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INCIDENTAL FLAME MODULATION OF S-BAND CONTINUOUS WAVE RADIATION

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DEPARTMENT OF THE NAVY ★ OFFICE OF NAVAL RESEARCH ★

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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INCIDENTAL FLAME MODULATION OF S-BAND CONTINUOUS WAVE RADIATION

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ABSTRACT

This report sets forth the instrumentation and results obtained for incidental modulation measurements along with some associated light, sound, and vibration data. The purpose of these measurements was to determine modulation effects in S-band radiation paths due to flames of acid-analine reaction motors of the "Lark" missile. Analysis of the modulation data obtained on two field trips, as well as recommendations for future efforts in this branch of the general problem, are included.

PROBLEM STATUS

This is the third in a series of interim reports by Radio Division III on "Propellant Gases".

AUTHORIZATION

NRL Problem No. R25-03 (BuAer Problem No. A-140R-C).

INCIDENTAL FLAME MODULATION

OF S-BAND CONTINUOUS WAVE RADIATION

INTRODUCTION

This report covers a portion of the field measurements made on the "Lark" acid-analine jet motors, specifically measurements having to do with any incidental modulation caused by the jet flames.* The data were taken, during the periods 12-20 March and 23-30 June 1947, by two field parties of Radio Division III equipped with an NRL truck-trailer mobile laboratory and operating in conjunction with the combined facilities of the Naval Ammunition Depot and Reaction Motors, Inc., both of Lake Denmark (Dover), New Jersey.

Of particular interest was the determination of the possible existence of sustained-tone amplitude modulation of low-frequency character, more particularly that which might have sustained frequency components below 100 cps. Random noise modulation of the radiant energy was also of

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* NRL Report No. R-3197, November 1947, "Propagation of Electromagnetic Waves through Propellant Gases," by F. Malcomb Gager, gives a general treatment of the problem of propagation through propellant gases, and serves as a fitting introduction to this report and to other reports in this series. NRL Report No. R-3209, December 5, 1947, "S-Band Propagation with Acid-Analine Flame Barriers," by F. Malcomb Gager, E. N. Zettle, H. M. Bryant, and F. E. Boyd, covers field measurements of quasi-optical propagation patterns with horizontal polarization at S-band.

special interest because of the general masking effect of a higher noise level on the operation of radio-control systems, which results in shorter ranges to which a missile may be controlled. It was also important to determine what correlation might exist between incidental modulation and other variations functionally related to the flame, such as light intensity, sound-field intensity, and the characteristic vibration (amplitude vs. time) of the reaction motor and mount.

EXPERIMENTAL ARRANGEMENT

Figures 1 and 2 show, among other things, the arc of dipoles employed as far-field electromagnetic detectors. These were used to determine the redistribution or loss of energy along principal paths from the transmitting antenna as indicated by any difference in received amplitude at the dipole probes due to flame-on, flame-off conditions. The chosen transmitting antennas, Figures 3 and 4, were arranged to direct their maximum vector down and slightly across the flame plume and trail as shown by Figure 2, or directly across the flame at normal incidence. In the former case, of special interest were those probe positions along the arc which intercepted: (1) the line-of-sight path through the flame plumes and trails, (2) the possible refraction paths through the flame and trail, and (3) the expected reflection paths from the flames. It was believed that the physical conditions attending these particular paths might be sufficiently dissimilar to change materially the character of the resulting modulation. The physical conditions attending transverse-flame paths at different points along the flame might likewise be considered.

Figure 1 - Arc of Dipole Probes Used for Propagation and Incidental Modulation Studies

GENERAL INSTRUMENTATION

The dipole probes located on the arc (Figures 1 and 2) were provided with S-band crystals located immediately behind the back plates. This arrangement provided rectified dc and modulation components for the recording equipment (Figure 5) in the mobile laboratory (Figure 6) which was located at a relatively remote point where the incidental modulation was least subject to the intense sound-field attending the firing of the motors. In addition to the above antenna facilities, special dipoles without crystal detectors were arranged to feed reception equipment in the mobile laboratory. These dipoles were placed at selected

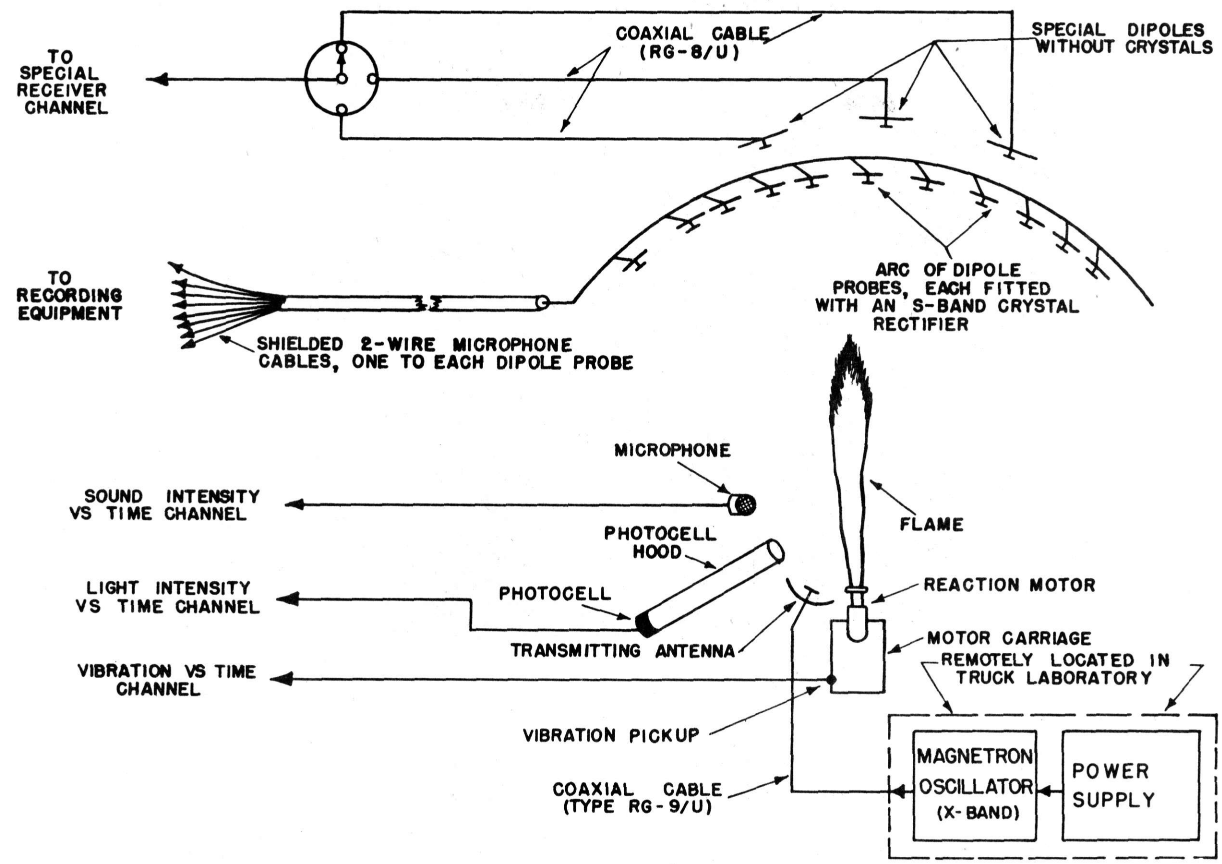

Figure 2 - Simplified Diagram of Incidental Modulation Observation Channels

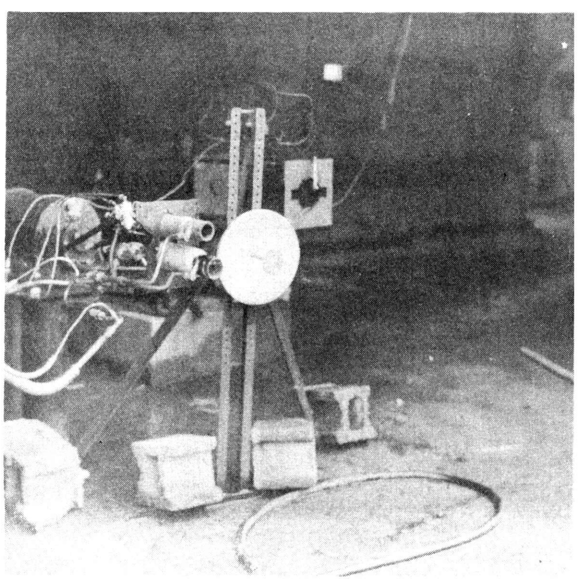

Figure 3 - Dish-Reflector, Dipole Type Antenna, 25 Degree Beam

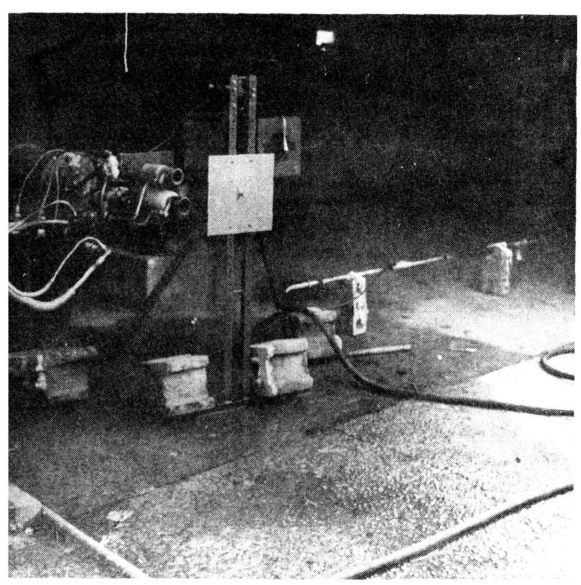

Figure 4 - Dipole Antenna with Back Plate, Wide Beam

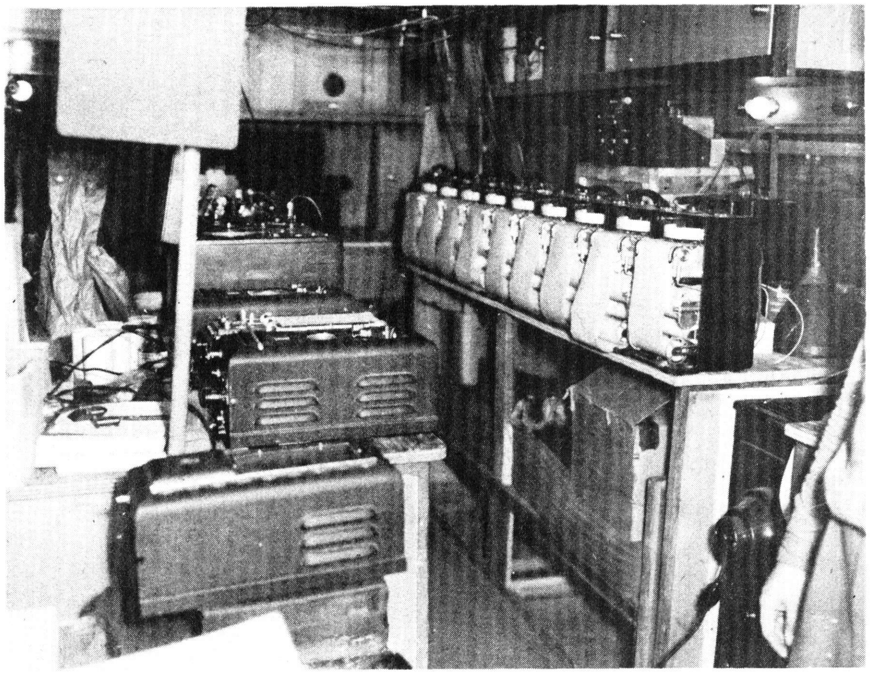

Figure 5 - Interior of Trailer Showing
Some of the Receiving and Recording Equipment

Figure 6 - Mobile Laboratory, Containing Transmitting,
Receiving and Recording Equipment in Operating Position

positions on the arc between the dipole probes (Figure 2). In addition, any dipole on the arc, with its crystal removed, could serve a similar purpose.

Figure 2 also indicates in a schematic manner the equipment for measuring light intensity, sound-field intensity, and vibration amplitude associated with the flame, for the correlation studies mentioned previously. Details of the instrumentation for each of the special channels are subsequently considered in turn.

INCIDENTAL MODULATION INSTRUMENTATION

The details of the incidental modulation instrumentation are shown in Figure 7. It should be noted that several channels are available for data observation purposes, each applicable for both down-flame and transverse-flame conditions.

The first channel (Figure 7A) is the one arranged to operate the disc recorder, (Presto, Type K-8), or a magnetic-tape recorder (Brush, Type BK-401). These recorders, capable of a frequency range 80 to 8000 cps and 100 to 5000 cps respectively, were connected through shielded cable for direct actuation by the modulation components from the dipole probes fitted with crystal detectors.

The second channel (Figure 7B) was used to feed an AN/SPR-2 receiver. This receiver was modified to provide voltages proportional to both audio and carrier levels. This explains the double output indicated in the figure. Input to this receiver arrangement could be obtained from any of the dipole probes on the arc when the crystal of the selected probe was removed. Facilities were also available to operate the equipment from special pickup dipoles arranged between, but slightly behind, those on the arc of dipole probes. Special switching between several of the latter type pickups was available by employing a coaxial radio-frequency switch (Bird, Model 74) as shown. One output from the modified SPR-2 receiver provided for observation of the carrier level and amplitude modulation of the carrier at frequencies below 5 cps. The other receiver output, not actuated unless incidental modulation took place, was arranged to operate two output subchannels.

One subchannel was fed directly to an electronic frequency meter (Hewlett-Packard, Model 500A). By the inherent nature of this instrument it would indicate the strongest sustained modulation tone, and record any slow frequency change in the latter by its connection to a recorder (Esterline-Angus, Model AW, 1 ma). The other output subchannel was fed through an amplifier (Western Electric, Type 124E) to one set of deflection coils of a dynamometer wattmeter (Weston, Model 310). The other set of deflection coils of the wattmeter were fed from a variable-frequency audio oscillator (Jackson, Model 652). This provided an extremely sensitive arrangement whereby manual variation of the frequency of the audio oscillator produced a means to sweep across the incidental modulation spectrum and to observe the frequency and relative amplitude of sustained low-frequency modulations.

In addition to the apparatus described above, a dual-channel pen recorder (Brush, Type BL-202) was arranged to plot the low-frequency waveform vs. time for both outputs of the SPR-2 receiver.

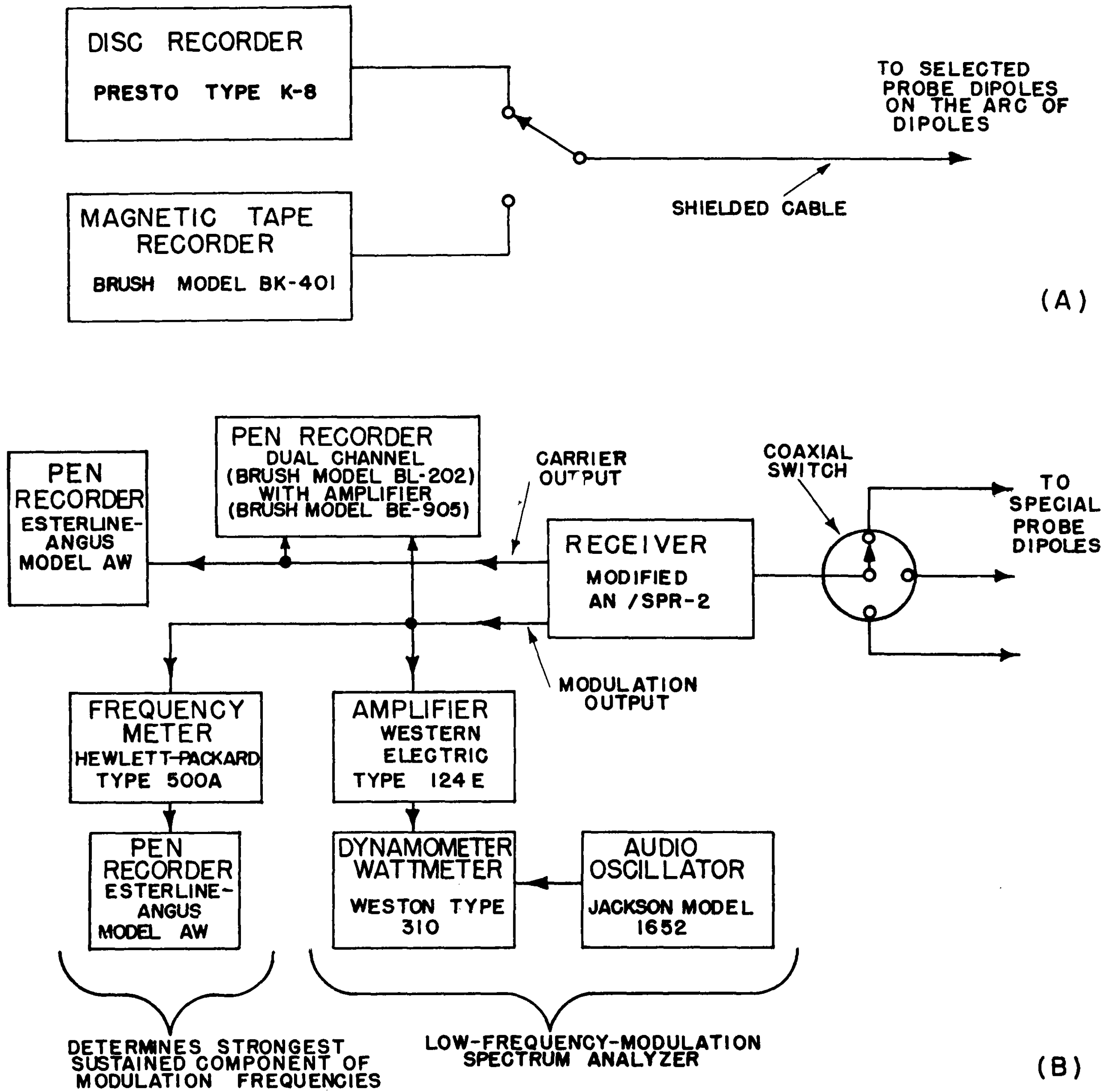

Figure 7 - Incidental Modulation Instrumentation

FLAME LIGHT-INTENSITY INSTRUMENTATION

A diagram of the instrumentation for light intensity vs. time observations is shown in Figure 8. A photronic cell (Weston, Type 594) was mounted in a brass collimating tube designed for special tripod mounting. The output of this cell was fed to an amplifier (Western Electric, Type 124E) the output of which actuated an electronic frequency meter (Hewlett-Packard, Type 500-A). This latter instrument was arranged to record the frequency of the

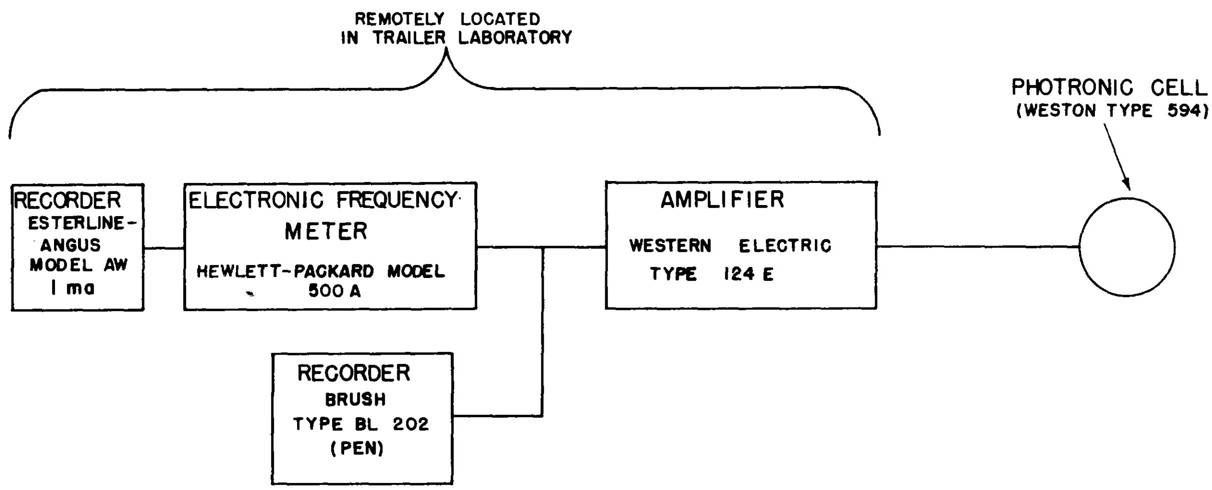

Figure 8 - Light Intensity vs. Time Instrumentation

strongest sustained tone, or slow change in tone frequency by connecting it to a recording meter (Esterline-Angus, Model AW, 1 ma.) as indicated. In parallel with the frequency-meter channel just described, an amplifier (Western Electric, Type 124E) was connected so as to drive a pen recorder (Brush, Type BL-202). This pen recorder allowed exploration throughout the frequency band 0.5 to 80 cps, a band of particular interest to the control system chosen for the "Lark" missile.

SOUND FIELD INSTRUMENTATION

The sound field instrumentation consisted of the apparatus shown by the diagram in Figure 9. A sound-level meter (General Radio, Type 759B) was fitted with a long input cable so that the microphone could be placed in the most intense sound field while the associated electronic equipment was located at a relatively remote point in the trailer laboratory where it was less subject to vibration and shock. The output from the sound-level meter was arranged to be recorded on a disc recorder (Presto, Type K-8) and a magnetic-tape recorder (Brush, Type BK-401). In addition, the output from the sound level meter was arranged for amplitude-time recording on a pen recorder (Brush, Type BL-202). The above equipment and facilities allowed examination of both light and sound intensity vs. time for the "Lark" motor flames. The significance of these measurements is found in an attempt to correlate these observations with incidental modulation data.

MOTOR VIBRATION INSTRUMENTATION

Figure 10 shows the arrangement of equipment used to study the motor vibration. Although it was appreciated that the dynamics of the motor thrust stand (Figure 3) are not the same as those of an airborne "Lark" airframe, it was felt that motor mount vibration might have some relation

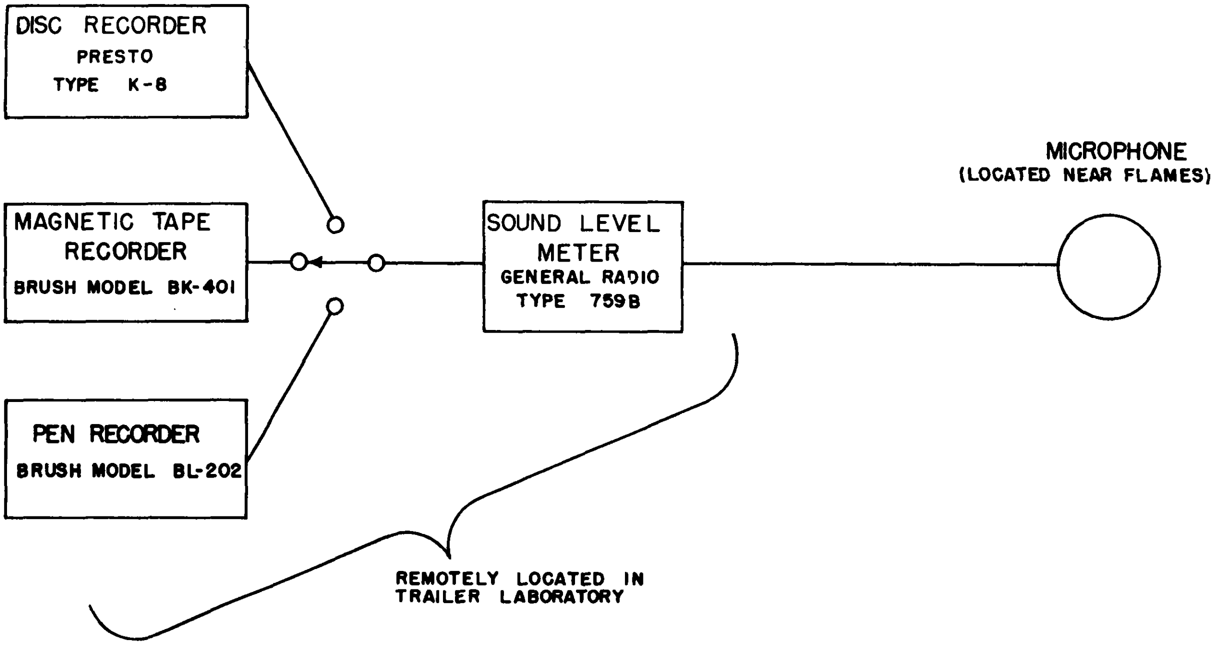

Figure 9 - Sound Field Instrumentation Showing Choice of Outputs

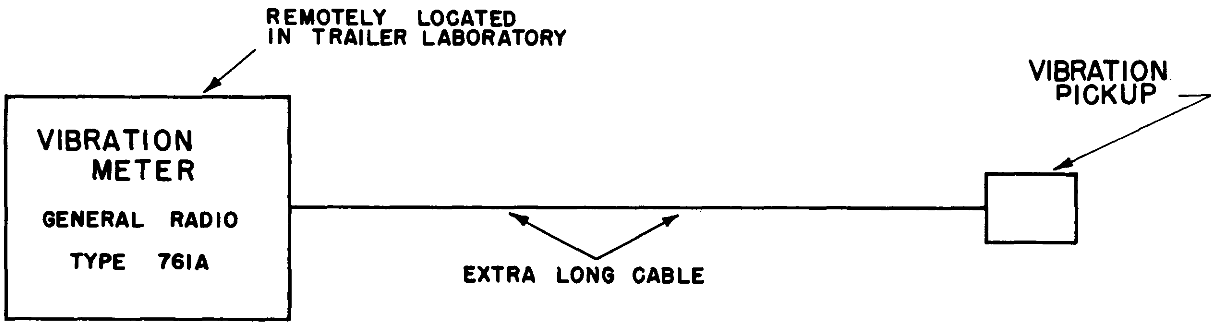

Figure 10 - Vibration Instrumentation

to other observed phenomena. The pickup (General Radio, Type 761-A) was secured to the reaction cylinder of the motor mount through which thrust was transmitted to a recording gauge. As with other equipments, a long extension cord was used between this pickup and the vibration meter (General Radio, Type 761-A) located in the trailer laboratory.

EXPERIMENTAL PROCEDURE

In the experimental procedure with the aforementioned equipment and facilities, numerous combinations of simultaneous recordings and measurements were taken. Data were taken for radiant energy incident upon the 400-lb thrust motor with and without the 220-lb thrust motor. Observations were also made with the incident energy directed between the flames in a down-flame direction with single and double motor operation. In addition, a number of observations were made with the 220-lb motor running continuously and with the 400-lb motor operating intermittently to simulate the "Lark" missile operation for maintenance of Mach number range. Sample recorder charts for the incidental modulation, vibration, light, and sound channels are shown in Figures 11 and 12. For the most part, the manipulation of each channel and of the individual equipments requires no further mention. It is of interest, however, to point out some special measurement precautions as well as the means whereby the most important sustained-tone detection channels were evaluated previous to their use on location.

An arc of dipoles was arranged on the roof of Building 28, Naval Research Laboratory, with a suitable transmitting antenna disposed to simulate a nearly down-flame incidence. With this arrangement the wattmeter analyzer and Hewlett-Packard electronic frequency meter (Figure 7B) were observed for the inherent power-supply hum from the magnetron r-f source. As a result of this preliminary evaluation, the magnetron source was slightly redesigned to reduce the power-supply modulation to a minimum. The equivalent amplitude modulation due to the hum was then measured. Further observations relating to the ability of the equipment to respond properly to a modulated electromagnetic field were made by placing a multi-bladed fan in the vicinity of the transmitting antenna with means provided to vary the speed of the fan motor. The modulation produced was readily detectable throughout the range of speed control afforded. It was also determined by this arrangement that the sensitivity of detection, controllable over a very wide range, was more than adequate.

A careful check of the photoelectric channel was made on location at Reaction Motors Incorporated to determine contamination of this channel by microphonic action. This was accomplished by firing the "Lark" motors and observing the photoelectric channel output when the photocell was capped.

RESULTS OF MEASUREMENTS

The results herewith presented are drawn from a large mass of data. No particular difficulties were experienced in obtaining the data, although from time to time certain S-band crystals (Type 1N21) were found to introduce erronious results. In these cases, the faulty crystals were replaced. The results of the measurements were as follows:

(a) Incidental modulation due to the flame was observed throughout all the measurements.

(b) Regardless of the point of observation, the incidental modulation was observed to be of a random noise nature with major components concentrated in the low audio-frequency range.

(c) The character of the noise detected by the sound-field channel was much like that observed by the photoelectric channel. This similarity extended even to the peculiar character of the propellant-valve noise associated with starting and stopping the motors. It should be emphasized here that microphonics from the photocell channel were not present.

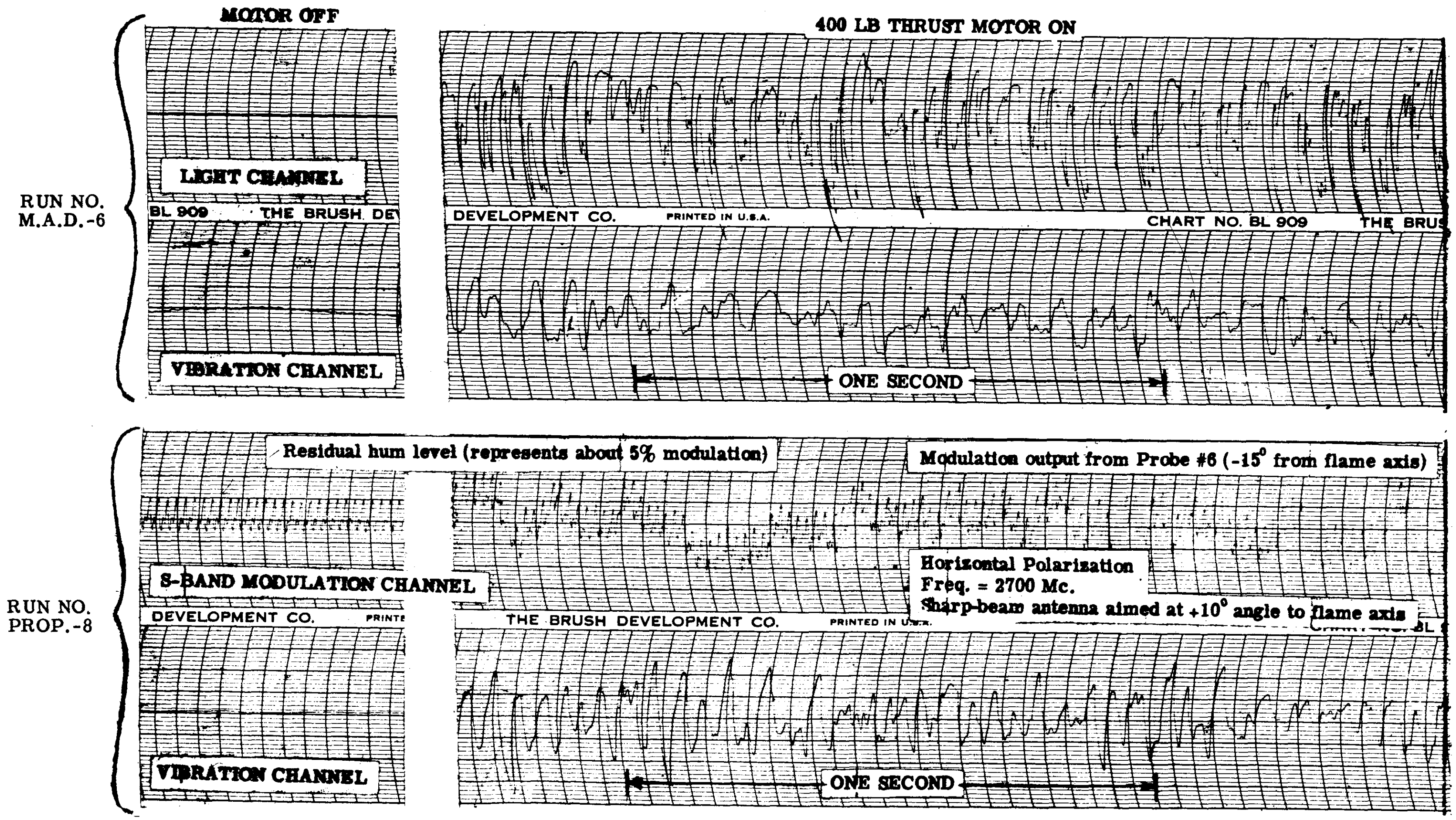

Figure 11 - Sample Chart Sections from Pen Recorder (Brush Type BL202) Showing, Output of S-band Modulation, Vibration, and Light Channels Before and During 400 Pound Thrust Reaction Motor Run

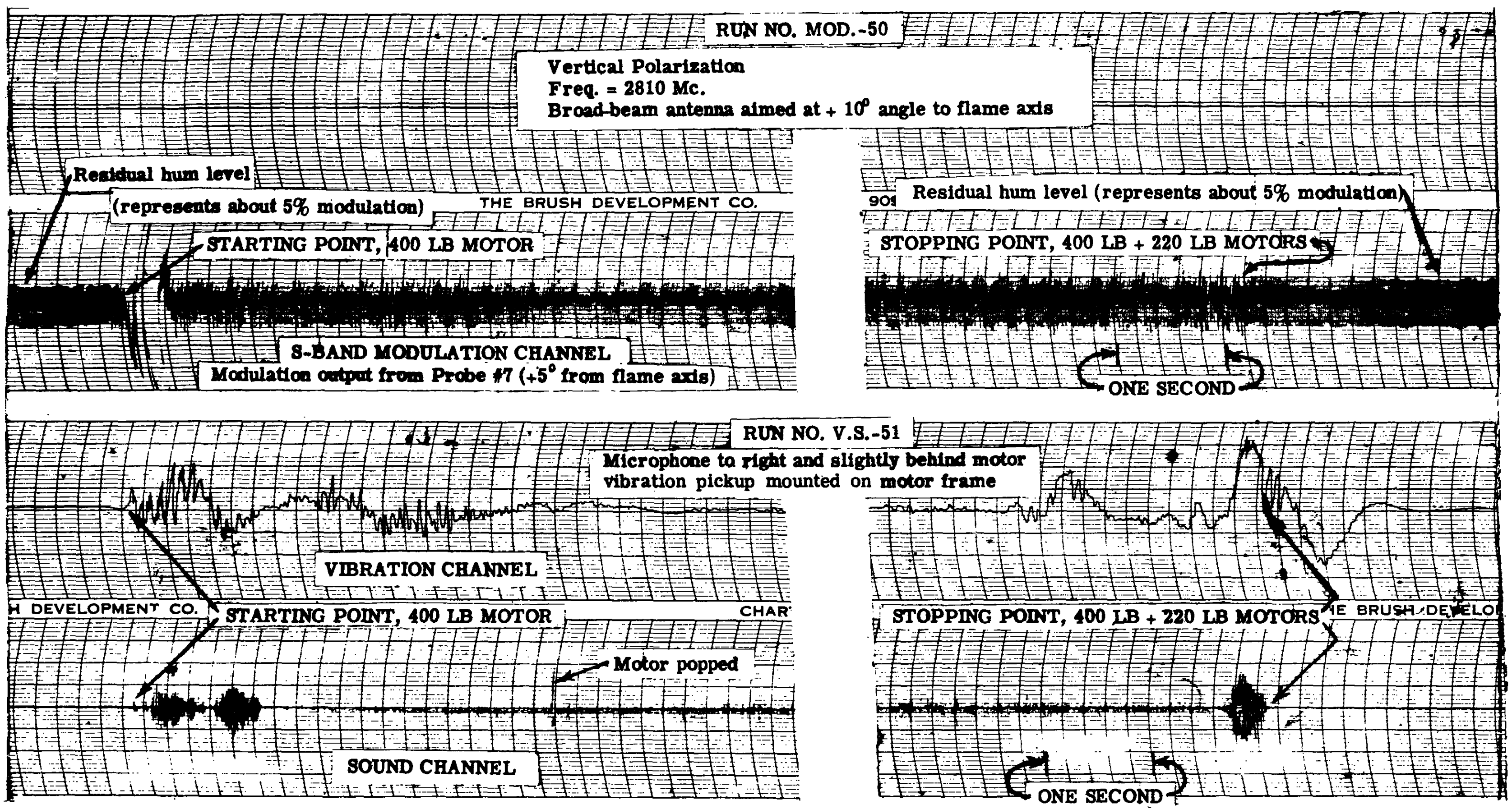

Figure 12 - Sample Chart Sections from Pen Recorder (Brush Type BL202) Showing Output of Incidental Modulation, Vibration, and Sound Channels, with Slow Speed Used to Illustrate Starting and Stopping Transients

(d) The 400-lb-thrust flame did not produce modulation peaks exceeding that of the power-supply hum; i.e., the flame modulation was less than 5 percent. Below 120 cps, the pen recorders indicated occasional noise peaks about equal to this figure. In the frequency range 80-5000 cps, components of noise above 120 cps were, on the average, 1/100 of the power supply figure, or approximately 0.05 percent modulation.

(e) Careful search of the incidental modulation spectrum below 120 cps, and particularly in the region of 24 cps, was of special interest to the "Lark" program. With the wattmeter analyzer set at a sensitivity which would produce better than half-scale deflection on the residual power supply modulation component (about 5 percent), numerous observations were made in the range 24 cps (±5 cps) and no measurable steady or erratic sustained tone modulation was observed.

(f) With the equipment arranged at a sensitivity setting equal to or greater than that indicated by (c) above, numerous slow and deliberate explorations of the frequency range, fifteen to several hundred cycles per second, were made with negative evidence resulting.

(g) The sound intensity within six feet at the side of the "Lark" motors was 124 db above 6 milliwatts; at 40 feet from the motors at an angle of 30° from the flame axis it was 138 db.

(h) The vibration amplitude vs. time pattern of the reaction-motor thrust stand showed no correlation with other observed phenomena.

(i) A comparison between the propagation variations and light emission variations was obtained for two firings. The results indicated closer correlation between the propagation and light levels than between any of the other quantities measured. Further investigations along these lines are in order.

CONCLUSIONS

The following statements relative to the results obtained are offered as conclusions.

(a) The means of determining the existence of sustained-tone modulation were adequate for the purposes intended. Residual-hum modulation from the magnetron was used as a reference. This could have been balanced out if other means of detection had dictated a necessity for such action.

(b) It is doubtful that the random nature of the incidental modulation observed was materially affected by ground effect or by the fact that the motors were operated in static thrust.

(c) It is doubtful that dynamic flight or change in altitude would so order the random nature of the incidental modulation as to make it of a sustained-tone type.

(d) The data obtained directly from the crystal detector probes was found to be generally reliable. Here it was frequently possible to note the starting and stopping transients of the reaction motors by the character of the noise modulation produced.

RECOMMENDATIONS

One of the limited production "Lark" receivers should be subjected to the severe vibration and sound field levels attending the firing of the "Lark" motors in static thrust so as to observe the character of the output of the control channels in the absence of input energy. In addition, receiver sensitivity measurements should be made to determine the incidental modulation output from the receiver since it may cause loss of range of control. The sensitivity measurements should also include a radiation path through the flames.

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CO, ONR Branch Office, Brooklyn for Princeton Univ., Princeton, N. J., Attn: Project SQUID	"	(34-36)
INSMAT for Radio Corp. of Am., Camden, N. J., Attn: Mr. T. T. Eaton	"	(37)
BAR, Burbank for Radioplane Corp., Van Nuys, Calif., Attn: Mr. F. Smith	"	(38)
INSMAT, Boston for Raytheon Mfgr. Co., Waltham, Mass., Attn: Mrs. H. L. Thomas	"	(39)
INSMAT, Brooklyn for Reeves Instrument Corp., N. Y., N. Y.	"	(40)
Ryan Aero. Co., Lindberg Field, San Diego, Calif., Attn: Mr. H. A. Sutton	"	(41)
INSMAT, Brooklyn for Sperry Gyroscope Co, Inc., Great Neck, L. I., N. Y.	"	(42)
BAR for U. A. Corp., Chance Vought Aircraft Div., Stratford, Conn. Attn: Mr. P. S. Baker	"	(43)
BAR for U. S. Corp., Res. Dept., E. Hartford, Conn., Attn: Mr. J. G. Lee	"	(44)
Univ. of Mich., Aero Res. Center, Willow Run Airport, Ypsilanti, Mich., Attn: Mr. R. F. May	"	(45)
BAR, Pasadena for Univ. of S. Cal., Naval Res. Proj., Los Angeles, Calif., Attn: Dr. R. T. De Vault	"	(46)
DCO for Univ. of Texas, Defense Res. Lab., Austin, Texas, Attn: Dr. C. P. Boner	"	(47)
Lockheed Aircraft Corp., Burbank, Calif., Attn: Mr. H. L. Hibbard	"	(48)
Univ. of Chicago., Ord. Res., Chicago, Ill., Attn: Dr. Walter Bartky	"	(49)