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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273205
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1954-03

ERB-349

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

A FREQUENCY METER ADAPTER

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MARCH 1954

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ABSTRACT

An instrument designed to provide rapid and accurate frequency determination for communications receivers in the range of 1 to 30 megacycles is described. The principle used was developed at the National Research Council of Canada, and is described in Proc. IRE, page 594, March, 1954. The meter interpolates between harmonics of a 100-kilocycle crystal and the local-oscillator frequency of the receiver. No adjusting knobs or settings are required, the interpolation being read off a stroboscopic dial directly in kilocycles. Although the instrument, as described, can be used in conjunction with only one or two receivers, a proposal is set forth in the Appendix, which suggests a means of connecting a number of receivers to the adapter through a switching system.

A FREQUENCY METER ADAPTER

- C.W. McLeish -

INTRODUCTION

This instrument has been constructed along the general lines suggested in a "Proposal for Adapting the NRC Frequency Meter to Communications Receivers" of August, 1953 (see Appendix A). The main purpose of the adapter is to provide accurate frequency indications of dial settings on standard communications receivers. The instrument meets two main operational requirements: (a) that of providing a very rapid indication of the frequency to which a receiver may be tuned; and (b) that of providing a means of setting up a receiver rapidly to a given frequency.

ACCURACY

The accuracy requirement is really that which allows the operator to set his receiver so close to a known frequency that there can be little doubt in identifying a transmission on that frequency, even under conditions of heavy interference. This means the error must be much less than the total audible range of frequencies produced by the beat-frequency oscillator. In fact it would be desirable if the operator could be sure that the desired transmission would always produce a relatively low beat-frequency tone, in the range where the ear has high discrimination of frequency. Another limit on the error is the loss of signal strength relative to noise and interference due to the narrowness of the intermediate-frequency bandwidth. A practical objective seems to be a maximum error of ±0.5 kc, so that two receivers set up on the same dial readings would have beat-frequency tones differing by a maximum of 1 kc on a common transmission. However, even if the instrument has an error of two or three times this amount and its effectiveness is decreased for some applications, it could still be useful compared with high-quality standard communications receivers which have tuning errors of 10-50 kc. Basically, the frequency meter system can give accuracies higher than ±0.5 kc, but in order to make a simple workable system which can be attached to most receivers without internal modification, and at the same time allow for variations in receiver gain and bandwidth across the frequency range, a number of compromises have been made. In the present adapter the accuracy depends largely on the extent to which the reading is independent of receiver characteristics and control settings.

PRINCIPLE OF OPERATION

The principle of operation[1] of the frequency meter is that of accurate interpolation between harmonics of a precision (crystal) oscillator. The receiver-dial calibration must be accurate enough to indicate to the operator between which harmonics the receiver is being tuned. The frequency meter performs the interpolation between the crystal harmonics by means of a stable mechanically swept oscillator ganged to a calibrated dial. The sweeping oscillator effectively scans the spectrum on either side of the receiver local-oscillator frequency, and the presence of crystal harmonic signals will produce pulses of energy which can be made to flash a neon lamp. If this neon lamp illuminates the rotating calibrated scale, a stroboscopic effect is obtained, which produces an apparently fixed scale reading. This reading is a direct interpolation performed at the rate of rotation of the sweeping oscillator. This rate is not critical, but should be high enough to prevent flicker that would be objectionable to the eye, and low enough to prevent loss of precision due to "ringing" in the tuned circuits of the frequency meter.

DESCRIPTION OF CIRCUIT OPERATION

The general layout is similar to the sketch (Fig. 6) in Appendix A. There are four main units in the adapter: (a) spectrum generator, (b) I.F. strip, (c) dial assembly, and (d) power supply.

The function of the spectrum generator is to produce, at a relatively constant level, all the harmonics of the 100-kc crystal oscillator which are necessary to cover the desired frequency range of the receiver. These are injected into the plate circuit of the first radio-frequency stage of the receiver through a short low-capacity cable. The total capacity of the cable must be kept low to prevent loss of spectrum energy on high frequencies due to loading on the cathode-follower output, and also to avoid introducing enough capacity to lower the primary resonance of the radio-frequency transformer, to which it is connected, appreciably; otherwise, the image ratio might suffer slightly on some bands. A secondary function of this chassis is to provide two harmonics at 400 and 500 kc to calibrate the ends of the stroboscopic dial. The "calibrate" position of the selector switch allows some of the harmonic output to feed directly into the I.F. strip for this purpose. The selector switch operates as follows. On "normal" it connects the antenna cable through to the receiver input, and reduces the plate supply voltage to the spectrum generator to such a low value that the crystal oscillator stops oscillating. On "read" it short-circuits the receiver input cable, restores voltage to the spectrum generator, connects the I.F. strip input to the mixer output of the receiver, and connects the spectrum generator output into the first radio-frequency stage of the receiver.

On "calibrate" the spectrum generator feeds directly into the I.F. strip instead of into the receiver, and the antenna cable is connected into the receiver as in "normal". On this position it is possible to hear on the receiver both outside stations and all the crystal harmonics. It is then possible by tuning to a station of known frequency (which must correspond to a crystal harmonic) to trim the crystal oscillator frequency. Then the operator can set up the dial calibration at "45" at both ends of the dial by using the "center set" trimmer condenser and the "range set" trimming inductance. Also, the receiver dial calibration can be checked every 100 kc, if desired. On the "calibrate" position, then, the frequency meter can be set up with the aid of a receiver to be accurate at the "45" points at each end of the dial scale. However, when on "read" position, frequencies are set up or read off with respect to the BFO tone, and as the dial is calibrated to read correctly only when the BFO is at exactly 455 kc there must be some means of determining this point on the "BFO tone" dial. With the main-receiver tuning dial turned to any point where zero ("00") appears on the frequency meter dial, a BFO tone will be heard. This tone should be adjusted exactly to zero beat, and the position of the knob on the "BFO tone" noted as the reference point for accurate frequency readings. Any outside signals picked up on the "normal" position and tuned in to zero beat with the main tuning knob will now be indicated correctly on the frequency meter dial. To operate on any other BFO frequency than 455 kc would require a different scale marking on the dial, and a readjustment of the frequency of the sweeping oscillator in the frequency meter. Such a change would be a major modification and cannot be made in the field. In other words the adapter unit is to be designed and built for specific intermediate frequencies. The present model operating on 455 kc may be used on the majority of modern receivers operating in the HF bands.

CIRCUIT DETAILS

(a) Spectrum Generator (see Fig. 1)

The first stage comprises a 100-kc crystal oscillator, using a Bliley type-KV3 crystal, trimmed by a Hammarlund type MAPC-15 condenser. In the second stage a high-gain pentode (type-6AH6) is connected as a monostable transitron oscillator. The synchronizing pulse is derived through a crystal diode from the 100-kc oscillator and a positive pulse about 2.5 microseconds long is produced at its plate. This pulse drives the final pulse-shaping stage through another crystal diode which passes the fast positive-going leading edge, but tends to retard the negative-going trailing edge of the transitron pulse. The final stage has simply an inductive load in its plate circuit which resonates with associated circuit capacitances. The pulse at this plate is about 0.025-microsecond long and is negative-going. To enable this pulse to be fed over a short coaxial cable to the receiver, a cathode follower is used between the pulse generator and cable. Providing the cable does not exceed about 25 micromicrofarads in capacitance the spectrum energy in the pulse is adequate. Fig. 1 illustrates waveforms at various points in the spectrum generator, and also gives a curve of output current versus frequency with loads of 1000 ohms resistive, and of 22 micromicrofarads in series with 1000 ohms resistive.

(b) I.F. Strip (see Fig. 2)

The first stage is a broad-band stagger-tuned amplifier in which the grid circuit is tuned to 400 kc and the plate is tuned to 500 kc. Input coupling is by means of a standard K-Trans miniature I.F. transformer, whose primary is tuned to 450 kc. Because the coefficient of coupling is low for this circuit, additional top coupling has been added in the form of a 100,000-ohm resistor. This is undesirable in as much as it reduces the re-jection of local-oscillator voltages also present in the input lead from the receiver. Therefore, it would be preferable to use a transformer in the input with a higher coefficient of coupling than to employ the top coupling. The plate circuit of this stage is a single tuned circuit capacity-coupled to the grid of a type-6BE6 converter. The oscillator section of the converter is controlled in frequency by the variable inductance mounted on the dial assembly, and sweeps from about 560 kc to 690 kc, thus covering the calibrated range from 575 to 675 kc, with adequate overlap. The screen of the converter is returned to the screen of the first tube which is controlled by A.G.C. There is a slight compensating action thus applied to the converter frequency as signal levels change, which tends to make the dial reading more constant. The third stage employs a type-6BA6 tube in a narrow-band amplifier operating at 175 kc with a K-Trans miniature I.F. transformer driving it from the converter plate. A.G.C. is applied to its grid. A modified K-Trans miniature I.F. output transformer with a center-tapped secondary is used in the output circuit. Both the above transformers are 262-kc types padded down to 175 kc with additional capacitance. The AGC circuit derives its voltage from the center tap of the discriminator circuit through an RC filter. A delay circuit using one section of a type-6AL5 diode and a high series resistor connected to the 150-volt supply keeps the AGC voltage at zero until the input signal rises to a certain useful level, and then allows the normal AGC action to take place. Without this delay circuit, a steady bias appears on the AGC line, owing to noise and spurious signals from the receiver, which holds down the gain when the input level of the desired signal is low.

The discriminator is designed so that the output goes negative, and then positive, as the frequency increases through 175 kc. Therefore, if the sweeping oscillator coil on the dial assembly is made to sweep from low to high frequency, the output of the discriminator will be of the above form when a signal appears at the input of the I.F. strip within the range 400-500 kc.

The final stage in this chassis is a type-6AQ5 blocking oscillator which feeds a neon lamp from its plate circuit. When triggered, this stage lights the neon lamp for less than 100 microseconds, which is less than 1/300 of the time of rotation of the dial (at 1800 rpm). This presents a fairly clear, steady, indication when the trigger is properly synchronized with the rotation speed. Triggering is accomplished by driving a type-6AU6 amplifier with the discriminator output. The plate of this stage is tied directly to the plate circuit of the blocking oscillator. When the discriminator waveform passes from negative to positive polarity, the plate of V_5 suddenly becomes negative, providing an effective triggering step.

(c) <u>Dial Assembly</u>

This is meant to include the motor, the cam which varies the inductance of the coil in the sweeping oscillator, the calibrated dial, and the neon lamp. The motor itself should have a speed range of about 900-1200 rpm, but because of procurement difficulties we have used a 1750-rpm phonograph motor (General Industries 4-pole Model RM). This is a very quiet motor, and there are only two objections to it. One is that when running with a horizontal shaft it has a slight tendency to hunt unless there is a thrust load put on the shaft. The other is that the speed is a little too high. This would become apparent if transformers of higher Q were used in the "narrow" band 175-kc I.F. section. A small amount of "ringing" or blurring of the indication on the dial might occur. Actually the Q of the transformers used in the circuits is about 50. A higher Q would be desirable in the transformers to provide more gain, and also to produce a sharper discriminator characteristic. It would be desirable from this point of view to achieve an operating Q of about 100 in the 175-kc circuits. This would likely require a reduction of motor speed to about 1200 rpm. The cam may be made of any material that is a good conductor; silver, copper, brass, and aluminum all seem to work equally well. One criterion is machinability, as the cam must be cut or formed to very high accuracy. The general shape is a linear spiral. As grinding limits are of the order of ±.0005", the cam can be cut only to this sort of linearity. If this error is to be small on the reading scale of 0 to 100 kc, say 0.25 kc, then the throw of the cam should be at least 0.200" over the scale length. To prevent difficulties at the end of the cam sweep when the frequency is returned from the high end to the low end of the range, a generous extension of the sweep is made. These difficulties are caused when discriminator voltages, built up near the high end of the range, are carried over into the beginning of the low end of the range. A sharper discriminator characteristic would improve this situation. As a solution, the scale range is compressed from a maximum possible of about 330° to about 270° on the present model. Thus the total cam throw in 360° is about 0.275" minimum. The maximum useable cam throw depends on the linearity of frequency change produced by inserting a cam between two halves of a powdered iron (or ferrite) pot core containing the coil of the sweeping oscillator. It has been found by experiment that the linear portion of the sweep occurs roughly between the points where the cam is half-way and three-quarters of the way through the gap. Therefore, if the useable portion of the cam throw is to be at least 0.200", the pot core should be at least 0.800" in diameter. We have used a Neosid dust pot core of about 1" diameter with the halves separated by about 0.1". There is a reason for using a thin cam section, as a very thick one forces the halves farther apart and makes linearity more difficult to achieve. About 0.025" is a suitable thickness. The cam diameter is more or less prescribed by the pot core diameter, as the cam must be several times as large to avoid large non-linearities due to cam curvature. At a maximum radius of about 2" the pot core subtends a small enough angle not to interfere with the proper operation of the cam. The clear dial is mounted on the same shaft as the cam, but with independent positioning of the setscrew. It should be set up close to a fixed hair line with the neon lamp very close behind the dial, to collect all the light possible. A reflector may be used behind the lamp to enhance the brightness. Fig. 3 shows some of the important dimensions.

A method is required of adjusting the sweeping oscillator at the front panel for calibration purposes. A trimming condenser (Hammarlund type MAPC-50) is used to set center-frequency, and a mechanical linkage adjusting the spacing between halves of the pot core sets the range of frequency sweep. About ± 1/32" control is needed on this setting.

The power supply provides regulated power at +150 volts, mainly for the converter stage. The minimum potential for successful operation of the neon lamp, which passes about 250 milliamperes on pulses, is +260 volts.

REFERENCE

(1) C.W. McLeish and D.H. Rumble, "A Stroboscopic Frequency Meter", Proc. I.R.E., p. 594, March, 1954.

APPENDIX A

PROPOSAL FOR ADAPTING THE NRC FREQUENCY METER TO COMMUNICATIONS RECEIVERS

August, 1953

(see Figs. 4,5 and 6)

It is proposed to provide accurate frequency reading (to ± 500 cycle) over the range of standard communications receivers, by adapting the radio-frequency meter developed at NRC. This would eliminate the present need for wavemeters which require a tedious setting-up procedure, and would permit high-speed tuning to desired frequencies (or high-speed reading of frequency setting).

The physical arrangement would comprise a small unit containing the 100-kc spectrum generator (3 to 4 tubes), the I.F. amplifiers, sweep converter, and pulse amplifier (5 tubes), and the motor-driven dial and condenser assembly. The power supply (2 tubes) would also be incorporated in this unit making it more or less self-contained.

There would be two adapter cables between this unit and the receiver. One would inject 100-kc spectrum signal into the plate circuit of the second R.F. stage (V_2 on the Hammerlund Type SP-600 receiver). The other would take signal from the plate of the second mixer (V_6 on the SP-600). Thus a slight modification of the SP-600 receiver would have to be made either by adding two receptacles wired to these points or by using adapter plugs in the tube sockets of V_2 and V_6. The capacitance of the interconnecting cables could be made to have a negligible effect on the tuning-up of the receiver by (a) coupling the spectrum generator through a very small capacitance at the receiver-end of the cable, and (b) resonating the mixer output cable at the I.F. frequency (455 kc in the SP-600 receiver). Only a slight readjustment of the alignment would be necessary when the frequency meter was attached.

The success of the scheme depends upon making the receiver dial accurate to about ±30 kc, to prevent ambiguity in reading the dial. Tests on two SP-600 receivers show that the local oscillator can be lined up using a crystal oscillator and the dial will then have maximum errors of about this amount up to 30 mc. Thus it appears that the existing dial calibrations are sufficiently accurate.

If this accuracy is not consistent in a number of receivers, it would be practical to adjust the dial calibrations slightly on the most difficult band (14.8-29.7 mc) on each individual receiver. Once in service, the spectrum generator in the frequency meter would serve as an excellent standard against which the dial could be checked occasionally.

The operating procedure with the frequency meter would be to throw a switch in order to read frequency on the 100-kc scale. The operation of this switch would, simultaneously, turn on the spectrum generator, start the motor-driven dial pointer, and break the signal path in the receiver to cut out signals coming in by the antenna. The effect would be that while reading frequency, the receiver would be dead to traffic, but this need only be a momentary operation. For setting up to a desired frequency, the switch would be held over until the coarse and fine dials gave the correct readings, and then released.

APPENDIX B

FREQUENCY METER ADAPTER PERFORMANCE SPECIFICATION

1. OPERATION

The adapter should be capable of reading the frequency setting of either of two receivers connected to it within the following limitations:

(a) On "Normal" position the interaction between receivers should be negligible when the receivers are operated in the normal manner (i.e., without overloading either one).

(b) On "Read" position for either receiver, the other receiver should not be adversely affected, except for weak harmonics of the 100-kc oscillator which may appear. Although the probability of these harmonics causing interference in the second receiver is not negligible, it was agreed at the time of testing that to eliminate them would entail much more complicated circuitry. Inasmuch as the reading time on the first receiver is short and at the discretion of the operator of both receivers, it was decided to leave the circuits as they are now shown in Fig. 1

(c) The frequency meter adapter itself should not radiate harmonics of the 100-kc oscillator or of the sweep oscillator, which will affect receivers within a distance of six feet.

2. SCALE READING PRECISION

(a) The scale should be clearly marked at 1-kc intervals, with at least every second (even) mark numbered.

(b) Parallax should be reduced so that a scale reading may be estimated to within ±0.2 kc, preferably to ±0.1 kc.

(c) Hunting and jitter should not exceed ±0.1 kc on the scale.

(d) Scale magnification may be used so that the figures are easily read 3 feet away from the front panel. If a lens is used, a very low f-stop (about 0.6 to 0.7) should be used to collect all the light possible from the neon lamp.

3. SCALE ACCURACY

(a) If the receiver gain control is set up to an optimum position so that injection level on "Read" is about equal to injection level on "Calibrate", then the overall accuracy should be better than ±0.5 kc at any frequency between 1 mc. and 50 mc.

(b) If the receiver gain is set up at any position that gives a presentable display (this includes all positions from max. to min. on most of the receiver bands between 1 mc and 50 mc), then the overall accuracy should be within ±1.0 kc.

(c) The above accuracies should hold at any line voltage between 95 volts and 125 volts, and any line frequency between 55 and 65 cycles, providing the calibration procedure is carried out under each condition.

(d) The shift of reading when line voltage on the adapter is changed (at 60 cycles) from 95 volts to 125 volts should be less than 0.25 kc without readjusting the calibration.

(e) The shift of reading when the gain control on a Hammarlund type-SP600 receiver is varied from maximum to minimum (consistent with a steady display) should be less than 0.5 kc.

(f) The shift of reading when a signal generator, feeding the I.F. strip of the adapter in the range of 400 to 500 kc, has its output varied from a minimum reading of 50 to 100 microvolts to a maximum reading of 1 to 2 volts should be less than 0.5 kc.

(g) Final calibration curves should show a difference between calibrations on single or double conversion receivers on all bands of not more than ±0.2 kc on one adapter when gain controls are held to optimum positions.

APPENDIX C

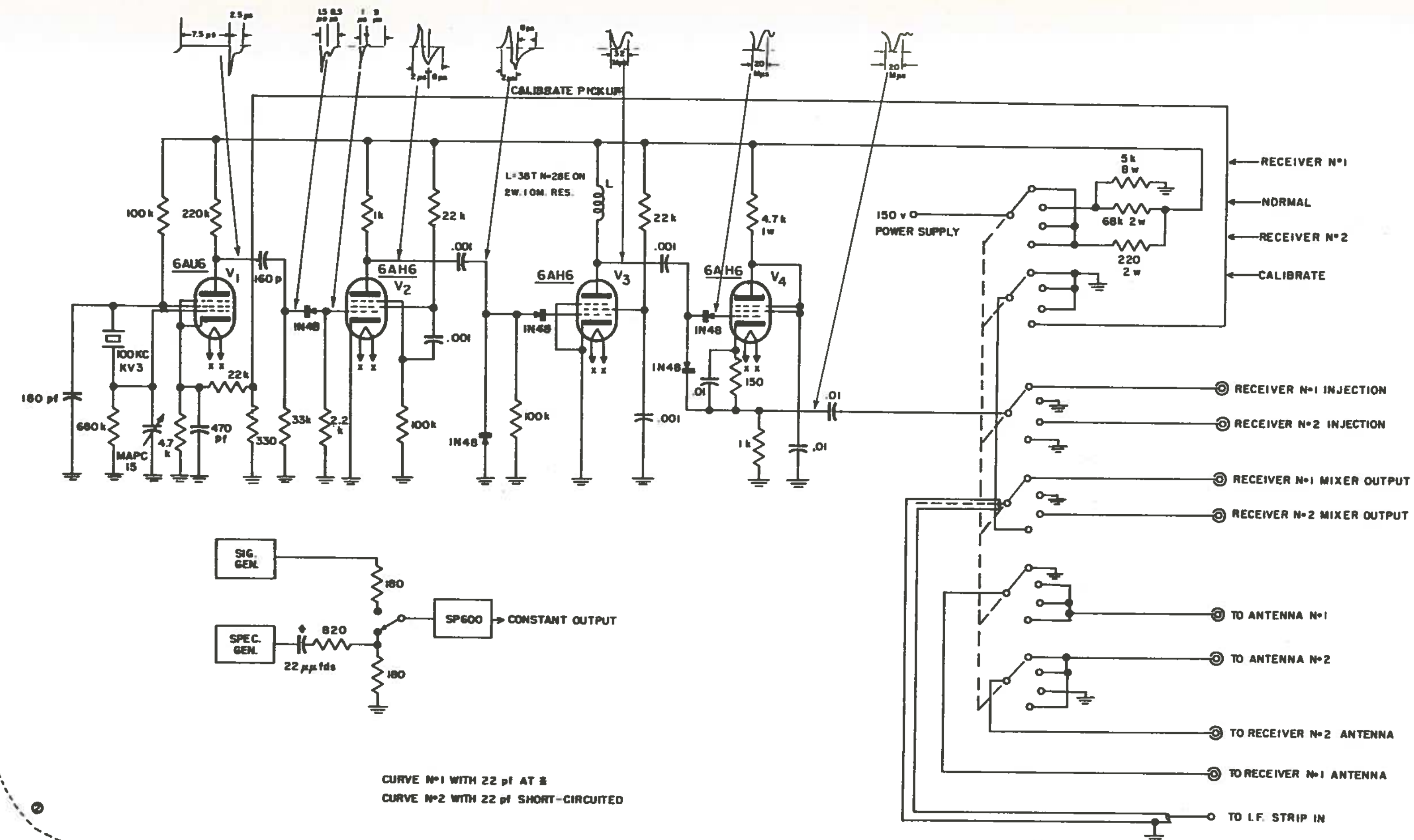
A PROPOSAL FOR MULTI-RECEIVER OPERATION FROM A SINGLE ADAPTER UNIT

This proposal was suggested as a possible application by Mr. Lyle Rocke, and some tests have been made to prove its practicability. The idea is to use one adapter unit for a number of receivers. Each receiver would have its own indicator unit (a motor, dial, and neon lamp) and a control switch for reading frequency. The motors on the indicators would all be synchronous, as well as the motor on the adapter unit itself. A phasing arrangement would be available on each indicator unit to enable it to be set up in phase with the adapter unit motor. All motors would be left running continuously, so that the phasing would remain correct unless some automatic phasing means made it possible to turn them off when not being used. It has been found that the neon lamp operates quite well on the existing circuit with over 100 feet of coaxial cable (RG62/U)) connecting it to the unit.

The spectrum generator would have to be modified to allow it to drive a long coaxial cable with sufficient spectrum energy. This might be accomplished by using a beam power tube (instead of a cathode-follower output stage) to drive a broad-band matching transformer into the coaxial cable. There would be no serious problem in extending the I.F. cable between the receiver and the adapter, as its capacitance could easily be tuned out.

To accomplish the switching at both ends, as is shown in Fig. 7, a stepping relay could be used in the adapter unit which would select the desired receiver as chosen by the operator's manual switch.

One uncertain point is the degree of hunting which might exist under practical conditions between two small synchronous motors, one in the adapter and the other at a receiver.



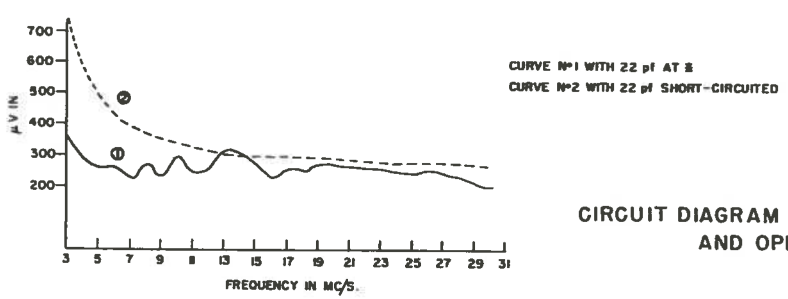
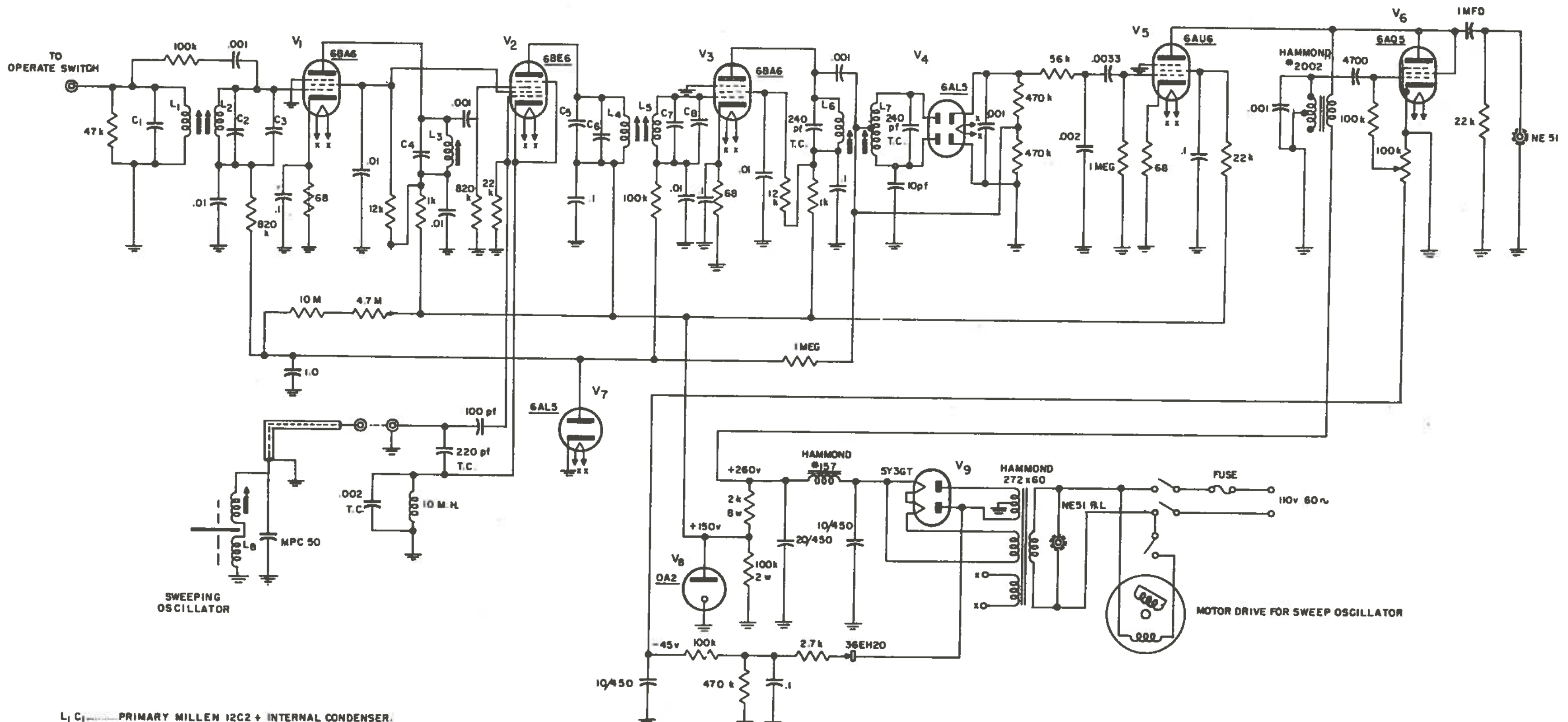


FIG. 1

CIRCUIT DIAGRAM OF SPECTRUM GENERATOR AND OPERATING SWITCH



L1 C1 .... PRIMARY MILLEN 12C2 + INTERNAL CONDENSER.
L2 C2 .... SECOND MILLEN 12C2 + INTERNAL CONDENSER.
C3 .... 100 pfd CERAMICON
L3 .... PRIMARY MILLEN 12C2 LESS INTERNAL CONDENSER
C4 .... 38 pfd CERAMICON

L4 C6, L5 C7 .... MILLEN 12H2

C5 C8 .... 100 pf CERAMICON
L6 .... PRIMARY 12H2 MILLEN
L7 .... CENTRE TAPPED SECONDARY 12H2
L8 .... 320 MICROHENDRIES MOUNTED IN NEOSID T10 POT CORES

FIG. 2
CIRCUIT DIAGRAM OF I.F. STRIP

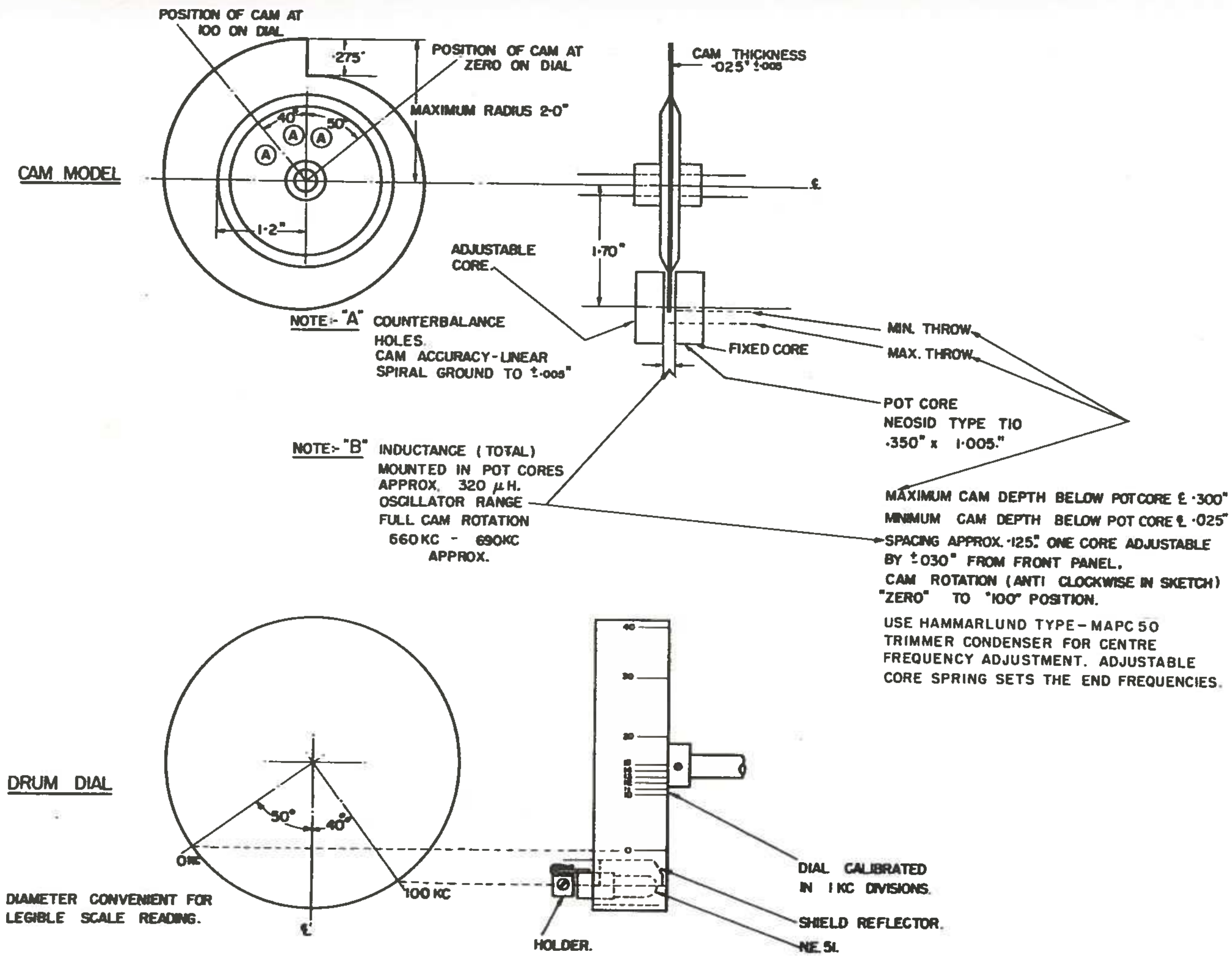


FIG. 3
FREQUENCY METER DIAL ASSEMBLY

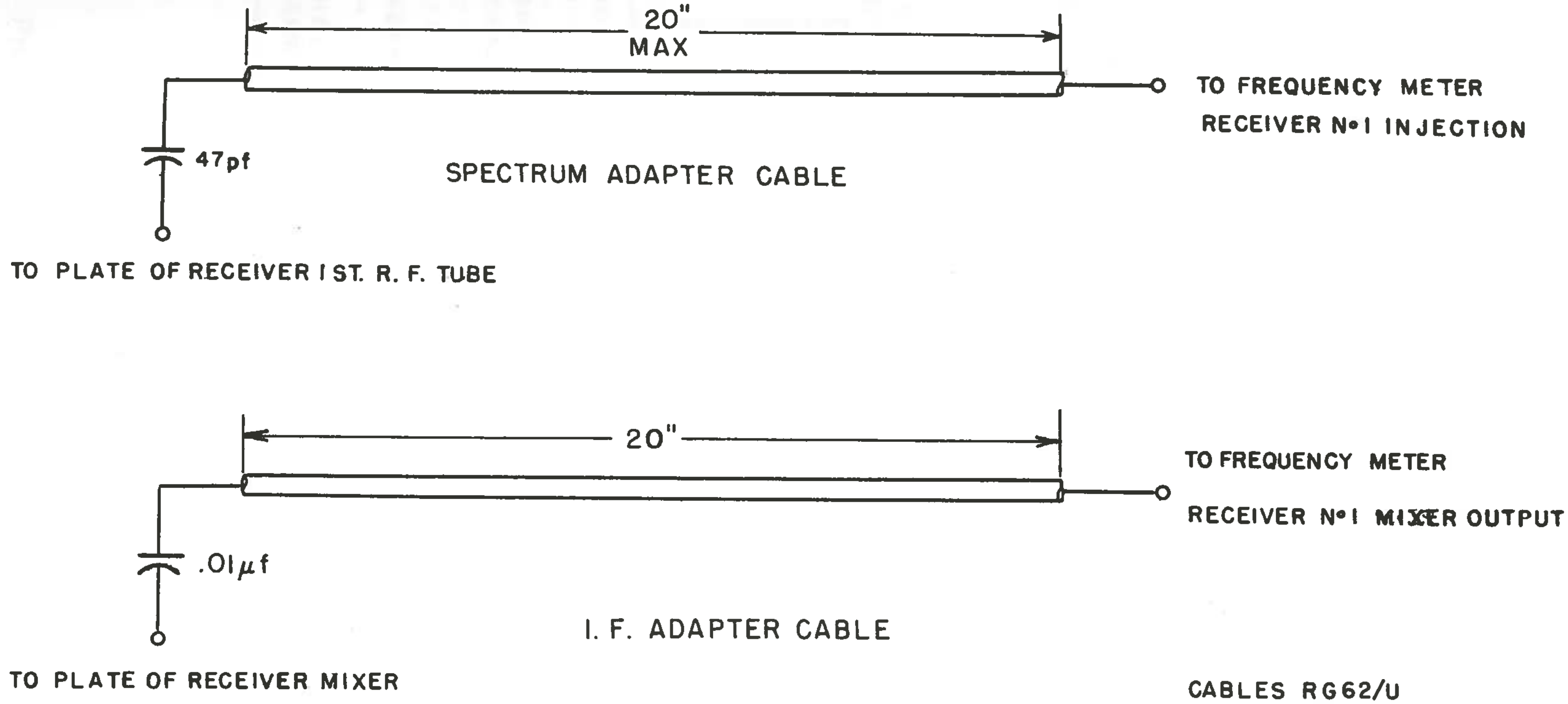


FIG. 4
ADAPTER CABLES

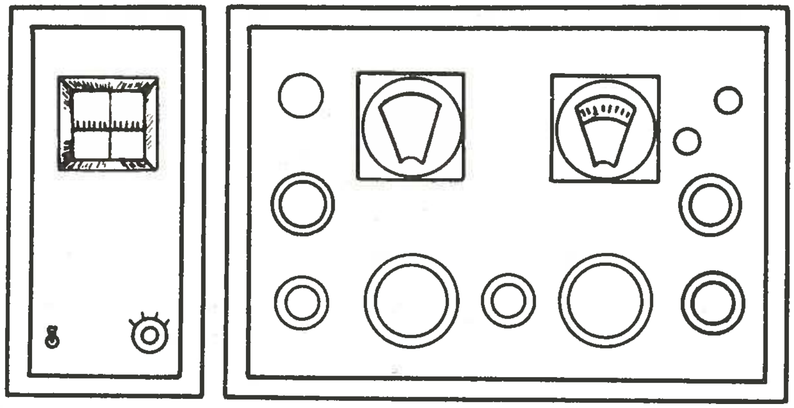


FIG. 5 PANEL LAYOUT OF RECEIVER WITH ADAPTER

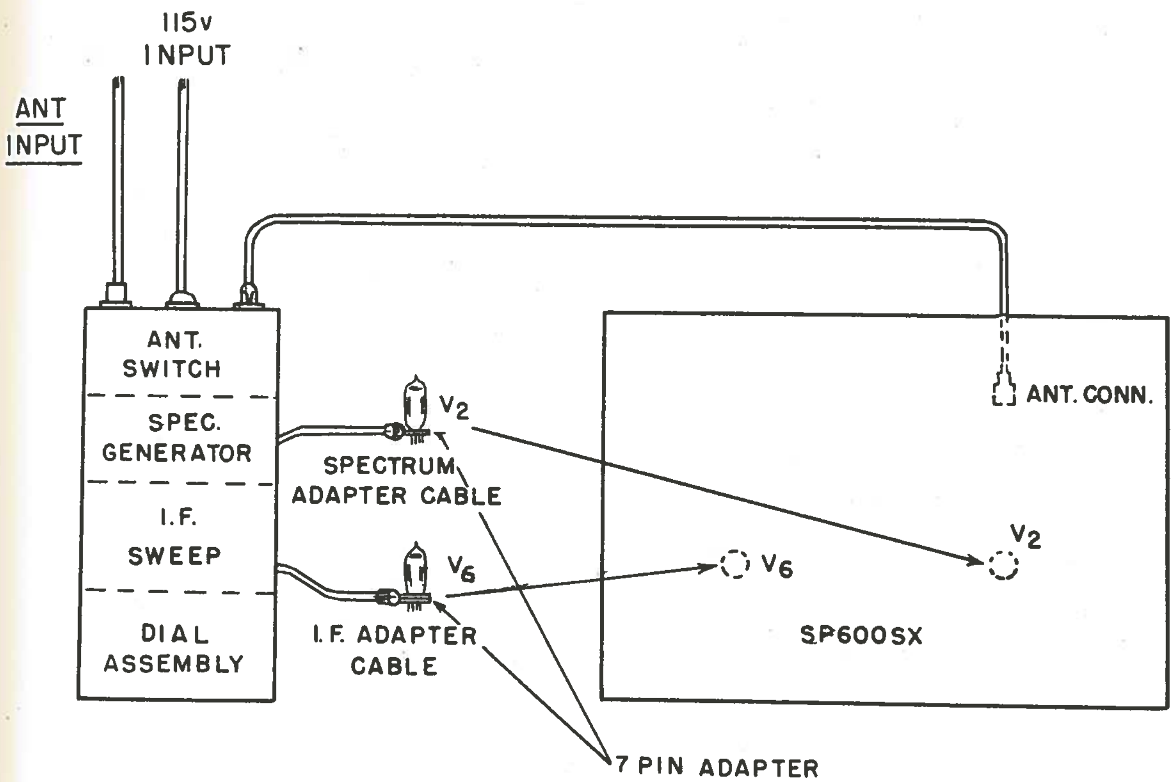


FIG. 6 PHYSICAL CONNECTIONS OF THE RECEIVER TO ADAPTER

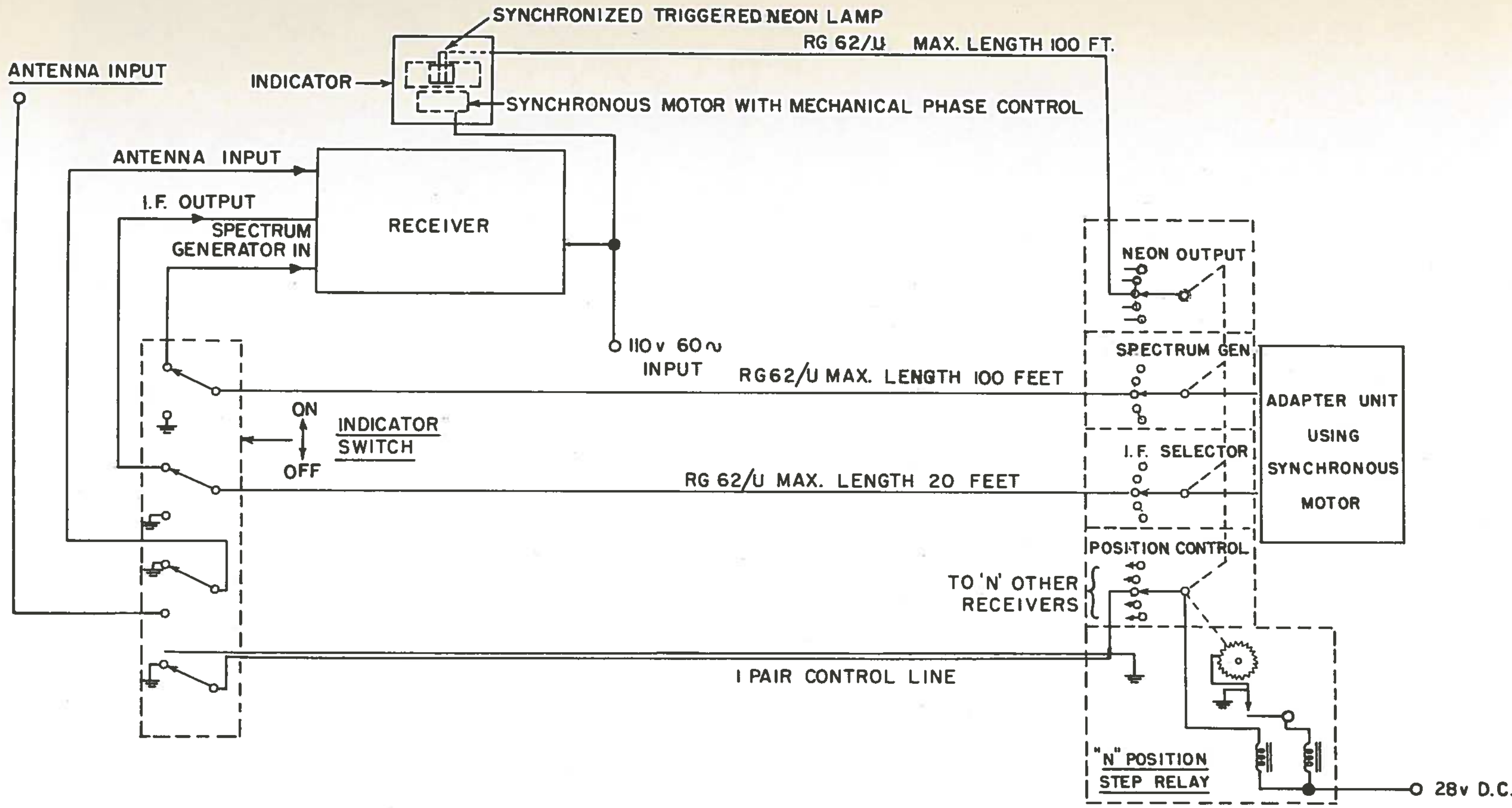
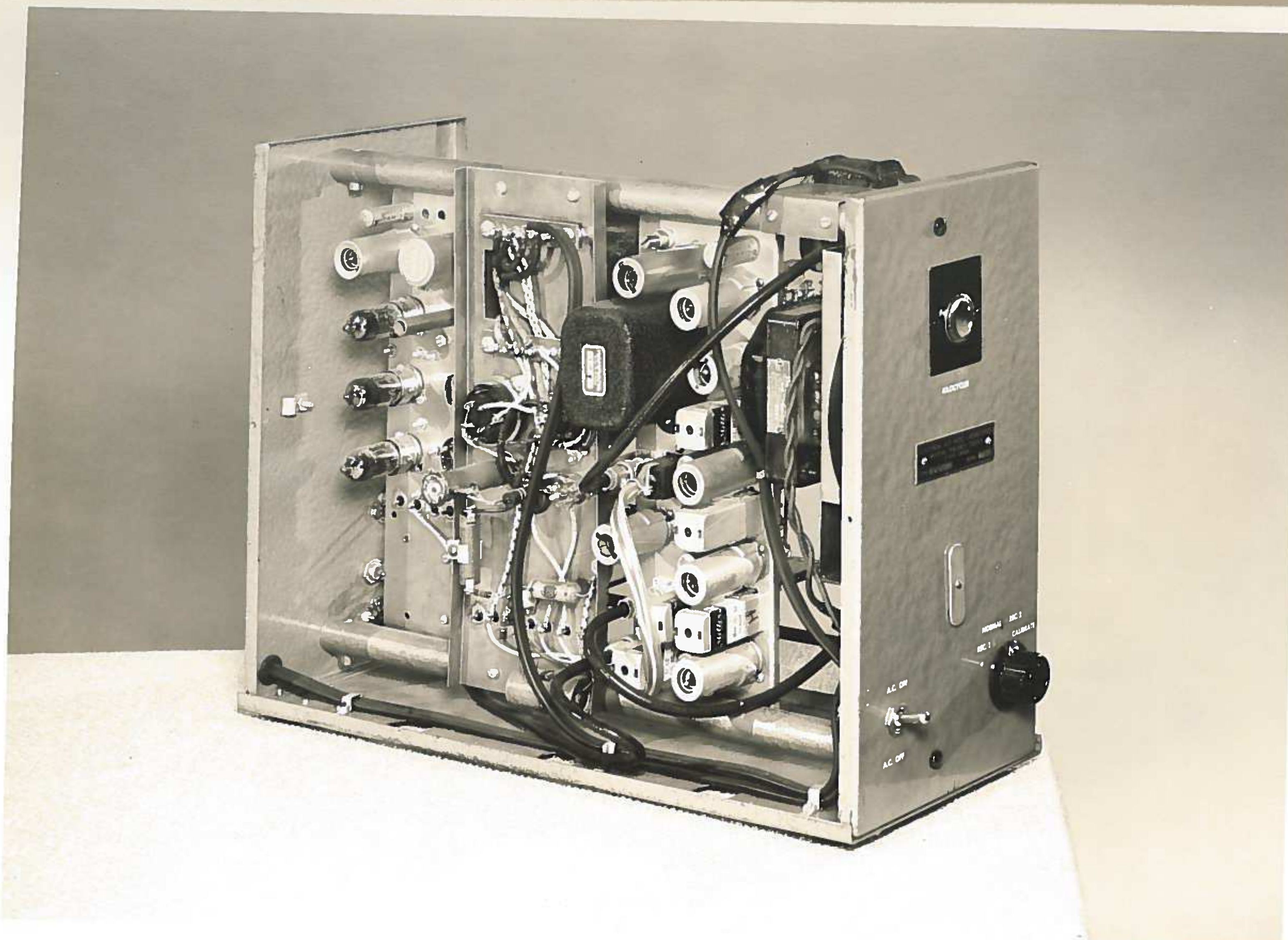


FIG. 7

MULTIPLE RECEIVER ARRANGEMENT

GENERAL VIEW OF FREQUENCY METER ADAPTER



FREQUENCY METER ADAPTER WITH COVER REMOVED