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A 0-200 cps frequency converter for audiomodulated radiosonde

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ABSTRACT. The paper describes a frequency converter developed in the laboratories of the India Meteorological Department at New Delhi. Its usefulness is in the new audiomodulated radiosonde system recently introduced by the Department. Basically, the instrument works on magnetic frequency detector principle and is capable of handling meteorological information being telemetered as pulse signals at repetition rates of 10 to 200 cps. Its output is a direct current voltage linearly proportional to frequency and is suitable for being applied to and recorded on a potentiometer type strip chart recorder.

1. Introduction

For modernising the existing radiosonde and radiowind systems, the India Meteorological Department recently embarked on the project of converting the existing radiosonde systems into the audiomodulated radiosonde system which is similar to that used by U. S. Weather Bureau. The balloon borne radiosonde consists of a radio transmitter, modulator and sensors to measure pressure, temperature and relative humidity of the upper atmosphere. The data in the form of audio frequencies which vary at a repetition rate of 10 to 200 cps are transmitted at a carrier frequency of either 1680 Mc/s or 401 Mc/s. These signals are received, amplified and demodulated by the receiving ground equipment (WBRT or METOX radiotheodolites ; *see* manufacturer's manuals for details) and the resulting MET. DATA is fed to the radiosonde recorder. The recorder is a potentiometer type strip chart recorder capable of directly recording amplitude of DC signals on a moving chart. Need, therefore, has been felt of a frequency converter to translate the meteorological information thus telemetered into a DC voltage of suitable characteristics for feeding to the recorder. The present paper describes such a frequency converter that has been designed, constructed and successfully tested under field conditions in the Electronics Laboratory of the Meteorological Office, New Delhi.

2. Design requirements

The frequency converter must satisfy the following specific requirements to provide satisfactory service —

(1) The instrument should be compatible with the available recorder (*Westronics*, Sec. VI—*see* Ref.).

(2) The input to the frequency converter is in the form of positive pulses with a recurrence frequency of 10 to 200 c/s and nominal width of 1750 $\pm$ 750 micro sec.

(3) The output shall be linearly proportional to input frequency. The variation from linearity should be within 0·2 per cent over the frequency range of 10 to 200 c/s and within 5 per cent below 10 c/s.

(4) The power supply should be regulated and free from noise or ripple. In addition to supplying B^+ voltage to the converter tubes, this power supply is also the source of current carried by the slide wires of the recorder. This current provides the reference voltage. Hence any noise present in the slide wire current will degrade the performance of the recorder. The design centre of the regulated B^+ shall be 175 volts and stability within 0·5 per cent with normal variations in line voltage or frequency.

(5) The layout of the circuit and placing of components should be such that the 50 cps (hum voltage) induced due to electrostatic or electromagnetic coupling is minimum. As the converter output will be of the order of millivolts, hum voltage from any cause should not be sufficient to impair the performance of the frequency converter or the recorder.

3. Principle of operation

The operating principle of the frequency converter is illustrated in a simplified block diagram shown in Fig. 1.

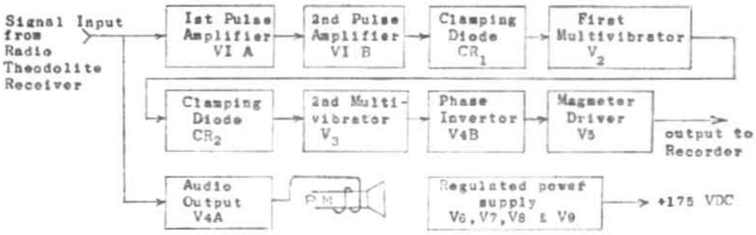

Fig. 1. Frequency converter block diagram

Note — The recorder is a potentiometer type automatic null-balance measuring type instrument in which balance is accomplished through the use of an electronic amplifier and motor driven servo system having the following essential parts.

1. Null-balance measuring circuit
2. Null detector and amplifier
3. Balance motor and linkage
4. Display system consisting of a strip chart recording and indicating device

The chart is divided into 100 equal divisions representing frequency in bi-cycles (*i.e.*, one division is equal to 2 c/s)

The AF output of the radiotheodolite receiver consisting of a series of MET. DATA pulses at a rate of about 10 to 200 pulses per second are fed to the frequency converter where they are amplified and shaped to a precise amplitude and form and fed to the MAGMETER driver. The pulses are then detected by the MAGMETER and filtered out to provide a DC voltage proportional to their recurrence frequency. This DC voltage is finally utilised by the recorder for recording and evaluation of the meteorological data. Part of the signal is also fed to the audio-amplifier for aural monitoring of the incoming signals. Details of the circuit are described as follows.

4. Circuit description

The circuit diagram of the frequency converter is shown in Fig. 2. The circuit essentially consists of two stages of pulse amplification, two crystal diode clampers, a monostable multivibrator, a second multivibrator, a phase inverter, a magmeter with driver and filtering circuit and an audio power amplifier for aural monitoring of the incoming meteorological signals. For ease of discussion and presentation, all wave forms shown on the circuit diagram are taken with 50 cps test signal. A brief stage-by-stage operation of the circuit is given below.

4.1. *First pulse amplifier* — The first stage is a pulse amplifier which consists of V_1 A, one half of the tube type 12 A×7, and associated circuit components. The positive square wave signals representing the meteorological data pulses from the radiotheodolite receiver are applied to the grid of V_1 A *via* connector J_1, resistor R_{49}, signal selector switch S_7, capacitor C_1 and signal level control R_1. The switch (located on recorder control panel) has four positions, and its rotor contract connects the input to the amplifier grid. One position, OFF, is used to ground the converter input and hence no output from it making the recorder read zero. The test voltage positions, 50 cps and 100 cps, supply either a 50 or 100 cps test signal derived from the regulated power supply to the input circuit which makes the recorder read 25 for 50 ordinates respectively. The fourth position, X, applies the radiotheodolite receiver output signals to the pulse amplifier input. Resistors R_3 and R_4 form a voltage dividing network between B^+ and ground. The cathode is connected to the junction of these two resistors whose values are so adjusted that the cathode is more positive than the grid and the tube operates below cut off the steady state condition. Therefore, the tube conducts when positive going pulses obtained from the signal level control R_1 are applied to the grid, but does not respond to noise or other undesired pulses which are normally of smaller amplitude. The signal is amplified and inverted by the action of the tube, and the negative square wave output, developed across plate load R_2, is applied to the next stage.

4.2. *Second pulse amplifier* — The second pulse amplifier consists of V_1B, the other half of 12A×7 and associated circuit components. The negative square wave output from V_1A plate is applied to the grid through coupling capacitor C_2; R_5 being the grid leak resistor. The grid of V_1B is connected to B^+ through R_{16} and the cathode is grounded; therefore, the tube conducts at saturation in the steady state condition. The negative going input signal pulse causes the tube to cut off for the duration of the pulse, and the plate voltage rises. This produces positive square wave. To obtain noise rejection, any sine wave or other positive content of the applied signal have no effect on this stage because the tube conducts at saturation in the steady state condition. Resistor R_6 is the plate load resistor. The positive square wave produced at the plate is then applied to the monostable multivibrator V_2 *via* the trigger circuit and clamping diode CR_1.

4.3. *First trigger circuit and diode clamper* — The trigger circuit consists of a RC network and a diode clamper CR_1. The positive square wave

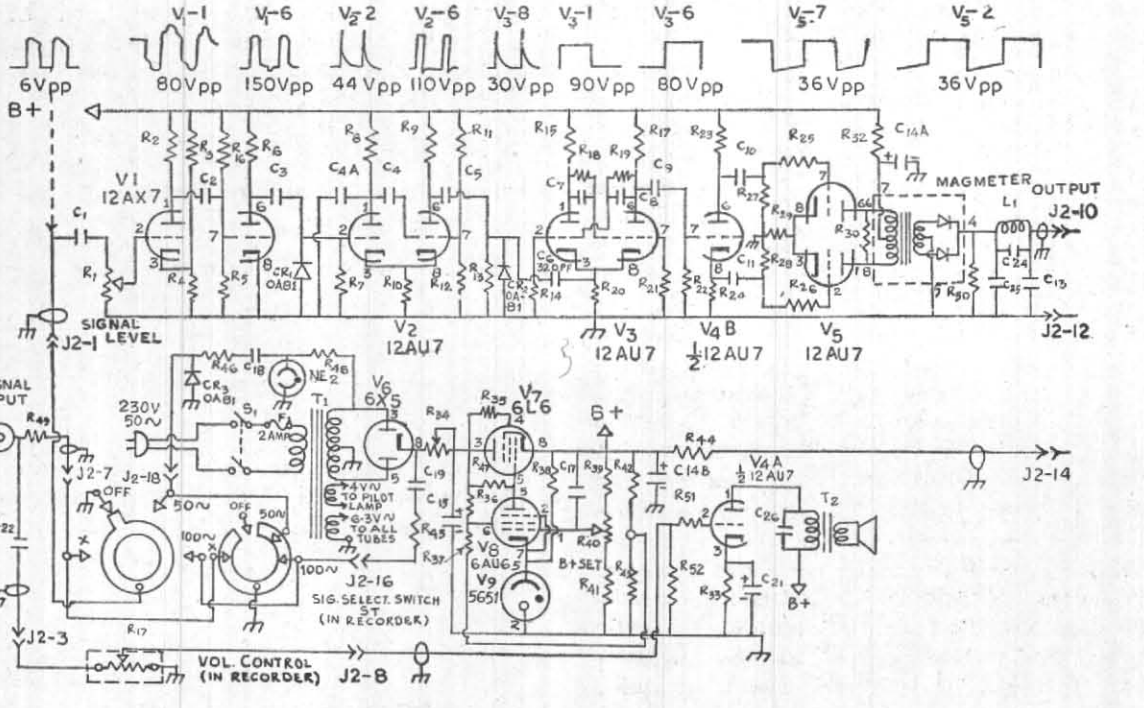

Fig. 2. Circuit diagram of frequency converter

input signal from the preceding stage is differentiated by C_3 and R_7. Since the RC time constant is short with respect to the period of the square wave, a series of sharp positive and negative pulses is developed across R_7. Clamping diode CR_1 shorts out all negative pulses and therefore only the positive pulse output of the differentiator acts as a trigger to the multivibrator. The purpose of the diode is also to remove any accompanying noise in the signal which may be capable of triggering the multivibrator for a false pulse count.

4.4. *First multivibrator*—The circuit is essentially a monostable multivibrator using both sections of a 12 Au7 tube, V_2 and associated circuit components. Its purpose is to produce a positive going rectangular pulse of constant duration and amplitude and a frequency same as that of the original input signal. The tube operates between the stable and quasi-stable states. In the stable state, V_2B conducts heavily because of its grid connected to a positive voltage obtained from the voltage divider R_{11} and R_{12}. The positive voltage produced across the common cathode resistor R_{10} is sufficient to make V_2A at cut-off.

When the positive trigger pulse is received, it overrides the negative bias on the grid of V_2A which causes the tube to conduct. The resultant fall in anode voltage of V_2A is fed *via* the time capacitor C_4 to the grid of V_2B, reducing the anode current in this section of the valve, and therefore the voltage developed across the cathode resistor R_{10}. This action reduces the bias of V_2A, enabling it to conduct more heavily. The action is cumulative and a rapid change over occurs in the valve, *i.e.*, V_2A to conduct and V_2B to cut off. The tube remains in this quasi-stable state, until the charging time constants of the circuit (determined by R_{11} and R_{12}, C_4 and C_4A) bring the grid of V_2B above the cut off point and re-establish the steady state condition. Capacitor C_4A is also a shaping capacitor and has been specially incorporated to eliminate spikes in the wave form of the pulse at the plate of V_2A. Resistor R_9 is the plate load of V_2B. Therefore for each positive trigger pulse applied to the grid of V_2A, a positive pulse of constant duration and amplitude is produced at the plate of V_2B and applied to the second multivibrator through a trigger circuit.

4.5. *Second trigger circuit and diode clamper*—The circuit is similar to one described in para 4·3 above except the designed values of its components. The positive pulse produced at the plate of V_2B is differentiated by capacitor C_5 and resistor R_{13} and put across the clamping diode CR_2. The positive trigger output thus produced is applied to both cathodes of second multivibrator tube V_2 through C_6 and R_{20}.

4.6. *Second multivibrator* — This circuit is essentially a bi-stable multivibrator having two stable states which generates a step function for each input trigger pulse and therefore requires two triggers for each complete cycle. In the stable state, only one section of tube V_3 will conduct at a time because of inter-connection between two sections of the tube by R_{18} and R_{19}. Each time the trigger pulse is applied, the conducting and non-conducting tubes are interchanged and regeneration initiated. The resulting square wave form developed at the plate of V_3B is fed to the phase inverter V_4B. The common cathode resistor R_{20} and the associated trigger circuit constants are so apportioned that degenerative effect is minimum. The trigger wave form as indicated in the diagram is triangular trigger with a fast rise and a slow fall thus ensuring reliability in operation of the circuit. The advantage of cathode triggering (Woodbury and Holdam 1949) has been taken so that capacitive loading of the cathode circuit does not interfere with regeneration.

4.7. *Phase inverter* — This is a single tube phase inverter circuit so that push-pull output is obtained with RC coupling and fed to the MAGMETER driver V_5. The square wave signal from the preceding stage is coupled to the grid of V_4B through capacitor C_9 and the output developed across the plate load resistor which is divided into two equal parts, R_{23} and R_{24}, one being connected to the plate in the normal way and the other between cathode and ground. Since the voltage at the plate and cathode are 180° out of phase, the grids of the following tube V_5 are fed equal square wave voltages in push-pull through an RC network made up of capacitors C_{10} and C_{11}, resistors R_{25}, R_{26}, R_{27} and R_{28}.

4.8. *Magmeter driver and filtering circuit* — The magmeter is a frequency detector delivering a DC output voltage proportional to input frequency. This is a relatively new circuit element used for the purpose of frequency detection. The saturating transformer of the magmeter provides a highly accurate volt-second limiting action on the first half of an input cycle, the core is saturated to its maximum flux condition. The second half input cycle then drives the core to its maximum flux condition in the opposite polarity. Prior to saturation, a pulse of constant volt-second area is supported on each input half cycle and once the transformer core saturates, no voltage is supported until the core is reset by driving it with a voltage of opposite polarity. The voltage induced in the secondary is —

$$e = -N\,(d\phi/dt) \times 10^{-8} \tag{1}$$

where N = number of secondary turns and ϕ = magnetic flux.

By intergration the average voltage is given by,

$$\int_{t_1}^{t_2} e\,dt = -N \int_{\phi_1}^{\phi_2} d\phi \times 10^{-8} \tag{2}$$

Using a transformer core having square BH characteristic, the flux limits are fixed. Equation (2) then becomes —

$$\int_{t_1}^{t_2} e\,dt = -N \int_{-\phi_{max}}^{+\phi_{max}} d\phi \times 10^{-8} \tag{3}$$

For any unique transformer design, the volt-second area of the supporting pulse is fixed, one pulse of fixed area is supported for each positive and negative portion of the driving voltage. Therefore, as the frequency of the driving voltage is increased, the number of fixed area pulses developed per unit time increases proportionally. These pulses are alternately positive and negative. Diodes are employed to rectify the secondary voltage and therefore, the output of the magmeter is a series of DC pulses. Hence, the average value of the driving voltage is proportional to the frequency of the driving voltage. This principle of operation of the magmeter circuit in Fig. 2 is illustrated in Fig. 3 with a hypothetical sine wave input signal for ease of discussion and presentation. Although the magmeter is relatively insensitive to driving voltage wave shape (sine, square or triangular) but maximum linearity is obtained with square-wave drive provided the input signal saturates the transformer on each positive and negative swing of the driving voltage. This has been obtained with a tube drive circuit using square-wave input as shown in Fig. 2.

The output of the magmeter is a pulsating DC voltage developed across R_{30} and is proportional to the input frequency of 10 to 200 c/s. The ripple from this pulsating DC voltage is filtered out by a single section pi-type filter made up of capacitors C_{24}, C_{25}, C_{13} and choke L_1. The output of the frequency converter is available at connector J_2–pin 10 for feeding to the recorder.

4.9. *Audio output* — The audio-output stage consists of V_4A, one half of tube type 12Au7, and associated circuit components which provides aural monitoring of the meteorological signals being fed to the converter input. All circuit components are available in the frequency converter chassis except the 'volume-control' which is mounted on the recorder control panel and connected through inter-connecting cable. MET. DATA signal at J_1 is applied to the grid of V_4A through C_{22}, volume control R_{17} and R_{51}; R_{52} being the grid leak resistance. The signal is amplified and fed through the audio output transformer T_2 to the speaker. The resistor R_{51} limits the grid current in case of an overloading sigaal and capacitor C_{26} by passes high frequency components of the pulses being applied to the primary of T_2 and hence produces a more pleasing sound to the ear. The resistor R_{52} has been specially incorporated in the circuit to safeguard the tube against drainage of heavy plate current due to zero grid bias (bias voltage developed across cathode resistor R_{33}) in the event of the inter-connecting cable not connected and power switch made on.

5. Power supply

The power supply furnishes an electronically regulated DC supply for the frequency converter tubes nominally adjusted to 175 volts by the B+ SET potentiometer R_{40}. From this DC supply, the reference voltage supply for the measuring circuit of the recorder is obtained using a series dropper R_{41} and filtering capacitor $C_{14}B$. In addition, it supplies 50 cps and 100 cps test signal voltages for the recorder. The 50 cps test signal from the secondary of T_1 through R_{48} is obtained across NE-2 and coupled to the SIG. SELECTOR switch S_7 (switch located on the recorder control panel) through C_{18}, R_{46} and CR_3. Diode CR_3 has been specially used so that only positive going signals are available to the input of the frequency converter. The 100 cps test signal is obtained from the cathode of rectifier tube V_6 and coupled to the selector switch through C_{19} and R_{45}.

The power supply has been designed in conformity with the performance requirements mentioned earlier. The circuit is more or less of conventional design consisting of power transformer T_1, full wave rectifier V_6, series regulator tube V_7, control amplifier tube V_8, voltage reference tube V_9 and RC filter network. The DC output is adjustable from 160 to 185 volts by means of B + SET control. The output is nominally adjusted to + 175 volts and stable

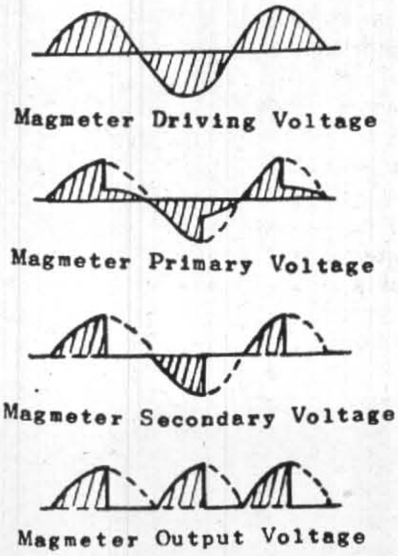

Fig. 3. Wave forms with Sine wave input to magmeter driver

to $\pm 0 \cdot 5$ per cent or better with a ripple content less than 100 millivolts.

6. Mechanical design and layout

The circuit has been wired on an aluminium chassis whose mechanical and electrical design is made to ensure easier operation and maintenance. The unit could be rack mouted in a standard radiosonde ground equipment cabinet used in India Meteorological Department. Power switch, fuse post, panel lamp, and loud speaker are mounted on the front panel and signal input jack and output connector J_2 (for inter connection with the recorder by a connecting cable) on the rear of the chassis. The signal level and B + control potentiometers have been fitted on the chassis top to permit easy access to their adjustments whenever required. The circuitory has been laid out in the same logical sequence as in the diagram. This arrangement facilitates quicker following up of the circuit including location of fault and preventive maintenance.

7. Performance and testing

Fig. 4 shows the output characteristics of the frequency converter. The curve has been drawn feeding signals from the 10–190 c/s audio frequency standard to the frequency converter input and measuring its DC output with a VTVM. It can be seen from the curve that the

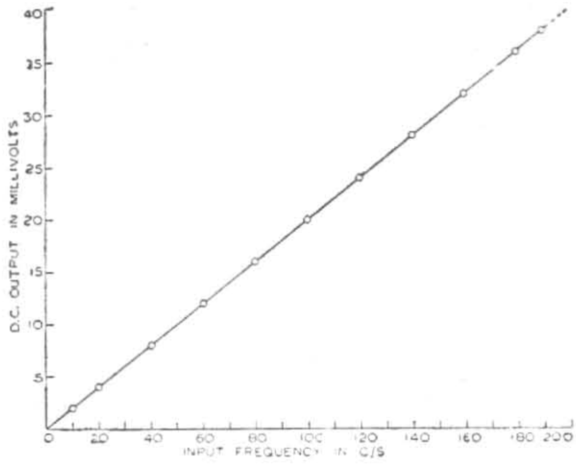

Fig. 4. Output characteristic of frequency converter

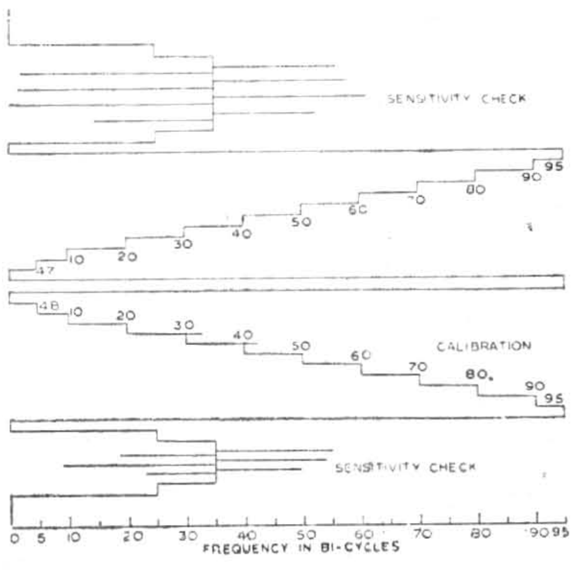

Fig. 5. Calibration and sensitivity check record

output is linear and the following relation holds good —

$$V = \frac{1}{5} f \text{ millivolts} \qquad (4)$$

where V is the frequency converter output and f is the input frequency in cycles per second.

The recorder calibration and sensitivity check made with the frequency converter in Fig. 5, also show its linearity in output to the input frequency and stipulates to the requirements of the India Meteorological Department.* The accuracy of the output performance of the

*Manual of Radiosonde and Radoiwind Observations, Chapter. 4, Para 4·6, India met. Dep., 1968

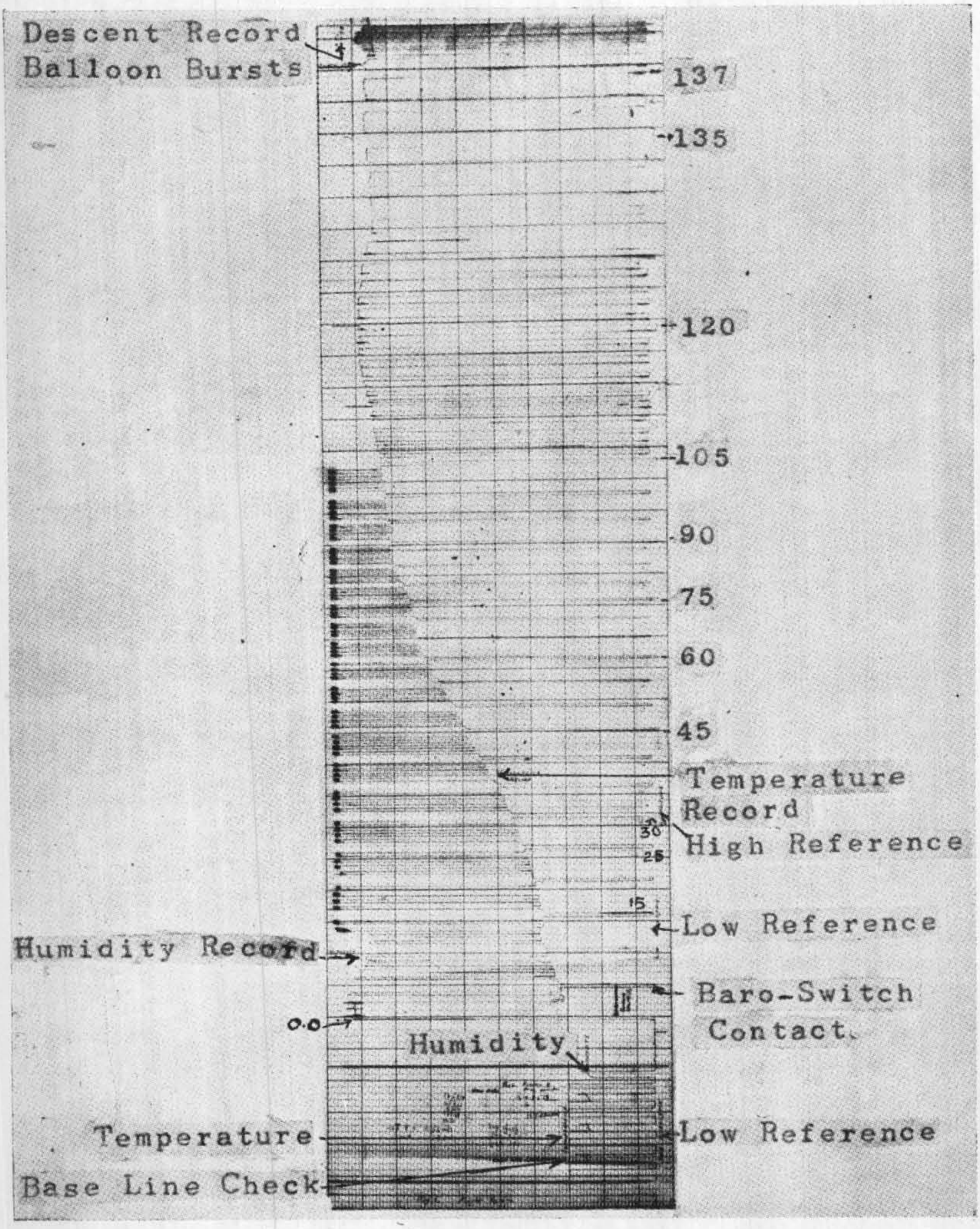

Fig. 6. Flight record on 19 February 1969 at 1655 IST

instrument, however, depends much upon the electrical stability of the circuit components especially those used in the output filter network. Those components should have stable characteristics having high insulation resistance and low temperature coefficient. The instrument is mostly made of indigenous components except for the special items like magmeter, vacuum tubes etc. The three semi-conductor diodes are of BEL make. The instrument has been extensively tested in laboratory and also in flights yielding satisfactory performance. A typical flight record is given in Fig. 6.

8. Acknowledgements

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