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## REPORT

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EQUIPMENT FOR RADIO TRANSMISSION
OF ELECTECAL STRAIN GAUGE DATA

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# Equipment for Radio Transmission of Electrical Strain Gauge Data

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AUTHORIZATION

1. The work on this problem was authorized by Bureau of Engineering 1st endorsement F31-1(8-3-W8) of 18 December 1937.

OBJECT

2. The object of this problem was to design and construct two transmitters for transmitting the vibration pick-up voltage from airplane to ground and to design receiving equipment to receive the transmitted vibration pick-up on the ground, for study on a string oscillograph.

3. The following specifications were given as the requirements to be met for vibration studies.

Transmitter:

(a) Frequency range from 10 to 300 cycles per second. (modulator)

(b) Vibration pick-up voltage generated 0.01 to 0.10 peak volts.

(c) Transmitter shall not weigh more than 100 pounds.

(d) The size of the transmitter shall be such as to utilize the mounting space for standard naval aircraft radio equipment.

(e) The transmitter shall have a range of five miles under normal conditions.

Receiver:

(a) The receiver output to be 0.5 watt into a load of 1 ohm impedance.

(b) The fidelity tolerance of 10% between 10 and 300 cycles per second be allowed.

(c) The relative phase distortion of the two channels shall not exceed 15 degrees from 10 to 300 cycles per second. No limit is set on the absolute phase distortion of the channels.

(d) The amplitude accuracy shall be ± 5 per cent.

4. The study of vibrations in aircraft presents a unique problem since the vibrations occur in flight where possibility of measurement is made more difficult. Any method of measurement used should be made under conditions which would not change the vibrations. The method should reproduce the character, frequency, and amplitude of the vibrations exactly.

5. In the method using the Ess-strip, the vibrating member would be loaded by fastening the Ess-strips to the member to be measured. Also, the necessary lead wires would be liable to change the nature of the vibrations.

6. It is proposed to employ the Ess-strip as a pick-up device in the present problem. A small voltage is produced by the bending of the Ess-strip, whose wave form is the same as the vibration producing it and whose amplitude is proportional to the amplitude of the vibrating member.

7. Two Ess-strips are required to get the character of the vibrations at any one point. One Ess-strip is fastened to either side of the member at which the vibration is to be measured. The output of one Ess-strip is fed into the modulator of one transmitter. The other Ess-strip is fed into the other transmitter. The two modulated carriers are then transmitted from the airplane to the ground station.

8. At the ground station are two receivers tuned to the carrier frequencies. The signals are detected and the audio outputs from the two receivers are studied by impressing them on a string oscillograph. The traces of the string oscillograph carry the desired vibration information providing the pick-up device is accurately reproducing the vibrations.

9. The Ess-strip consists of carbon impregnated bakelite sheets which are stacked between plain bakelite sheets and then pressed together forming a single sheet. Strips cut from this sheet constitute an Ess-strip. Leads are attached at preselected points. Upon bending this strip as connected in the circuit of Fig. 1, a small voltage change is caused in the circuit due to a change of resistance of the Ess-strip. This voltage is proportional to the bending of the strip. These strips are cemented to the point to be measured.

10. The first step in the development work was to determine whether an amplifier covering the range of 10 to 300 cycles per second could be built to have little or no phase shift and could amplify an input signal of from 10 to 100 millivolts to produce the necessary power for modulation. It was found that voltage amplification could be obtained but it was exceedingly difficult to obtain any appreciable power. Since a pentode may be modulated by applying the modulation voltage to its suppressor without the necessity for more than one or two milliwatts of power, this system was chosen. After trying various types of tubes and circuit combinations, the final circuit, Fig. 2, using three type 6N7 tubes with plates and grids of the twin triodes connected in parallel was used for the modulating equipment. It was found that a separate battery B-supply was necessary for the modulator amplifier.

11. The phase shift was apparently in the volume control resistor and was increased by adding the capacity of the suppressor grids. Large by-pass condensers are necessary throughout the circuit. A phase shift of less than 15° was obtained for the frequency range of 10 to 300 cycles.

12. Trouble was experienced in the development of these circuits due to the fact that below 30 cycles/second the beat frequency oscillator gave poor wave form and its output was no longer constant. Measurements requiring the use of the cathode ray also introduced undesirable fluctuations at some frequencies. With the modulator amplifier satisfactory, the next step was to design the transmitter. Suppressor grid modulation was chosen because of the low power which would be necessary from the modulator. In order to insure frequency stability, a crystal controlled oscillator is necessary. A Type 6L6 tube was tried in an electron coupled circuit. Some trouble was experienced in the vibration of the coil in the oscillator circuit and also undesirable coupling due to location of oscillator circuit parts. Relocation of the coil eliminated this difficulty.

13. In order to keep to a minimum the number of tuning controls, the tuned output circuit of the crystal oscillator was replaced by an r-f choke and capacity coupling was used to the power amplifier stage.

14. Type 802 tubes were first tried and later replaced by Type 837 tubes because these tubes require less modulating power and have a slightly higher output than the Type 802 tubes.

15. Inductive coupling was used between the output of the power amplifier stage and the antenna circuit, the antenna circuit being tapped in order to operate into different types of antennas, all of which were of comparatively low impedance.

16. The circuit diagram of the transmitter is shown in Fig. 3.

17. The receiver was next considered. It was decided to use the NC-100 but to design a resistance coupled audio circuit to replace the transformer coupled audio circuit incorporated in the NC-100 receiver.

18. The second detector output was fed into the resistance coupled amplifier, thereby retaining the AVC features of the NC receiver.

19. In order to use a push pull output stage, some method of feeding a push pull stage from a single tube was necessary. Several types of inversion schemes were used, but the circuit of Fig. 4 shows the one which gave the least phase shift and the required output into a 1 ohm resistive load.

20. Self oscillation in this circuit was found to be coupling into the first stage and was eliminated by using a decoupling resistor in the plate circuit as shown in Fig. 4.

21. In complying with the phase shift requirements of this equipment, the actual phase shift through each set of equipment was kept as low as possible. If the phase shift through each channel is the same, then the phase shift between the outputs of the two channels would be zero. Although the phase shift through the one channel might be many times more than in the other channel, yet if the phase shift would be (n x 360°) more (where n is any whole number) the outputs of the two channels would still show no relative phase shift.

## METHOD OF TEST

22. In determining the phase shift through the modulator and audio amplifier circuits, the signal from the beat frequency oscillator was fed through an audio microvolter to the amplifier so that a signal of known voltage and frequency could be obtained. A cathode ray oscillograph was used to determine phase shift. One pair of plates was connected directly to the beat frequency oscillator, while the other pair of plates was connected to the output of the amplifier. The phase shift then can be observed for various frequencies and for various input levels to the amplifier. A straight line inclined 45° to the vertical shows no phase shift between the input and output signals. The voltages of both pairs of oscillograph plates are equal for a line inclined 45°. If any phase shift occurs through the amplifier it shows up as an ellipse on the oscillograph. The minor axis of the ellipse is proportional to the phase shift. For a 90° phase shift a circular pattern occurs.

23. To determine the percentage modulation, one pair of plates of the oscillograph was connected to the beat frequency oscillator and the other pair of plates was coupled to the antenna circuit of the transmitter.

24. To study the operation of the system, a signal from the beat frequency oscillator was fed into the modulating amplifier, suppressor grid modulating the transmitter. The radiated signal was received on the NC-100 where the output was observed across a 2.5 ohm load.

25. When the Ess-strip studies were made, the Ess-strips were mounted on a piece of power hack saw blade. The blade when fastened in a vise could be vibrated and the outputs viewed on the cathode ray oscillograph. During further tests the saw blade was clamped to the shaft of a d-c motor. A d-c voltage was connected across the field terminals. An audio voltage from the beat frequency oscillator was applied to the rotor terminals through a 30 watt audio amplifier. Only frequencies corresponding to the periods of the saw blade combination could be studied since for other frequencies, insufficient input voltages were produced to modulate the transmitters.

26. In the tests conducted in the airplane, the Ess-strips were mounted on some member of the airplane or were mounted on the saw blade which was bolted to the airplane. The receivers were located at the ground station and the receiver outputs were studied by means of the cathode ray oscillograph.

27. In all these tests a milliwatt output meter was used as a load on the output of the receiver circuit.

28. In using the Ess-strips, it was necessary to shield the leads in order to prevent feedback into the audio circuits.

29. During the flight tests it developed that the pick-up from the Ess-strips [illegible] small and that the output of the ground station receiver was not due to the vibration pick-up by the Ess-strip but due to tube microphonics and vibrations of the equipment.

30. Upon investigation it was found that the chassis was transmitting noises to the tubes, causing microphonics, which were amplified and transmitted to the ground. The tubes were checked for microphonics under vibration and were found to be within Navy specifications. Several of the resistors used were sensitive to vibrations. The resistors were of the glass rod type and were replaced by wire wound resistors.

31. In order to reduce tube microphonics, the input tube of the modulator amplifier was shockproof mounted by means of coil springs between the tube socket and chassis. It was found that this was insufficient so all the modulator tubes were shockproof mounted by coil spring mounts and a rubber restraint to keep the tubes from rocking sideways in the set.

32. The transmitter cases are both shockproof mounted in addition.

33. The following are the weights of the equipment:

| | |
|---|---|
| Dynamotor and cable | 31 pounds |
| #1 transmitter | 24 pounds |
| #2 transmitter | 24 pounds |
| Battery for Ess-strip | 14 pounds |
| Cables | 2 pounds |
| Total – | 95 pounds |

RESULTS OF TESTS

34. The total power input is 26 amperes at 12 volts. Power output into a phantom antenna of 2.15 ohms (plaque resistor) 150 micromicrofarads was 7.3 watts. Using a 12.32 ohm antenna of 200 micromicrofarads, 11.35 watts was obtained. Approximately 70% modulation was obtained on the transmitter over the range 10 cycles to 300 cycles.

35. The receiver audio amplifier has little phase shift from 300 cycles to 20 cycles and an undistorted output of approximately 1 watt in a 2.5 ohm load.

36. In the first series of flight tests in the XSOC-2 airplane #0416 the results were unsatisfactory due to tube microphonics. The oscillograph patterns showed very complex vibrations bordering on hash. The second series of flight tests in the XSOC-2 airplane showed some improvement after the first modulator tube was shockproof mounted. A large amount of complex vibrations appeared at the receiver output. In these tests the oscillograph patterns were free of hash but appeared to contain vibration due to tube microphonics.

37. In the third series of flight tests made in the SBU-2 airplane #9222, after all modulator tubes were shockproof mounted, the receiver output gave patterns, as viewed on the oscillograph, comparable to patterns which might be expected from vibrations in a plane. The patterns showed complex vibrations superimposed on sinusoidal wave forms which were continually changing in character. Occasionally very good sinusoidal patterns appeared. Violent manual vibrations of the transmitters in addition to the normal airplane vibrations still produced [illegible].

38. The turning of the airplane in flight changing the directivity of the transmitting antennas produced changes in the received signals. Higher carrier frequencies would probably accentuate these difficulties.

39. Vibrations of very low frequency were produced by the Ess-strips, probably as low as one cycle per second or less. Very good wave form was also produced during the bench tests using the Ess-strip as a source of vibration.

CONCLUSIONS

40. The system described in these tests is a complex system and the results indicate that the possibility of errors entering into the results is very great unless extreme care is used in operation. The fact that very small voltages are generated by the pick-up strips requires high amplification in the modulators, thereby increasing the difficulties in the amplifying circuits such as tube microphonics which show up in the receiver output as complex vibrations.

41. The system requires battery leads to the pick-up strip, which may cause feed-back into the system and may cause loading of the point to be measured.

RECOMMENDATIONS

42. It is recommended that the equipment be tested for comparison with present systems at the Naval Aircraft Factory, Philadelphia.

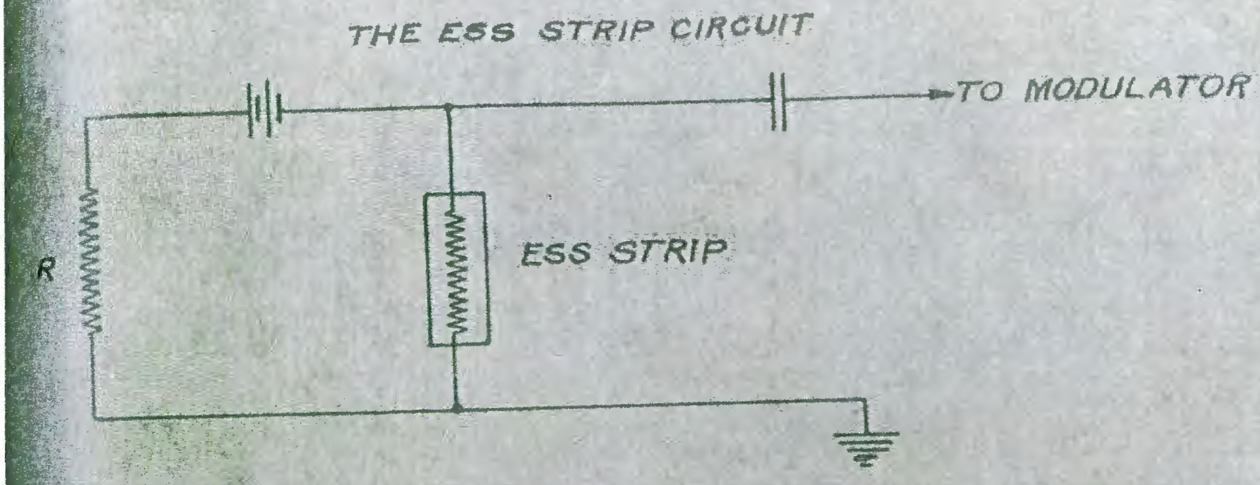


FIG. 1 - R IS EQUAL TO ESS STRIP RESISTANCE ±10 %

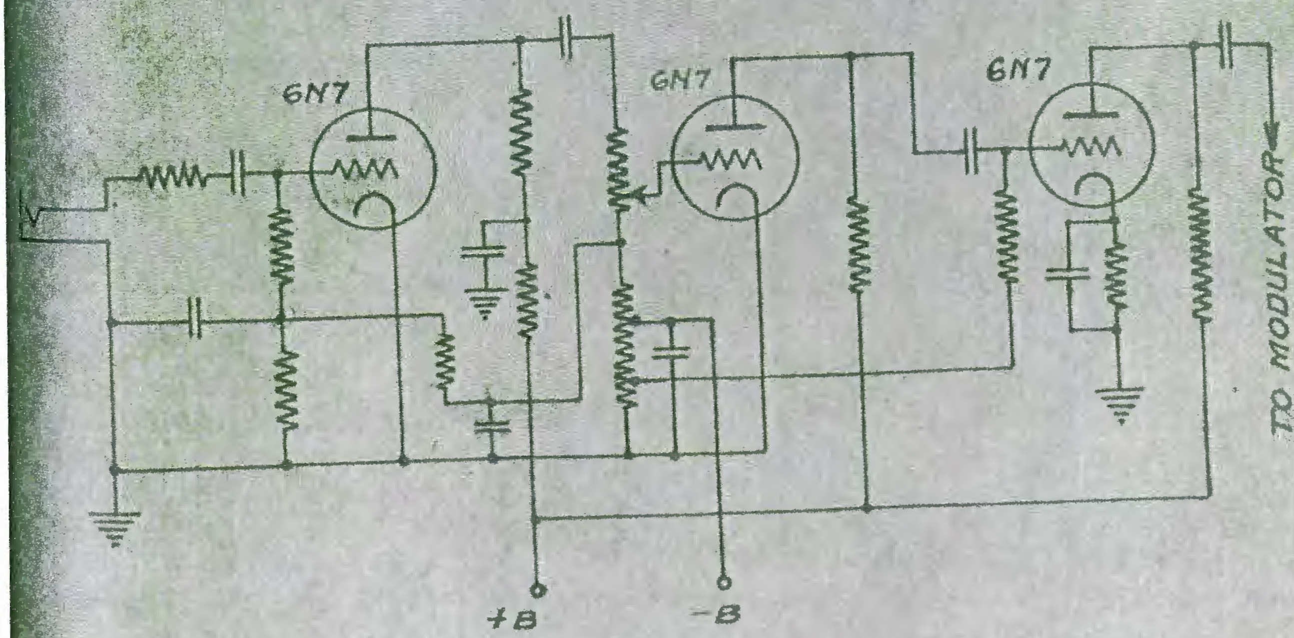


FIG. 2 - MODULATOR CIRCUIT DIAGRAM

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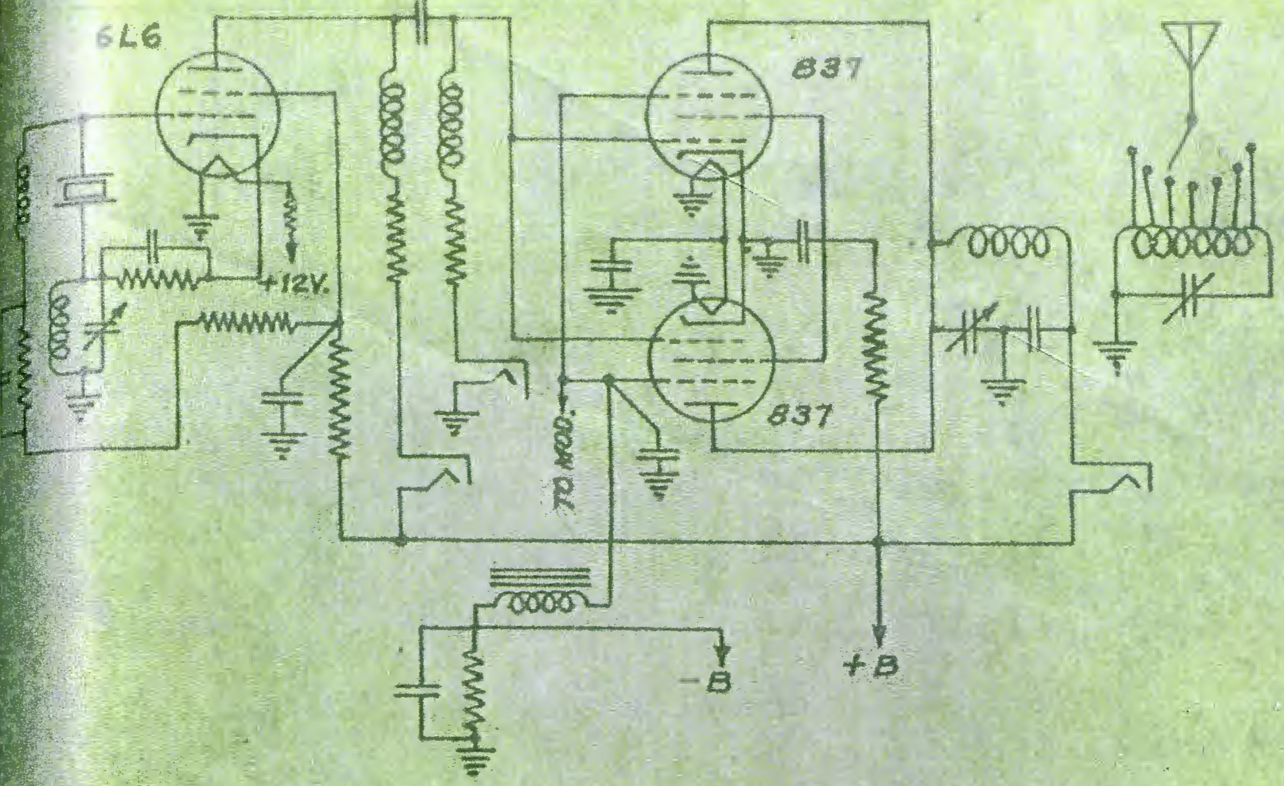


FIG. 3 – CIRCUIT DIAGRAM OF TRANSMITTER UNIT

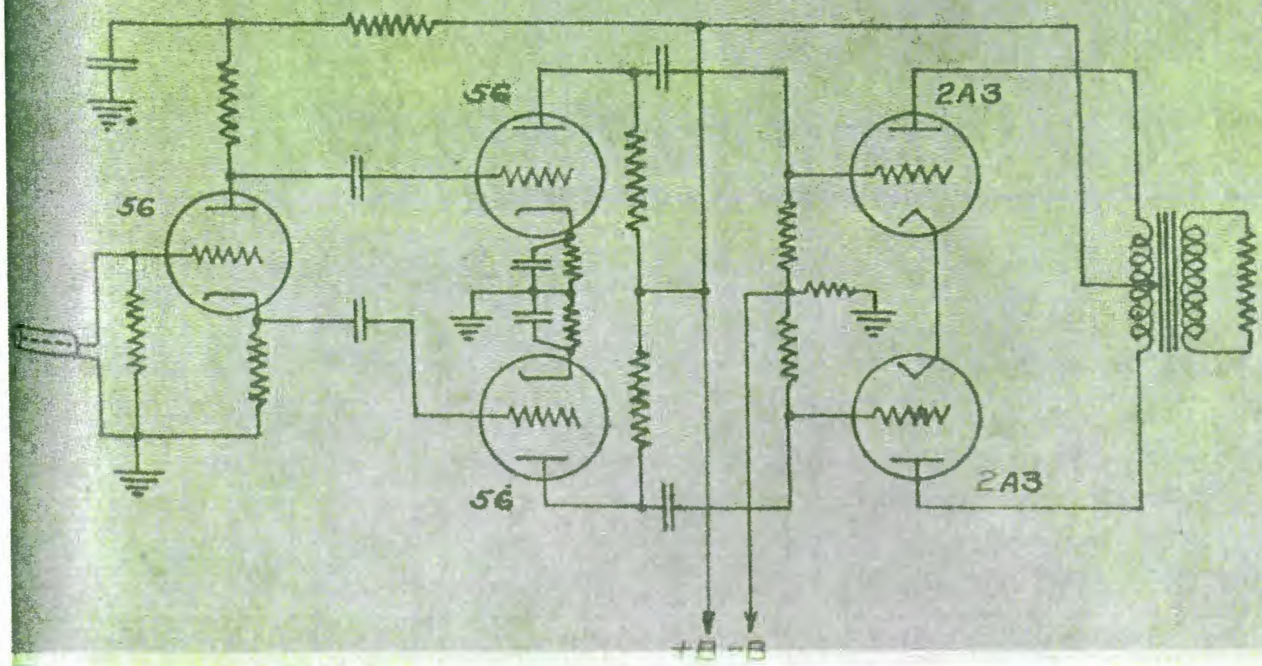


FIG. 4 – CIRCUIT DIAGRAM OF AUDIO AMPLIFIER UNIT FOR RADIO RECEIVER.