USE OF A CAPACITANCE INFLUENCE PROBE FOR MEASURING WAVE PROFILES

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ABSTRACT

This report describes the features of electronic instrumentation for measuring and recording the wave amplitudes and configurations of water waves.

The gaging element of this system consists of a small flat metal plate suspended above the surface of the water. This plate acts as one plate of a capacitor and the surface of the water acts as the other plate. The dielectric of this capacitor is the air space between the water and the probe plate.

The capacitance of this unit is an inverse function of the distance between the water and the probe plate. The capacitor is connected in a resonant circuit which oscillates in the region of 7 megacycles. This frequency is changed by the variation in capacitance between the water and the probe unit and is eventually discriminated and fed into a recording galvanometer.

This report includes schematic and block diagrams of the instrument and data gathered in the process of design and development of the various component parts.

INTRODUCTION

For the accurate measurement of small water waves, it is desirable to use a method whereby the surface of the water is not disturbed in any way by the gaging device.

In January 1957 work was begun on a gaging device which would fulfill the requirements of continuously gaging the surface of a body of water at some given point.

The initial requirements which were set forth included the measurement of water waves no more than one inch in amplitude and whose frequency did not exceed 2 cycles per second. The unit was required to furnish a signal to a recording galvanometer of such an amplitude that the actual heights of the waves would be recorded on the oscillograph record.

The influence probe system described herein meets or exceeds these preliminary demands. It is capable of producing oscillograph records up to a ratio of 10:1 and as low as 0.1:1. The frequency limitations are above 20 cycles per second at the upper end and zero cycles per second as the lower extreme. The frequency limitations are actually due to the resonant frequency of the recording galvanometer and not due to any circuit constants of the influence probe.

This probe system has been developed from the basic circuitry presented by F. W. Kellum in "An Electronic Gage for Measurement of Small Waves and Ripples" Bulletin Beach Erosion Board, Vol. 10, No. 1, July 1956.

MEASUREMENT SYSTEM

The measurement system described in this report is known at the Colorado State University Wave Basin as the Influence Probe. For discussion, it may be divided into three major functional parts: The probe unit, the electronic circuitry attached to the probe, and the electronic circuitry used to control the signals fed to the recording oscillograph.

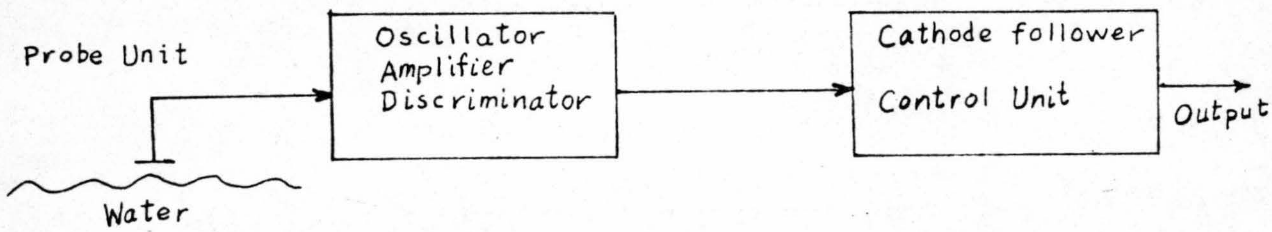


Fig. 1 — Functional Block Diagram

The principle of operation may be described as follows: When the spacing between the probe unit and the water surface is changed, a resonant circuit operating at 7 megacycles is also changed. The change in capacitance produces a change in frequency. This frequency is mixed with a reference frequency and is amplified and fed into a discriminator which produces an output voltage proportional to the frequency change. This output signal is then fed into a cathode follower control circuit where it is adjusted to give a 1:1 deflection as viewed on the recording oscillograph.

PROBE UNIT

The probe unit consists of a flat piece of aluminum with an area of two square inches. This plate is suspended rigidly four inches above the static water level. It is attached to the center conductor of a coaxial cable by a short length of brass tubing in order to reduce the capacitance between the plate and the outer conductor of the cable. This mounting procedure also minimizes the variations in capacitance between plate and cable which could be caused by vibration or bending. The cable, a 6 ft length of RG/63-U, is connected at its other end to the resonant circuit.

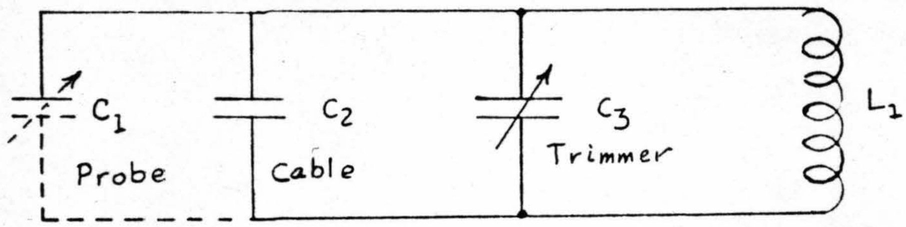


Fig. 2 -- Equivalent Circuit

The circuit is composed of a fixed inductance, L_1 , a trimmer capacitor C_3 , stray capacitance and cable capacitance C_2 , and the probe-water capacitance C_1 .

The size of the plate has a direct bearing on the optimum spacing above water. This spacing will always be a compromise between sensitivity and linearity. It was found that a plate area of less than two square inches could be made very sensitive by lowering it quite close to the water surface, but the system linearity was lost. If the plate were lowered far enough, linearity could be obtained but with the allowable wave height reduced so much that it was useless for the purposes intended.

The two square inch plate was chosen as a compromise with good sensitivity and acceptable linearity when operated with wave heights (double amplitude) up to one inch. The residual capacitance between plate and water was 0.11 micromicrofarads with a maximum change of 0.015 micro-microfarads with one half inch of water level deviation in either direction.

ELECTRONIC SYSTEMS

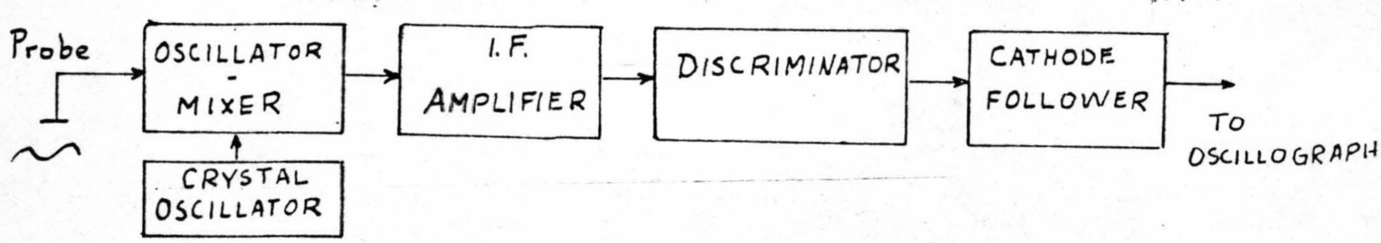


Fig. 4 — Detail Block Diagram

The summary of operation of the electronic systems may be made with reference to the block diagram, Figure 4.

As the distance between the water and the probe varies, the frequency of the resonant circuit shown in Fig. 2 varies directly with this change. This circuit is part of a conventional pentagrid converter. A fixed, crystal controlled frequency is also fed to the pentagrid converter where it is mixed with the frequency determined by the probe. The difference of these two frequencies is 160 kc. This new or I.F. frequency is then passed through an I.F. transformer and is amplified. After passing through the amplifier, the signal is fed through a discriminator transformer which will pass 160 kc $\pm$ 4 kc. This broad band width assures a linear voltage output over the entire range. This 160 kc signal is then discriminated by means of a dual diode stage. When the frequency is slightly above 160 kc the output of the discriminator is positive. When the frequency is slightly below 160 kc the output of the discriminator is negative. Since all other circuit constants are fixed, the output voltage varies directly and linearly with frequency changes around the center frequency.

The circuit diagram for the oscillator, amplifier and discriminator is shown in Fig. 5.

This output voltage is developed across 2-one megohm resistors which means that this is a high impedance output. In order to convert this high impedance to a low impedance which will match that of the recording galvanometer, it is necessary to feed the signal through a cathode follower stage. However, in the present status of the equipment, there is a 200 ft cable between the discriminator and the cathode follower. Therefore a certain amount of 60 cycle ac pickup will be present at the grid of the cathode follower unless it is passed to ground prior to reaching that point. An integrating network with a drop of 6 db per octave has been incorporated in the grid circuit of the cathode follower. This is accompanied by a gain control which will determine the ratio of presentation on the recording oscillograph.

The output of the cathode follower is taken off a 1000 ohm resistor and is referenced to a voltage divider network which is supplied by a 1.3 volt mercury cell. This voltage divider network is adjustable

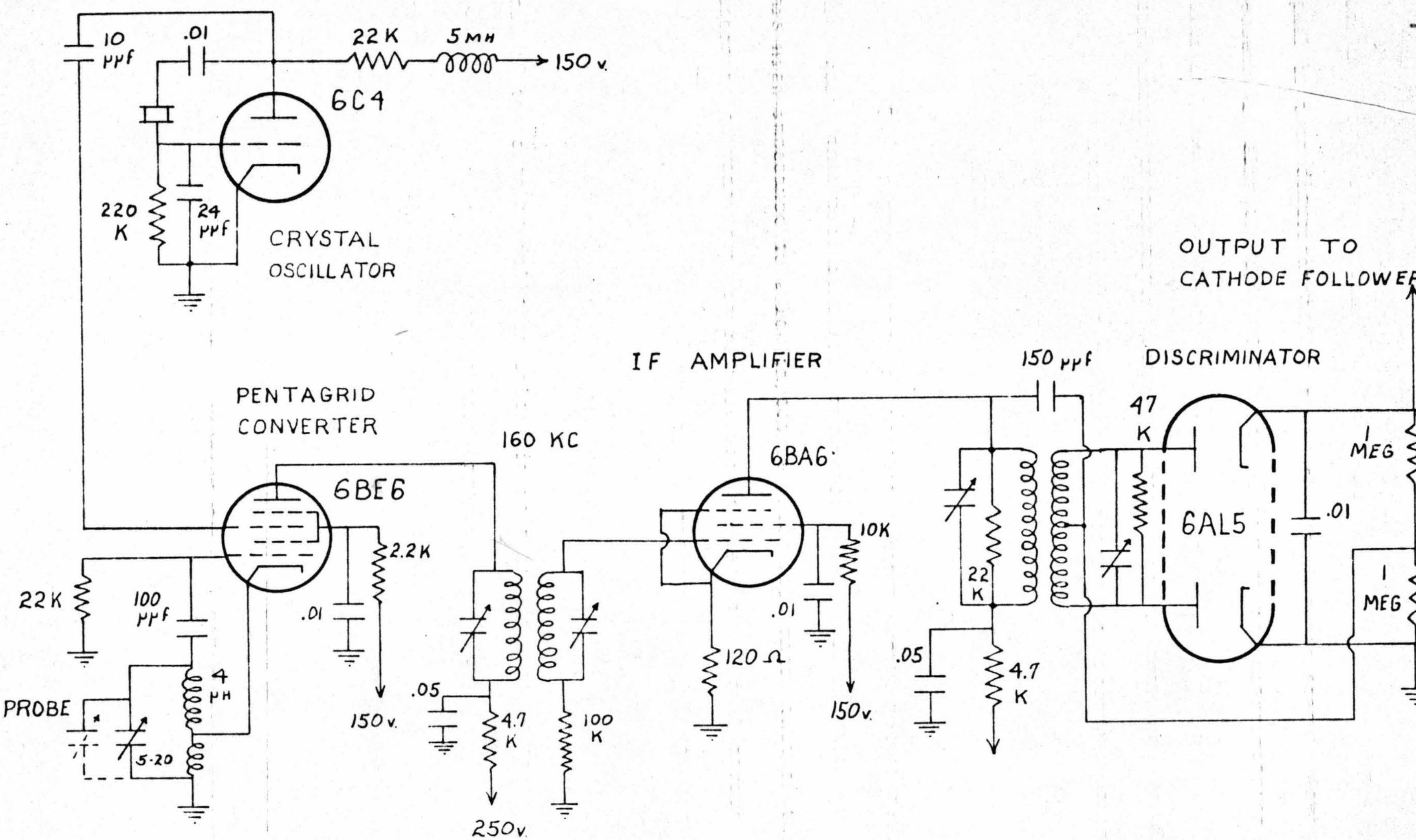
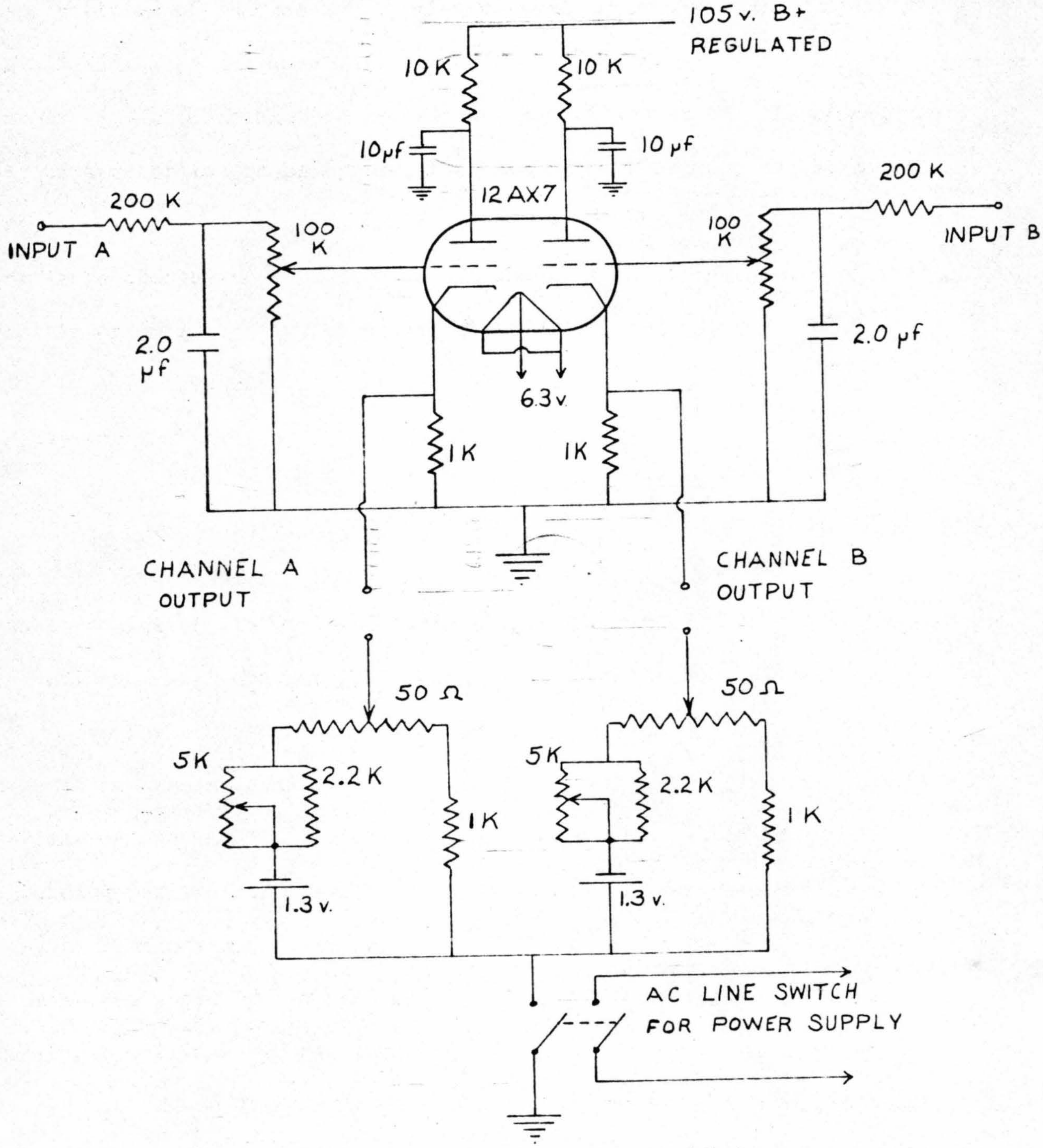


Fig. 5- AMPLIFIER - DISCRIMINATOR



TWO CHANNEL

Fig. 6 - CATHODE FOLLOWER CONTROL UNIT

which provides an auxiliary centering control for precisely locating the zero position of the recording galvanometer. The galvanometer sensitivity is 3.5 microamps per inch deflection.

Due to changes in atmospheric conditions which will affect the capacitance of the probe system, two methods of frequency adjustment are supplied. The trimmer capacitor in Fig. 2 may be used to compensate for large changes in capacitance and a brass slug which is part of the oscillator coil L_1 may be positioned for fine tuning.

The cathode follower diagram is shown in Fig. 6. The power supply for the entire unit is shown in Fig. 7.

OPERATION

For operation the electronic equipment may be powered from a stable source of 115 volt, 60 cycle single phase power. The two channels of equipment will consume less than 1/4 ampere at rated voltage.

The probe unit and the electronic package attached to it are mounted on a movable carriage which rides on a steel bridge over the surface of the water. The cathode follower control unit and the recording oscillograph are located inside the control room.

When the unit is initially installed, the probe is located four inches above the surface of the water. This distance should always be within 0.1 inch of the specified value. The unit should then be turned on for one hour in order to stabilize the frequency of operation. After a stabilized temperature has been reached, the oscillator may be adjusted to its proper frequency by means of the trimmer capacitor

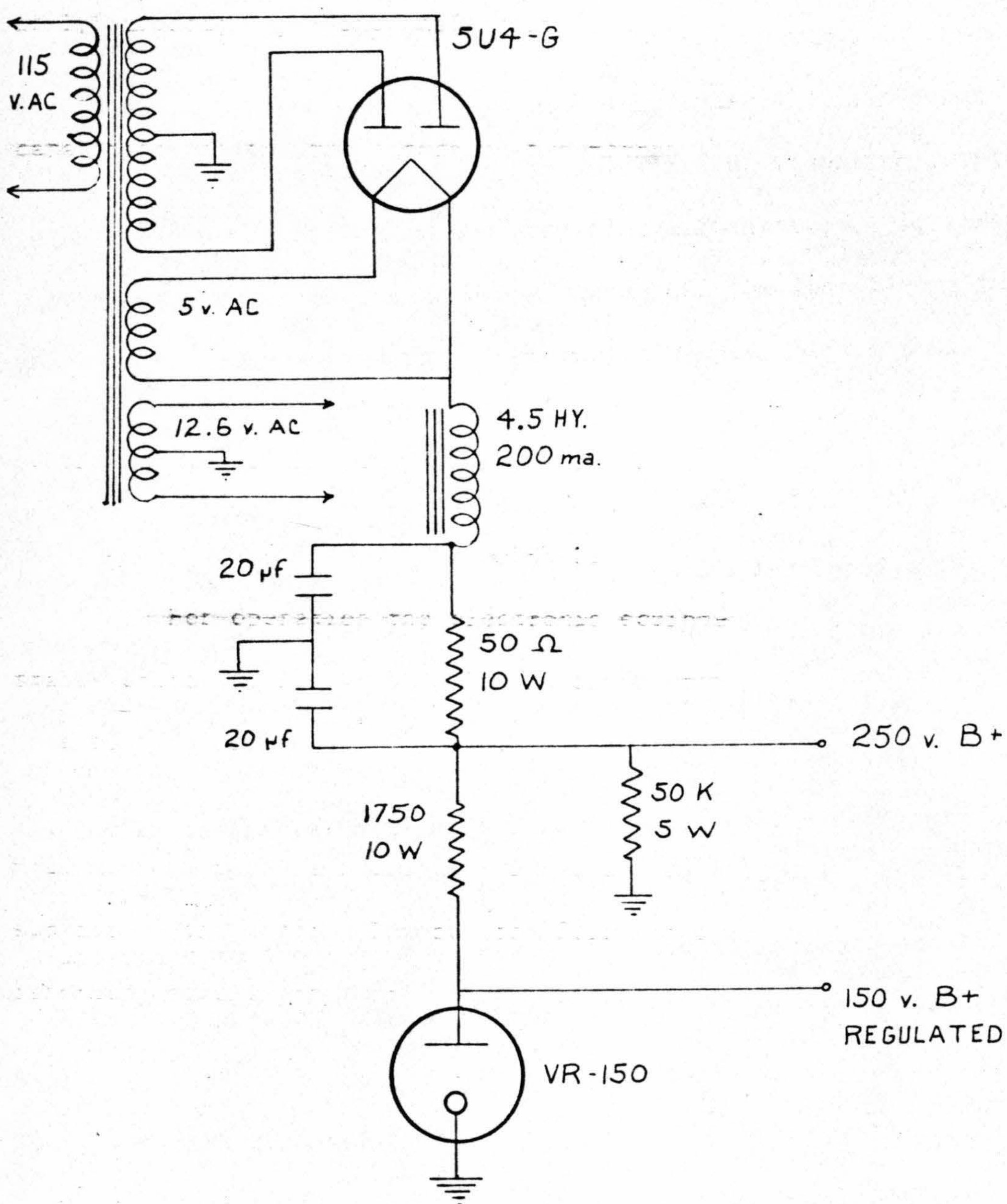


Fig. 7 - PROBE UNIT POWER SUPPLY

and the tuning slug in the oscillator circuit. This adjustment may be monitored by a zero centering microammeter which can be switched in or out of either channel at the output of the discriminator. The recording ratio gain control may then be adjusted by generating a standard wave or a wave whose amplitude is measured by careful visual observation and adjusting the deflection of the recording galvanometer. Centering the galvanometer is accomplished by switching off the incoming voltage to the cathode follower and adjusting the reference voltage until the galvanometer is properly centered.

LIMITATIONS

The purpose for which this probe was developed was the comparison of phase changes of the same wave at two points along its crest line. For this purpose the probe unit operates quite satisfactorily. However, if the actual pattern of the wave outline is to be recorded, a more linear system is desirable particularly if the wave amplitude should be greater than one inch. This can be accomplished by increasing the area of the probe plate to about nine square inches and increasing the probe-water spacing. A less desirable method would be to triple the frequency of the oscillator and use the two square inch plate and simply place it farther above the surface of the water. Fig. 8 shows the relationship between capacitance and spacing for a two square inch plate.

The dimensions of the smallest wave to be observed are primarily the restricting conditions on the maximum size of the probe plate. For example, if the wave length is 40 inches, the length of one side of the probe plate should be 4 inches or less. The smaller the probe dimensions are with respect to the dimensions of the wave, the more detailed will be the final presentation. This is due to the fact that averaging of the capacitance between the wave and the probe plate will be minimized.

The most important limitations placed on the operation of this unit are caused by temperature and humidity variations. As the temperature changes, the capacitance of the cable connecting the probe plate with the oscillator circuit changes. This produces a change in frequency which is undesirable. Humidity changes produce capacitance variations due to the change of dielectric constant. These changes are relatively minor however, and occur over a relatively long period of time. It has been found that testing at night is the best time for obtaining stable operation because temperature and humidity are less subject to sudden changes then. Temperature changes and slight movement of the coaxial cable connecting the probe plate to the oscillator cause sizable changes in the capacitance of the system. These shifts cause calibration difficulties.

The oscillator must be mounted as near the probe plates as as practicable in order to reduce the residual capacitance. This requirement makes it necessary to mount most of the electronic components on the moving carriage. Several disadvantages result:

1. Adds approximately 8 pounds weight per probe unit to an otherwise light-weight carriage,
2. Fine tuning controls are located on carriage away from the other major control center,
3. Electronic components located out-of-doors on carriage subject to weather damage,

4. In spite of all the steps taken, the coaxial cable is still of appreciable length (6 feet) and this length is subject to carriage accelerations and solar radiation.

Further development of this probe unit is anticipated. Future plans call for the elimination of the cable capacitance and weight problem on the carriage. It is expected that six probe units will be built and mounted to the towing carriage so that detailed information of the wave amplitude and phase changes may be obtained in the vicinity of the moving model. The proposed new innovations include:

1. Using a transistor oscillator,
2. Build the transistor oscillator and the probe plate as a single encapsulated unit. Thus the cable capacitance problem is eliminated,
3. Use a radio link between the probe and the remaining parts of the circuit.

Transistors are now available which are suitable for use in the oscillator circuits required to provide a multi-channel configuration required in seaworthiness studies. In spite of the inherent difficulties with capacitance circuits of this type, it is believed that the advantage offered by a light-weight, inexpensive probe which does not disturb the waves it measures is worth the effort required to overcome the limitations.