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AN EQUIPMENT TO MEASURE THE IONOSPHERIC ELECTRON CONTENT (FARADAY ROTATION ANGLE) USING VHF WAVES RECEIVED FROM A GEOSTATIONARY SATELLITE

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ABSTRACT

An equipment developed to measure Faraday rotation to determine the total electron content (TEC) of the ionosphere using geosynchronous satellite ATS-6 is described. All the circuits used in the equipment were designed and fabricated at Physical Research Laboratory with mostly indigenous components. The equipment is capable of measuring Faraday rotation to an accuracy of ± 2°. This equipment design can be used for measuring Faraday rotation of other geosynchronous satellites, with a little modification in the front-end converter. It consists of a rotating antenna, a VHF receiver, a phase meter and a chart recorder. The receiver and phase-meter can be used as separate modules for other applications too.

Six of these equipments were deployed at various institutes in India and all them have functioned satisfactorily without major breakdowns. The data collected from these equipments have yielded wealth of scientific information regarding the total electron content over the Indian sub-continent which was not available earlier. Using the total electron content data, the TEC contours have been made for Indian sub-continent. Range and range rate error corrections to estimate orbital errors for tracking any satellite have been worked out. Travelling ionospheric disturbances have also been detected over the

Indian sub-continent. The speed of TIDs ranges from a few metres to 200 metres. Further scientific work is under progress.

1. Introduction

NASA planned to launch a geostationary satellite ATS-6 for satellite instructional television experiment (SITE), radio beacon experiment and other experiments. Initially the satellite was in the western hemisphere for one year and was moved to 35°E by middle of July 1975. The radio beacon experiment on board consists of carrier frequency transmissions at 40.016 MHz, 140.056 MHz and 360.144 MHz[1]. These beacons can be made use to study the following characteristics of the ionosphere:

(a) Total electron content (TEC) by measuring the Faraday rotation of the electric vector of the incoming electromagnetic wave,

(b) Group delay caused to VHF waves, and

(c) Amplitude and phase changes to VHF waves due to the ionosphere.

The present article describes a simple experimental set-up developed to measure the TEC of the ionosphere using 140.056 MHz beacon signal. We have developed six such units and deployed them at Patiala (Lat. 30.3° N, Long. 76.4° E), Udaipur (Lat.24.6° N, Long.73.7° E), Ahmedabad (Lat.23.0° N, Long.72.6° E), Rajkot (Lat. 22.3° N, Long.70.7° E), Bombay (Lat.19.1° N, Long.72.9° E) and Waltair (Lat.17.7° E, Long.83.3° E). TEC measurements are useful to investigate characteristics of the travelling ionospheric disturbances, solar flare effects, ionospheric storm effects, etc.

Such a coordinated effort to investigate the ionosphere has been made for the first time at low-latitudes.

2. Calculation of Total Electron Content

The VHF beacons from the satellite travel through part of the exosphere and entire ionosphere including lower atmosphere. Titheridge[2] pointed out that the electron content in the exosphere is about 5% and in the ionosphere is about 95%. Hence, most of the Faraday rotations of the beacon signals take place in the ionosphere.

At VHF range (140.056 MHz) where the frequency is much greater than the electron gyrofrequency of the ionosphere (1.4 MHz) and where in the absence of appreciable refraction, Faraday rotation is given by Browne et al.[3] as:

$$\Omega = \frac{K}{f^2}\int_{o}^{hs} B \cos\theta \sec\gamma \; N dh \qquad .....(1)$$

$$\Omega = \frac{K}{f^2} \bar{M} \quad N_T \qquad .....(2)$$

where Ω = Angle of rotation of the plane of polarization

N_T = Total electron content

f = Wave frequency

N = Electron density

B = Earth's magnetic field

θ = Angle between the magnetic field and the direction of propagation

γ = Zenith angle of the satellite hs = Height of the satellite

$\bar{M}$ = Weighted mean of B Cos θ Sec ψ around the altitude of F2 peak

K (is a constant) = 2.97×10^{-2} mks units.

The instrument described in the next section records continuously Faraday rotation with time on the chart and hence TEC with time can be calculated without any tedious computations.

3. Instrumentation

(i) System block diagram - Fig.1 shows block diagram of the equipment. Plane polarized signal at 140.056 MHz is received by yagi antenna rotated at 1 Hz. When the plane containing the antenna elements coincides with that of the incoming signal, the received output reaches maximum; a minimum is obtained when the antenna plane is orthogonal to the incoming polarization plane. Hence the effect of antenna rotation is to amplitude modulate the signal with a frequency of 2 Hz. For Faraday rotation measuremen a reference signal of the same frequency is generated by two permanent magnets (M_1 and M_2) attached to the rotating shaft of the antenna and a sensing coil fixed near the shaft. The detecte output of the receiver and the reference signal are passed throug two independent phase-matched active filters at 2 Hz with a bandwidth of 0.1 Hz to get clean 2 Hz sine waves. These waves are further squared and phase compared. The phase difference between the two is integrated and amplified in a d.c. amplifier an fed to a chart recorder. Thus the changes in Faraday rotation ang are continuously recorded on chart. Fig.2 shows a typical Faraday rotation angle plot for daytime.

(ii) Receiving antenna system - An eight element yagi antenna with folded dipole as the driven element is used. The antenna has 10 db gain over half wave dipole and has an output impedence of 50 ohms. It is rotated at 1 Hz by 1/4 h.p. motor. The beacon signal received by the antenna is passed on to the preamplifier through induction coupling via a rotary transformer made on printed board cards. Two permanent magnets (M_1 and M_2) are also mounted on the rotating shaft. The sensing coil for reference signal is mounted close to magnets. Due to the rotation of antenna, lines of force of magnets cut the sensing coil, thus inducing a 2 Hz electrical signal in the coil. This serves as a reference signal for phase measurement.

(iii) Receiver - A double superhetrodyne receiver at 140.056 MHz has been built mostly with indigenous solid-state components. It has the following characteristics:

(1) Input impedance : 50 ohms
(2) Frequency : 140.056 MHz
(3) Sensitivity : Better than -135 dbm
(4) Overall gain : 140 db
(5) Bandwidth : ± 3.0 kHz at -3 db points
± 10 kHz at -60 db points
(6) 1st IF : 10.7 MHz
2nd IF : 455 kHz
(7) Image rejection : Better than 45 db.

The receiver is made up of preamplifier, down converter and beat frequency oscillator. The preamplifier (Fig.3) consists of two stages and has a measured noise figure less than 3 db and a gain of 35 db. Bandwidth at 3 db point is 1.5 MHz. D.C. power to the preamplifier is sent through the output cable with output signal riding over it, thus avoiding additional cable for D.C. supply. Input and output impedances are 50 ohms and are matched with the cable impedance ensuring maximum power transfer.

The signal from preamplifier is translated first to 10.7 MHz in the first down converter and then to 455 kHz in the second down converter (Fig.4). The first down converter consists of a crystal controlled oscillator at 43.1187 MHz, which is trippled to 129.3561 MHz and mixed with the incoming signal giving rise to 10.7 MHz as first IF signal. It is amplified in one stage amplifier and is mixed with a crystal controlled oscillator of 11.1548 MHz to give an IF of 455 kHz. This IF signal is amplified and detected in a two stage IF amplifier having a gain of 60 db. An integrated circuit is used in the last stage of IF amplifier which also gives detected output, and AGC output to monitor signal strength.

To facilitate audio-monitoring of satellite signal a beat frequency detector (Fig.5) and a variable frequency oscillator using a varicap diode, which generates waves of 455 kHz ± 5 kHz, have been incorporated. The 455 kHz IF signal is mixed with BFO signal to produce a ± 5 kHz audio, thus indicating the presence of the satellite signal.

(iv) Phase meter and filter circuit - The detected outputs from receiver as well as reference signal from the sensing coil are passed through two identical channels consisting of a buffer stage and an active filter with multiple feed back loop. To balance out the phase error introduced to signals as they pass through their respective channels, both the filters are matched for gain and phase (Fig.6). The filtered outputs are clean 2 Hz sinisoidal waves, which are squared in two stages of a hexinverter. These processed square waves are applied to a R-S flip-flop whose output is a pulse with width proportional to the phase difference between the two square waves. This pulse is integrated and then amplified in a D.C. amplifier whose gain and zero setting can be adjusted according to the requirement. The output of the D.C. amplifier is recorded on a strip chart recorder.

4. Discussions

The overall accuracy of phase measurement by the equipment described above is of the order of ± 2°. The total variation of phase due to ionosphere i.e. Faraday rotation, at 140 MHz is of the order of three cycles. Hence the above accuracy of ± 2° is a good achievement for measuring Faraday rotation.

With modification in the front-end converter of the equipment it can be used for any other geostationary satellites. In addition the phase meter can also be used for other applications involving the measurement of phase. Six such equipments were operated successfully at six different locations in India and have given valuable data on total electron content for equatorial and low latitudes.

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2. TITHERIDGE, J.E., Planet. Space Sci., 22 (1972), 353.
3. BROWNE, I.C., EVANS, J.V., HARGREAVES, J.K. and MURRAY, W.A.S., Proc. Phys. Soc., B69 (1956), 901.

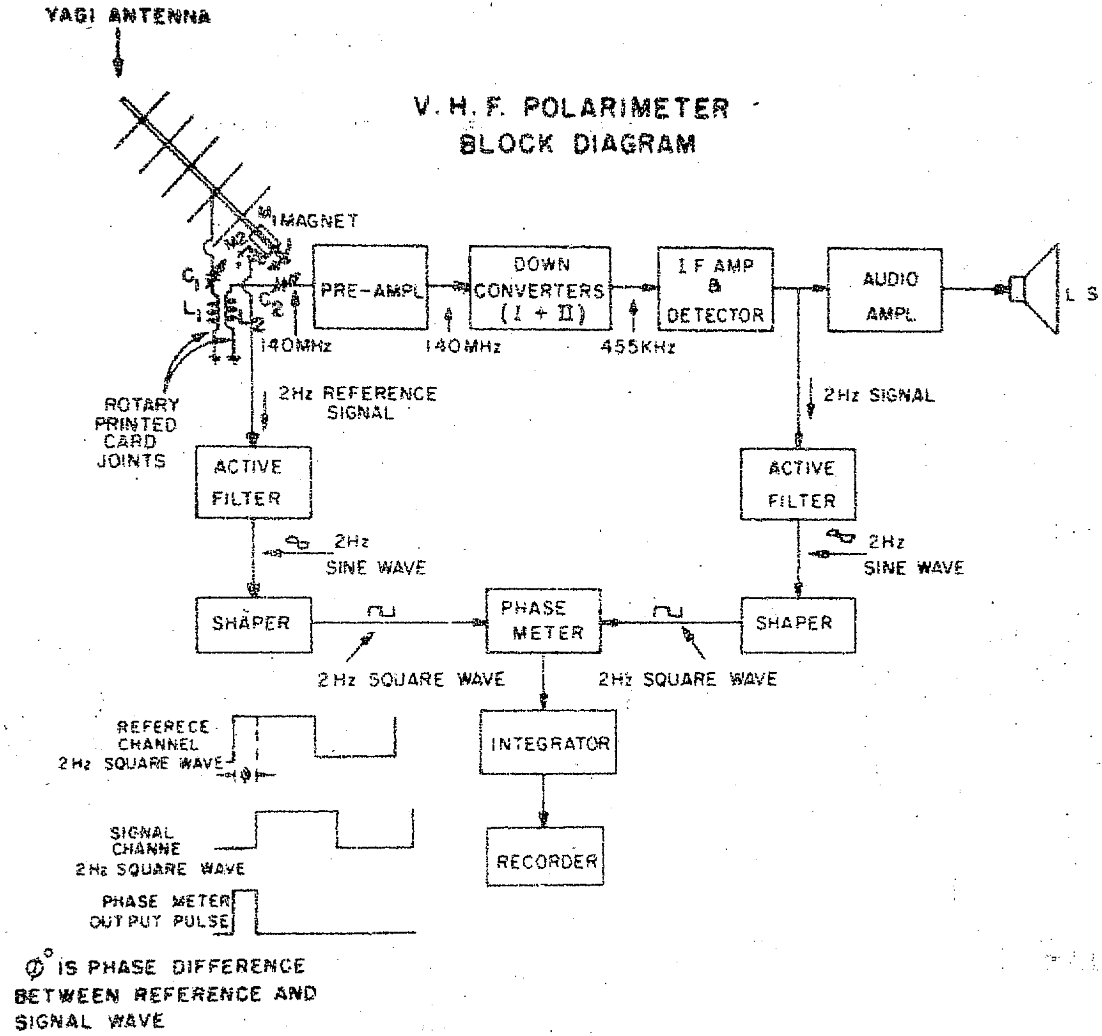


Fig.1 : System block diagram

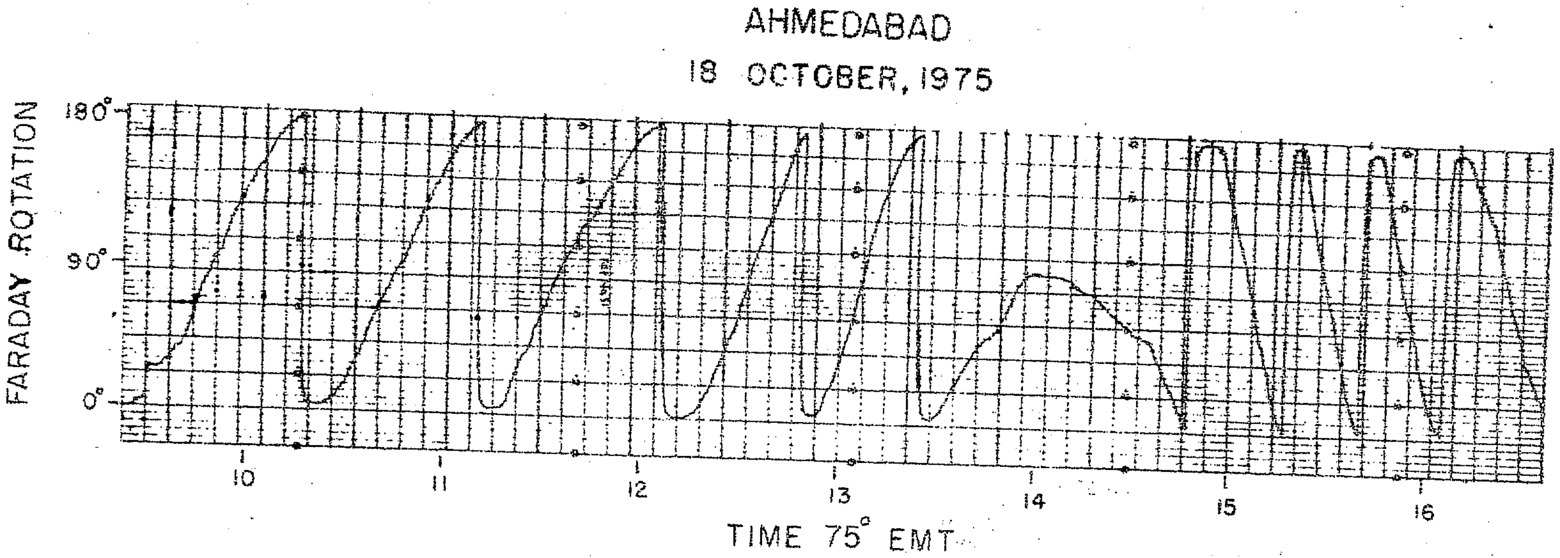
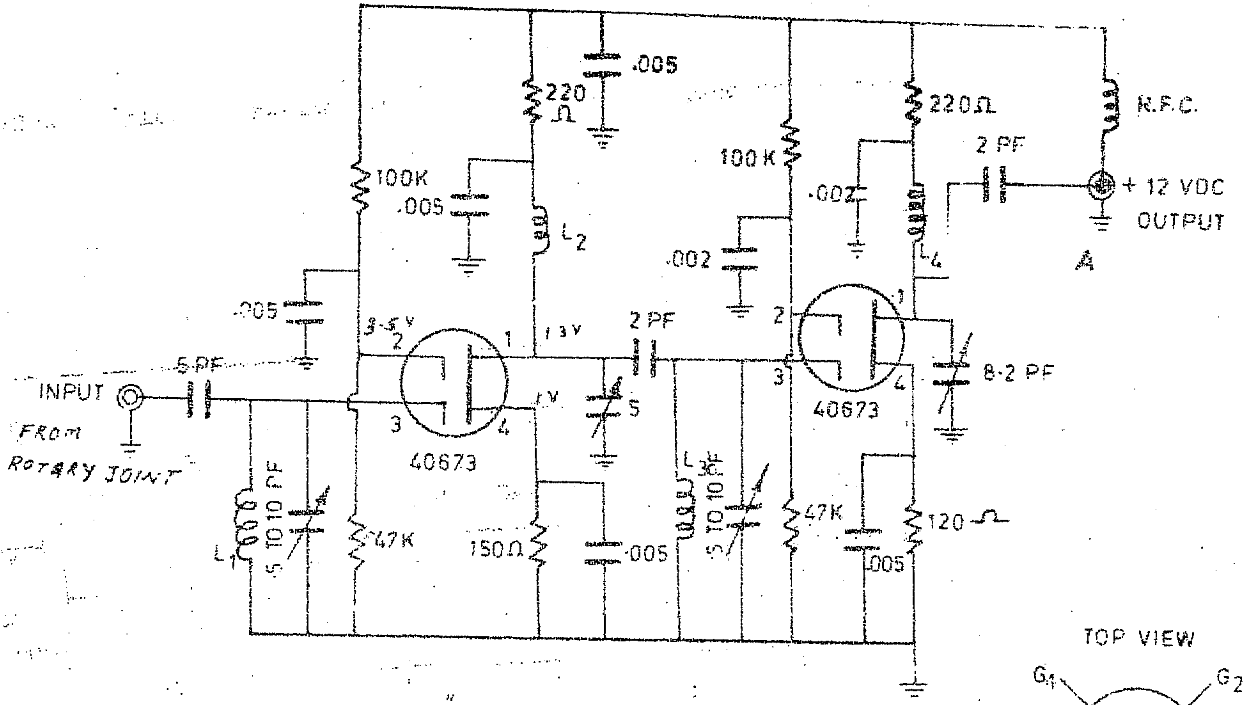


Fig.2 : Sample Faraday rotation angle record

PRE AMPLIFIER (140 MHz)



L1 3T 18 SWG ON 3/8" DIAMETER OR 1 cm D

L2 = " " "

L3 = " " "

L4 = " " "

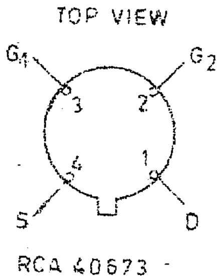


FIG.

Fig.3 : Circuit diagram of low noise preamplifier.

DOWN CONVERTERS AND IF AMPLIFIER

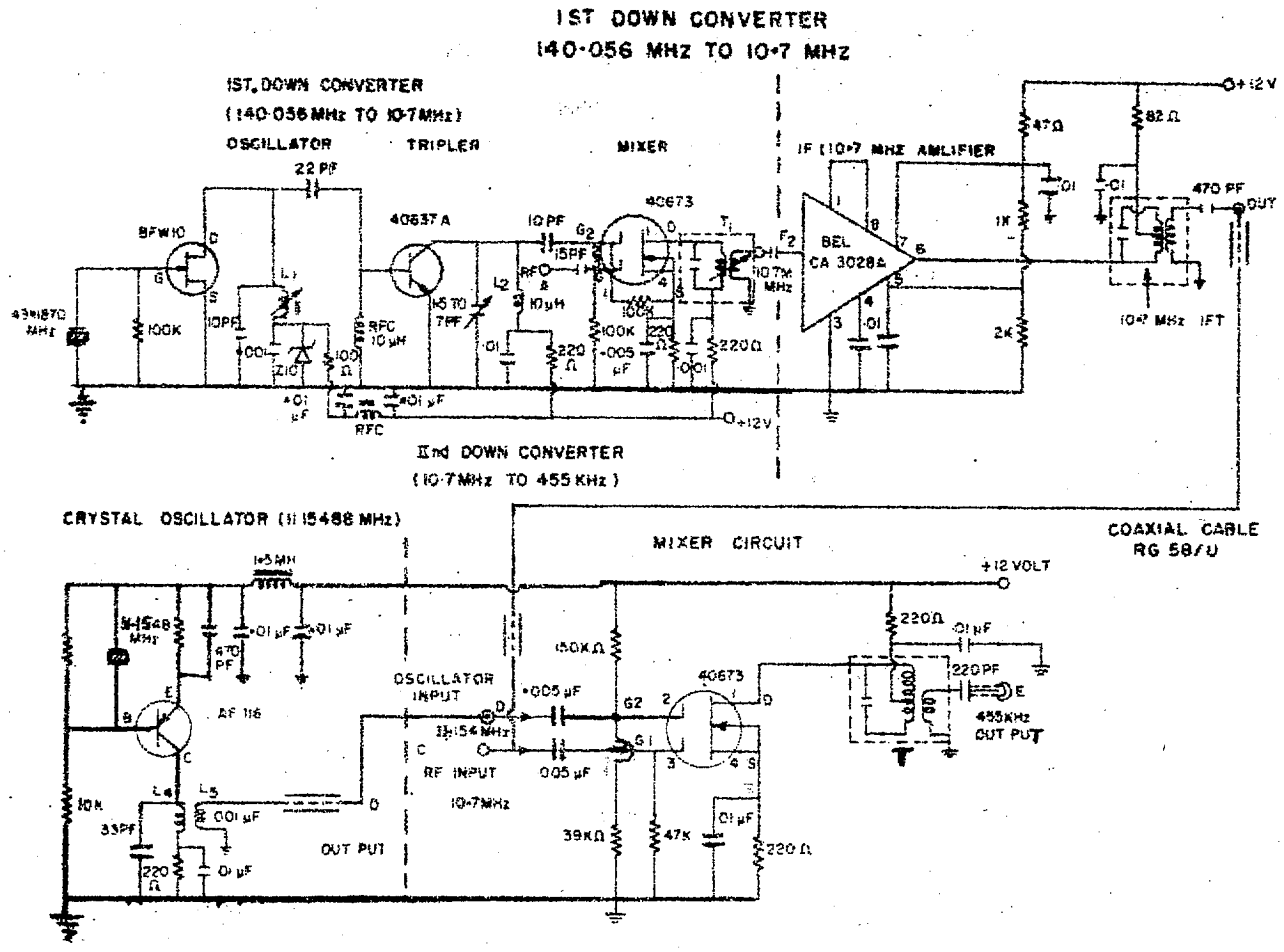


FIG.

Fig.4 : Circuit diagram of first and second down converters.

BEAT FREQUENCY DETECTOR

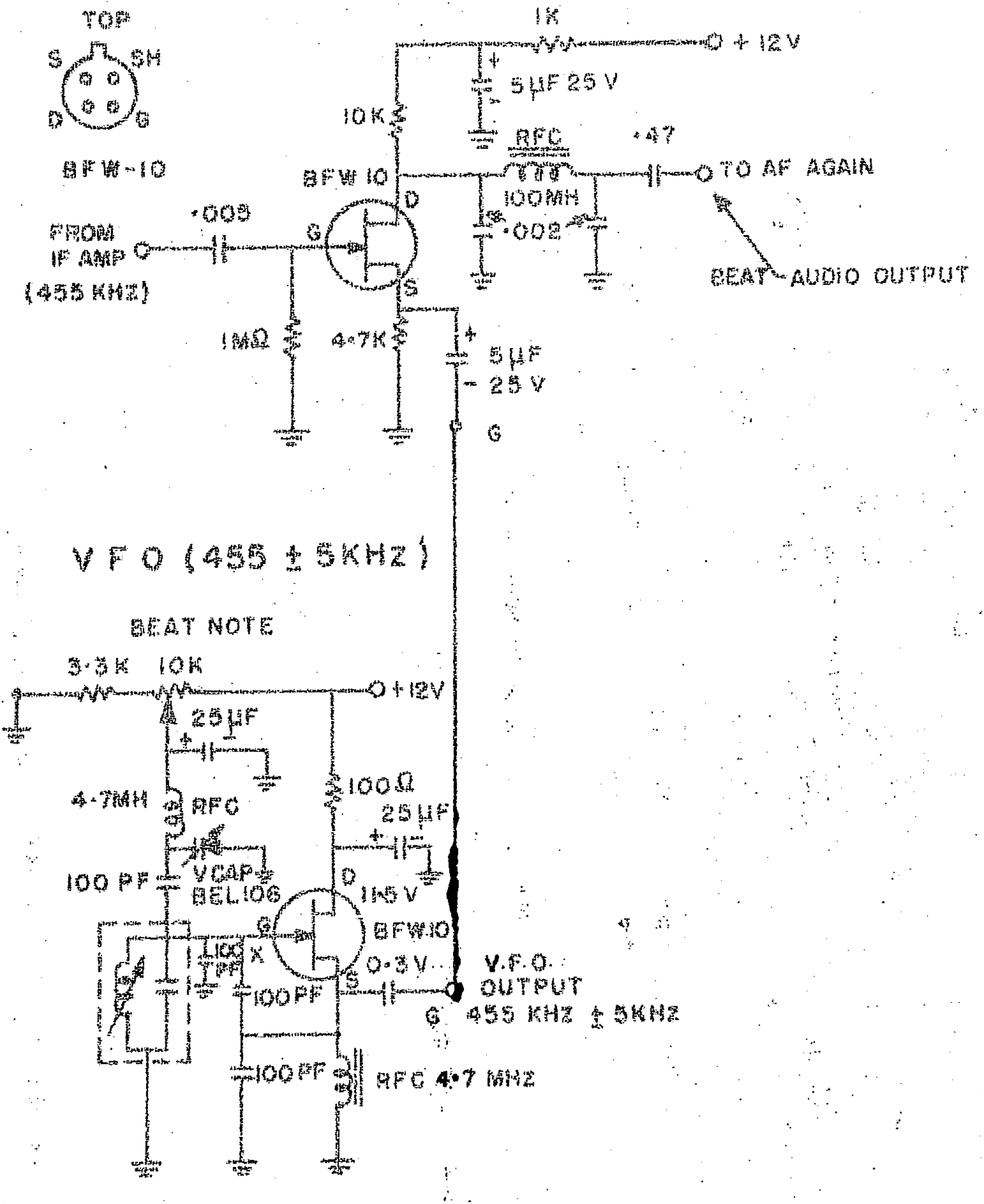


Fig.3 : Circuit diagram of beat frequency detector.

FILTER AND PHASE METER

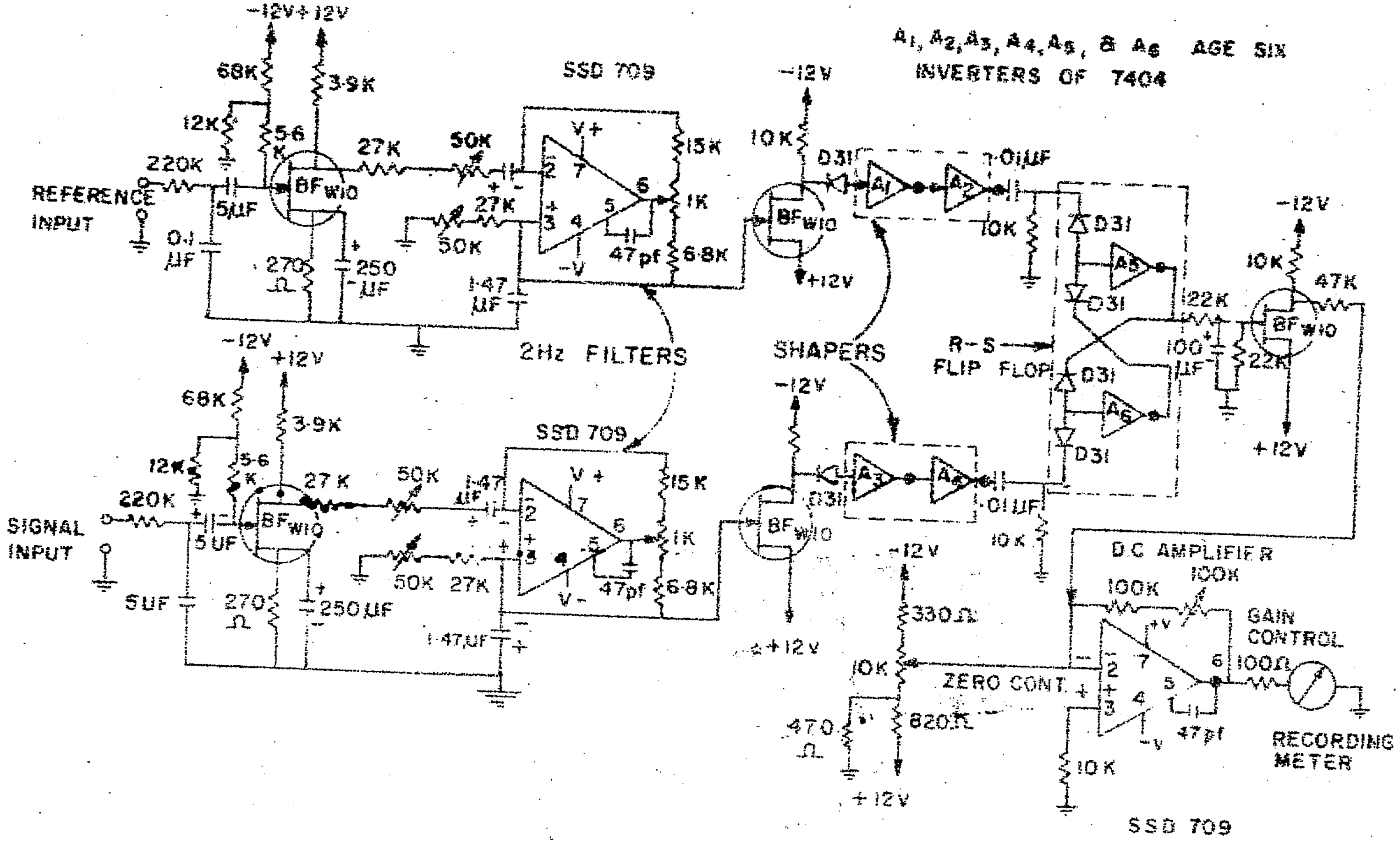


Fig.6 : Circuit diagram of Filter and Phase meter.