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An automatic telemetering raingauge system

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ABSTRACT. The paper describes an automatic telemetering raingauge system designed and constructed in the Instruments Division, Meteorological Office, Pune. A novel feature of the present system design is that the mode of the rainfall data broadcasts from the field station can be pre-selected by a switch provided for the purpose in the field end system.

The system is designed to be modular to facilitate any rare fault location and quick servicing in the field. It uses two standard crystal controlled transmitters. The system can operate in 100 per cent humid environment, since the field unit electronics package and power supply are completely enclosed in a weather proof housing. The complete field unit is light, rugged and easily transportable in a jeep trailer.

1. Introduction

Work on the development of an automatic telemetering raingauge system was started in the Instruments Division, Meteorological Office, Pune in 1960. The first laboratory model of an automatic radio reporting raingauge was completed and tested in 1961. A prototype model was field tested at Simhgarh, 1000 m above sea level near Pune during 1962-64 An improved model constructed by Adept Laboratories, Pune, under the technical guidance of the Instruments Division was field tested in Koyna Hydroelectric Project area in 1966 (Mani 1966, Datar *et al.* 1967). These earlier models were electromechanical and were not quite suitable for unattended operation over long periods. A completely electronic system was, therefore, developed in collaboration with the National Aeronautical Laboratory, Bangalore in 1970 and field tested in the *Narmada*, *Tapti* and *Teesta* river catchments during the period 1972-75 (Alexander 1972). Design and development work on the telemetering rain and river level gauges is presently continuing at the Instruments Division, Meteorological Office, Pune. The present paper describes a simple automatic telemetering raingauge system designed entirely by the authors, its principle of operation and the design considerations.

2. The System

The system is capable of broadcasting cumulative rainfall data from a remote location at predetermined intervals and the data can either be received manually by an operator who need not be specially skilled or it can be teletyped automatically at predetermined intervals at a central receiving station. In the manual mode the broadcast from the field station takes about 3 min 12 sec while in the RTT mode the reception time is reduced to about 7·5 sec. The audio broadcast comes in as a sequence of high or low frequency audio notes giving the 3 digit station identification code repeated 4 times followed by the four digit rainfall data ; also repeated 4 times.

In the teletype mode, the printout is in a predetermined format. The field unit is battery operated. The receiving end system operates on mains. For manual reception the field units can be as far as 200 km away from the central receiving station. The equipment is easy to transport and install. The field unit is housed in a weatherproof dome. The receiving station can collect and printout the rainfall data sequentially from a large number of field stations by time staggering the broadcasts. Typically at one receiving station it might be expected to receive data from 4 to 6 transmitting stations in river catchment. The RTT broadcasts are also receivable on the standard departmental RTT data terminals.

The nominal specifications for the system developed are given below and the details concerning the principle, the main design considerations and the design of the system electronics package are given in the subsequent paragraphs.

Nominal specification

1. Sensor	Tipping bucket raingauge.

2. Range of rainfall measurement in one operation cycle	Upto 9999 mm of rainfall
3. Least count of the sensor	±1 mm
4. Overall sensor accuracy	About ± 3% depending on terrain, winds etc.
5. Distance between the transmitting and receiving stations	(*a*) 200 km or more for manual operation with 15 watt transmitter. (*b*) 25 km for T/P with 15-30 watt T_x.
6. Power radiated	Nominal 15 watt for BEL, GE 524 transmitter used.
7. Type of aerial	Half wave horizontal dipole.
8. Frequency	2 spot frequencies in HF, *e.g.*, 6·5 MHz for day, 4·5 MHz for night etc.
9. Systems electronics package	(*a*) Rainfall register. (*b*) Programming, Multiplexing, Data encoding and Formatting circuits. (*c*) Crystal controlled clock.
10. Power supply	(*a*) 48 Eveready 6 G cells for transmitter power at 12 V. (*b*) 2 Eveready cells for system power at 9 V.
11. Housing	Electrically shielded weather-proof fibregass dome.

Receiving end system

1. *Receivers* :

   (*a*) RG 2003, BEL, Bangalore or GE 524, BEL, Bangalore

   (*b*) Siemens Receiver Model FUNK 745, 309A or

   (*c*) RACAL—RA17 LB BEL, Bangalore

2. *Converter/Keyers* :

   (*a*) RA 70 AB/PV78B to go with the RACAL receiver RA17LB BEL or

   (*b*) HEL 309B converter Keyer to go with Seimens Receiver Model FUNK 745 E, 309A.

3. *Antenna* : Half wave dipole.

4. *Teleprinter* : Hindustan Teleprinter Model.

3. Principles of operation

The rainfall sensor used is a tipping bucket raingauge in which the volume of rainwater collected on a collector of 100 sq. cm area (measured at its rim) is measured by conveying the catch through a funnel to a twin tipping bucket mounted on a horizontal axle. Each of the twin buckets tips alternately for every 1 mm (or 10 cc) of the rainwater received by it, at the same time the earlier emptied bucket is positioned under the funnel and is ready to tip once again for the subsequent 1mm of rainfall. The tipping action of the bucket actuates a magnetically operated reed switch placed in a circuit so that every time the bucket tips there is one closure of an electrical circuit giving rise to an electrical impulse. The total numbers of these impulses are counted and the count is stored in an electronic counter, named "rainfall register". The rainfall register thus stores the cumulative rainfall reading in mm at any time. At a predetermined instant of time, with the arrival of an initial system "start" clock pulse, the broadcasting programme is initiated and the stored data in the register as well as the station identification number are encoded in a 8 bit teleprinter compatible two tone mark/space code, the entire coded information is BIT serialized in a certain format and impressed on the transmitter to give an AM broadcast. In the audio mode broadcast, the bit serialized sequence is run through at rather much slower rate to permit manual monitering of the two tone signal. For teletype operation the signal output from the receiver is fed to filter and comparator circuits which recover the mark-space format required for driving the printer. Suitable time gaps have to be provided in the coding programme of the field unit operation for distinguishing the successive mark space, etc symbols during the audio mode broadcast as discontinuous audio notes (Table 1). These points are covered in detail in subsequent paragraphs. The mode of the field system operation, *i.e.*, audio manual Receiving/Radio Teletype is selectable by a switch. The field system uses AM or SSB transmission with proper coding tones.

4. Design

In addition to the main system electronics package designed for the rainfall measurement, storing of the data and the data conversion and

TABLE 1

5 Unit CCITT alfabet No, 2 used in the telemetering raingauge

	1	2	3	4	5
<				●	
≡		●			
↓	●	●	●	●	●
↑	●	●		●	●
□			●		
R		●		●	
O		●	●		●
1	●	●	●		●
2	●	●			●
3	●				
4		●		●	
5					●
6	●		●		●
7	●	●	●		
8		●	●		
9				●	●

LEGEND

< Carrjage Return
≡ Line feed
↓ Letters
↑ Figures
[●] Marking Impulse
[ ] Spqcing Impulse

coding for automatic transmission at regular intervals in the overall scheme of the system, it is also necessary to consider certain other important aspects, namely the power supply requirements of the field unit and the choice of the operating frequencies and the propagation mode for an all weather day/night data telemetry link between the field end transmitting and the receiving end systems.

While UHF transmitters are small and compact they need a clear line of sight between the transmitting and the receiving aerials which involves incurring rather high costs for putting up high towers in plain terrain situations. HF transmitters are, therefore, preferred even though they need comparatively larger power and rather somewhat extensive antenna installations which are sometimes difficult to make in hilly terrain. Since it is difficult to provide large battery power at the field installations, the ground mode of propagation is not preferred though for distances of the order of much less than 50 km it can sometimes be used.

In most practical situations the data from 4 to 6 strategically placed field stations in a river catchment is required to be received at a central receiving station. With the field stations thus typically being between 70 & 200 km or so away from the central receiving station, the HF radiation from the aerial need to be placed at high angles ranging from 50° to 85° for a single reflection mode of reception. Such a situation generally dictates the use of horizontal dipole aerial rather than a vertical one. In practice such high angle radiation is best realised for the horizontal dipoles stretched at a height $0 \cdot 20\lambda$ to $0 \cdot 30\lambda$ above ground (Henny *see* Ref.). The vertical antennae on the other hand are useful for relatively low angle radiation $<50°$ patterns (Jasik 1961, Henny—*see* Ref.). Further, the radiation resistance of a horizontal half wave antenna above a perfect ground gradually increases from about 0 to 97 Ohms as its height above the ground is increased from 0 to $0 \cdot 37\lambda$ and again drops down to about 55 Ohms at about $0 \cdot 6\lambda$ (Kraus 1950). The radiated field strength in free space in decibels above 1 μV/m at 1 km from the horizontal half wave antenna is proportional to the logarithm of power radiated in watts and is about 87 db above 1μV/m for 15 watt radiated power (*i.e.*, 220 mV/m for 1 KW radiated power 1 km from antenna).

For most practical automatic telemetry raingauge links single reflection mode of propagation is adequate. The noise limited sensitivity of the receiver (for a signal power to noise power ratio of 20 db) is assumed to be known (1 μV or better). Knowing the location of the station the point of reflection for any ionospheric layer (such as F_2) is known and from this effective path length can be worked out. From the ionospheric data published by the National Physical Laboratory, New Delhi, it is possible to estimate the value of the maximum usual frequency (MUF). The optimum working frequency is taken to be $0 \cdot 85$ of the MUF to provide some margin for ionospheric irregularities and the lower limit for the usable band of frequencies is taken as 50 per cent of the MUF. Spot frequencies to best suit during the time of day or night (usually 3 are chosen for best results; only 2 are presently being used by us to save on the transmitter cost) are then chosen and used after obtaining the permission of the concerned wireless planning authorities. Knowing the distance between the transmitting and the receiving stations from published curves, it is possible to read-out the effective path length but for distances of up to 200 km or less a good thumb rule is that the path length is nearly double the height of the ionospheric layer (E—100 km, F Day—200 km, F_2 Night—300 km, F_2 layer Day—400 km) being considered. From the published data corresponding to the path length worked out it is possible to work out the ionospheric absorption for the frequencies selected (this is of the order of 1 to 10 db per 100 km for frequencies 10 to 4

MHz). In order to take fading effect into account (6 to 40 db) a mean value of +20 db is taken. Knowing the above losses one can evaluate the radiated field strength at the receiver antenna site by subtracting the total correction factor from the free space radiated field strength at the receiving antenna. This later is obtained by subtracting the path loss (in db above the signal strength at 1 km) for the effective path length. (This is about 10 db per 200 km of wave path length). These calculations may be further refined to take into account the atmospheric static, cosmic etc noise. A mean value of 17 db at 1·5 MHz decreasing to 0 db at 10 MHz in a linear way is good enough for most practical work. In view of the above considerations, in the present system, horizontal half way dipole aerials were chosen. For HF spot frequencies the performance of the HF communication link between any two stations can easily be assessed (atleast qualitatively) as discussed where the transmitter power is known. Thus, for example, let it be desired to operate at 6·5 MHz (Day) and 4 MHz (Night) frequencies. Assuming an antenna efficiency of about 70 per cent, the actual power radiated from a 15 watt transmitter is about 10·5 watts. The space wave field strength at 1 km from the transmitter for 10·5 watts of radiated power works out to be 85 db above 1μ V/m. Taking a worst case path length figure of 800 km between the transmitting and the receiving station the ionosphere absorption loss works out to be 40 db. To this an average loss due to fading 20 db may be added. Thus the field strength expected at the receiving aerial will be 25 db nominal.

On the other hand for a receiver with a sensitivity of 1μV/m (0 db), assuming a worst case atmospheric and static noise level of 10 db, and a signal to noise ratio of 10 db for adequate manual reception the field strength required at the receiving end works out to be (10+10) db, *i.e.*, 20 db above 1μV/m level. Allowing a further degradation of 3 db due to receiver antenna, the field strength required for manual reception works out to be 23 db. Thus it is clear that the 15 watt transmitter and 1μV/m sensitive receiver will be just adequate for our manual radio link except when fading is worse than 20 db. In actual practice, however, the quality of the link performance is also adversely affected by stray signal interference or sporadic increase in noise (*e.g.*, due to city ignition noise etc) to levels several tens of decibels above the nominal assumed value of 10 db. In the present system 15 watt BEL GE 524 transmitters manufactured by M/s BEL, Bangalore have been used. Other transmitters can also be used if required. For a good RTT reception an overall signal to noise ratio of 20 db (*i.e.*, signal power to noise ratio of 100) is generally recommended and the 15 watt Tx power is not adequate.

The power consumption at the field end is mainly in the transmitter since the remaining electronic system has been designed using extra low drain COS/MOS integrated circuits. Dry batteries (about 42) type Eveready 6G can thus be used without replacement for long periods. High quality engineering materials are necessary for the weather-proof housing, aerials, masts etc. All the exposed components need to withstand severe environmental conditions and be free from rusting, mould growth etc. The system should be light and portable, easy to install and be capable of long term trouble free operation.

5. Description

A block diagram of the telemetering raingauge system is given in Fig. 1. It consists of the field unit (one or more) and the receiving unit.

5·1. *The field unit*

The field unit mainly consists of the following:

(*i*) Electronics Package

- (*a*) Sensor — a tipping bucket raingauge.
- (*b*) The rainfall register.
- (*c*) Electronic circuits for programming, multiplexing, data encoding and formatting.
- (*d*) Crystal controlled clock.
- (*e*) Two transmitters (for day and night operation) with aerials etc.

(*ii*) Battery power supply.

(*iii*) Weather-proof housing.

5·2. *The receiving unit*

The receiving unit mainly consists of the following:

- (*a*) Receiver (with aerials etc) to receive either the day or night rainfall data broadcasts.
- (*b*) Filter, comparator and signal shaping circuits.
- (*c*) Receiver teleprinter.

The details, regarding the various sub-units of the system shown in Fig. 1, are given in subsequent paragraphs.

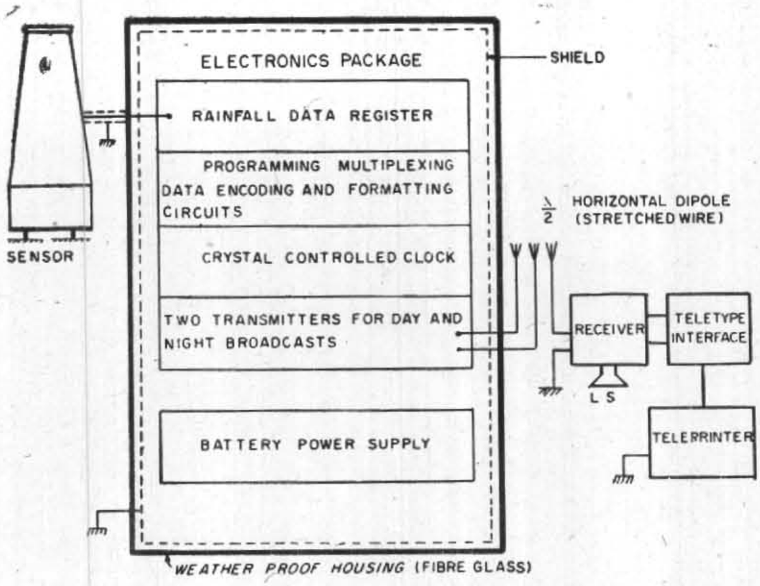

Fig. 1. Automatic telemetering raingauge system

5.3. *The sensor*

The sensor consists of a tipping bucket raingauge which has a twin bucket mounted on a horizontal axle to tilt for each 1 mm of rainfall received from a 112·9 mm diameter collector. This tipping of the bucket actuates a magnetic reed switch and causes an electrical impulse for every 1 mm of rainfall. These pulses are registered in the field unit electronic counter.

5.4. *The electronics package*

A schematic of the electronics package is shown in Fig. 2. The pulses from the tipping bucket raingauge are stored in the 4 digit COS/MOS IC counter which stores their cumulative total. The BCD output of the rainfall counter (register) is suitably latched and digit multiplexed to a BCD to decimal decoder, at whose output the decoded decimal digits for the thousands, hundreds, tens and units figure (of the stored rainfall number) appear in succession, under the control of one of the programming counter, designated hereinafter as K counter (with states K_0, K_1,......., K_6) *vide* Figs. 4 and 5.

With the arrival of the system "start" clock pulse at a predetermined instant of time (*i.e.*, one hourly or three hourly) the 'repeat data' counter is reset and R_4 output comes to zero state (Fig. 2). At the same time 10 msec pulses from the crystal controlled system clock are enabled to the 4 bit character generator binary counter referred to as ABCD counter in Fig. 5. By suitably gating the outputs for different state of this counter certain T. P. drive characters in CCITT/II code (Table 1) are continuously generated in the system when it is broadcasting the data. The different teletype characters to which the fixed and the so called seven and a half bit sequences of low or high ('space'/'mark') voltages correspond, are generated and sequenced further for the data transmission in a manner depending on the final format in which it is proposed to transmit the data. In the present design the single line format chosen is of the form:

R 123 123 123 123 1234
1234 1234 1234 or

R $S_tS_tS_t$ $S_tS_tS_t$ $S_tS_tS_t$ $S_tS_tS_t$ DDDD
DDDD DDDD DDDD

wherein S_t S_t S_t represents a 3 digit station number and DDDD represents the rainfall data stored in the rainfall counter. It should be mentioned here that the choice of the format is quite arbitrary (*e.g.*, it may be possible, to use 2 digit number for station index and three digit number for the rainfall data or some other format etc). In order to get the rainfall data printed in the above format on teletype it is necessary to incorporate the proper teletype drive functions at the appropriate locations in the printout format. With these functions included (for the HTL teletype used in the present design) the format looks like (with station index No. 123 and rainfall data as 1234 mm say).

< ≡ ↓ R□ ↑ 123 □ ↑ 123 □ ↑ 123 □ ↑ 123
□ ↑ 1234 □ ↑ 1234 □ ↑ 1234 □ ↑ 1234

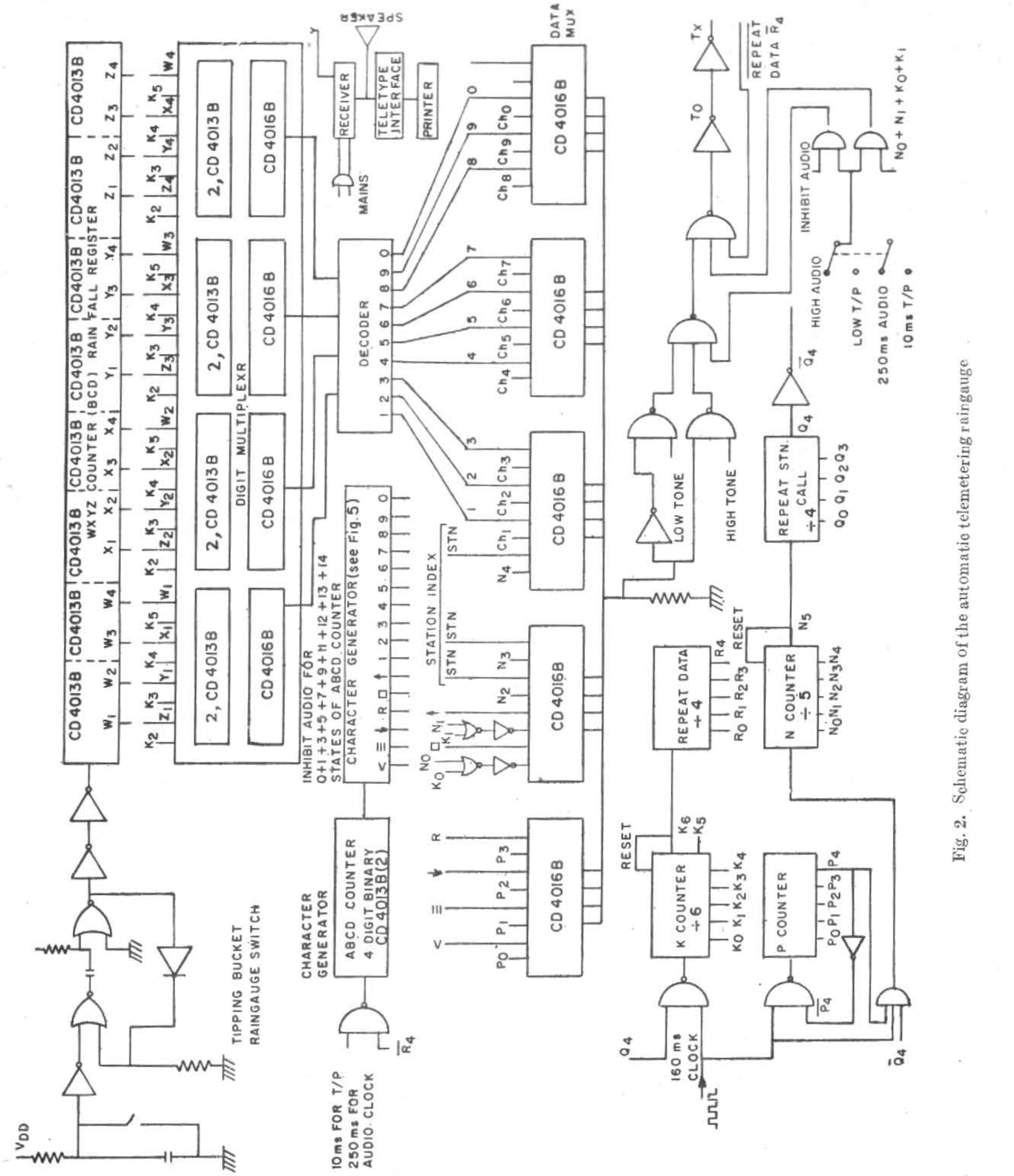

Fig. 2. Schematic diagram of the automatic telemetering raingauge

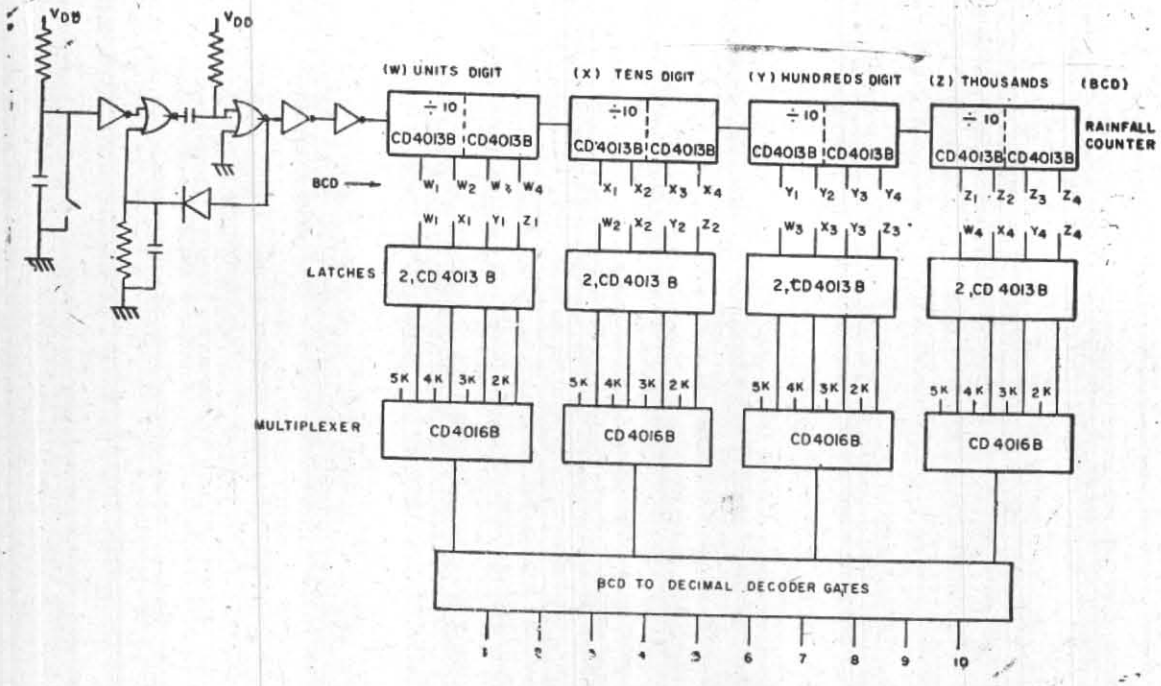

Fig. 3. Schematic diagram of rainfall counter, controlling gates, latches and decoder

Thus in order to implement the above format it is necessary to generate the T/P drive characters in CCITT II Code for < (carriage return), ≡(line feed), ↓ (letter shift), R,[ ] (space) and ↑ (figure shift) as well as for the ten decimal numerals from 0 through 9 (*see* Table 1). As stated earlier, these are generated by suitably gating the outputs for the different states of the ABCD character generator binary counter driven by 10 msec pulses. Fig. 6 shows one possible way of circuit implementation to achieve this goal (other implementations for further minimising the component count are also possible though not shown here). Design procedure remains essentially similar for other T/P codes, *e. g.*, ASCII code.

Fig. 4 shows the schematic of the programming counters for generating the teletype format including the four repetitions of the station index number and the rainfall data. With reference to Fig. 4 the 4 successive states, say P_0, P_1, P_2 and P_3 of the P counter which is driven by the 160 ms system clock when gated suitably and sequentially with the teletype characters <, ≡, ↓, R (Fig. 5) give the first four characters of the teletype format. At the beginning of the P_4, the 160 msec clock pulses derived from the ABCD counter are disabled from the P counter and are enabled to the station index counter referred to hereinafter as 'N' counter. The states N_0, N_1, N_2, N_3 and N_4 are gated suitably and sequentially with the characters [ ], ↑ and teletype characters corresponding to the three digits of the station index number respectively, *e.g.*, 123 or 746 etc. The N counter is itself reset at the beginning of the state N_5 and at the same time it advances the station index number repeat counter (Q counter) to the next state. Thus for every one cycle of the N counter (from N_0 through N_4) the Q counter advances by 1 and hence from its initial state Q_0, as the Q counter gradually advances to the Q_3 state, the station index number is repeated 4 times as per the teletype format given earlier. At the beginning of the Q_4 state, the 160 msec clock pulses to the N counter are disabled and they are now enabled to the K counter. The successive states K_0, K_1, K_2, K_3, K_4 and K_5 say of the K counter are gated with the teletype characters for (space), ↑ (figure shift) and four decoded digits, namely the thousands, hundreds, tens and units digit in that order, of the decoded rainfall register data. The K counter is reset at the beginning of the K_6 state and at the same time advances a repeat data counter (R counter). The R counter stops the system operation at R_4 state after allowing the four repetitions of rainfall data as in the format, *i.e.*, after advancing through the states R_0, R_1, R_2, and R_3 at the beginning of every K_6 state of the K counter during the successive cycles of the latter. At R_4 state of the R counter, the 10 msec pulses to the character generator, and hence the 160 msec pulses to the programming counter are disabled and the programme ends.

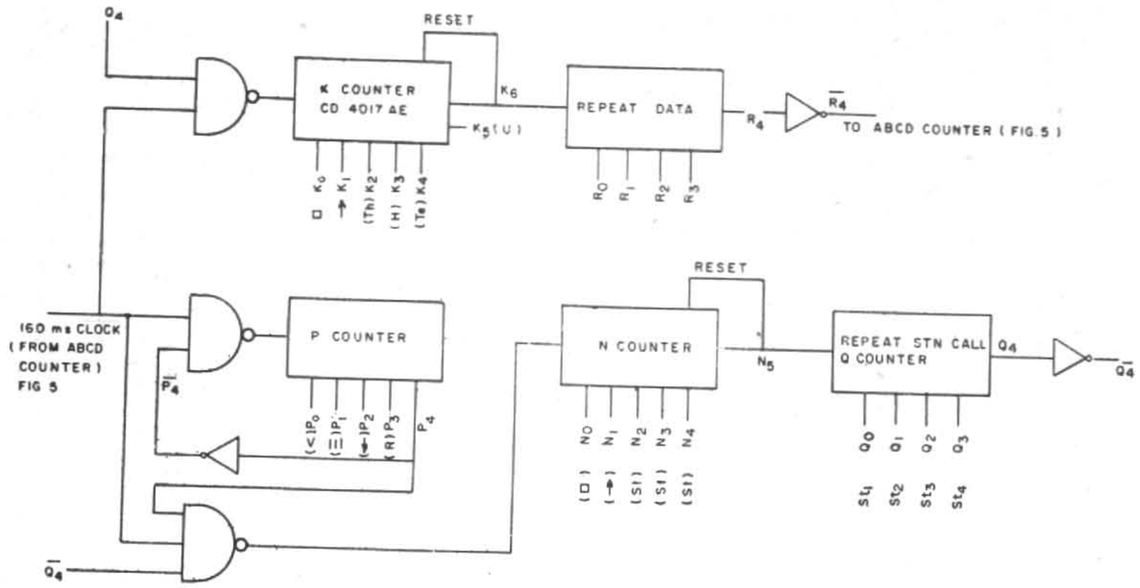

Fig. 4. Station code and data programming counter

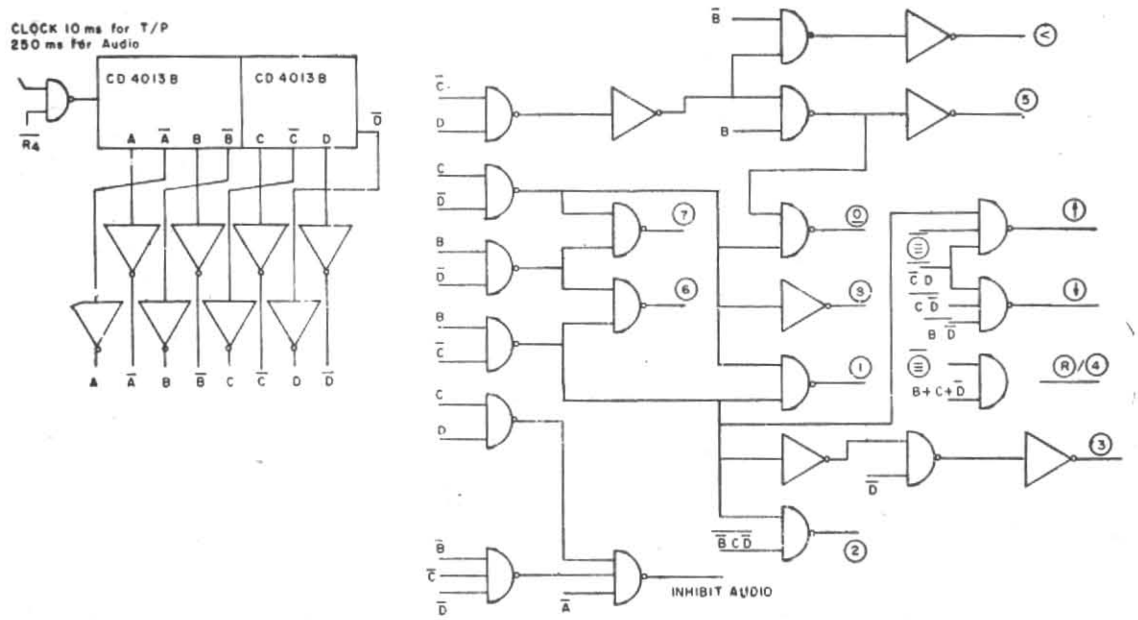

Fig. 5. ABCD counter and character generator

The formatted output as above is available as a series of low or high voltage pulses in a sequence which corresponds to the teletype 'space', 'mark' sequence of the chosen format. For transmitting this information, the two audio tones (also generated) from the crystal controlled clock (Fig. 6), *viz.*, 1·6384 or 1·024 KHz (low tone) and 2·340 or 1·6384 KHz (high tone) are respectively impressed on the proper day or night transmitter which is selected and switched in automatically, and these two low and high tones then correspond to the teletype 'space' and 'mark' respectively. The day or night transmitter is automatically selected in the following manner. The repeat data counter (Fig. 2) stops the system operation cycle in the state R_4. Every time the R_4 output goes to 0 state a transmitter programming counter is advanced by 1 (This counter has to be divided 'by 8' for three hourly operation or 'by 24' for hourly

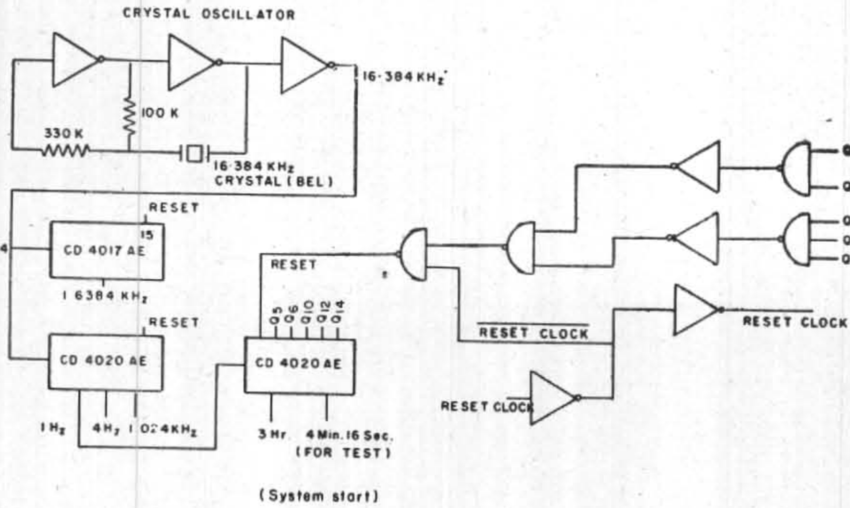

Fig. 6. Clock

operation etc). The outputs of this programming counter are suitably grouped and decoded to control the relays which make or break the day/night transmitter power as required and select the proper transmitter for the day or night frequency operation. At the receiving end it is possible to reconstruct the T/P drive mark/space signal by employing the filtering, the comparing and the pulse shaping circuits as shown schematically in Fig. 7.

From the above discussion it becomes clear that the data could also be received manually if (*a*) the system clock is run slow enough and (*b*) suitable time gaps are provided between the high or low tones so that the adjacent notes Mark Mark....Space Space.... etc could each be identified separately. These requirements are achieved by (*i*) driving the ABCD character generator counter by 4 Hz clock pulses (Fig. 6) and (*ii*) inhibiting the audio output for the states 1, 2, 3, 5, 7, 9, 11, 13, 14, 15, 16th of the ABCD counter to generate an "inhibit" signal (Fig. 6). A DPDT switch is provided in the field unit which can (*a*) select either the fast 100 Hz or the slow 4 Hz clock to ABCD counter and (*b*) correspondingly enable or disable the "inhibit" function $\overline{BCD}+\overline{A}+CD$ and thus the mode of the field station operation, *i.e.*, the teletype or the manual mode is pre-selectable in the field.

5.5. *The housing*

The field unit is installed in a specially designed rugged but light easy to transport weather proof fibreglass housing which is electrically shielded by providing an inner metal lining. Lightning arresters (which are fairly well known and are not described here) are also provided to protect the system against atmospheric lightning and electrical discharges.

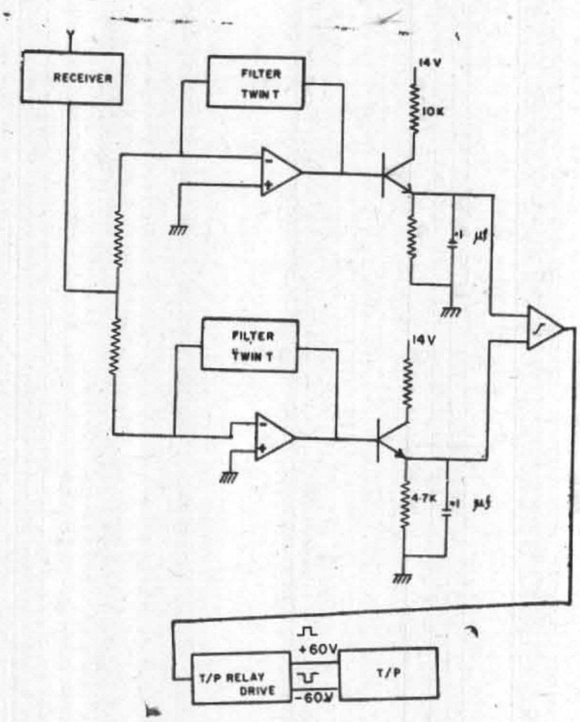

Fig. 7. Schematic diagram of receiving end

5.6. *The receiving unit*

The mains operated receiving unit mainly consists of an AM or SSB receiver, the receiver teletype interface and the teleprinter. In RTT mode of operation, the two tone output of the receiver is passed through two differently tuned active filters whose outputs are compared and the resulting waveform is shaped to reconstruct the original teletype format sequence generated at the field station. This is used to drive the tele-type through a relay. In the manual receiving mode the receiver audiotone (high tone, low tone) output is manually monitered by an operater and data is recorded and later decoded (Table 1). An RG 2003 or GE 524 receiver manufactured by M/s. BEL, Bangalore was used. The data in RTT mode is also receivable on India met. Dep. RTT receiving stations, using Seimens RTT Receiving Equipment or RACAL-RA 17LB, BEL with RA70 AB/PV 78 B converter/keyer.

6. Conclusion

The simple telemetering raingauge system described above has been found to work quite satisfactorily in the laboratory simulated trials as well as in the actual field trials carried out from Khandala hills about 70 km from Pune during the monsoon seasons of 1975 and 1976. The field trials are also to be continued in 1977. The correspondence in the observed and reported rainfall was found quite satisfactory. Work is also being done to incorporate the station command identifying circuits in the field system electronics and suitable command circuitry in the receiving end system which would permit interrogating the field stations in automatic sequential or random manual mode. Work is also in progress with the lightning arrestor circuits for obtaining improved field performance.

Automatic telemetering hydrological networks are primarily designed to supplement the rain and river level data in the flood forescasting and reservoir management schemes by providing information inputs from critical remote unmanned locations (Incidently by modifying the rainfall counter to an up-down counter and with a suitable float type sensor, the data telemetering system described in the paper could also be adapted for automatic river level telemetry). The choice of frequencies to be used and selection of station is largely based upon the actual network topography. The overall system costs for installation of these systems are variable depending upon the terrain, the type of logistic support required etc. The cost of the central receiving and the field station is also variable and proportional to the degree of sophistication required in the network operation. At present the cost of operating a simple network with 5 to 6 remote field stations and a central receiving station works out to be about Rs. 4 lakhs and probably represents the lowest initial cost for starting the network. The operation and maintenance costs are comparatively much smaller. The COS/MOS/IC's used presently are also required to be imported at present and it is hoped that it may not be long before they become available indigenously.

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