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TELEMETRY SYSTEMS AND SIGNAL ANALYSERS FOR DATA TRANSMISSION

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SUMMARY

Data transmission is an integral part of any data acquisition system. The link between the sensor and the recording system can be physical or telemetric i.e.signal from the sensor is converted into radio signals and transmitted for subsequent recording at a recording site which could be far away from the sensor. Telemetery systems are suitable for long distance data transmissions, covering large aerial distances. Components of various telemetry systems, e.g.radio based, satellite-based, meteor-burst etc., have been reported. For efficient and reliable transmissions, generally data is converted into digital form and then initial analysis is performed on the signal. Pre-processing operations include amplification, filtering, trend removal, decimation, calibration etc.

In order to make the input signal compatible to the recording system, these processes are required for increasing the signal to noise ratio of the input. Improvement of accuracy and dynamic range of the system is also desired, which is obtained by processes such as conversion of the raw signal into appropriate units before proper analysis. The signal is transmaitted in coded message format which is recovered and decoded at the receiver end. Various operations are available for signal analyses for use with these telemetry systems. These are briefly discussed in the report. Applications of these telemetry systems and associated signal analyzers in hydrology, water resources and related field have been reviewed.

1.0 INTRODUCTION

Various hydrological forecasting applications e.g.flow forecasting, flood forecasting etc. require collection of reliable hydrological and meteorological data, mostly on near-real-time basis. This may require monitoring at remote sites as well. Generally, volume and urgency of the data to be collected necessitates transmission of the data from remote sites to a central recording/collection station. This has led to introduction of automated data acquisition systems in recent years.

All automated data acquisition systems invariably involve data transmission systems. Basically, any data acquisition system (DAS) comprises of three components (figure 1)-sensors, data collection system and data transmission system. Two basic situations are found-in one, various sensors are transmitting their data to a single data collecting system. In the second situation different sensors are connected to local computers (microcomputers) and the network transmits the data to a central data collection system for processing.

Function of a data transmission system is to provide a link between the sensors and the data collection system. In a number of systems sensors are integral part of the collection system. However, it is generally possible to decouple them in varying field conditionsIt may often be required to transmit the values of these measurements from sensors to a remote (central) location for purposes of performance computations, or for the data to be recorded for statistical calculations and other analyses.

The link between the sensor and the recording system can be physical or telemetric i.e.signal from the sensor is converted into radio signals and transmitted for subsequent recording at a recording site which could be far away from the sensor. A number of variations are possible on data transmitting system-

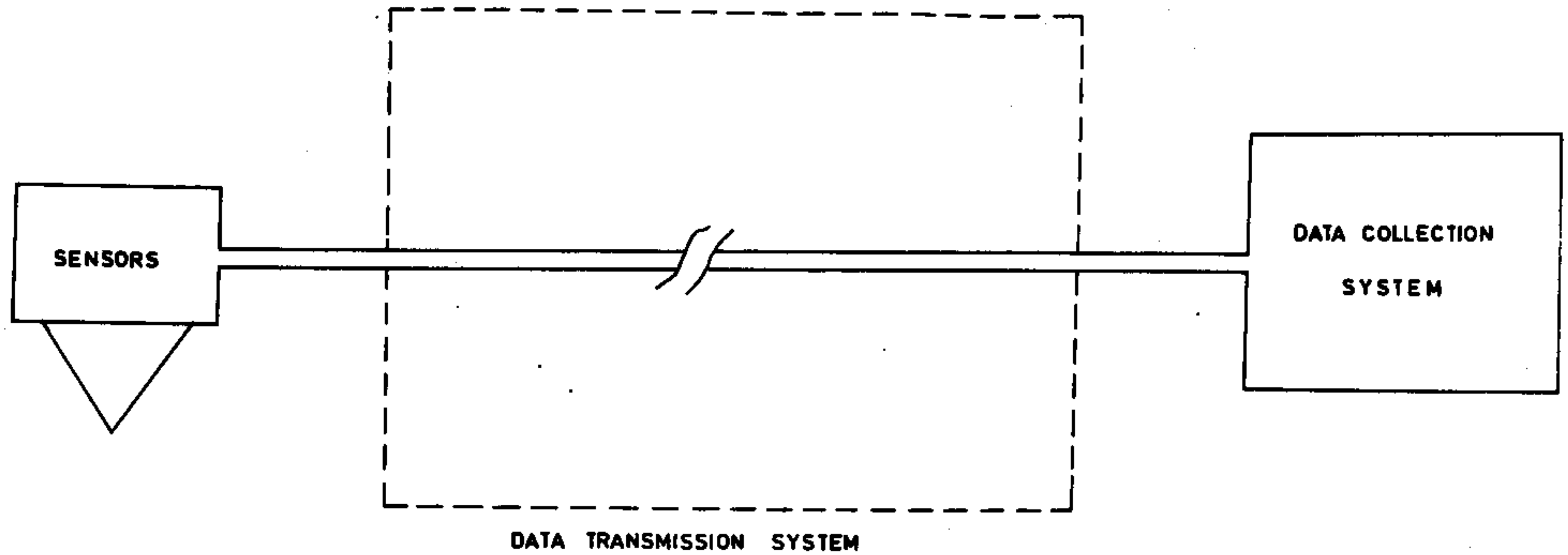

FIG. 1 - ELEMENTS OF A DATA ACQUISITION SYSTEM

direct wired connection, through telephone line, short range radio telemetry, satellite telemetry and telemetry through meteorburst.

In cases of large distances between sensors and data collection sites, it is not generally possible to link the two systems through wired connection. Then the other types of data transmission systems are used.

In almost all cases, the signals have in general to be processed in one way or other, for which the data can be transmitted using analog or digital techniques. Analog transmission is suitable in cases, when the number of measured parameters is limited. In case of multiple parameters, involving large amount of data, digital methods are efficient. Moreover, digital transmission provides data in computer compatible form which can be directly used for computations resulting in a nearly on line system. Digital methods are less prone to corruption of signal because of noise resulting in enhanced data integrity. With the advent of microprocessors, offering enormous flexibility in programming of performance etc., a number of operations like handling of voluminous data, computations, presentations, iterations etc. can be performed conveniently and efficiently.

The data transmission can be achieved in two basic modes :(i) analog data transmission and (ii) digital data transmission. While digital transmissions are relativelyimmune to noise, analog transmissions are extremely sensitive to noise. Also, in the latter case, the increasing resistance of long transmission lines attenuates signals and the use of amplifiers adds distortion to analog voltages. Therefore, analog signals should be converted to digital as soon as possible. Digital systems also provide flexibility of handling large amount of data through the use of multiplexers etc.

In modern data acquisition systems, signal coming from the sensors is analysed either before or after transmission of data. Generally, preliminary analysis before transmission is known as pre-processing while that after transmission is being called processing. Signal analyzers, specifically pre-processors, may become part of the sensor itself or they may form seperate units. In either case, analysis is performed before actual transmission of data takes place. The most important consideration in data transmission is the signal to noise ratio, which basically represents the strength of signal as compared to the noise level.

Sometimes measured signal is so weak that is needs to be amplified before transmission. Moreover, volume and variety of signal also contribute to the complexity of the problem. The solution to these problems lies in appropriate processing, both at the transmitting and receiving ends. This is because signals and noise have very different average properties, and by detailed processing, involving analysis of a long piece of received signal, the information be extracted. Generally, random nature of noise facilitates its cancellation by applying standard statistical techniques. As another standard technique, certain regular patterns are introduced in the transmitted signal. Since noise interference disrupts such patterns, it can be detected and rectified.

Recently, some new technologies, like use of earth satellites and meteor burst have been used for transmission of data through telemetry. They are suitable especially for applications involving large areas over which the data is to be collected and transmitted.

Satellite data collection and transmission systems vast aerial view of the earth's surface gives satellite telemetry a large advantage over ground-base systems for the collection of real-time data for applications like flood warning, reservoir management, irrigation water control hydropower generation and the operation of hydrologic and meteorologic stations.

Meteor burst technology is also used for telemetry of data in harsh environments with no botheration of requirements of multiple frequencies of transmission and use of repeaters. Data transmission by bouncing signals off ionized meteor trials provides a reliable means of short and large range communications. Typical applications of this technique include hydrological, meteorological and oceanographic data collection.

Pre-processing is nearly always carried out at the time of data acquisition. The two main operations involved in the process are signal amplification and filtering. Sometimes it may be required to carry other forms of signal modificiaotions as well, such as trend removoal, decimation and calibration before it is recorded for final analysis. Pre-processing helps in bringing the data to a standard format which is either computer compatible or suited otherwise.

In many cases, signal as measured by a sensor is so weak that it is not compatible to input level of the measuring system. Amplifiers are used to match compatibility of the signal and the system. Also, filtering is an important element in pre-processing operations. Continuous or analog filtering is necessary to precede digitisation if the distorting effects of aliasing are to be avoided. Some processing of the digitized data will also be required and discrete or digital filters are used for this purpose.

To make a signal sufficiently clear for useful analysis, trend removal and similar techniques are used. For example, it may be required to reject the signal if its standard deviation falls outside a permitted value. This implies continuous monitoring of the raw signal to detect this characteristic, and a control action to modify the processing operation. Sometimes the unwanted information added to the required signal can represent a modulation of the signal by the characteristics of the measuring device, such as a decrease in sensitivity a function of temperature or time. It may also be found that the refined data for analysis is defined or represented by a combination of signals recorded on a number of seperate channels. To achieve a signal-to-noise enhancement, ensemble averaging by parallel addition of these signals may be required. Even other complex techniques may be necessary in the process

The raw signal or data consist of sequence (continuous or discrete) of numbers representing a measured parameter. In order to carryout calculations on these numbers, conversion into appropriate units is necessary which means calibration is required. The process of calibration may be obtained within the computer analysis program, but it is often convenient to carryout the necessary arithmetic operations in the pre-processing stage in order to improve accuracy or dynamic range of the signal. Pre-processing also includes organisation and coding of data for proper identification of data.

The report reviews various pre-processing operations, methods of telemetering of data, and some typical applications of these in hydrological studies.

2.0 REVIEW

2.1 Signal Analyzers

2.1.1 Concept of pre-processing

In many cases, signal as measured at the sensors are so weak that it need be amplified before transmission. Also, volume and variety of signal poses problems in appropriate handling of data. This is considered necessary to ensure compatibility of the signal to the input level of the data acquisition system. In order to make the data acquisition system efficient, the signal-to-noise ratio should be as high as possible. Amplification and filtering are the two main operations involved in bringing the signal-to-noise ratio to an acceptable level. Filtering helps in eliminating the noise component which is the factor corrupting the desired signal and amplification brings the signal to an acceptable level.

Sometimes other forms of signal modifications are also required for elimination of undesired components of data. These may include operations like trend removal, decimation, calibration etc. For these, the raw signal need be continuously monitored to detect some particular trends e.g.limits of standard deviation etc. and necessary control actions applied wherever required. Sometimes parallel averaging, addition or subtraction may be required, if the signal is coming through a number of channels.

The raw signal or data may consist of sequence (continuous or discrete) of numbers representing a measured parameter. In order to carry out calculations on these numbers, conversion into appropriate units is necessary which requires calibration. This results in improving the accuracy or dynamic range of the signal. Organisation and coding of data for proper identification may also be required.

All these processes, as described above, are categorised in operations known as pre-processing. It helps in bringing the data to a standard format which is either computer compatible or suited otherwise.

2.1.2 Elements of pre-processing

Amplification

Although main function of an amplifier is to amplify signal in data acquisition systems, sometimes these are used to match impedence of the signal to that of the equipment. Amplifier performs the initial conditioning of the acquired signal and the accuracy of the complete system independent on it.

The basic constitutent of a signal amplifier is the operational amplifier. This is a high-gain, solid-state device which is capable of operation down to zero frequency (d.c.level). When used in conjunction with simple feedback circuits it is capable of providing a moderate gain with high stability and a performance determined almost entirely by the values of the resistive feedback element

The modern operational amplifier is a small encapsulated unit making use of integrated circuit technology in which the active elements are field-effect transistors(FET) or metal oxide silicon (MOS) bipolar transistors. To function adequately, it must have a very high gain (at least 10^5) and be carefully designed for stability and freedom from d.c.voltage drift. Apart from its power supply connections, it will usually have two input terminals in addition to a common (earth) terminal so that balanced input can be applied. The output is unbalanced, i.e.one terminal only, and at a low impedance level, while the input has high impedance so that only a negligibly small input current is drawn from the signal source.

Various types of amplifiers are available now-a-days in the market. Functional details of these amplifiers are different as they are used for different purposes. Basically all amplifiers comprise of operational amplifiers. Brief description of these amplifiers is given in the following paragraphs:

Instrumentation Amplifiers :

These are used to measure the difference between the voltages existing at its two input terminals, to amplify this difference by a precisely set gain, and to present the result between a pair of terminals at the output circuit. Instrumentation amplifiers are especially suitable for applications requiring a balanced input, a high input impedance, low offset and drift, low non-linearity stable gain and low effective output impedance. In cases where transducer system is located some considerabie distance from the proprocessing unit and the long electrical leads are susceptible to induced signals from adjacent power lines or electrical equipment etc., balanced input line connections are used. This helps in improving performance of such systems. To achieve a balanced input a slight variation in the circuitary is necessary. This type is known as differential amplifier.

Capacitive Amplifiers

These type of amplifiers form the basis for the integrating and differentiating elements of an analog computer and for a number of specialised amplifying circuits for pre-processing and signal conditioning. Here operational amplifiers are used as integrating elements. Charge accumulation because of passage of current through a capacitor in the circuit is responsible for the amplification process. Sample-and-hold amplifiers(SHA) are also part of this class of amplifiers. SHAS are commonly used for maintaining the input to the analog-to-digital converter constant at a value representing the analog input occurring at a certain precisely known time. Because of the need to charge a storage capacitor, these amplifers have a slower response indicated by longer settling time and poorer gain bandwidth product.

Filtering

As already discussed, filters are also important element in pre-processing operations. Typical applications are found in signal-to-noise ratio improvement, smoothing of data, bandwidth reduction and avoidance of aliasing effects. Broadly filters are classified into three groups: low pass filters, high pass filters and pass band filters. These correspond to operations on signals in which only low frequencies, only high frequencies and a band of frequencies, respectively, are allowed to sustain. For these three class of filters, a high cut, a low cut and a high as well as low cut, respectively, frequencies need be specified, depending upon the requirement of the system. Response of the system involving respective filters outside the specified frequency ranges would be considerably attenuated. In ideal case, within the frequency range there would not be any signal attenuation.

Two common classes of filters are: analog filters operating on continuous signals and digital filters applicable to signals which have been quantised and converted into binary digital form. Analog filters are designed traditionally from passive electrical elements, i.e.resistors, inductors, and capacitors. In many cases, filters are used in series, the process being called 'cascaded' filtering.

The operation of an analog filter is considered in terms of its transfer function, which is defined as the ratio of the transformed input and output functions. The most general way to consider this transformation is through the use of the Laplace transform. Generally it is advantageous to arrange the filter transfer function to correspond to certain mathematical functions since these provide filter amplitude and phase characteristics in specific applications. Butterworth Chebychev and Bessal filters belong to this class of filters.

Tables of component values for the R.C.elements are available for various filter characteristics (Butterworth , Chebychev, etc.) and cut-off frequencies (Henlein and Holmes, 1974 and Garrett, 1978), so that it is easy to construct a filter using a unity-gain operational amplifier as the active element.

Digital filters

Digital filters may be realised either by suitably interconnecting electronic logic elements or by programming a digital computer(also microcomputer). These two types are called hardware implemented and software implemented digital filters, respectively.

A digital signal consists of a series of sampled and quantised values forming a series, x_i, where i=1, 2, ..., N. Filtering of this series amounts to multiplying the individual members of the series and combining them in such a way as to produce a new modified series, y_i. Frequency characteristics of the output series y_i are modified depending upon the type of filtering operation. Modified series y_i is given by

$$y_i = \sum_{k=0}^{P} b_k \, y_{i-k} + \sum_{k=0}^{M} a_k \, x_{i-k} \quad (i = 1 , 2 ,\ldots N)$$

where P and M are positive integers and a_k and b_k are real constants. Software implemented digital filters have various forms, such as recursive filters, non-recursive filters, etc., with variations in the size of computer memory and attenuation characteristics.

Three fundamental techniques used for digital filtering through software are: (i) convolution (direct filtering), (ii) Fourier transformation (indirect filtering), and (iii) autoregression (use of difference equations). The first two techniques are generally to the non-recursive filter and the third to the recursive filter. Recursive filters are particularly suitable for implementation on small computers and microprocessors.

As discussed above, any digital filter implementation consists of a series of multiplications of the input and output sampled signals by constants and the addition of their products. These operations may also be performed using logic devices such as semiconductors and integrated circuits(ICS), etc. In order to design hardware implemented digital filter, the basic functional elements for these operations are :(i) memory cells, (ii) adders, (iii) multipliers, (iv) delay units, and (v) control and timing logic. A vareity of digital filters can be designed by suitably arranging some or all of these elements in a circuit.

Trend Removal

During the course of data acquisition, sometimes signal is accompanied by a trend or base line modification, which results in distortion of the measured signal. One such common trend is constant d.c.shift of the baseline. This needs be removed before signal undergoes any processing since the trend will introduce error term which can produce large errors in calculations. Removal is easy, if value of d.c.shift is known, otherwise its mean value can be estimated & then subtracted from the signal.

Other trends may be introduced by the transducer and are related to its behavioural characteristics. This type of trend is also generally eliminated by using some form of filtering. Tracking filters, high-pass filters, notch filters, etc. may be used for these operations. Moving average and curve fitting techniques are also used to remove the latter type of trend. Further, an experimental method of removing a back ground trend is to select the minimum values of the signal on the assumption that these represent the hend alone and to smooth these samples to form a continuous waveform. The inverse of this may be taken and added to the signal to cancel the estimated trend.

Decimation

During the process of analaog-to-digital conversion, a high rate of digitisation is used which results in enormous volume of data. In digital processing, it is important to reduce the quantity of data to be analysed to a realistic minimum. This is logical because computing time is expensive an in many cases is not linearity related to data length. The process of data reduction involving the selection of a limited samples of the digitised data at intervals spaced uniformly throughout the data sequence is called decimation.

Calibration Techniques

Calibration plays an important role in any data acquisition system. It is not always easy to extract meaningful information from the measured data, more so if one acquisition process was not planned previously. With proper planning, interpretation is eased by data reduction involving scaling or curve fitting to reduce the raw data to significant values. Calibration will be required to perform the following tasks(Beauchamp and Yuen, 1980): (i) relate the characteristics of the transducer to the parameter being measured, (ii) Check the linearity, gain, dynamic range, frequency response, etc., of the system following the transducer, (iii) Check the changes that may have occurred during the actual period of recording, e.g.amplifier drift, change of transducer characteristic, etc.

The calibration information can be made available at the following periods: (i) prior to the measuring of the data(pre-experiment calibration), (ii) during the meaning of data- the calibration information either multiplexed with the signal data or recorded on a parallel channel (real-time calibration), (iii) after the data has been measured (post experiment calibration).

In addition, following techniques are also sometimes used for calibration: (i) direct calibration on the transducer within its environment, (ii) substitution methods in which the transducer is replaced by an equivalent source generator.

Some or all of the calibration techniques, as described above, may be used for extracting meaningful information from the measured data.

2.2 Telemetry Systems

Data from data acquisition systems, for example automatic weather stations in hydrometeorology, in addition to or instead of being recorded our site, may also be transmitted to a distant base. As already pointed out, this is important mainly for two seasons. Real-time analysis of data for rapid forecasting purposes and requirement of data-collection from remote, unaccessible sites.

Out-stations may be called-up from the base-station manually, by an operator, or they may be called automatically by computer. Alternatively, or additionally, they may report in at set times, or when set lends are exceeded. Which procedure, or combination of procedures, is used will depend on the purpose of telemetering the data.

Data may be transmitted from an outstation to a base-station by direct wire, radio, telephone, satellite, meteor-burst or by any combination of these. Each of these systems have been discussed and reviewed in the following test for use with radio and satellite-based systems, the radio frequency spectrum has been subdivided into various groups and this classification (Strangeways, 1985) is given in table 1.

Table 1 - Subdivisions of the radio frequency spectrum

Frequency from	Frequency to	Name of band	Abbreviation of name	Wavelength from	Wavelength to	
30 GHZ	Upwards	Extremely high frequency	EHF	1cm	Downwards	↑
3 GHz	30 GHz	Super high frequency	SHF	10 cm	1cm	Mic-rowa-ves
300 MHz	300 GHz	Ultra high frequency	UHF	1m	10cm 30cm	↓
30 MHz	300 MHz	Very high frequency	VHF	10m	1m	
3 MHz	30 MHz	High frequency	HF	100 m	10m	
300 KHz	3MHz	Medium frequency	MF	1 km	100m	
30 KHz	300 KHz	Low frequency	LF	10 km	1km	
3 KHz	30 KHz	Very low frequency	VLF	200 km	10 km	

In practical situations, it is rarely feasible to implement the direct-wire transmission of measured signals from the transducer to the remote data collection system. The disadvantages with such a simplified system is the cost of setting up and maintaining the communication lines which would be extremely high for distances greater than a few hundred metres, even if it were technically feasible. In addition, signals propagating over such lines are subjected to attenuation as well as interference so that the signal received would be unreliable.

Direct transmission, through pair of wires, is also subject to physical characteristics of the transmission line. A parallel pair of electric wires spaced in some insulating medium behaves as an electrical capacitor. This, combined with the inductance of the long conductors and their resistive values, causes the line to have frequency-dependent characteristics. This leads to distortion of the shapes of the transmitted pulses, and also limits the rate of transmission. The above mentioned problems are more applicable for analog signals. Direct transmission of digital signals is easier and more reliable. This is so because in digital transmission, where signal is transmitted in binary form, a distinction is required between just two levels of signal i.e. 1 and 0. Level 1 means signal is present and level 0 implies absence of signal. A typical form of digital data is shown in figure (2). In this method, however, timing becomes more critical, since the receiving end must be able to recognise where one digit ends and

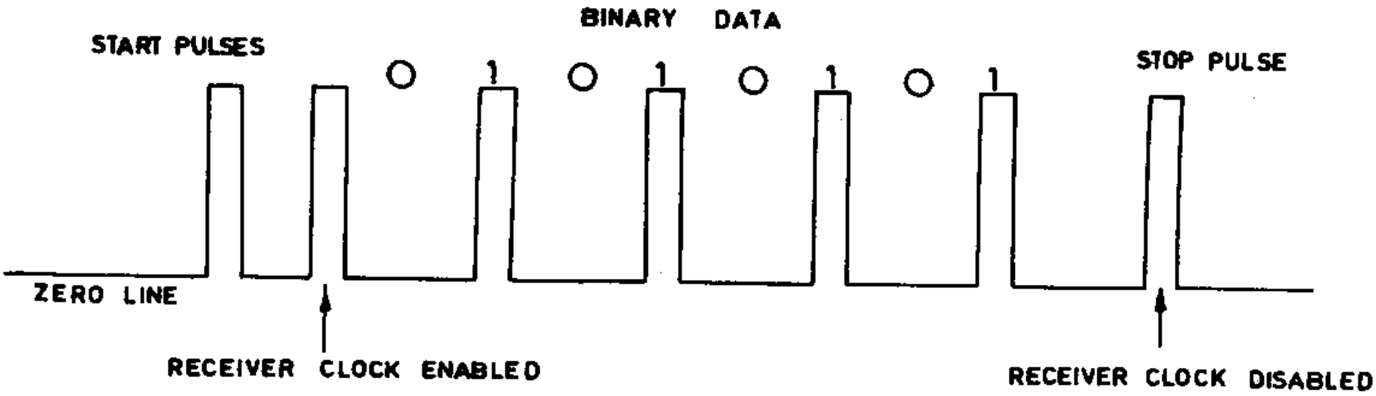

Fig.2 Typical form of digital data

the next starts. Usually the transmitter and the receiver have timing generators or 'clocks' set at the same rate, so that the latter will accept bits (each 1 or 0) at the same rate as the transmitter sends them. The data, comprising of number of bits, is grouped into individual numbers (words or bytes), since the significance of a individual bit depends on its position within a byte.

A simple method for sending digital (binary) data is the asynchronous method. Data are sent in eight bit units(bytes), preceded by two START pulses and followed by one STOP pulse(Figure 2). The first START Pulse initiates the timing of check pulse generator of the receiver, which will produce pulses at the prescribed rate. The second clock pulse coincides with the arrival of the second START pulse. If both are receiver together then this indicates that transmission is proceeding correctly and the next eight pulses are accepted as the transmitted data by opening the input path with each clock pulse. The last pulse, the STOP bit, halts the receiver clock generator, which will remain inactive untill it is restarted by the START pulse of the next transmitted kyte. The method is simple, though somewhat slow, since it requires the transmission of pulses carrying no information and sufficiently slow transmission rate to allow the receiver time to start and stop its clock pulse generator. Other complex methods more suitable for faster efficient digital transmission, e.gsynchronous method etc. can be referred in texts by Gregg (1977) and Fitzerald and Eason (1978).

In most telemetry applications, signals are transmitted by means of 'Carriers' (Beauchamp and Yuen, 1980). A 'Carrier' is a high-frequency signal conveyed over transmission lines or transmitted by radio and capable of being modulated by the signal or message it is desired to transmit. This signal can be at a low frequency so that the carrier system will enable the small bandwidth required to convey the information to be translated into a higher frequency band which is easier to convey through communication equipment. For ground as well as radio transmission the system uses special high-frequency carrier signals that can be generated, transmitted and received through the system conveniently and economically. The information contained in the data is imposed upon a carrier, to produce a signal that satisfies both the needs of the system as well as those of the user. The process is called modulation. At the receiving end the combined signal is demodulated to recover the original information.

Michler and Wuschansky (1985) have reported the development of a microprocessor based system for continuous measurement of hydrometeorological and climatological parameters of lake Ammer in Federal Republic of Germany. Various operations like measurement, transmission, reception and processing are based on a microelectronic system and hence are automated. The signals from different analogue sensors are multiplexed and converted into parallel digital form using analogue-to-digital converter(ADC). This is transmitted to the base station using a pair of wires. Telephone line or radio transmitters like AM or FM Walkie Talkie can also be used with this system.

2.2.1 Telemetry through telephone lines

A special form of modulation-demodulation system is used for the transmission of digital data over telephone lines. This is widely used to transmit computer information to remotely connected terminals and to link computers together. The unit that carries out the process of conversion of digital data into a modulated form (tones) suitable for transmission over telephone lines and the reverse process from modulated data to a digital data stream is known as MODEM (Modulator-DEModulator). The technique is known as frequency-shift-keying (FSK). Basically, it is an interface between telephone line and the computer equipment. A modem is required at both ends of the transmission link (figure 3). A communication channel may be able to carry more data than one terminal can produce. It is possible to use this spare capacity by connecting several

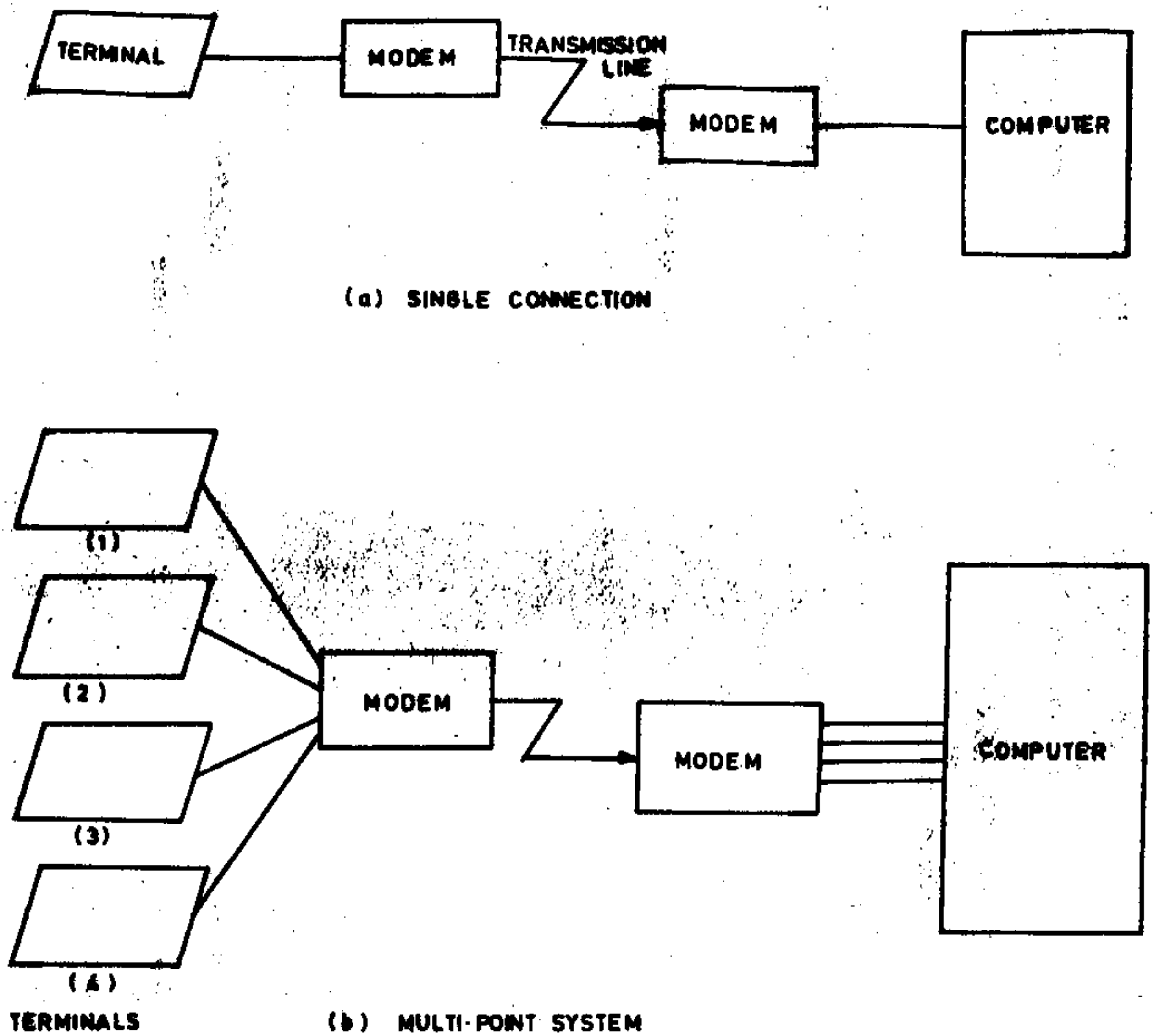

FIG. 3 - USE OF MODEMS IN TRANSMISSION THROUGH TELEPHONE LINES

terminals to the same line

It is also possible to use an acoustic coupler instead of a modem, enabling stations to be called from any telephone, regardless of whether it is equipped with a modem or not. However, the quality of such a link is sometimes inferior to that of a modem, because the data have to be converted into sound and back again into electrical form. Provided the signal is strong, however, there is usually no difficulty. These methods are now very familiar being used widely for data interchange between computers.

Koch and Lang (1984) have reported development of an automatic data collection and transmission system. The system was installed for use in hydrological research basin Reetholzbach, in the northeastern part of Switzerland. It consists of one central unit alongwith two field stations for collecting parameters like water level, temp. and hydrometeorological data. Distance between the catchment basin and the central unit is about 60 kms, and in this case field stations are connected to the public telephone network. Connection is made with thehelp of a modem. It connects the transmitting unit to the data bus of the system's microprocessor. All signals from and to the modem are galvanically disconnected by Opto-isolators. The control processes of the modem are determined by a program stored in memory of the microprocessor, and are being decided by the user. Essentially, the modem converts the digital signals into acoustic signals in the range of 300-3600 Hz, the mode of telephone transfer uses parallel transmission processing.

In India, M/s Gujarat Communications and Electronics Ltd.(GCEL) are manufacturing telephone instruments for transmission of data. These are manufactured to CCITT standard(GCEL, 1985) and are especially suitable for use in harsh environmental conditions.

2.2.2 Radio telemetry

In rural areas and inaccessible terrain, it is difficult to provide reliable communication of data by means of telephone lines. Moreover, if data is required from a number of remote field stations, telephone transmission is of limited use. In such cases, radio telemetry provides a better transmission link between sensors and the central receiving station. This may take the form of a VHF or UHF link for short distances, or HF for very long distances.

In this method, signal, after pre-processing operations, is transmitted into space through antenna. These pre-processing operations may comprise of analog-to-digital conversion, encoding and modulation processes.

Size of antenna and frequency of transmission are two important parameters in radio telemetry. For efficient transmission, it is necessary for the size of the aerial to be compatible with the wavelength transmitted. The best reception is obtained when the transmitting and receiving antennas are within line-of-sight of each other, or only a small distance beyond. With high masts at each end, a span on 40 km or more can be achieved in this way and if the transmitter or receiver are on high ground, quite considerable distances can sometimes be covered. Transmitter powers range from around 5 watts for short distances upto 25 watts for the more distant or difficult paths. Multi-element Yagi antennas, with gains of upto 12 dB are normally used to direct the transmitted power in a narrow beam in the direction of the receiver. 'Simplex' transmission is normally used, that is with communication in one direction only at a time, for example, the base-station calling the out-station which ten replies by sending the data back on the same frequency. The data are transmitted in a similar form to that used for telephone telemetry, that is with digital zeros and ones being transmitted as two frequencies (FSK), the radio frequency carrier being shifted between the two.

Depending upon the Wavelength of the carrier wave, two variations are possible in radio-telemetering. Long-range and short range telemetry are distinguished on the criterion of carrier-wavelength being higher or smaller. Long-range telemetry transmitters are bulky in size while size is considerably small for short-range equipment. Both the variations may perform in active, i.e.two-way telemetry mode. In this, the remote device receives as well as transmits information to or from the central station. This may have purpose, such as enabling observers to switch the transmitter on or off to save batteries. The receiver in the remote device is always on and it controls the switch of the transmitter, which operates only when the observers wish to receive data. Since the transmitter uses much more power than the receiver, there is an overall saving.

Sinhval and Goyal (1985) have developed a radio-telemetered data collection system based on microprocessor technology. The system is a general type of data collection system. Depending upon the type of parameters to be measured, sensor-circuitary can be modified accordingly in order to provide compatibility with the system. Complex transmission systems, for greater aerial coverage etc.,have also been suggested.

In course of geophysical explorations, high sensitivity of sensors, difficult terrains and related logistic problems require installation of measuring systems in remote, mostly inaccessible areas. Measurements of basic data e.g.seismic data needed to be transmitted to short distances for recording at some central station, require portable instrumentation. In such cases, telemetering of data becomes an essential part of the program. Goyal et.al(1985) have reported a short range seismic telemetry system for transmission of geophysical data through radio-telemetry. These systems are all based on modern integrated-circuit (IC) technology, resulting in very compact and versatile systems. Necessary preprocessing of the data is also performed by the on-board microprocessor circuit.

Gujarat Communications and Electronics Ltd. have been actively engaged in developing various transmission equipment for use with automatic data acquisition system. They have developed radio-telemetry equipment, in various frequency ranges, and reported (GCEL, 1985) applications of these equipment in (i) Pipeline communication from Mathura to Julundar for the Indian Oil Corporation, (ii) Yamuna basin flood forecasting system for Central Water Commission, and (iii) Multiacces radio telephone for Oil and Natural Gas Commission. Transmission are done in both very high frequency (VHF) and ultra high frequency (UHF) ranges, and few hundred kilometers distances are covered by these systems.

Flood control is usually attempted by means of hydraulic works for regulation, conduction and protection. The works such as dams, channels and levees built for this purpose can reduce the risk of flooding considerably.

A system capable of 'forecasting the magnitude of floods with the greatest possible anticipation would provide the tools required to ensure the improved management of the control mechanisms of hydraulic structures. The forecast may be based on discharge volume of water levels measured upstream of the site to be protected, on the measurement of precipitation in the catchment basin, on meteorological parameters that determine the precipitation or upon a combination of these.

In any flood forecasting system, basin data on water level and rainfall is collected from sites situated at various points of a river basin. This data is transmitted to a control room/forecast centre, where forecasts are formulated and then sent to higher offices for review and dissemination. The forecasts are also sent to flood control authority alongwith advertising media e.g.radio, T.V. and social newspapers for wider publicity.

Reliable and nearly on line communication is required in flood forecasting applications to increase the warning time and improve the reliability of forecast. Telemetry of specified river gauge, rainfall temperature and other measurements is done through very high frequency (VH), ultra high frequency (UHF) or microwave transmission links. Sometimes number of repeater stations are also used to overcome earth curvature. Signal is transmitted in amplitude, phase or frequency modulated form to minimize transmission losses.

Singh and Chopra (1985) have critically discussed various steps needed in planning for a remote data transmission network in a hilly region for flood forecasting purposes. Selection of various sensing stations and radio path routes, taking into consideration all the factors e.g.terrain, inhabitation, land use pattern, weather conditions, present and expected constructions, availability of electric supply etc. has been discussed and guidelines suggested for such projects in similar environments. Characteristics of transmitting and receiving systems including antennas and path losses are also reported. Various procedures for calculation of these parameters have been suggested for use of concerned users.

Yamuna basin flood forecasting system of Central Water Commission, Govt. of India, exemplifies a typical application of radio-telemetry technique in operational hydrology. Under United Nations Development Project(UNDP) scheme, this system is reported to be first of its kind in India (Singh and Muazzam, 1984).

This microprocessor-based telemetry system of Central Water Commission, as above, comprises of 14 data collection stations and repeater stations. 'Slave' data collection and repeater stations at unmanned or manned remote sites in the Yamuna catchment, a master teleprocessor system at a central station at New Delhi and a computer (HP 1000 F) at the same place for processing the data for forecasts, have been installed in the system. The data and other messages are communicated between master and slave stations through VHF equipment after converting the digital data into audio tones. Repeater stations are also used in cases where line-of-sight imposes restrictions for long distance transmissions.

In 1975, the Institute of Engineering, National University of Mexico had initiated design of a network for flood forecasting purposes. In order to protect hydroelectric plant during construction and spillway gate operation, a telemetric network was established at the choicoasen dam site for flood forecasting (Quass et.al., 1980). The system comprised of 18 rainfall and 3 water level measuring stations and a central data collecting station alongwith repeater stations. Data transmission is continuous, frequency multiplexed and through the help of FM transmitters on the VHF band. A similar telemetric network was established in the catchment basin of the project Cerro de Oro Dam for collection and storage of hydrological data. In this case, the network is divided into independent branches which transmit consecutively at pre-established sampling intervals. Once a branch is brought in, it transmits the data accumulated over the previous periods by all its stations in sequence. As a consequence of the short transmitting periods, a considerable economy in power consumption is achieved and the radiophonic links are optimized, minimizing the number of frequencies required, as well as interference.

Water level measurements are carried out in open water systems e.g. the river for examining head losses in the river or for information about propagation of flood waves after flow disturbances etc. A new system has been reported (Dahlback et.al.,1985) which utilizes a centrally placed base station for recording and storage of data from remote places. It is based on a microprocessor which helps digital recording on a magnetic device.

The telemetric system consists of one base station and twelve slave stations. Each slave station contain a communication radio with antenna, a battery and a transmitter box. To the transmitter box upto 15 analog transducers can be connected. The transmitter boxes used for analog-to-digital conversion, can be connected in series thereby reducing number of radio stations. This type of radio communication is good enough within a range of 10 to 50 kilometers, varying with type of terrain.

Iyer(1982 and 1983) has reported various improvements and modifications in automatic telemetering raingauge. For last many years, the India Meteorological Department is in the process of developing automatic telemetering type raingauges. The India Meteorological Department (I.M.D.) operates an automatic telemetering raingauge (ATRG) network during monsoon seasons to facilitate flood forecasting and warning by the Central Water Commission. These raingauges are equipped with signal recorders and printer for extended operations.

Various transmitting stations have communication links with central receiving stations which in turn transmit the data to the flood forecasting centre. A CW transmitter is used for data transmissions. The system is based on digital logic circuitary and is capable of considerable flexibility in operation.

Water level and stream velocity data are useful in other hydrographical studies also. For example, Hari (Date unknown) has reported a telemetering system which was established in sea-shore area around Helsinki city for measurement of current, water level and temperature data.

The reported system comprises of 70 channels, in which sensors are connected to the telemetering stations by cables upto 1.5 km. long and the telemetering stations are connected to the logger station by radio links 2 to 12 km long. Current measurement is based on the determination of the position of a buoyant kite sensor by two potentiometers mounted orthogonally. Water level meter is a version of the servo motor linograph. And the thermistor consists of a simple d.c.bridge with YSI 3000 NTC resistors.

The information from a sensor is fed to the inputs of a telemetering station as a d.c.signal. 0 to 1000 mv. The d.c.signal is converted to an analogous frequency signal, which is transmitted to the logger station via a V.H.F.radio link.

Radio telemetry is effective in many agricultural engineering applications. Optimum and timely irrigation is important to obtain maximum crop production. Even improved management practices are not always feasible because of many factors including labour disruptions etc. In such circumstances, resort is taken to design automatic or semi-automatic irrigation systems in order to minimize such problems.

King and Amend (1984) have reported a system using radio-or clock activated semi-automatic irrigation gate controller for graded border and border ditch irrigation methods.

Semi-automatic control of irrigation gates provides considerable labour savings as well as more efficient water use. The irrigation control unit uses a down-field water sensor connected by a low-power, radio link to a solenoid operated trip mechanism. The radio link is secured by a tone-encoder circuit that may be set by switches in the field. The enwder circuit prevents interference from adjacent installations or high frequency radio transmitters. This type of system optimizes labour requirements resulting in an increase of efficiency of irrigation methods.

2.2.3 Satellite based telemetry

Radio telemetry is of limited use when very long distances transmissions are required. If the data is to be collected from a very large area and real time analyis is required, communication satellite can be used for transferring data from collection points to the central recording station.

Many countries, including India, have already completed pilot studies on hydrological data collection by communication satellites. These studies have shown that the system appears to be cost effective . Now, the use of satellite telemetry is playing a major role in the collection of hydrologic data. Advancing technology and availability of government satellites have permitted many agencies to take advantage of new procedures for acquiring data from automated remote data collection stations. The data relay satellites vast aerial view of the Earth's surface gives satellite telemetry a large advantage over ground base systems for the collection of real-time hydrologic data in applications like flood warning, reservoir management, irrigation water control, operation of hydrologic stations, etc.

A satellite based acquisition system is made up of three primary components: data collection platform(s) including transmitter, an Earth-orbiting satellite, and an Earth receive and data processing station. Data from a number of stations (sensors) is collected at a Data Collection Platform(DCP) which transmits the same to a satellite at present times. A number of such DCPs can be linked to a central recording station via a satellite.

In United States, a considerable amount of research and development started as early as 1950 to develop communications via satellite. Among the Operational systems, LANDSAT, synchronous Meteorological Satellites(SMS), GOES, METEOSAT, Geostationary Meteorological Satellites (GMS) and ARGOS, have been successfully used and most of them still used for data communications. Since 1980, there are in operational use in U.S.(Paulson and Shope, 1984) for various hydrological and water resources applications.

In United Kingdom, the existing system of water level and stream flow data collection has been in operation since sixtees and, therefore, needs replacement. At most stations the stage data are automatically punched on paper tape, the tapes being collected at monthly intervals for processing by computer. The system has a time lag of some 6 weeks before the data are quality-control checked, the tapes edited and processed. In order to replace this system a new cost effective and near real-time data acquisition system has been planned. The use of telemetry is considered as an alternative (Herschy 1982). The satellite-based system, using METEOSAT WEFA facility comprises of all essential components viz.sensors, DCP, Geostationary satellite and earth receiving stations. The DCP data are retransmitted directly to the user's operations centre via the satellite where they may be interfaced with the user's computer.

In India, India Meteorological Department conducted a pilot experiment in collaboration with Indian Space Research Organisation (ISRO) to operate a few DCPs, transmitting very SEO satellite to the main ground receiving stations at Shriharikota Rocket Range(SHAR) during 1979-80. Experiments concluded that orbitting satellites are not suitable for quick collection of meteorological data from DCPs spread over a large area. However, they may not be abandoned altogether due to various reasons, as for example the relatively lower costs involved.

The geostationary satellites, on the other hand, monitor continuously almost a third ofearth's surface and are therefore much more suitable for DCP work. In order to reduce power consumption, beside 'self-timed' and interrogated mode, the DCPs operating with a geostationary satellite may also be designed to operate in an 'emergency or alert' mode wherein a DCP can transmit an alert signal to the control centre whenever the value of any parameter exceeds a pre-set limit. On receipt of such an alert, the control station can interrogate the DCP and receive the data. With launch of the Indian National Satellite, INSAT-1 in 1982 , India also started transmission of meteorological data from remote stations via satellite (Datar et.al.,1983). Central Water Commission has established a network of DCPs, with the help of M/s Gujarat Communications and Electronics Limited, for collection and transmission of meteorological, hydrological and oceanographical data from remote locations. This is required for real-time hydrological, mainly flood forecasting applications. The project covers Yamuna Catchment and comprises of 10 channels, in first phase, for flood forecasting purposes. Data on river stages, discharge, rainfall, temperature and snow accumulation are transmitted for hydrological forecasting purpose. Hydrological models and necessary software has also been developed for the purpose (Ghanekar, et.al., 1984).

2.2.4 Meteor burst telemetry

Data transmission by bouncing off ionized meteor trails provides another reliable means of communication. The system is called meteor burst telemetry and can be used for distances upto 2,000 km. Micrometeor leave heated and ionized trails while entering into earth's atmosphere. Communications are relayed on the ionized trials to radiate or reflect radio waves in the low VHF frequency range. Billions of meteors large enough to give usable trails enter the atmosphere every day.

The typical meteor trail has a useful duration of a few hundred milliseconds, while wait times between suitably located trails can range from seconds to minutes depending on time of day, time of year, and system design factors. Hence the transmission consists of bursts of high-data rate transmissions of tens to hundreds of characters, separated by a period of silence. One important by-product of this characteristic is the ability of many links to share a common transmission frequency, a feature important in data collection systems.

The meteor-burst transmission system consists of two master polling stations plus remote stations where the hydrological observing sites are located. The master stations can be linked to a central computer over dedicated telephone circuits, if required. The system can operate unattended and interrogation can be computer-controlled. Remote stations can be powered by batteries charged by solar panels.

The master station transmits a continuous, coded signal, usually in the 40 to 50 MHz region. When a meteor appears in the proper locations, it reflects that signal to a receiving remote station. The station decodes the signal, recognizes the signal path, and turns on its transmitter to reflect a signal back along the same path to the master station.

The exchange of information can be in either direction: it can consist of short messages such as sensor data readout, coded messages of up to several hundred character, text messages of a few words, or long messages achieved by splicing together the transmissions of successive bursts. In such an application, average throughputs of up to several hundred words per minute can be achieved with relatively simple edquipment. A meteor burst system is ideally suited for operation in harsh environments for the collection of hydrological, meteorological, and oceanographic data. Figure 4 illustrates the basic principles of a meteor burst communications system.

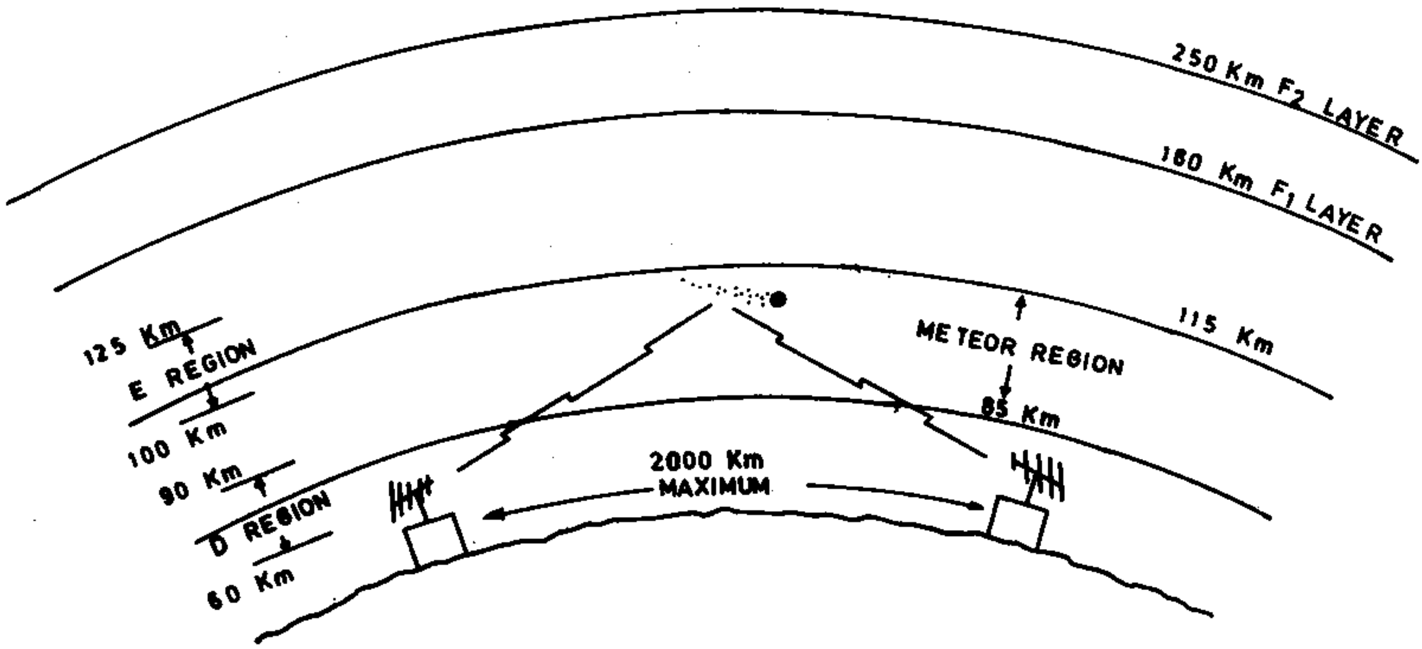

Fig.4 Basic principles of meteor burst telemetry

As compared to other transmission systems, meteor burst telemetry offers following advantages.

(i) Range of the order of 0-2000km, without the need for repeaters,

(ii) Remote stations may be added, relocated or deleted with no changes required at the master station,

(iii) The system may be expanded to several thousand remote stations,

(iv) Independent ownership of communication network.

Meteor burst communications can be readily established for variety of purposes such as remote oil and mineral exploration activities, airborne platforms, ship borne use and communication with work crews in remote locations. Its rapid deployment capability also makes it deal for disaster and emergency communications. Generally, the equipment is compact, making it better suited for mobile and buoy applications. Systma and Leader (1982) have reported application of meteor burst telemetry in data acquisition networks at U.S.Dept. of Agriculture's SNOTEL system and the Alaskan Meteor Burst Communication

System (AMBCS).

The SNOTEL system contains over 500 remote data sites spread over 11 western states. The sites, which are unattended and powered by a solar panel and battery, are polled daily for accumulated snow, precipitation, and temperature data. These data are then used for streamflow forecasting and for making assessments of the water resources in the Western United States. The remote sites are microprocessor controlled and provide data averaging and event reporting. Within the SNOTEL system, a network of event reporting sites are suited around Mt.St.Helens to provide immediate reporting of sudden moisture and temperature changes to alert people of impending floods. The SNOTEL network is planned to be expanded to over 1000 sites over the next few years. The Alaska Meteor Burst System, with a master station located in Anchorage, is owned and operated by six federal agencies.

It performs multiple applications in both data acquisition and message communications. These applications include:

1. Air temperature, windspeed and direction, precipitation, snowpack, humidity, and river stage,
2. Message communications from remote BLM survey campus,
3. Flight weather data from remote air fields, and
4. Gulf of Alaska wave data from buoys located near Kodiak.

The Federal Emergency Management Agency owns several portable master stations and a number of remote communications terminals for rapid deployment of emergency communication to disaster areas.

Another application that has found repeated use is the combination of a Loran C receiver with meteor burst for transmitting position data. Ships have been tracked from Valdez to Seattle and from Seattle to San Diego. An extension of this application will be the position monitoring of icebergs and drifting buoys.

REMARKS

Telemetry systems are used in almost all modern data acquisition systems. Data telemetering can be performed in two modes-analog and digital. A variety of telemetry systems have been developed in recent years, including radio telemetry, telephone lines, satellite-based and meteor-burst type. Different telemetry systems have varying capabilities and therefore their suitability for different applications depends on the nature of the application.

Various telemetry systems differ in their complexity of equipment, cost of fabrication and installment, and the expenditure on regular operation and maintenance. Direct-wired and telephone line telemetry are simpler and least expensive methods. Satellite-based systems need a substantial expenditure on fabrication and installation, and the operational expenses involve battery charging and payment for satellite link charges. Being based on a natural phenomenon, meteor-burst telemetry eliminates the expenditures like satellite-link charges or tariff for telephone-lines. Otherwise instrumentation involved is quite complex in the latter method.

Direct wired connection as well as radio and telephone-line based telemetry systems are suitable for short distance transmissions. Direct wired connection can be used for maximum distances around 50 m, whereas for radio-based and telephone-line telemetry this limit could be of the order of 100 m and few tens of kilometres respectively. Applications involving very large distances i.e., hundreds or thousands of kilometres as well as large aerial coverages, require the use of satellite-based and meteor-burst telemetry systems.

Invariably all telemetry systems provide pre-processing operations on the data to be transmitted. Using various operations like amplification, filtering decimation, calibration, etc. data is made compatible to the input/output level of the system. In addition, analog-to-digital conversion of the data also helps in efficient and reliable transmission of data because digital data is less immune to noise.

Recent trend in telemetering of data is to design various systems with sufficient pre-processing capabilities. Microprocessors are being effectively used in performing a variety of these pre-processing operations. Multichannel, multiplexed and bidirectional mode of transmission, preferably in digital form, is another aspect in which improvements are being made. In order to reduce power consumption, use of solar panels etc. is also gaining popularity.

With recent improvements in hydrometeorological instrumentation, user agencies are more and more concerned about timely receipt of data. Large spatial coverage in order to make their interpretation and forecasting more reliable is another demand. To meet these requirements, telemetry systems are being increasingly used in modern data acquisition programs.

Various types of telemetry systems have different capabilities and limitations as well. This results in their problem specific uses for a cost-effective applications in different fields of hydrology, meteorology, water resources etc. Some specific examples of these applications are also included for better understanding of the use of telemetry systems.

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