the slot time determination ,could be implemented by a digital PLL whose input signal is obtained by "differentiating" the D/A output to yield pulses with -at most -intermediate period durations at the transition between various frequency slots.These pulses should enable finding the slot synchronization.The former implementation approach is given in Fig.5.

IV. Median Filtering

As the presence of spikes would yield spikes in both period and frequency data ,a median filter would smooth such local roughness or sharp discontinuities in the required data signal . Merits of median filtering compared to linear filtering can be found in [7,8].

As to the algorithm ,the median filter is defined by the following input-output relation :

$$y(A) = \text{the } (N+1)\text{-th largest value of } \{ x(A-N),..,x(A-2),x(A-1), x(A),\ x(A+1),...,x(A+N) \}. \quad (3)$$

out of the (2N+1) data values .Thus the algorithm should search the middle value of the (2N+1) data values put in order .This means the data values are to be sorted and perhaps this is the reason of considering that median and ranked-order filters time consuming compared to linear or averaging filters .A Solution to such sorting problem in both hardware and software configurations are given in [7] and such solutions favorizes median to linear filters computation-wise. In Fig.6, the result of actually measured reference frequency for VIZ radiosonde is shown . "Negative" spikes are explained by the counter overflow due to excessive spikes .Applying 5-point filtering ,the reference frequency was found to be 180 Hz.The median filter has been also tested by injecting a shot noise process from a generator built as in [9] with the number of spikes given as in section 2 with signal level decay defined by the balloon height and wind speed from real field data and their interarrival time a Poissonian process.

V. The Data Processor Implementation :Hardware and Software

To sum up ,the atmosphere telemetry system :radiosonde and telemetry receiver leave to the processing system to realize some modules that should allow :

- -Gated frequency measurement .
- -Synchronization / Timing and sampling rates security .
- -Data demultiplexing into :pressure , temperature , humidity and reference.
- -Further processing :filtering ,conversion and storage ...etc.
- -End user data presentation

The latter three functions are handled by a developed software while the first and second functions are implemented by hardware

Fig.7 collects the various modules considered before for the frequency measurements and synchronization along with the Meteo-to-computer interfacing module.

A software package has been developed using BORLAND C++ to manage the data acquisition ,filtering ,measurand-to-physical data conversion ,and end user presentation functions. Moreover, a simulator for real radiosonde baseband data is developed and its output is passed to the computer speaker and the parallel port so as to drive the implemented hardware.

The collected meteo data by the RAM is to be acquired by the computer for further processing .A PPI chip is fully dedicated to reach this objective.Two ports are dedicated to RAM addressing and control while the third port is left for inputting the measured frequency data. Data sheets for the used components could be found in [10-12].

5.1. The Data Demultiplexing and Extraction Task

The demultiplexing function is partially realized by hardware in Fig.7. The software gathers the successive frequency data for each sensor as the balloon rises up .To have the physical data for each of the used three sensors (P, T and U), calibration data and sensor (Describing) characteristic equations are required.

As to both of the temperature and humidity ,conversions involving Frequency-to- resistance-to-Temperature and similarly as well Frequency-to-Hygristor resistance -to- Humidity are needed. If such relations are unknown , measurements and regression should help finding them. This is what has been actually done for VIZ radiosonde ;i.e. equations are derived and software algorithms are developed .

<u>Temperature Relations</u>

For the used rod thermistor, the following equation were shown to be valid:

$$R(T1) = R(T0) * \exp\left[\beta(1 / T1 - 1 / T0)\right] \qquad (4)$$

$\beta \in (3000 - 4800)$; and was found from regression calculations.

T1 : Current temperature in Kelvin degrees.

T0 : Lock-in temperature in Kelvin degrees. T0 = 273 + 30
R(T0) : Lock-in resistance, interactively supplied by the user.

For the used sonde RC oscillator, the frequency is given by:

$$F = 1 / 2\pi * R(T1) * C \qquad (5)$$

From this equation, the temperature T1 will be deduced in terms of the measured frequency and the capacitor C within the radiosonde. To bypass errors in resistors as well as in 1-sec oscillator period ;relative (to reference frequency)values can be used. This is done as follows :

$$T_{ref} = const * R_{ref} * C$$

$$T_{var} = const * (R_{ref} + R_{var}) * C \qquad (6)$$

Hence $$T_{var}/T_{ref} = (R_{ref} + R_{var})/R_{ref} \qquad (7)$$

$$R_{var} = R_{ref} * (T_{var}/T_{ref} - 1) \quad \& \quad R_{var} = R_{ref} * (F_{ref}/F_{var} - 1) \qquad (8)$$

This last relation is to be used in the system programming.

Humidity Relations

Several types of sensors are used for relative humidity measurements.Of these types,VAISALA use capacitive film types while resistive carbon film type hygristor is adopted by VIZ . Its resistance was found to increases with the relative humidity from several kilo ohms to megaohms. Its lock-in resistance is often measured at 25°C and relative humidity 33%. It is predicted that the carbon film resistance varies exponentially with the relative humidity and it has been fitted from measurements of several hygristor in the following relation :

$$R(u) = R(0.33) * \exp [\, 25.322 * (u - 0.33)^3 \,] \qquad (9)$$

where R(.33) is the lock resistance of the hygristor . Relative-to-reference calculations as in the temperature case will be also done since both sensors are switched in the same oscillator .

Pressure Relations

As a pressure sensor ,Aneroid capsule is used by VIZ(replaced by Aneroid capacitance in modern versions) and Aneroid capacitance is adopted by VAISALA for continuous delivery of pressure .The Aneroid capsule is coupled to switches for several values of resistors that define a multifrequency sequence related to pressure by a supplied calibration curve.This should deliver the actual pressure the Aneroid capsule is subjected to.
As to the capacitive case a frequency-to-Aneroid capacitance -to- pressure conversion relation is to be used .

5.2 End User Software

Pressure ,temperature and humidity profiles are generally required in both tabular as well as graphical format . Such profiles are displayed as function of height and tagged with real time or with relative time .Relation of height to time defines the ascent rate which is usually 5-7 meter/sec. Typical pressure and temperature profiles are presented graphically in

Fig. 6 ,usually known as Metagraph display. They depict the behavior known for the standard atmosphere and for Egyptian environment. For specific application, the data are presented in standard message formats such as the NATO STANAG formats to be used by artillery computer systems.

Conclusions and Future Work

The present work is devoted to the processing function of meteorological system so as to perform :
-Frame and clock"slot" synchronization.
-Data extraction and smoothing.
-Measurand-to-physical data conversion.
-Meteo data profiles and even graphical display.
-End-user meteo reports and data logger functions.
Data processor hardware for acquisition ,synchronization and filtering has been discussed here .Examples of graphical data displays for real data are presented with the developed software. Filtering algorithms that combine both median and linear filtering need further testing for real data .

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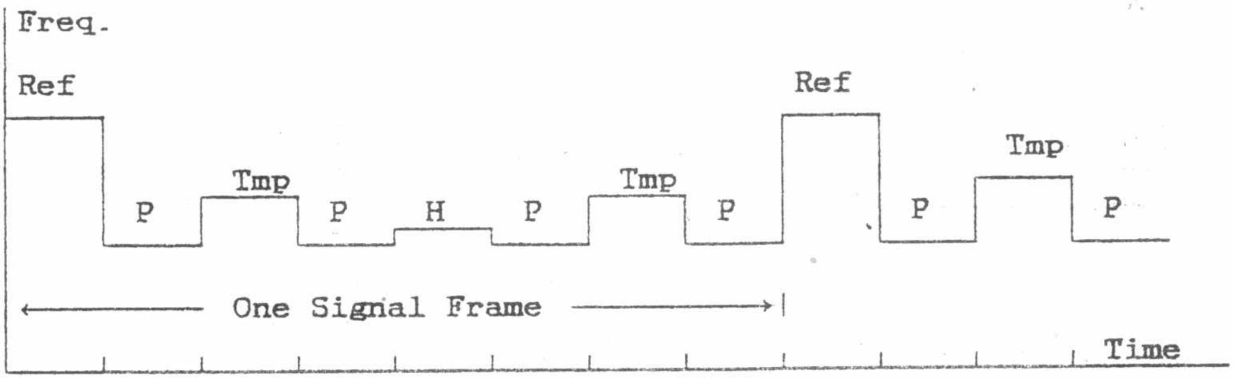
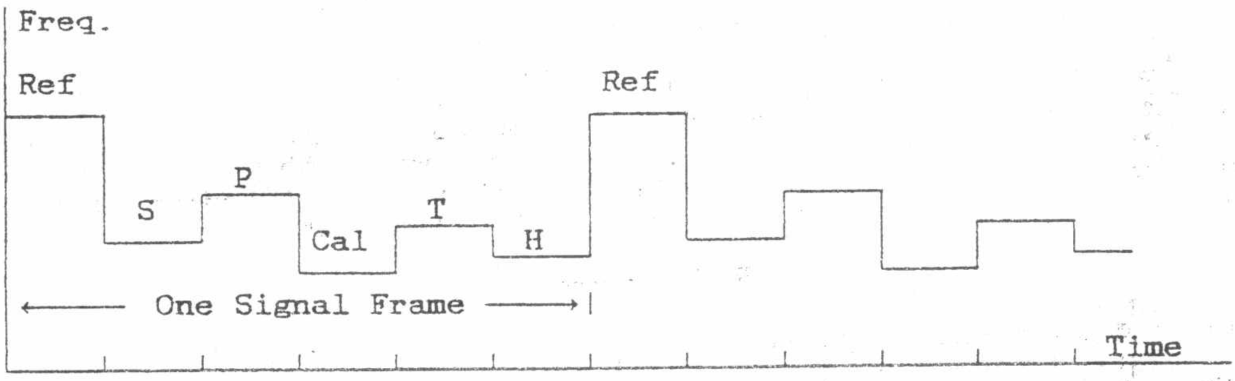


a- VIZ Signal Format



b- VAISALA Signal Format

Fig.1.Analog Radiosonde Baseband Signal Format

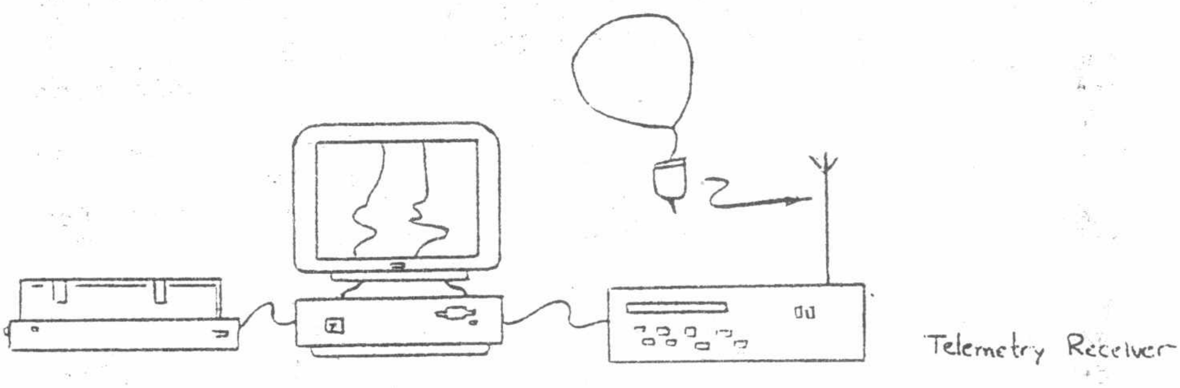


Fig.2.The Atmosphere Sounding System Functional Blocks

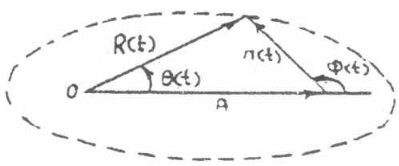


Fig.3. The Signal Phasor Diagram (How Spikes are generated)

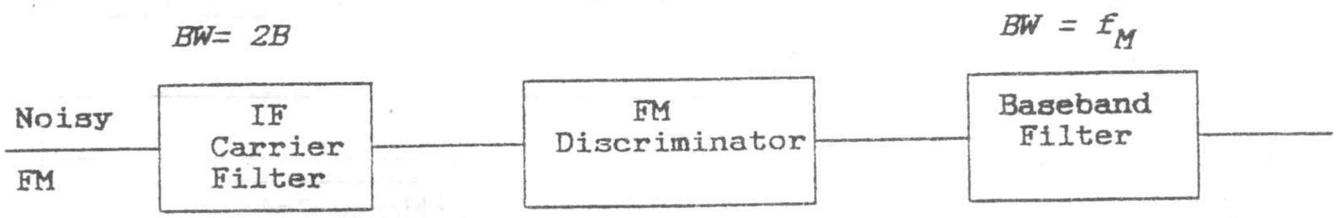


Fig.4.The Rear-End FM Processing Section

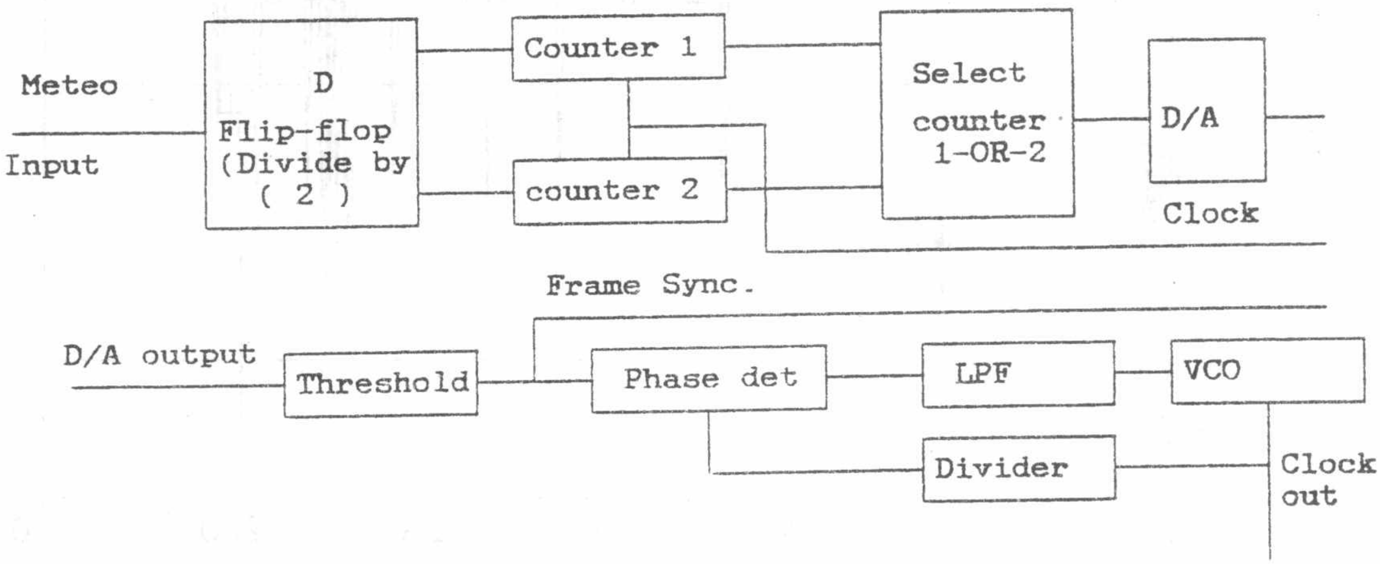


Fig.5. Frame and Clock Synchronization Module

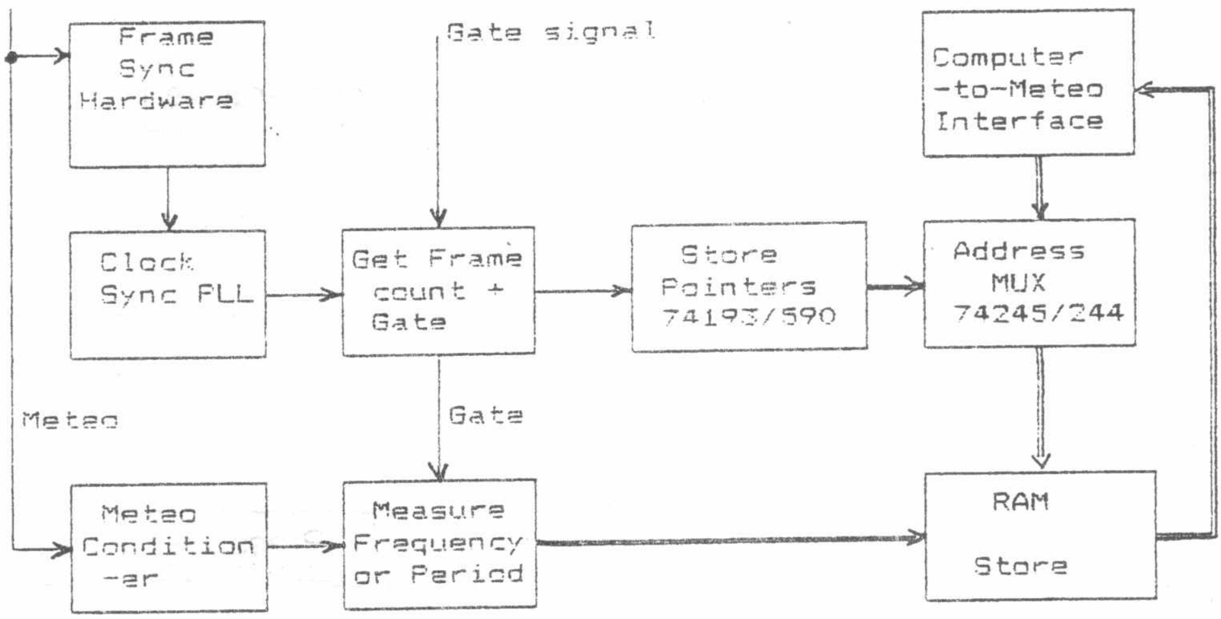


Fig.7.The Digital Processor Hardware Basic Functions

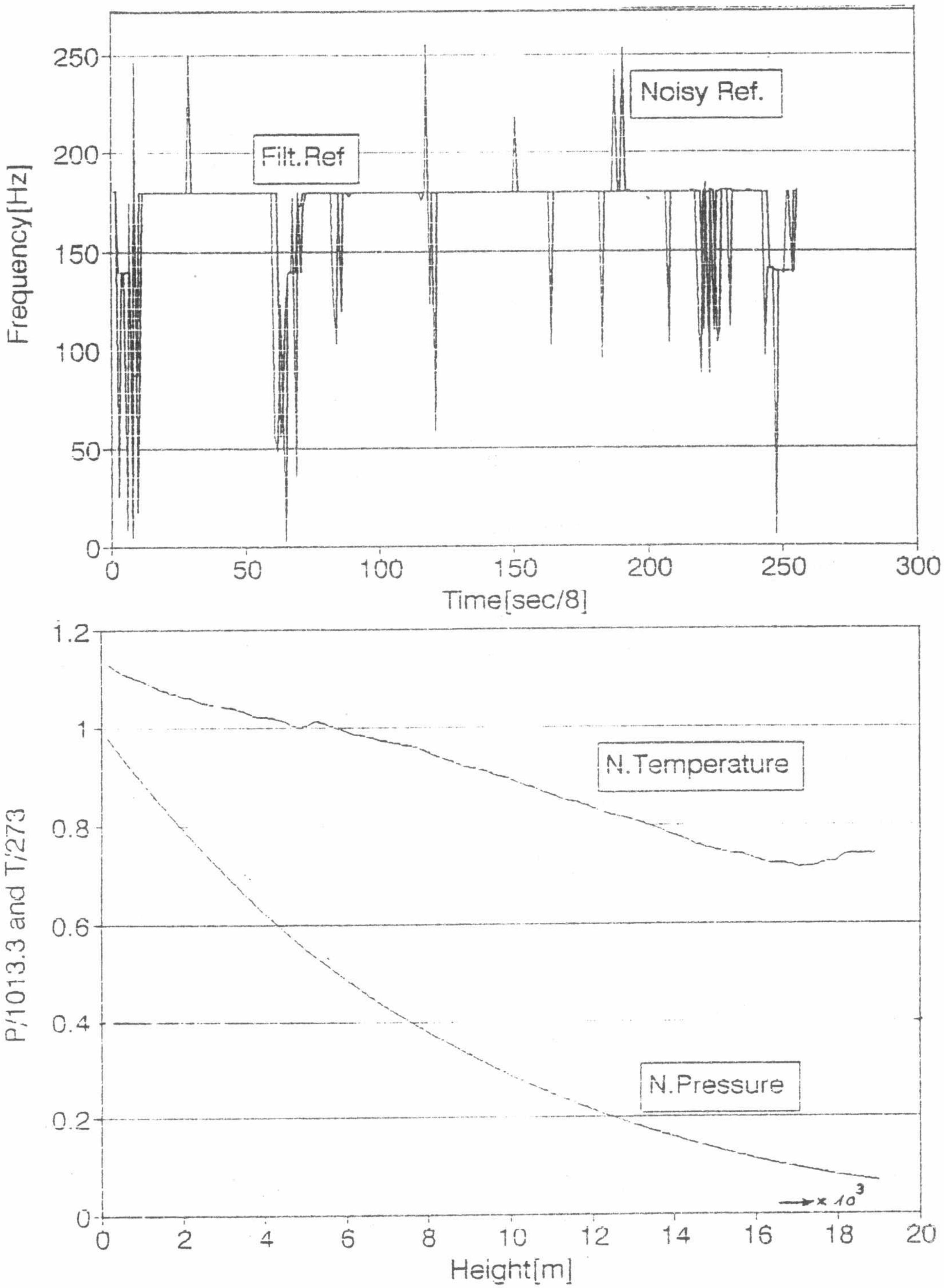


Fig.6.Typical Atmosphere Data (reference signal & P and T Profiles)