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HF ATMOSPHERIC RADIO NOISE ON HORIZONTAL DIPOLE ANTENNAS IN THAILAND

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By: GEORGE H. HAGN   RANGSIT CHINDAHPORN   JOHN M. YARBOROUGH

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Approved: W. R. VINCENT, MANAGER
Communication Laboratory

D. R. SCHEUCH, VICE PRESIDENT
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I INTRODUCTION

A. Historical Background

Noise, in one form or another, provides the ultimate limitation on the performance of any system. The principal type of noise affecting HF radio communication systems in the tropics is (in the absence of interfering signals) the atmospheric noise resulting from lightning discharges. In the past, obtaining reliable measurements of this noise has proven difficult. Although many measurements have been made, it is even more difficult to interpret and compare radio noise data than to obtain reliable data, because of differences in the receiving systems used (antenna, bandwidth, etc.). Significant progress in documenting atmospheric radio noise has been made during the last decade (from the International Geophysical Year to the present) as the result of the operation of a world-wide network of identical noise recorders under the supervision of the U.S. National Bureau of Standards. Sixteen National Bureau of Standards Radio Noise Recorders, Model ARN-2, using standard vertical-monopole antennas, have been located around the world to measure the vertical component of the mean noise power.[1,2*] Data from this measurement program have been used to improve existing noise maps (based on meteorological data and previous noise measurements) to yield a capability for prediction of an equivalent vertically polarized ground-wave noise field strength incident upon a given receiving site as a function of site location, frequency, time of day, and season of the year. However, many communication systems employ horizontally polarized antennas, and relatively little is known about the noise voltages induced in horizontally polarized antennas. Consequently, a study of the noise on horizontal dipole antennas was undertaken in Thailand.

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[*] References are listed at the end of the report.

B. Current Study

This report discusses atmospheric noise data obtained on horizontal dipole antennas in Thailand with a receiving system patterned after (and having the electrical characteristics of) the ARN-2 system.[3] This unit was operated from August 1967 through February 1968. Calibration permitted comparison with data taken on the standard ARN-2 vertical monopole at the same site, Laem Chabang, Thailand (see Fig. 1).[4,5] The effects of local electrical storms on the noise power received by the dipoles is investigated briefly. In addition, data obtained on horizontally polarized dipoles with different equipment at other sites in Thailand[6,7] are presented and compared with the results from the Laem Chabang tests. Finally, suggestions are made regarding modification of the International Radio Consultative Committee (CCIR) Report 322 noise maps[8] of vertically polarized noise to yield estimates of noise on horizontally polarized antennas in Thailand.

II SUMMARY OF MAJOR FINDINGS

The major findings of this experiment were as follows:

(1) The monthly-median atmospheric noise power available during nighttime from an equivalent lossless horizontal dipole (F_{am}) at 23 feet above good ground in Thailand is relatively independent of frequency (and season, at least for summer, autumn, and winter) in the lower part of the HF band, in direct contrast to observations of noise on a vertical monopole at the same site. Typical values lie between about 55 and 70 dB (to the nearest 6 dB) above the thermal noise available from a passive resistor at $T_o = 288^oK$ (approximately room temperature). There is a significant daytime variation of the noise in the frequency range 2.3 to 10 MHz, with a minimum in observed power occurring between about 1000 and 1100 hours local time. Observed minimum monthly medians of F_{am} at 2.3 MHz vary between about 20 and 30 dB, values at 5 MHz vary between about 25 and 35 dB, and values at 10 MHz vary between about 30 and 45 dB above kT_ob.

(2) The HF atmospheric noise picked up by a horizontal dipole is relatively independent of dipole orientation, although the noise does seem to become slightly greater on the E-W dipole at 2.3 MHz most of the time and on the other frequencies during winter.

(3) The noise power available from a horizontal dipole is significantly less than the noise power available from a vertical monopole in the lower part of the HF band; this difference tends to decrease as frequency increases, becoming negligible at 10 MHz.

(4) The diurnal variation of atmospheric noise observed on horizontal dipoles tends to be greater than the diurnal variation of noise on vertical monopoles, the difference becoming less as frequency increases from 2.3 MHz to 10 MHz.

(5) In the absence of any predictions for noise on horizontal dipoles, we decided to apply the CCIR Report No. 322 map predictions for atmospheric noise power available from a vertical monopole directly to the horizontal dipoles (even though these predictions had not predicted enough noise for the monopole--see Ref. 5), and to observe the resulting difference in "predicted" and observed values. At 10 MHz, when applied directly to our horizontal dipoles, the map predictions for the monopole gave values that were too low by 5 to 10 dB during day and by 15 to 20 dB

during night. The noise maps give reasonable estimates of the noise power available from horizontal dipole antennas located at λ/4 to λ/8 above good ground for the frequency range 5 to 6 MHz during daytime; the map values were too low by about 5 to 10 dB at night. The maps yield values too high when applied to 2.3-MHz horizontal dipoles at one-sixteenth wavelength above ground by about 0 to 5 dB during day and 5 to 10 dB at night. Corrections for other antenna heights are discussed.

(6) The effect of local storms on the average 2.3-MHz noise power observed during a 12-minute interval on either dipoles or the standard ARN-2 monopole is to cause a substantial increase (20 to 30 dB) over the monthly median value for the same hour. Local storms produce much less significant effects at higher frequencies, causing only about a 3-dB increase at 10 MHz.

III DESCRIPTION OF MEASUREMENT SITE

The site at Laem Chabang, Thailand, was selected in the winter of 1964 as the result of a survey. The criteria used for site selection can be summarized as follows:

(1) It must be at least 0.5 km, and preferably 1 km, from all main roads. (Our subsequent measurements show at least 1 km required.)

(2) It must be 3 km from electrical power distribution lines above 5 kV.

(3) It should have a low horizon (4 degrees or less) in all directions, in order to compare data taken on a CCIR standard ARN-2 whip antenna with data from the CCIR world noise-measuring network.

(4) It should be located not more than two hours by automobile from the MRDC Electronics Laboratory in Bangkok.

(5) It must be accessible from a main road in all seasons.

(6) It must have a usable area of approximately 300 by 300 meters.

(7) Its surrounding area must be free of structures and man-made activity, except for the normal agricultural operations.

(8) It requires a house, or similar structure, suitable for housing electronic gear. An air-conditioned van with floor dimensions of 8 by 24 feet would be suitable if a house cannot be found. Generator and storage sheds would have to be constructed, if not available.

(9) It should be on land controlled by an agency of the Thai government, since permission must be obtained to pour concrete pads, construct sheds, erect antennas, and install electrical power generators.

(10) It should have a man-made noise level considerably lower than that at the Bangkok Laboratory site at all frequencies, VLF and higher, and a reasonable prospect of remaining "quiet."

The Laem Chabang site (13.05^{o}N, 100.90^{o}E) adequately met these criteria. The site consisted of a sandy area along the eastern coast of the Gulf of Thailand. For the first several hundred feet inland, the beach is relatively open and free of vegetation. Beyond about

400 feet inland, the site is covered with scrub growth composed of shrubs, bushes, climbers, and thorny succulent herbs, including cacti. Few trees taller than 30 feet can be found in this area. The elevation angle of the horizon is less than 3° in all directions--0° toward the west (Gulf of Thailand). Figure 2 is a photograph of the beach area.

The soil beneath the antennas was single-grained, noncoherent, dry, loose sand, classified as SW under the United States Classification System (USCS) and as well-graded sand under the United States Department of Agriculture (USDA) nomenclature.[8,9] Consistency when wet is nonplastic and nonsticky. Soil permeability to water is good. The electrical constants of the soil were measured to a depth of 6 feet with a short open-wire-transmission-line probe along the open beach and beneath the scrub vegetation (see Fig. 3).[10] While the ground exhibits slightly higher conductivity nearer the salt water (and where there is no vegetation), the ground can be classified as electrically "poor" at this site. It should be noted that wire ground screens were used beneath both the vertical monopole and horizontal dipoles to increase antenna efficiency and stabilize (and standardize) antenna impedance.

IV DESCRIPTION OF EQUIPMENT

A. Antennas

1. Trapped Horizontal Dipoles at Laem Chabang

A trapped horizontal dipole constructed from No. 14 AWG stranded copper wire (see Fig. 4) was used at Laem Chabang for the atmospheric noise measurements. Parallel-resonant RLC traps, enclosed in fiberglass containers for weather protection, were used to produce an approximation to a half-wave resonant horizontal dipole at 2.3, 5.0, and 10.0 MHz.

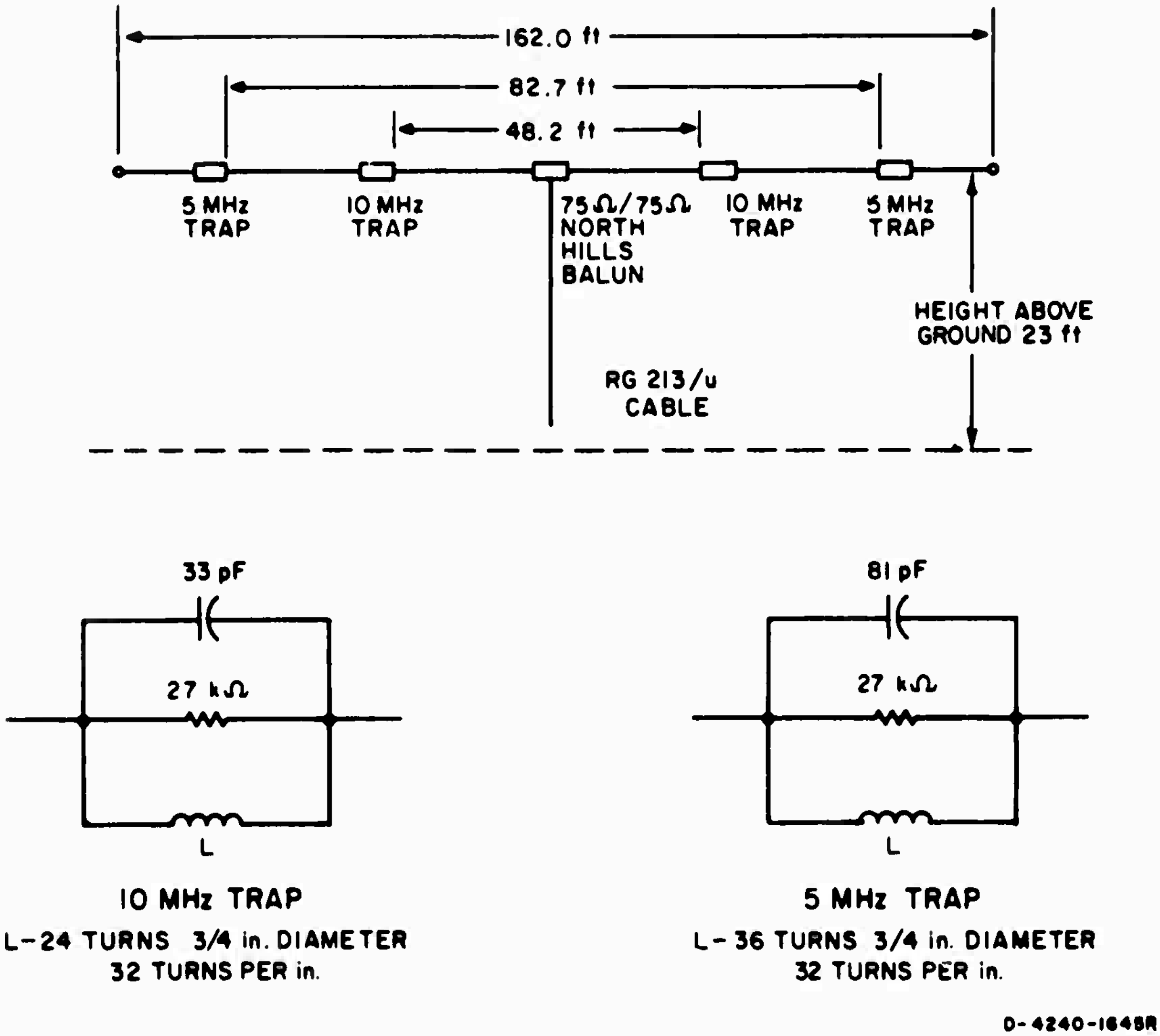

FIG. 4 THREE-FREQUENCY TRAPPED DIPOLE

A 75-ohm-to-75-ohm balanced-to-unbalanced ferrite-core transformer (balun),* located at the dipole feed point, connected the antenna to a 281-foot-long coaxial cable (RG-213/U) which ran to the noise-measuring-equipment shelter. Two identical antennas, oriented magnetically north-south and east-west in the form of a cross, were constructed and installed at 23 feet above a ground screen at Laem Chabang. The ground screen was constructed of 2-inch chicken wire in the form of a 165-foot strip 6 feet wide, obtained by the bonding, at 1-foot intervals, of two pieces each 3-feet wide. These strips were positioned symmetrically beneath the antennas. Twelve 3-foot copper ground rods were used to attach the ground screen to the earth, one at each corner and one at each intersection of the two ground screens. Measured values of impedance for both antennas are presented in Appendix A.

2. Standard ARN-2 Monopole

The standard ARN-2 monopole antenna was constructed from drawings supplied by the U.S. Environmental Science Services Administration (ESSA), Boulder, Colorado, and is identical to the antennas used with the U.S. National Bureau of Standards (NBS) ARN-2 atmospheric noise recorder.[1] The antenna consists of a 21.75-foot telescoping vertical monopole (1.5-inch diameter at base) mounted over an extensive ground plane consisting of 90 radials of #12 copperweld wire each 100 feet long and equally spaced. The ground plane is supported from the top of the equipment van--about 8 feet above ground--and forms a 200-foot-diameter circle (see Fig. 5). The outer ends are supported on guyed posts. The ground platform is connected to a one-square-yard copper plate buried 6-feet deep by a copper strip 1/16-inch thick by 4-inches wide. The base insulator is a 6-inch plastic sphere (see Fig. 6), and the antenna base is connected to a length of special low-capacity coaxial cable that enters the van through a watertight packing. Protection against lightning strokes was afforded by a small copper tube placed near the base of the antenna (3-mm gap) and connected to the ground system. The approximate impedance of this antenna is presented as a function of frequency in Fig. 7.[1]

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* Model 1100BB, North Hills Co., Glen Cove, New York.

3. Full-Length Half-Wave Horizontal Dipoles

Full-length $\lambda/2$ dipoles were used at several sites for atmospheric noise and impedance measurements.[6] These antennas were constructed of No. 12 AWG solid copper wire and were fed with RG-8/U coaxial cable. No baluns were used with these antennas. The center conductor of the cable was attached to one dipole element and the outer conductor (shield) fed the other dipole element. At Laem Chabang, the impedance of such a structure was measured over the ground screens (which were extended--during these impedance measurements only--to cover the full length of the 2.3-MHz dipole).* Ground screens were not used at the other sites discussed in this report.

B. Receivers and Recorders

1. Laem Chabang

The receivers and recorders used at Laem Chabang were designed to have essentially the same characteristics as those of the ARN-2 system. The nominal parameters of the system operated at Laem Chabang, designated ARN-3, are given in Table I. A block diagram of the ARN-3 system is shown in Fig. 8. A more complete description of this system is given in Ref. 3.

A special switching unit (see left side of Fig. 8) was designed and built by one of the authors (J. M. Yarborough) to facilitate cycling the input to the receiver between the standard monopole and the trapped dipoles. The timing control unit is built around an electromechanical unit employing a synchronous motor driving a series of cams to activate microswitches. This method was chosen over an electronic approach, to minimize both the design and installation times. The switching cycle provides five 12-minute measurement periods.

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* These ground screens were always maintained at the same length when used with the trapped dipoles, but the trapped dipoles are slightly shorter than a full-length 2.3-MHz dipole.

2. Other Sites in Thailand

Additional atmospheric noise recordings were obtained in conjunction with several experiments conducted at field sites in Thailand. Usually, R-390/URR receivers were used with various recorders. (See Sec. VII of this report or Refs. 6 and 7 for more detailed or specific information.)

C. The Calibration Unit

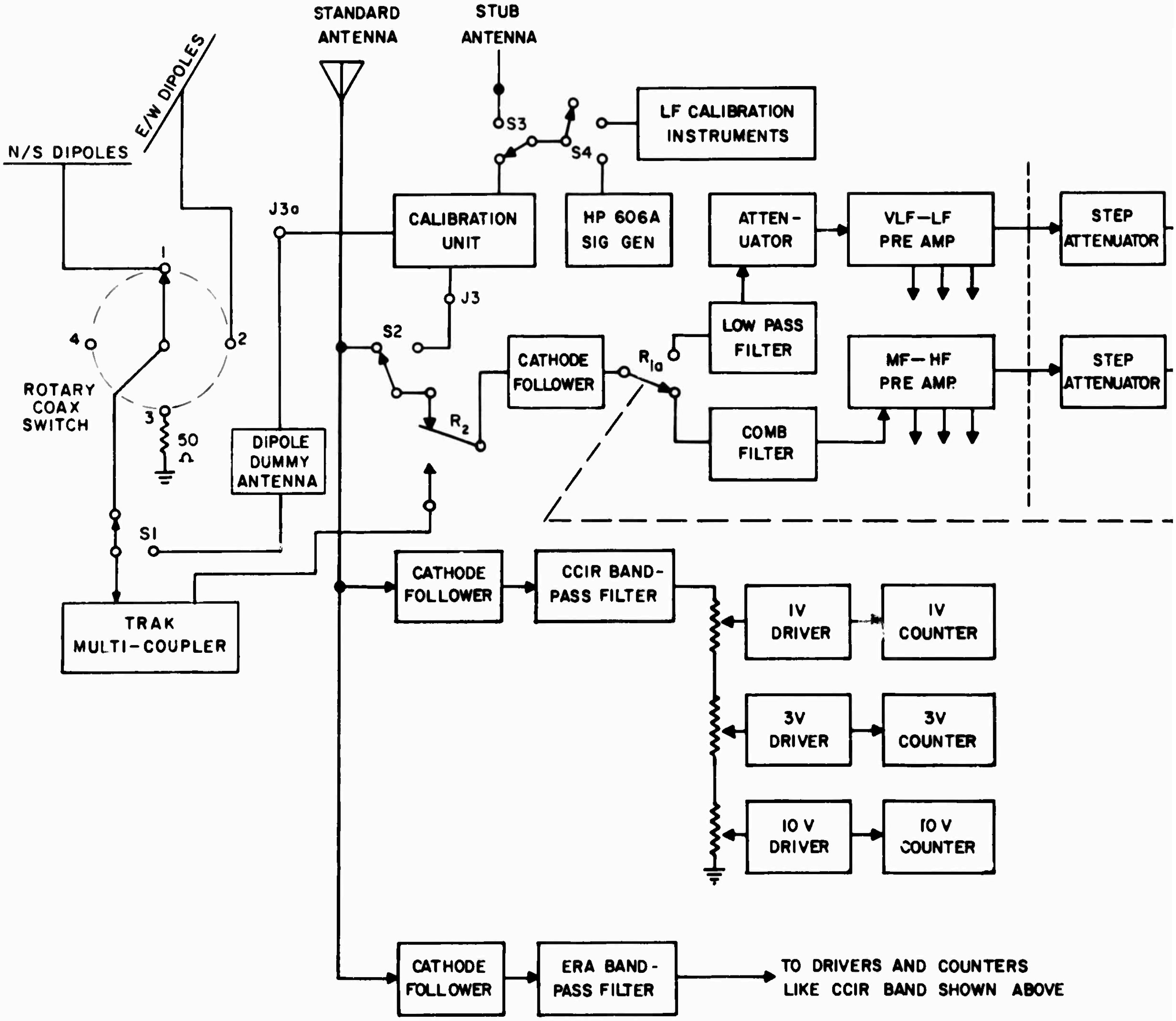
The calibration unit of the ARN-2 system (Fig. 9) contains a noise diode with provision for varying its filament temperature and metering its plate current, as well as dummy loads with impedances corresponding to those of the monopole antenna at the various measurement frequencies. A BNC connector ($J3_a$) was added on the front panel for use in calibrating the system for dipole measurements. A coupling capacitor of 0.47 μF (see Fig. 9) was used to facilitate driving the low-impedance dummy antennas required to simulate the dipole antennas. The dipoles' dummy antennas were constructed in separate mini-boxes (see Appendix A for calibration details).

Table I

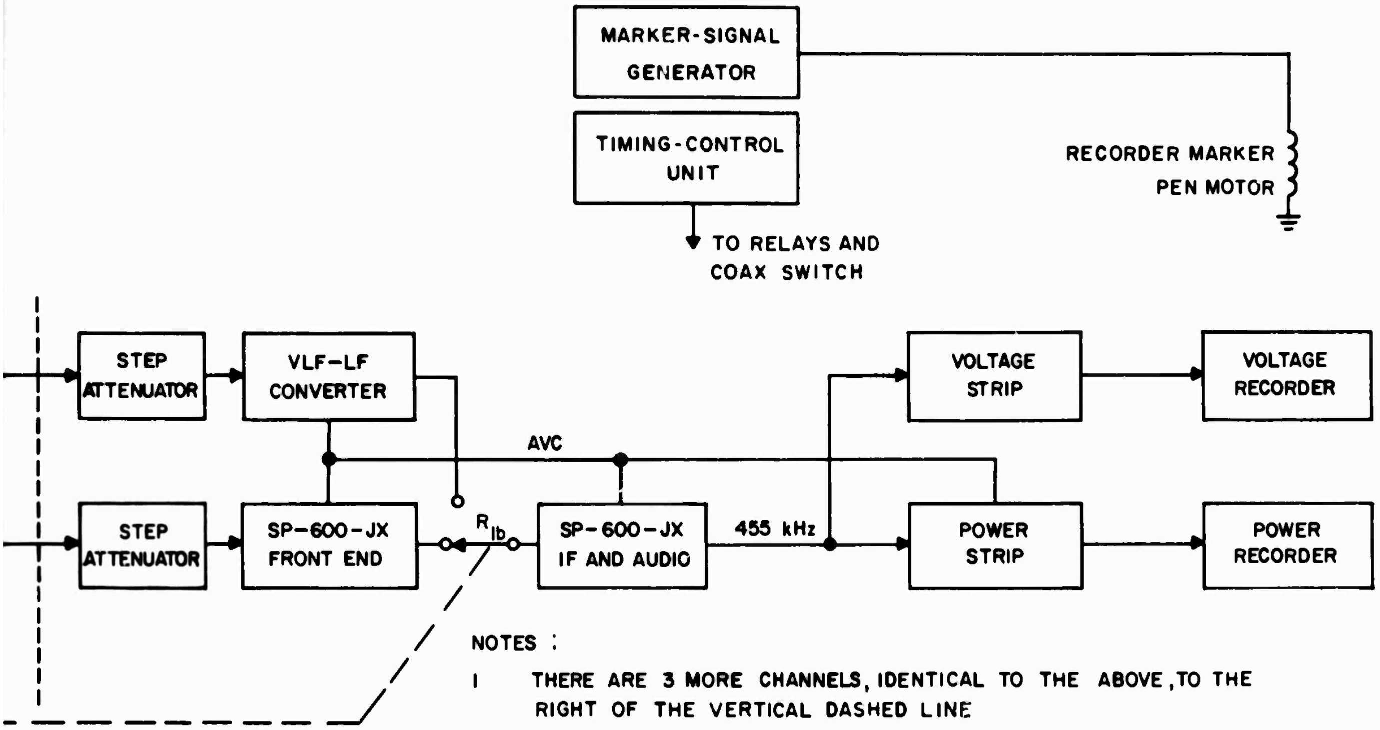
EQUIPMENT SPECIFICATIONS FOR ARN-3 SYSTEM

Frequencies:	MF and HF, 4 channels each tunable 0.53 to 54 MHz, normally tuned to 0.53, 2.3, 5.0, and 10.0 MHz respectively. VLF and LF, 4 fixed-frequency converters accepting 6, 13, 27, and 160 kHz respectively.
Receivers:	Four Hammarlund SP-600
Recorders:	One Brush Model RA-5680-01 Eight Brush Model RD-5211-13 } with amplifiers
Band-Pass:	HF, 200-Hz normal operation (adjustable in steps up to 13 kHz). LF, 200 Hz. LFA; ERA band 100 Hz to 2500 Hz; CCIR band 2 kHz to 50 kHz.
Sensitivity:	HF, -97 dBm, LF -46 dBm, LFA, 1-V, 3-V, and 10-V thresholds.
Time Constants:	Power integration, 0.5 s, 5 s, or 500 s,* Voltage integration, 0.1 s, 1 s, or 100 s,* LFA, 0.6, dead time.
Dynamic Range:	40 dB (30 dB on chart) plus 70 dB attenuation in 10-dB steps.
Outputs:	Integrated power and voltage in 4 channels (chart recorded).
Timing and Switching:	Internal time standard with power amplifier to drive clocks and recorders. Switching of ARN-3 channels available each 15 or 30 minutes. Photograph of LFA taken automatically each 30 minutes or each hour. External switching unit added to permit accommodation of trapped horizontal dipoles, with switching each 12 minutes (see Table II).
Packaging:	Three standard five-foot relay racks and two seven-foot relay racks.
Power Requirement:	115 V, 60 Hz, 20 A.
Ambient Temperature:	18 to 24°C, 22°C nominal (65 to 75°F), maintained by air conditioning.

* The longest time constants were used during data aquisition.


STANDARD ANTENNA
STUB ANTENNA
E/W DIPOLES
N/S DIPOLES
S3
S4
LF CALIBRATION INSTRUMENTS
J3a
CALIBRATION UNIT
HP 606A SIG GEN
ATTEN-UATOR
VLF—LF PRE AMP
STEP ATTENUATOR
1
2
3
4
J3
S2
LOW PASS FILTER
ROTARY COAX SWITCH
CATHODE FOLLOWER
R_{1a}
MF—HF PRE AMP
STEP ATTENUATOR
R_2
50 Ω
DIPOLE DUMMY ANTENNA
COMB FILTER
S1
TRAK MULTI-COUPLER
CATHODE FOLLOWER
CCIR BAND-PASS FILTER
IV DRIVER
IV COUNTER
3V DRIVER
3V COUNTER
10 V DRIVER
10 V COUNTER
CATHODE FOLLOWER
ERA BAND-PASS FILTER
TO DRIVERS AND COUNTERS LIKE CCIR BAND SHOWN ABOVE

A.



NOTES :

1 THERE ARE 3 MORE CHANNELS, IDENTICAL TO THE ABOVE, TO THE RIGHT OF THE VERTICAL DASHED LINE

2 RELAYS R_1 AND R_2 ARE SHOWN IN THEIR DE-ENERGIZED POSITIONS; R_1 IS ENERGIZED DURING TIME PERIOD 1 AND R_2 DURING TIME PERIODS 3 THRU 5.

THE ROTARY COAX SWITCH IS IN POSITION 3 DURING PERIODS 1,2, AND 5, POSITION 1 DURING PERIOD 3, AND POSITION 2 DURING PERIOD 4.

3 FREQUENCY ASSIGNMENTS ARE AS FOLLOWS :

	MF–HF	VLF-LF
CHANNEL 1	530 kHz	160 kHz
CHANNEL 2	2.3 MHz	27 kHz
CHANNEL 3	5 MHz	13 kHz
CHANNEL 4	10 MHz	6 kHz

4 EACH 30 MINUTES THE LFA COUNTERS ARE DISABLED FOR 4 SECONDS WHILE FLOOD LAMPS ARE TURNED ON AND A PICTURE IS TAKEN BY THE RECORDING CAMERA. THE COUNTERS THEN AUTOMATICALLY RESET TO 0.

5 SWITCHES S1 THRU S4 ARE USED IN THE CALIBRATION PROCESS

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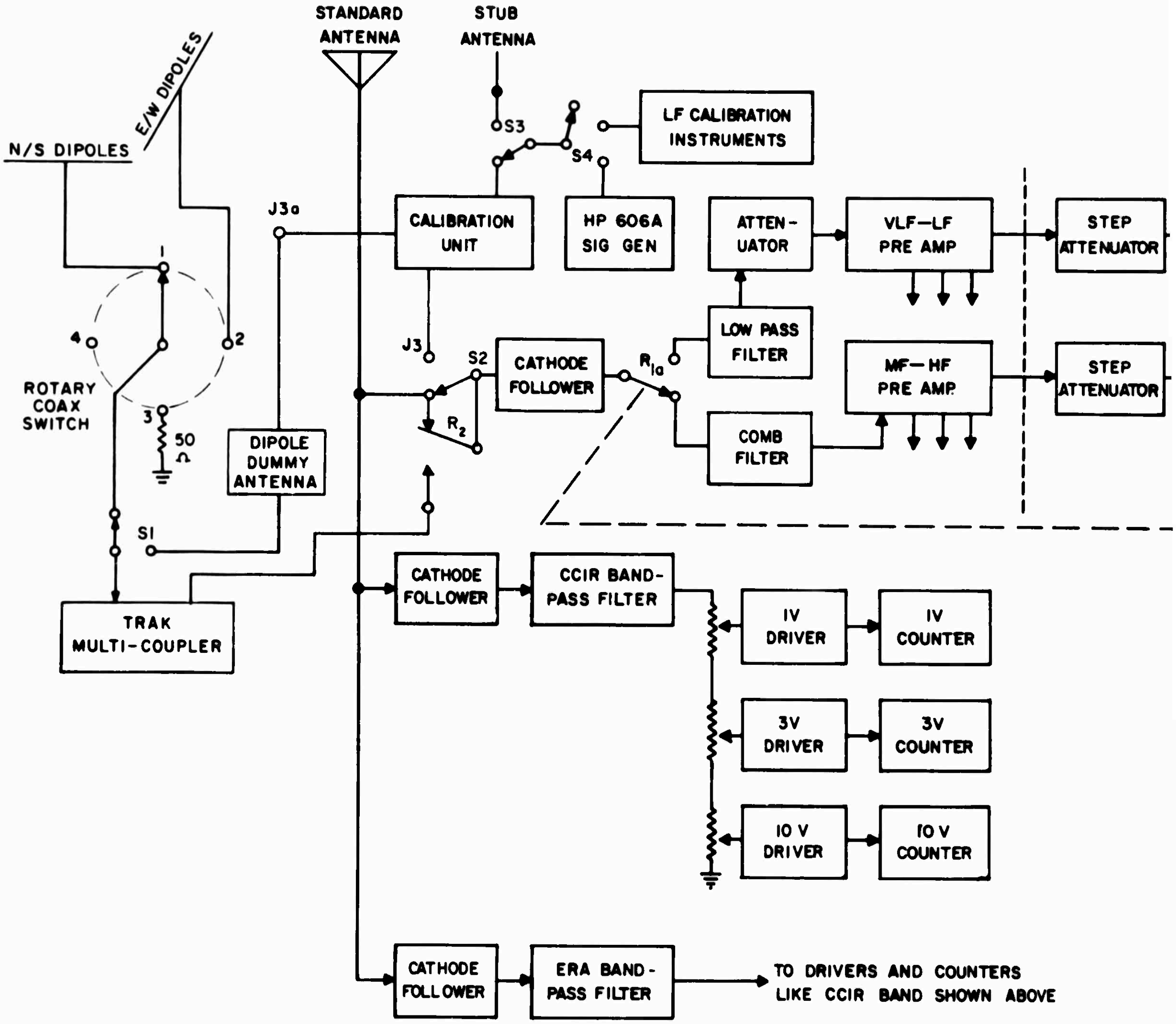
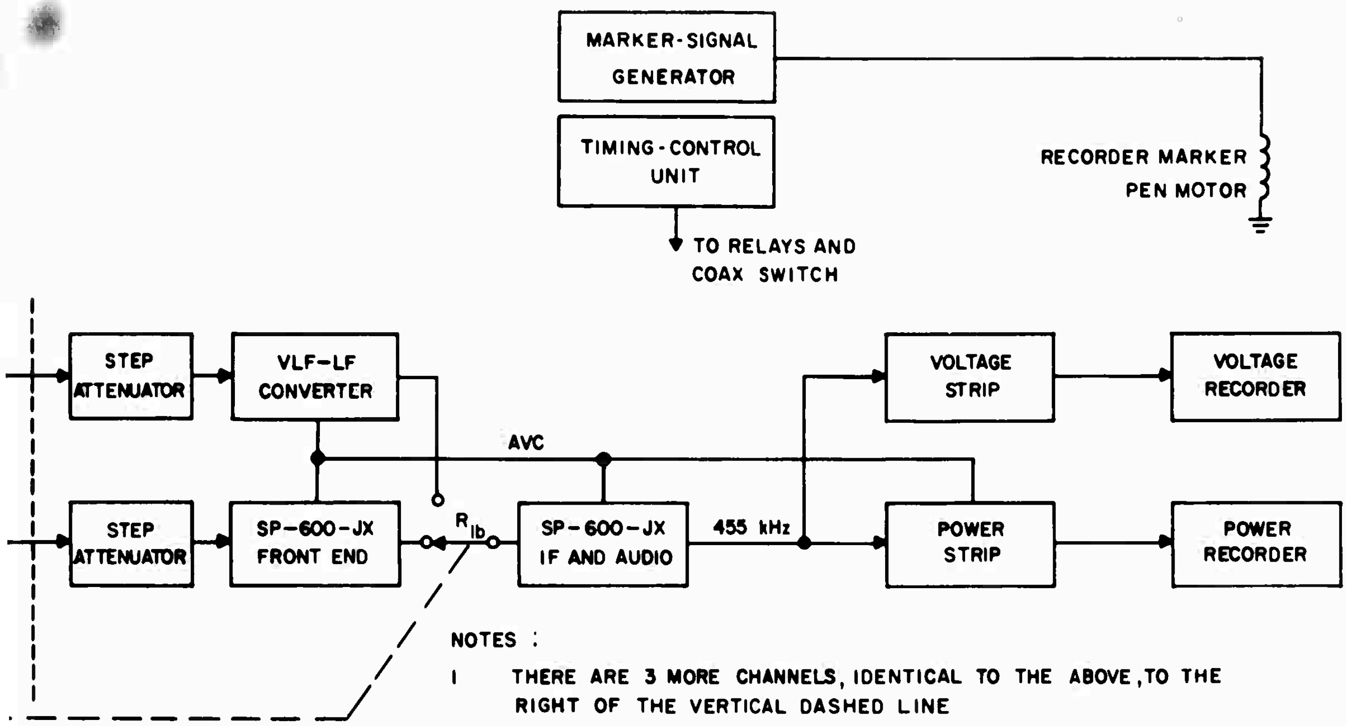
ERS
ABOVE

FIG. 8 FUNCTIONAL BLOCK DIAGRAM (REVISED)

B.


STANDARD ANTENNA
STUB ANTENNA
E/W DIPOLES
N/S DIPOLES
S3
S4
LF CALIBRATION INSTRUMENTS
J3a
CALIBRATION UNIT
HP 606A SIG GEN
ATTEN-UATOR
VLF—LF PRE AMP
STEP ATTENUATOR
1
2
3
4
ROTARY COAX SWITCH
50 Ω
J3
S2
CATHODE FOLLOWER
R_{1a}
LOW PASS FILTER
MF—HF PRE AMP
STEP ATTENUATOR
R_2
COMB FILTER
DIPOLE DUMMY ANTENNA
S1
TRAK MULTI-COUPLER
CATHODE FOLLOWER
CCIR BAND-PASS FILTER
IV DRIVER
IV COUNTER
3V DRIVER
3V COUNTER
10 V DRIVER
10 V COUNTER
CATHODE FOLLOWER
ERA BAND-PASS FILTER
TO DRIVERS AND COUNTERS LIKE CCIR BAND SHOWN ABOVE

A.



NOTES :

1 THERE ARE 3 MORE CHANNELS, IDENTICAL TO THE ABOVE, TO THE RIGHT OF THE VERTICAL DASHED LINE

2 RELAYS R_1 AND R_2 ARE SHOWN IN THEIR DE-ENERGIZED POSITION. RELAY R_2 IS ENERGIZED DURING TIME PERIODS 3, 4, AND 5. THE ROTORARY COAX SWITCH IS IN POSITION 3 DURING PERIODS 1, 2, AND 5, POSITION 1 DURING PERIOD 3, AND POSITION 2 DURING PERIOD 4.

3 FREQUENCY ASSIGNMENTS ARE AS FOLLOWS :

	MF-HF	VLF-LF
CHANNEL 1	530 kHz	160 kHz
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CHANNEL 3	5 MHz	13 kHz
CHANNEL 4	10 MHz	6 kHz

4 EACH 30 MINUTES THE LFA COUNTERS ARE DISABLED FOR 4 SECONDS WHILE FLOOD LAMPS ARE TURNED ON AND A PICTURE IS TAKEN BY THE RECORDING CAMERA. THE COUNTERS THEN AUTOMATICALLY RESET TO 0.

5 SWITCHES S1 THRU S4 ARE USED IN THE CALIBRATION PROCESS

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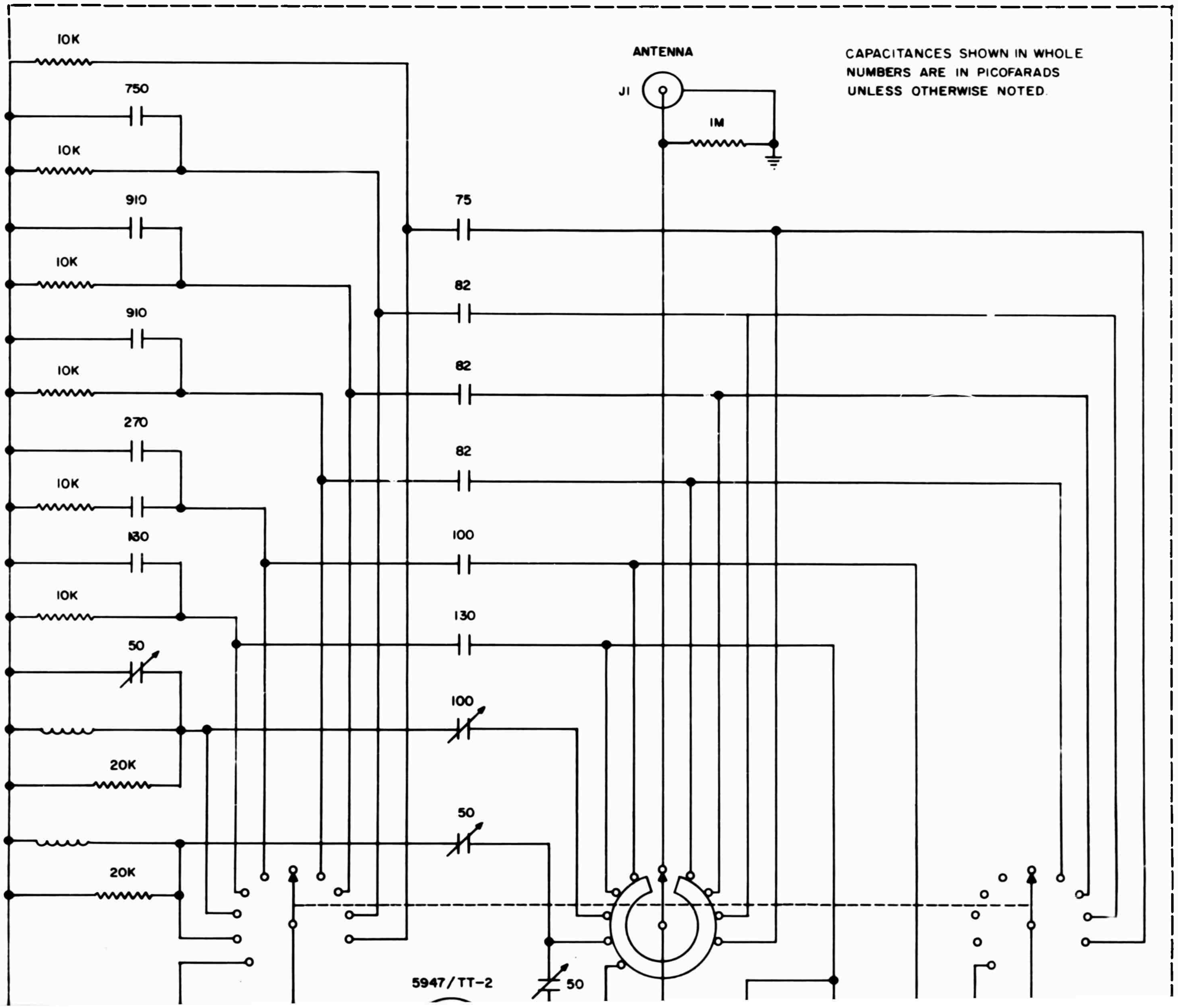
IS
ABOVE

FIG. 8 FUNCTIONAL BLOCK DIAGRAM

B.

A.


CAPACITANCES SHOWN IN WHOLE NUMBERS ARE IN PICOFARADS UNLESS OTHERWISE NOTED.

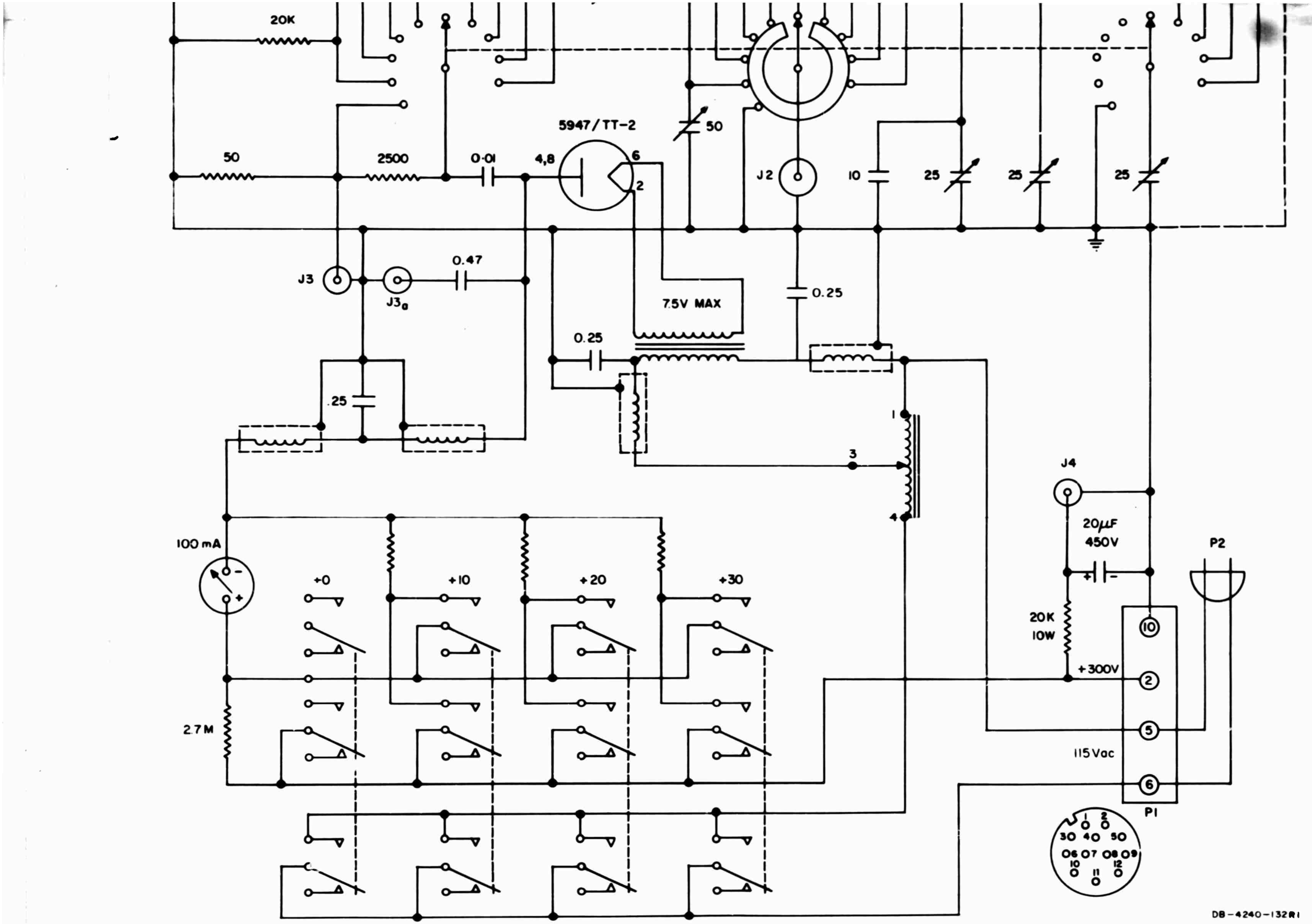


FIG. 9 CALIBRATION UNIT SCHEMATIC

B.

VIII COMPARISON OF TRAPPED-DIPOLE RESULTS WITH MEASURED AND PREDICTED RESULTS FOR STANDARD ARN-2 MONOPOLE

A. Comparison with Standard ARN-2 Monopole Results

We wanted to compare the noise power available from the trapped dipoles (as tabulated in Appendix B) to that from the standard ARN-2 vertical monopole used at Laem Chabang with the ARN-3 system (as tabulated in Ref. 4). The curves of Appendix C show the diurnal variation of the noise data for the three antennas by month for the period August 1967 through February 1968.

To summarize the observed differences in more compact form, the month-hour values for the dipoles (see Appendix B) and for the standard ARN-2 monopole (see ref. 4) for the period August 1967 through February 1968 were grouped according to day (0800 hours to 1600 hours local time) and night, (1600 hours to 0800 hours local time) and the dipole results for a given frequency, month, and hour were subtracted from the monopole results for the same frequency and period. The median and decile bounds on these differences were determined and plotted in Fig. 17.

At 2.3 MHz, the noise on the trapped dipoles typically was about 15 dB lower than on the monopole at night (see Fig. 17). During the day this difference increased to about 25 dB. The diurnal range of variation was about 10 dB greater for the dipoles than for the monopole for this frequency.

At 5.0 MHz, there typically was only about 5 dB less noise on the dipoles at night. The August values (see Fig. C-1) were typical, but this differential decreased during the autumn until the antennas picked up about the same noise at night during November and December (see Appendix C). In January and February 1968 the nighttime noise on the dipoles was again less than on the monopole. The daytime noise was less on the dipoles (typically 10 dB less), although in February 1968 this difference was about 25 dB.

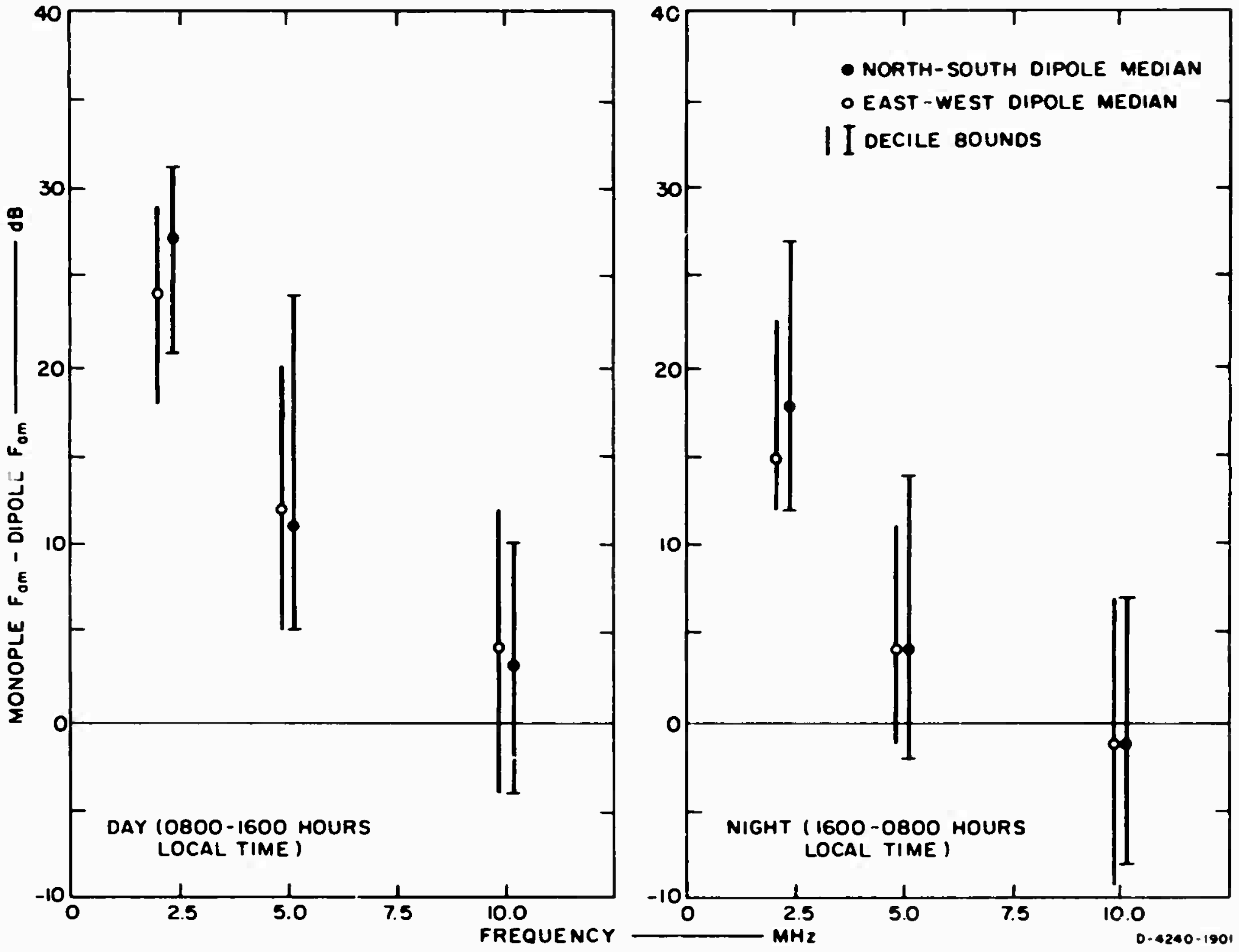


FIG. 17 EXCESS OF MONTHLY MEDIAN EFFECTIVE ANTENNA NOISE FACTOR FOR STANDARD ARN-2 MONOPOLE OVER TRAPPED DIPOLES AT LAEM CHABANG — AUGUST 1967 THROUGH FEBRUARY 1968

At 10.0 MHz, the magnitude of the noise at night was about the same on all three antennas during autumn and winter, and the diurnal range decreased from about 35 dB in August to only about 20 to 25 dB during autumn and winter. The daytime noise on the dipoles was about 10 dB less during August, but became increasingly like the noise on the monopole as time went on during the observation period, with the result that the noise on the dipoles was typically only 3 dB less than on the monopole.

B. Comparison with CCIR Report 322 Noise Maps

The CCIR predictions for the standard ARN-2 monopole for Laem Chabang[8] are shown for autumn (September, October, November--see Fig. 18), and winter (December, January, February--see Fig. 19),* along with values observed with the ARN-3 system using the standard ARN-2 monopole and the trapped dipoles. Estimates of the seasonal median values for each four-hour time block and frequency were obtained by averaging the appropriate monthly median values (i.e., 12 values averaged to give one seasonal data point). These values should be within a few dB of the actual seasonal medians, which could have been obtained by the more laborious process of rank-ordering all the values in a given season and time block and selecting the middle value. The maps always predicted less noise than was observed on the monopole--this is discussed fully in Ref. 5. The maps predicted more noise for the standard ARN-2 monopole than was observed on the 2.3-MHz trapped dipoles but less than was observed on the 5- and 10-MHz dipoles during both autumn and winter. The results of these comparisons can be summarized as follows:

(1) At 2.3 MHz, the CCIR values were lower than the values observed on the standard ARN-2 monopole, but 0 to 10 dB higher than the dipole values.

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* The predictions plotted are for atmospheric noise only since the observations were made at a very low-noise site. The CCIR predictions for man-made noise on 2.3 MHz (43 dB above kT_ob) and 5.0 MHz (36 dB above kT_ob) were greater than the predictions for atmospheric noise during the 0800-1200 hour time block for both seasons and during the 1200-1600 hour time block for winter.

(2) At 5 MHz, the CCIR values were still lower than the noise observed on the standard monopole, but they provided reasonable estimators of the noise observed on the dipoles during most of the day. At night the predictions were too low by about 5 to 10 dB when applied to the dipoles.

(3) At 10 MHz, the CCIR values also predicted too low for the standard monopole during the day, but they gave a reasonable estimate for the dipoles, being too low by only about 5 dB. At night, the CCIR values predicted too low for all three antennas by about 15 to 20 dB.

C. Suggestions for Use of CCIR Report 322 Noise Maps to Predict Noise on Dipoles in Thailand

The data sample is very small, and consequently, any correction function for the CCIR Report 322 noise maps so that they can be applied to horizontal dipoles must be rather crude. Data from the trapped dipoles at Laem Chabang and from the unbalanced dipoles at the other sites in Thailand were compared with the CCIR predictions for the standard ARN-2 monopole, and an approximate correction function generated. Figure 20 shows these corrections as a function of frequency for day (defined as 0800 until 1600 hours local time) and night (defined as 1600 until 0800 hours local time). To obtain an estimate of F_{am} for a dipole of arbitrary orientation located one-quarter wavelength or less above ground,* scale the noise maps to get F_{am} for the standard ARN-2 monopole and add C_d. The curves were prepared using data obtained primarily during autumn and winter; consequently, the curves are probably better for these seasons. In the absence of other data, these curves may be used for any season and for any location within Thailand.

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* It should be emphasized that the correction function of Fig. 20 is, strictly speaking, only good for horizontal dipoles at about 23 feet above ground (i.e., $\lambda/4$ at 10 MHz, $\lambda/8$ at 5 MHz and about $\lambda/16$ at 2.3 MHz). Since the directivity pattern of dipoles at heights between about $\lambda/16$ and $\lambda/4$ above good ground is approximately independent of antenna height, it is possible to estimate the change in available noise power from an equivalent lossless dipole with antenna height by estimating the change in gain with height above a perfect ground plane (e.g., for the 2.3- and 5-MHz dipoles at $\lambda/4$ above ground one would anticipate an increase in available noise power of about 8 dB and 2 dB respectively). Therefore, during daytime, $C_d \approx 5$ dB ± 3 dB for dipoles operated at $\lambda/4$ above ground in the lower part of the HF band.

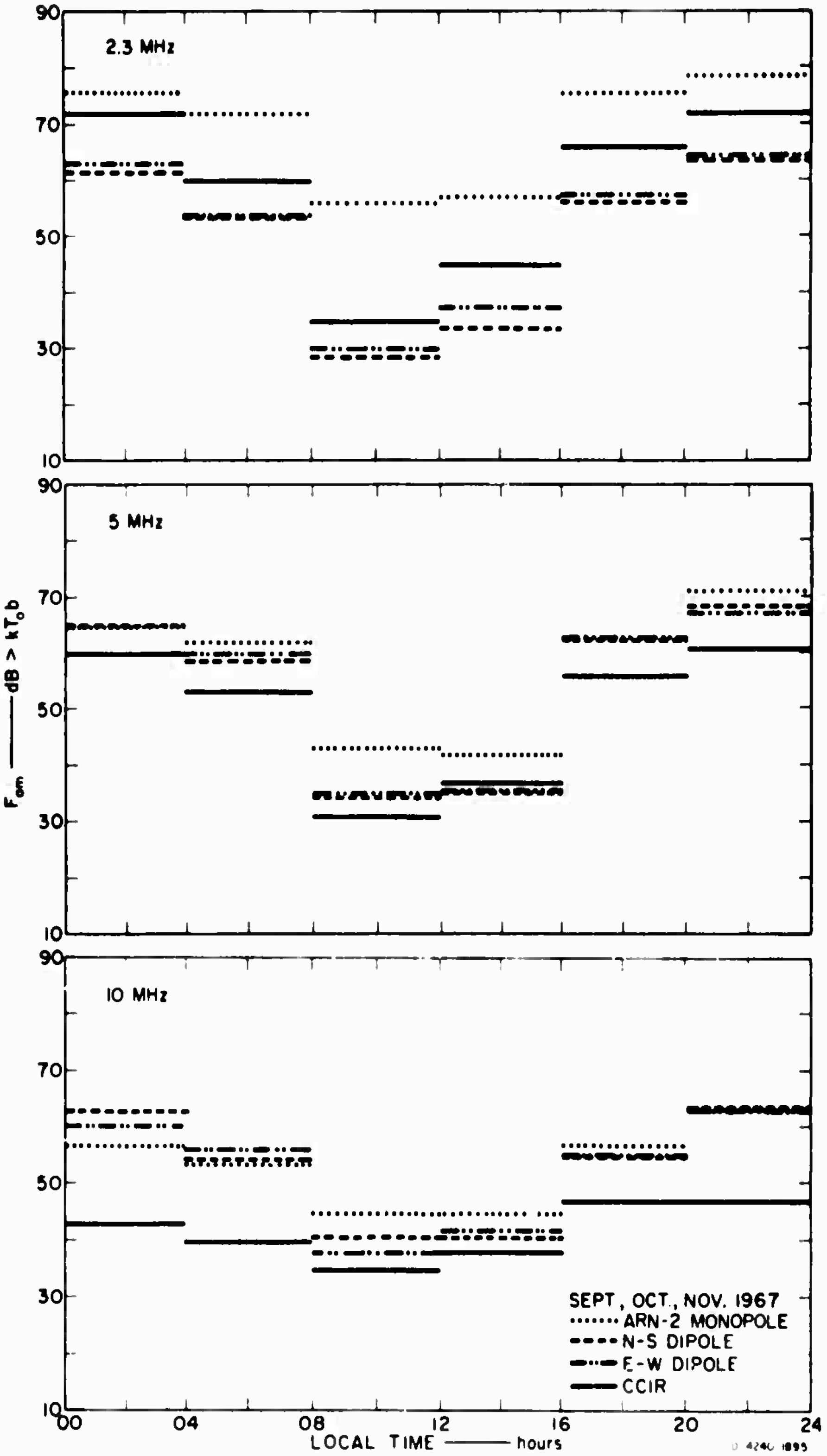

FIG. 18 COMPARISON OF ARN-2 MONOPOLE AND TRAPPED DIPOLE OBSERVED NOISE WITH CCIR REPORT 322 PREDICTIONS, LAEM CHABANG, THAILAND, AUTUMN 1967

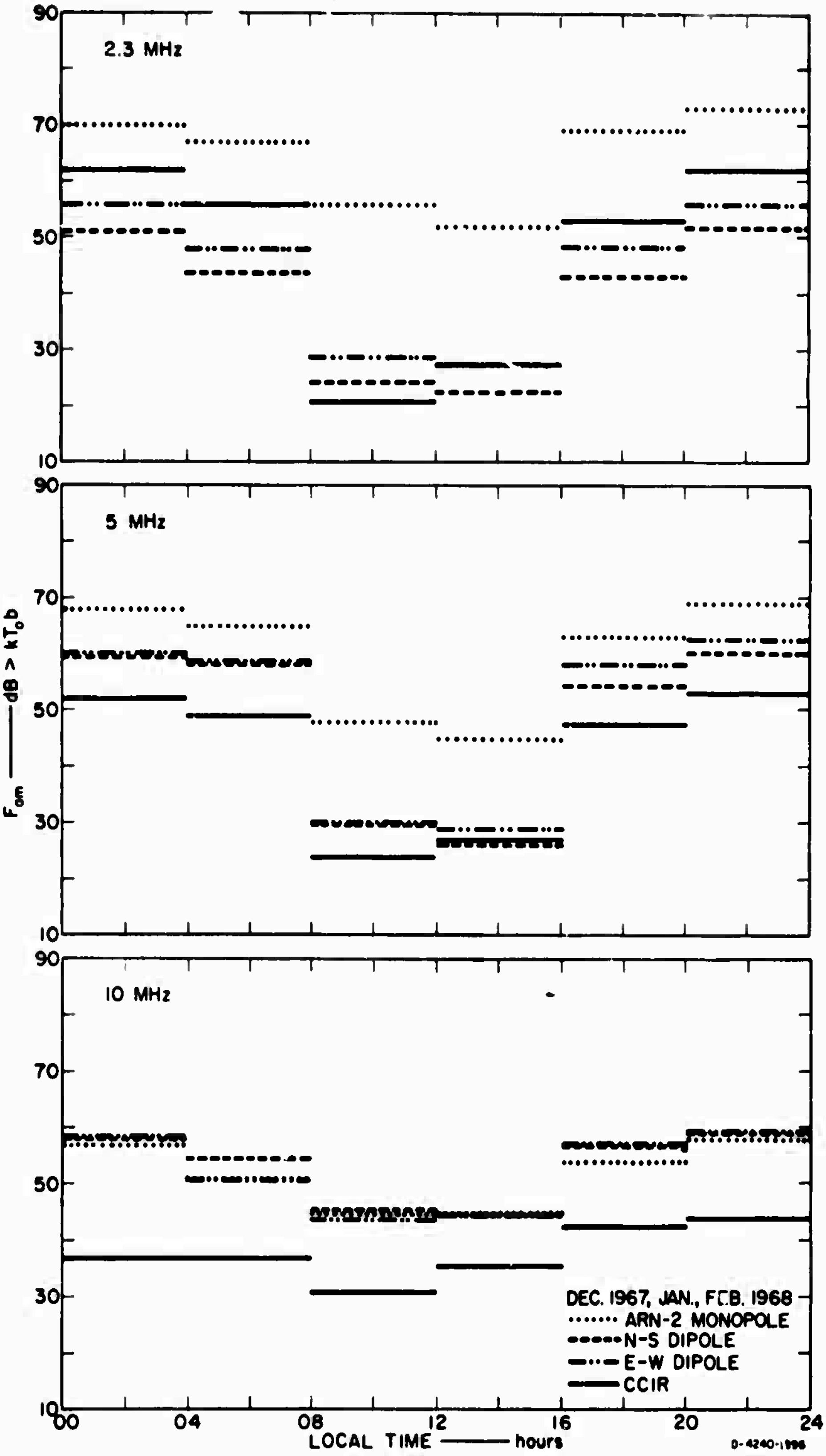

FIG. 19 COMPARISON OF ARN-2 MONOPOLE AND TRAPPED DIPOLE OBSERVED NOISE WITH CCIR REPORT 322 PREDICTIONS, LAEM CHABANG, THAILAND, WINTER, 1967 — 1968

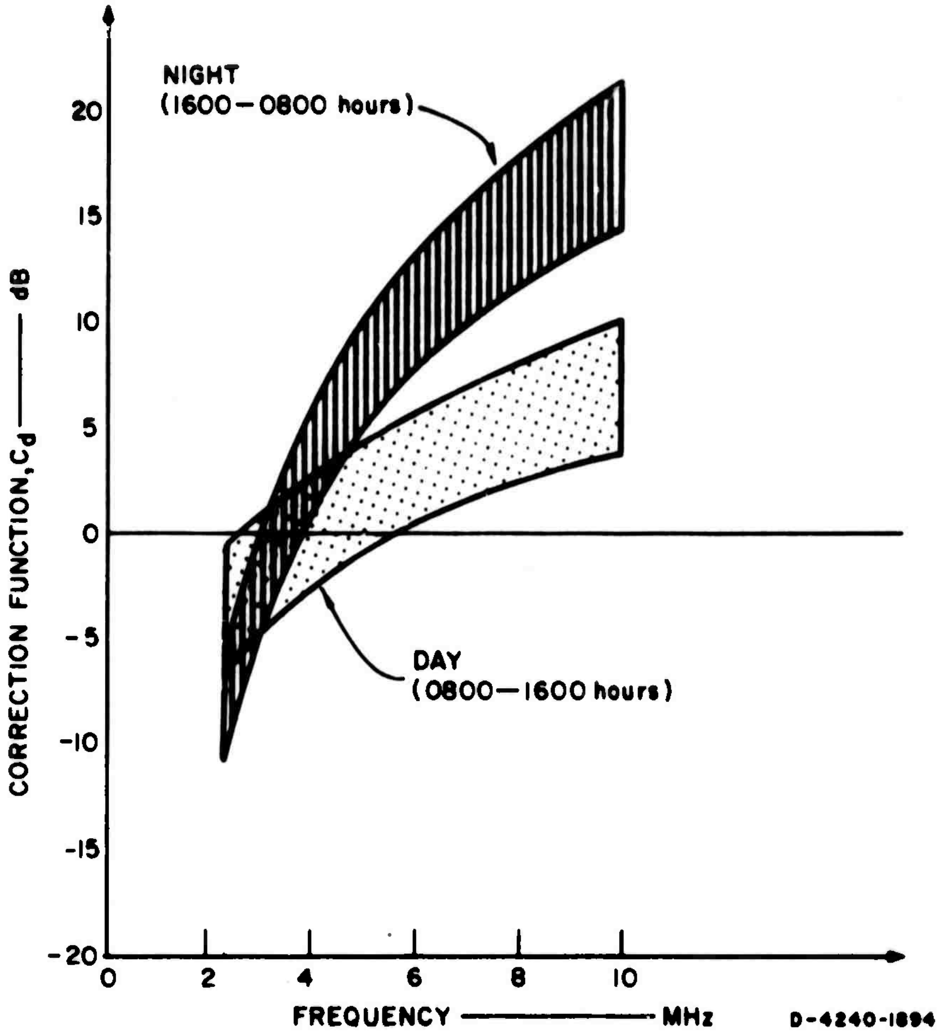

FIG. 20 CCIR REPORT 322 NOISE MAP CORRECTION FUNCTION FOR HORIZONTAL DIPOLES PLACED 23 ft. ABOVE GROUND IN THAILAND

Appendix A

CALIBRATION THEORY AND TECHNIQUE

1. Theory

The vertical component of the mean noise power, averaged over a period of several minutes, is the basic parameter measured by the ARN-2 system.[1,2] This noise power is expressed as an effective antenna noise figure, F_a, the noise power available from an equivalent lossless antenna. The units of F_a are dB above kT_ob--the thermal noise power available from a passive resistance at room temperature, T_o (taken as 288 degrees Kelvin),[18] when $hf \ll kT$,* where

h = Planck's constant
f = Frequency (Hz)
k = Boltzmann's constant (1.38×10^{-23} J/°K)
T = Temperature (°K)
b = Equivalent noise bandwidth (Hz) $= \frac{1}{A_o^2}\int A^2(f)df$
A_o = Maximum voltage amplitude response of the system
$A(f)$ = Overall voltage spectral response of the system.

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* The mean square noise voltage developed across an equivalent passive resistance of R ohms is, in general, given as[19]

$$\overline{V_n^2} = \frac{4kT}{A_o^2}\int_o^\infty \frac{R(f)(hf/kT)}{(e^{hf/kT} - 1)} A^2(f)df \quad .$$

When $hf \ll kT$ (true for frequencies of interest to us) then the exponential term can be replaced by the first two terms of its series expansion. When R is independent of frequency, then the expression for mean-squared noise voltage simplifies to

$$\overline{V_n^2} = 4kTbR \quad .$$

When $T = T_o$, the available power is, by definition,

$$\overline{V_n^2}/4R = kT_oB \quad .$$

We seek to determine F_a for the horizontal dipole as observed with the ARN-3 system. Therefore the calibration process consists of determining the power available from the actual horizontal dipole antenna terminals (in dB above kT_ob) and determining antenna losses.

The problem of determining the power available from the actual antenna terminals can be restated as the problem of constructing a noise source (1) with the same internal impedance as the actual antenna, and (2) whose available power is known in terms of dB above kT_ob. Then the calibration can be effected by comparison of the recorder deflection produced by this source of known properties with the deflection produced when the actual antenna is driving the receiver/recorder system.

A convenient noise source of known characteristics is a vacuum-tube diode whose current is limited by temperature rather than by the voltage applied between the anode and cathode. It is well known that the shot-noise component of the rms noise current (i.e., alternating current), i_n, flowing through such a diode is given by:[20]

$$i_n = \left[2qI_{dc}b\right]^{1/2}$$

where

i_n = rms noise current in equivalent bandwidth, b
q = Electronic charge (1.59×10^{-19} coulombs)
I_{dc} = Direct current flowing between anode and cathode (amperes).

If a resistance, R_a, is coupled so that all this ac noise current flows through it, then an available power, P_{av}, is created such that

$$P_{av} = \frac{i_n^2 R_a}{4} = \frac{qI_{dc}bR_a}{2} \quad .$$

As previously stated, a resistance, R_a, at absolute temperature, T, has an available power of kTb. Therefore, the power available from a temperature-limited diode, in dB above kT_ob, is given by

$$10 \log_{10} \left[\frac{qI_{dc}R_a}{2kT_o}\right] \quad .$$

Notice that this available power is independent of the equivalent noise bandwidth of the device with which we observe the noise. If we measure the dc plate current of our temperature-limited diode and know its ac load resistance, then we can use such a source to drive our receiver/recorder system and calibrate the deflection produced in dB above $kT_o b$. The next questions are, where should we inject this noise into the system, and what ac load resistance is required?

For convenience, let us inject the noise from our diode into the system at the place where the coaxial transmission line from the trapped dipoles injects the atmospheric noise during the actual measurement--the Trak multicoupler input (see Fig. 8). If we look into the coaxial transmission line toward the trapped dipole from this point we see a certain $R_a' + jX_a'$, which corresponds to the impedance of the "source" driving the Trak multicoupler input during the normal noise measurement. The real part of this impedance, R_a', is therefore, the ac load resistance required for our noise diode. Consequently, we need measured data on apparent antenna impedances, as observed at the transmission line output with the antennas actually installed, in order to construct appropriate "dummy antennas" for use with our noise-diode source. The actual dummy antennas each should have a measured impedance $R_a + jX_a$ very nearly equal to the required impedance (i.e., $R_a + jX_a \approx R_a' + jX_a'$).

The circuit of Fig. A-1 provides the noise source we seek: one with known available power, and output impedance the same as the source supplying atmospheric noise to the receiver (Trak multicoupler) input. If the filament voltage of the noise diode is adjusted to provide full-scale deflection of the dc milliammeter (I_{dc} = 100 mA), then the noise power available from the source is $10 \log_{10}(qI_{dc}R_a/2kT_o)$; this equals 36 dB

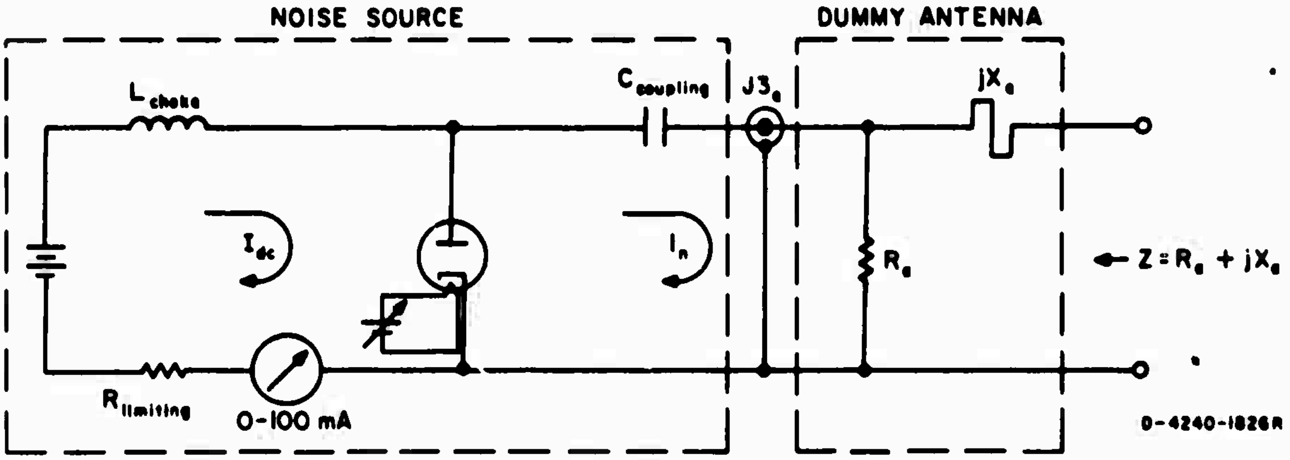

FIG. A-1 SIMPLIFIED SCHEMATIC OF DIODE NOISE SOURCE above kT_ob when R_a is equal to 2 kΩ (the calibration unit of the ARN-3 has an equivalent ac load resistance of about 2 kΩ[*]--see Fig. 9), but the output impedance of the transmission line from our horizontal dipole has a value much lower than 2 kΩ (see Table A-I).[†] If we consider R_a as a variable, then the noise power available from our source can be expressed in dB above kT_oB as $36 + 10 \log_{10} [R_a/(2 \times 10^3)]$. Under these conditions (I_{dc} = 100 mA, which gives full-scale deflection of the meter), when the switch of the calibration unit of Fig. 9 is in the ANT position and the standard ARN-2 antenna is disconnected, the BNC output jack $J3_a$ (which was added for calibration of the dipoles) will be the desired noise source of Fig. A-1. We need only connect the dummy antenna (see Fig. A-2) in series between $J3_a$ and the Trak multicoupler input to produce the desired deflection on the recorder.[§]

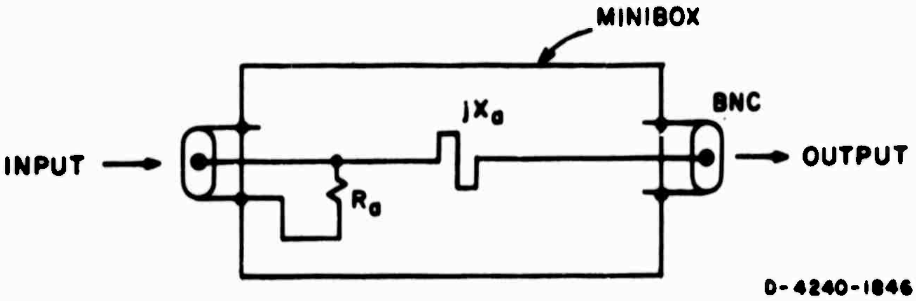

FIG. A-2 SCHEMATIC OF DIPOLE DUMMY ANTENNA

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[*] The 2-kΩ ac load resistance for 2.3, 5.0, and 10.0 MHz is obtained by the series combination of a 2.5-kΩ resistor and a 50-Ω resistor both in parallel with a 20-kΩ resistor shunted by a dc choke with effective ac resistance of about another 20 kΩ.

[†] The cable output impedance was measured at various times during the test program; the observed values are summarized in Table A-1. The results are reasonably consistent, except for the 5-MHz E-W dipole and 10-MHz N-S dipole measured in January 1968. The dummy antennas actually used are reasonably representative except for the 5-MHz (and possibly the 10-MHz) N-S dipoles; even for these antennas, the error is less than 2 dB.

[§] BNC jack $J3_a$ has an ac source impedance of about 2 kΩ (before the dummy antenna is added in series) when the switch is in the ANT position and when the standard antenna is disconnected. With the dummy antenna in position, the shunting effect of 2 kΩ on dummy antenna resistance R_a is negligible, however; since the largest value of R_a is less than 100 Ω. Therefore, the diode noise current passes almost exclusively through R_a.

Table A-1

MEASURED ANTENNA CABLE OUTPUT IMPEDANCE AND DUMMY ANTENNA DATA

Dipole	Freq. (MHz)	Cable Input Impedance, $Z_a' = R_a' + jX_a'$ (ohms)				Dummy Antenna $Z_a = R_a + jX_a$ (ohms)	$F_d' = 36 + 10 \log_{10}\left(\frac{R_a}{2 \times 10^3}\right)$ (dB)
		July 1967	Nov. 1967	Jan. 1968	Mar. 1968		
N-S	2.3	35 + j87	42.5 - j27.5	31 - j5	35 - j10	31 + j18	+16.9
	5.0	not done	29.5 - j2	32.5 + j21	35 - j8	50 - j5	+20.0
	10.0	not done	34 - j43.5	50 + j21	36 - j20	53 - j2	+20.2
E-W	2.3	35 + j87	36 - j22.5	30 - j5	33 - j5	34 + j17	+18.3
	5.0	not done	62.5 + j4	35 - j9	54 - j8	59 - j2	+20.7
	10.0	not done	52 - j4	57.5 + j0	49 - j2	60 - j4	+20.8

When we use the appropriate dummy antenna, and adjust the noise-diode-filament voltage to produce a dc current of 100 mA, we are able to calibrate only one deflection level on the recorder. Since we expect the noise power available from the actual antenna to vary considerably with time of day, season, antenna orientation, etc., we need to calibrate the entire dynamic range of the receiver/recorder combination in decibels relative to the deflection produced by our known noise source. This is most conveniently accomplished with a CW signal generator and an attenuator. The CW signal generator, with step-variable attenuator in series, is used to drive the receiver/recorder system as indicated in Fig. 8. The procedure is to adjust the signal generator output to give maximum deflection on the noise-power chart recorder and then insert attenuation in 5-dB steps until the minimum deflection of the chart recorder is obtained. Then, instead of trying to match the input noise power from the actual antenna to the noise from the diode source,* we can calibrate the chart in the arbitrary dB-scale chart reading, R, using the CW signal generator, and relate this scale to the level D produced by the noise diode (with appropriate dummy antenna) at a fixed I_{dc}. For convenience and accuracy (since the full-scale deflection of the milliammeter in the calibration unit is 100 mA--see Fig. 9), we define

$$F_d' = 36 + 10 \log_{10} [R_a/(2 \times 10^3)] \quad .$$

Values of F_d' are summarized in the right-hand column of Table A-1. Therefore, when the noise from the antenna produces a chart deflection R, the noise power available from the actual antenna, F_d, is given by the following expression:

$$F_d = 36 + R - D + 10 \log_{10} [R_a/(2 \times 10^3)]$$

or

$$F_d = R - D + F_d' \quad .$$

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* This could be done by adjusting the filament voltage of the noise diode every few minutes to cause the noise diode to produce enough noise to equal the average of that observed from the antenna and noting the I_{dc} required.

Now we need only consider antenna efficiency to be able to specify the desired parameter F_a, since $F_a = F_d + L$, where L represents the effective antenna losses in dB (i.e., loss in available power).

The effective antenna losses are composed of transmission-line losses, balun losses, and losses in the antenna itself (heat losses in the antenna wire and traps, and losses in the ground due to the finite conductivity of the ground). Let us define the effective antenna losses, L, in the following way to obtain an estimate of the loss in available power:

$$L = L_T + L_B + L_A$$

where

L_T = Insertion loss of the transmission line in dB[*]

L_B = Insertion loss of the balun in dB[*]

and

L_A = Actual antenna losses (inverse of antenna efficiency)

$= 10 \log_{10} (R_A/R_R)$

where

R_A = Real part of the driving-point impedance of the dipole on the antenna side of the balun

R_R = Radiation resistance of a lossless equivalent of the trapped dipole at the same height above a perfect ground plane.

The measured values of L_T are presented in Table A-2. These values were obtained with 50-Ω load and source impedances (i.e., flat line), but they are reasonable estimates for the actual system as installed.

The insertion loss of the balun is stated by the manufacturer (North Hills) to be 0.25 dB at the frequencies of interest and when source and load impedances are 75 Ω. The insertion losses of the baluns actually

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[*] These insertion losses can be measured and used as estimates of the loss in available power in the transmission line and balun.

Table A-2

MEASURED INSERTION LOSS OF TRANSMISSION LINE, L_T

Frequency (MHz)	Insertion Loss, L_T (dB)	Cable Length (as installed--ft)
2.3	0.64	281
5.0	1.15	281
10.0	1.61	281

used were measured for the case of the balun driven with a 50-Ω source and terminated with a 50-Ω load. These results are summarized in Table A-3. The values for both baluns (North-South and East-West trapped dipoles) were the same to within the accuracy of the measurement--±0.1 dB--and are probably representative of the balun losses as employed.

Table A-3

MEASURED BALUN INSERTION LOSS, L_B

Frequency (MHz)	Balun Insertion Loss, L_B (dB)
2.3	0.7
5.0	0.3
10.0	0.6

Measured values of R_A for the trapped dipoles at 23 feet above ground are given in Table A-4.* The input impedances of actual half-wave horizontal dipoles at the same height above the same ground plane (extended to equal the dipole length) and measured at the same site are also given in Table A-4 for comparison.* Notice that the real part of the

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* These impedances were measured on two different occasions several months apart. The values given in the table were obtained by averaging the results of these two measurements. The actual observed values were within ±5 percent of the average values (i.e., within the accuracy of the bridges used for the measurements).

Table A-4

MEASURED* AND CALCULATED DIPOLE IMPEDANCE AND LOSS VALUES

Dipole	Freq (MHz)	R_R' (Ω)	λ/2 Dipole		Trapped Dipoles		
			R_A (Ω)	L_A (dB)	R_A (Ω)	L_A (dB)	$L = L_T + L_B + L_A$ (dB)
N-S	2.3	7.5	33.5	6.5	27.5	5.7	7.0
	5.0	28.5	36.7	1.1	98.7	5.4	6.8
	10.0	79.3	85.2	0.3	95.0	0.8	3.0
E-W	2.3	7.5	37.0	6.9	29.7	6.0	7.3
	5.0	28.5	35.5	0.9	81.0	4.5	5.9
	10.0	79.3	80.5	0.1	97.0	0.9	3.1

* See footnote on previous page.

feed impedance of the trapped dipoles agrees reasonably well with the values obtained for the full-length λ/2 dipoles on 2.3 and 10 MHz. Observe that the ground plane caused the dipoles to be relatively efficient at 10 MHz. We determine R_R', the radiation resistance of an equivalent lossless half-wave dipole at the same height above a perfect ground plane, from the relationship given by Kraus.[21] These calculated resistance values are summarized in Table A-4. Values for $L_A = 10 \log_{10} (R_A/R_R')$ are given for the full-length λ/2 dipoles. When calculating L_A for the trapped dipoles we assumed that R_R' of a λ/2 dipole at 23 feet over perfect ground is a good estimator of R_R for the trapped dipole at 23 feet over the chicken-wire ground screen as it is installed at Laem Chabang, and we used the formula stated above.

We can now calculate the system constant (K_d) used in the expression to determine F_a for the trapped dipoles, as follows:†

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† By definition, $F_a = K_d + R - D$. Here R is the average noise power level over the observation period for which F_a is being determined, in dB, on the R scale established during the calibration with the CW signal generator; and D is the level produced by the noise diode source with the appropriate dummy antenna in series, in dB, on the same R scale (determined during weekly calibration).

$$K_d = 36 + 10 \log_{10}\left(\frac{R_a}{2 \times 10^3}\right) + L \quad ,$$

where $K_d = F_d' + L$, and the values for F_d' and L come from Tables A-1 and A-4 respectively. Table A-5 summarizes the values of the system constant, K_d, determined from the foregoing discussions.

Table A-5

SYSTEM CONSTANTS FOR TRAPPED DIPOLE NOISE MEASUREMENTS, K_d

Dipole	Frequency (MHz)	K_d (dB)
N-S	2.3	+23.9
	5.0	+26.8
	10.0	+23.2
E-W	2.3	+25.6
	5.0	+26.6
	10.0	+23.9

This concludes the calibration section. The values of F_a obtained in this manner for the trapped dipoles at Laem Chabang may be compared directly with those obtained by the ARN-3 system to determine the relationship between the noise power available from the equivalent of lossless half-wave horizontal dipole antennas at 23 feet above ground planes to the noise power available from the equivalent lossless 21.75-foot vertical monopole.

2. Technique

The calibration of the trapped dipoles to obtain the 5-dB steps on the chart recorder of the ARN-3 equipment will usually be performed after the calibration for the monopole on the corresponding channels has been completed. Calibration for the dipoles is performed at the same power gain and sensitivity control settings as for the monopole calibration. The calibration procedures are as outlined below.

The signal generator is connected to the input of the Trak multicoupler as shown in Fig. A-3 and tuned to the receiver frequency, and the attenuator is adjusted to 10 dB in order to suppress the set noise. (This ensures that the lowest calibration signal is above the set noise level.) The function switch is set to the TCS (short-time-constant) position, the signal generator output is adjusted to inject a signal level giving full-scale deflection on the power strip chart, and the signal generator output level in dBm is logged on the chart. Then the attenuators are used to reduce the generator output level in 5-dB steps and the resulting deflections are indicated on the chart. This procedure produces the R scale.

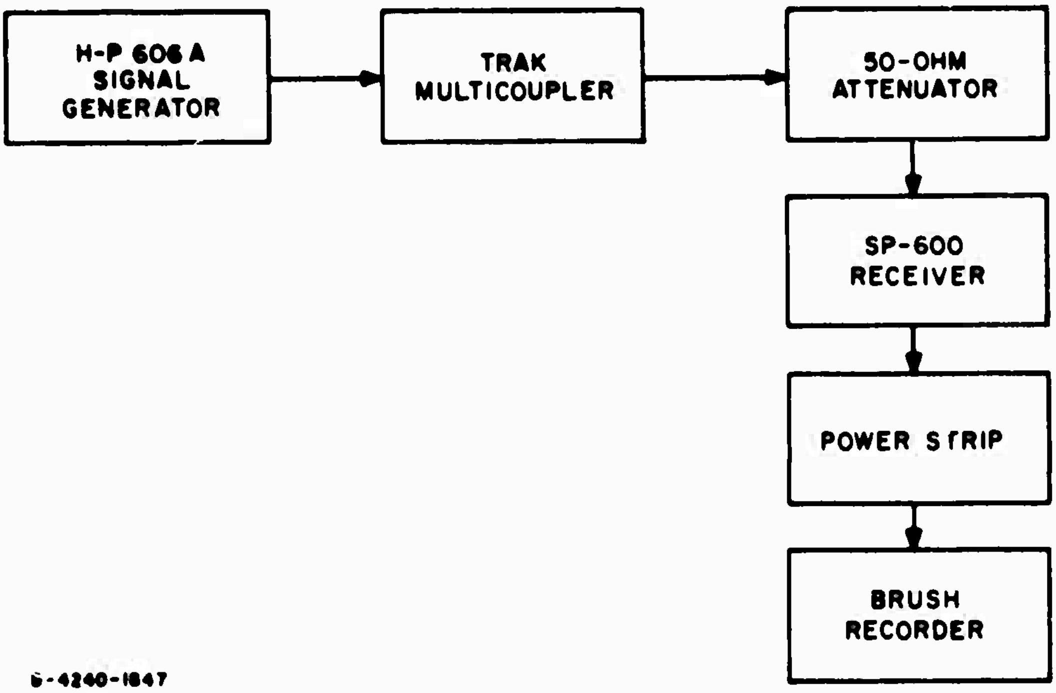

FIG. A-3 CW SIGNAL GENERATOR CALIBRATION SET-UP

To make the noise-diode measurement the input of the dummy antenna for the corresponding frequency is connected to $J3_a$ (diode-plate-current output) and the output of the dummy antenna is connected to the input of the Trak multicoupler and through the attenuators to the receivers (see Fig. A-4).

With the meter-strip function switch set to the TCS position the attenuator is adjusted to 0 dB and the calibration function switch is set to the antenna (ANT) position. The noise diode switch is depressed and

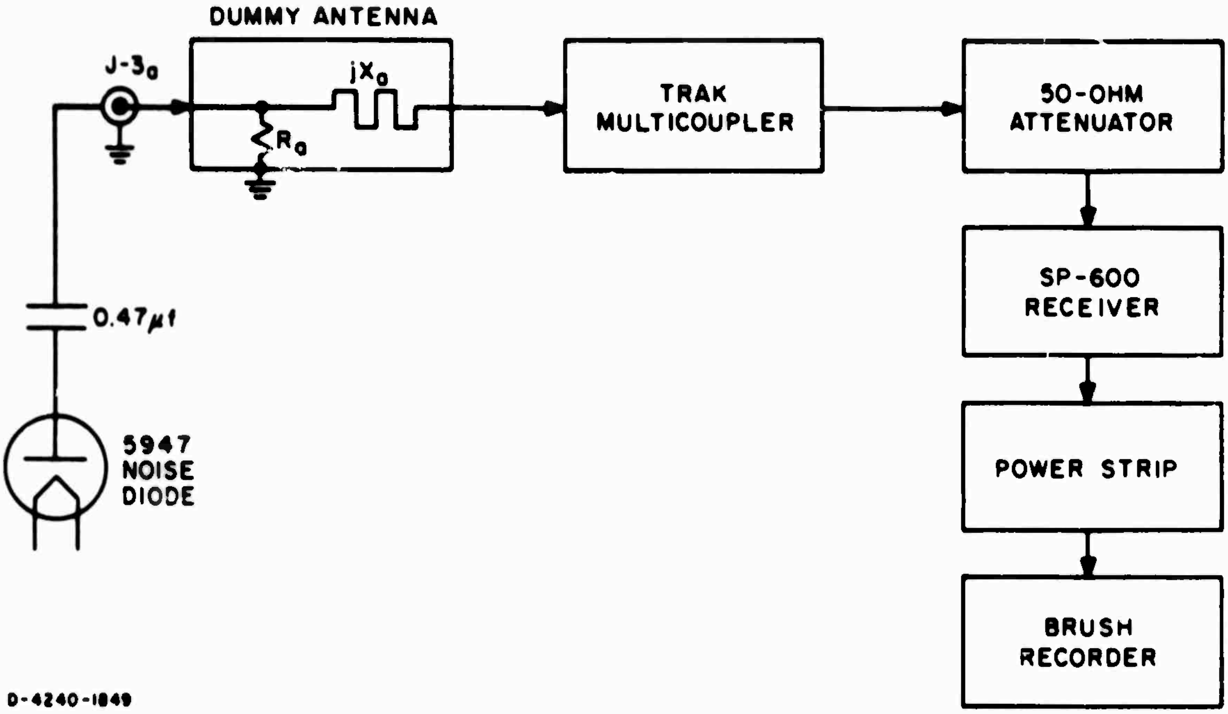

FIG. A-4 NOISE DIODE FACTOR CALIBRATION SET-UP

the diode filament voltage adjusted to give a full-scale (100-mA) noise diode current. The noise diode factor, D, is then logged on the chart in units of the R scale. Then the diode current is turned back and the noise diode switch released. The dummy antenna is disconnected and again the signal generator is fed directly into the Trak multicoupler (see Fig. A-3). The generator output level and frequency are adjusted for the same chart deflection as produced by the noise diode. The output reading of the generator in dBm should indicate the value of the noise diode factor in dB, previously determined. Prior to the measurements of the diode level, it should have been determined that with 0 dB attenuation the receiver set noise level registers on the chart recorder and that this set noise level is lower than the noise diode level. The above procedure completes the calibration of the ARN-3 system for use with the trapped dipoles.

The calibration of the standard ARN-3 system is discussed in Ref. 3, but the authors wish to discuss here the measurement of the stub factor. This is determined only for the standard monopole. The procedure for finding the stub factors is as follows: The receiver is tuned to the desired frequency and retuned (if necessary) to ensure that there is no man-made interference strong enough to be significant. A signal is transmitted through the stub antenna (0.203 m height, and 0.00229-m-diameter copper wire) on top of the vertical antenna ground plane and the signal is received with the standard vertical whip antenna (the distance between the stub antenna and the vertical whip antenna is 1.22 m) and recorded on the power-strip-recording chart. The deflection produced is compared with that caused by a signal generator being fed directly to the input of the system. The difference in the signal level produced by the two methods of driving the receiver will determine the stub factor of the monopole. The trapped-dipole calibration does not use the stub factor technique to determine antenna efficiency. Instead, the equivalent of this stub factor is determined by calculating the antenna system losses, L, as discussed in Sec. 1 of this Appendix.