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INVESTIGATION OF AIRCRAFT GENERATED VLF INTERFERENCE

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Reception distances of VLF/LF transmissions, on board the KC-135 aircraft, have been severely restricted by electromagnetic interference generated by the aircraft's equipment. This interference has prevented the accurate measurement of propagation data at distances greater than 1000 miles when using the aircraft's omnidirectional antenna. With the use of a directional loop antenna

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mounted on the aircraft's boom, reception distances of up to 6000 miles have been attained. The restriction of directionality prevents measurements along paths which are of great importance to the MEECN. The reduction of aircraft interference for VLF/LF reception is of paramount importance to the Air Force and the success of this segment of the Tri Service Propagation Program.

This report describes the investigation of the VLF aircraft generated interference by RADC giving the characteristics of the noise in both the frequency and time domains.

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INTRODUCTION

Air Force and Navy Very Low Frequency and Low Frequency (VLF/LF) communications assets are an important segment of the Department of Defense's Minimum Essential Emergency Communication Network (MEECN). The maintenance of reliable VLF/LF communications from the CONUS to the North, East and West requires knowledge of radio transmission amplitude and phase characteristics together with atmospheric noise levels and time distribution. Since reliable and up-to-date measurements of these properties have been sparse, both Services have augmented the available propagation data with sophisticated mathematical prediction models.

Sufficient geophysical propagation data has been accumulated to substantiate the accuracy of these models in the temperate regions. Unfortunately, data in other regions (Northern Area, Atlantic, Pacific) was non-existent, and the validity of predictions in these areas is dubious at best. In order to obtain measurements to validate the prediction models, the Defense Communications Agency organized the Tri Service Propagation Measurement Program.

One portion of this program is the gathering of geophysical parameters of VLF/LF transverse magnetic waves measured at high altitude. This is accomplished by the use of an RADC KC-135 aircraft. Since the primary importance of VLF/LF communications is message transmission over great distances, propagation data at points far from the transmission site are of the greatest importance.

Reception distances of VLF/LF transmissions, onboard the KC-135 aircraft, have been severely restricted by electromagnetic interference generated by the aircraft's equipment. This interference has prevented the accurate measurement of propagation data at distances greater than 1000 miles when using the aircraft's omnidirectional antenna. With the use of a directional loop antenna mounted on the aircraft's boom, reception distances of up to 6000 miles have been attained. The restriction of directionality prevents measurements along paths which are of great importance to the MEECN. The reduction of aircraft interference for VLF/LF reception is of paramount importance to the Air Force and the success of this segment of the Tri Service Propagation Program. Similar VLF/LF aircraft interference has been documented by personnel operating equipment onboard the Airborne Command Post (ABCP).

This report describes in detail the interference characteristics, both in the time and frequency domain, and their effect on reception from different antenna locations on the RADC KC-135 aircraft structure (see Figure 1).

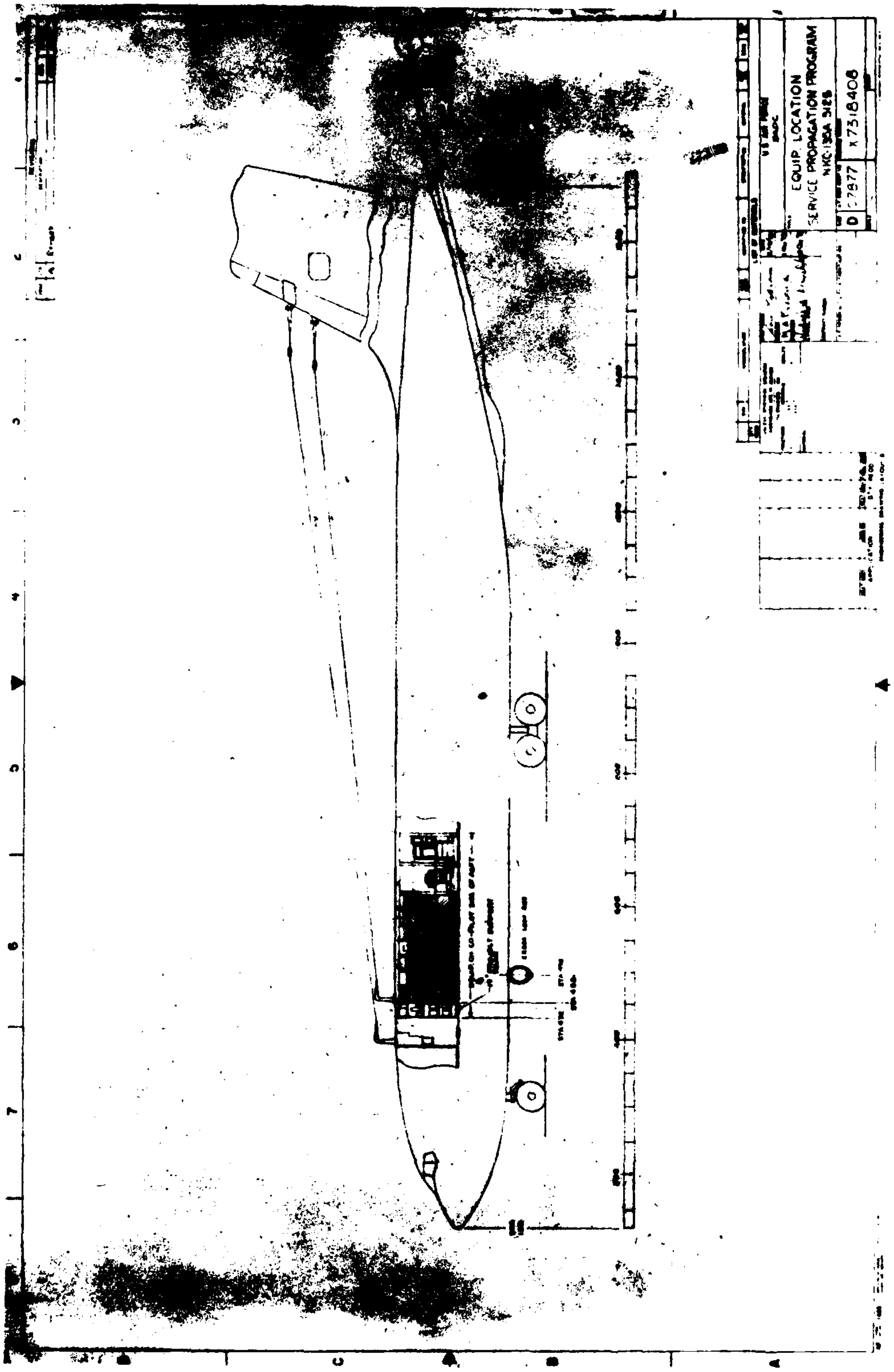

EQUIP. LOCATION
SERVICE PROPAGATION PROGRAM
NKC-135A
K7318408

FIGURE 1

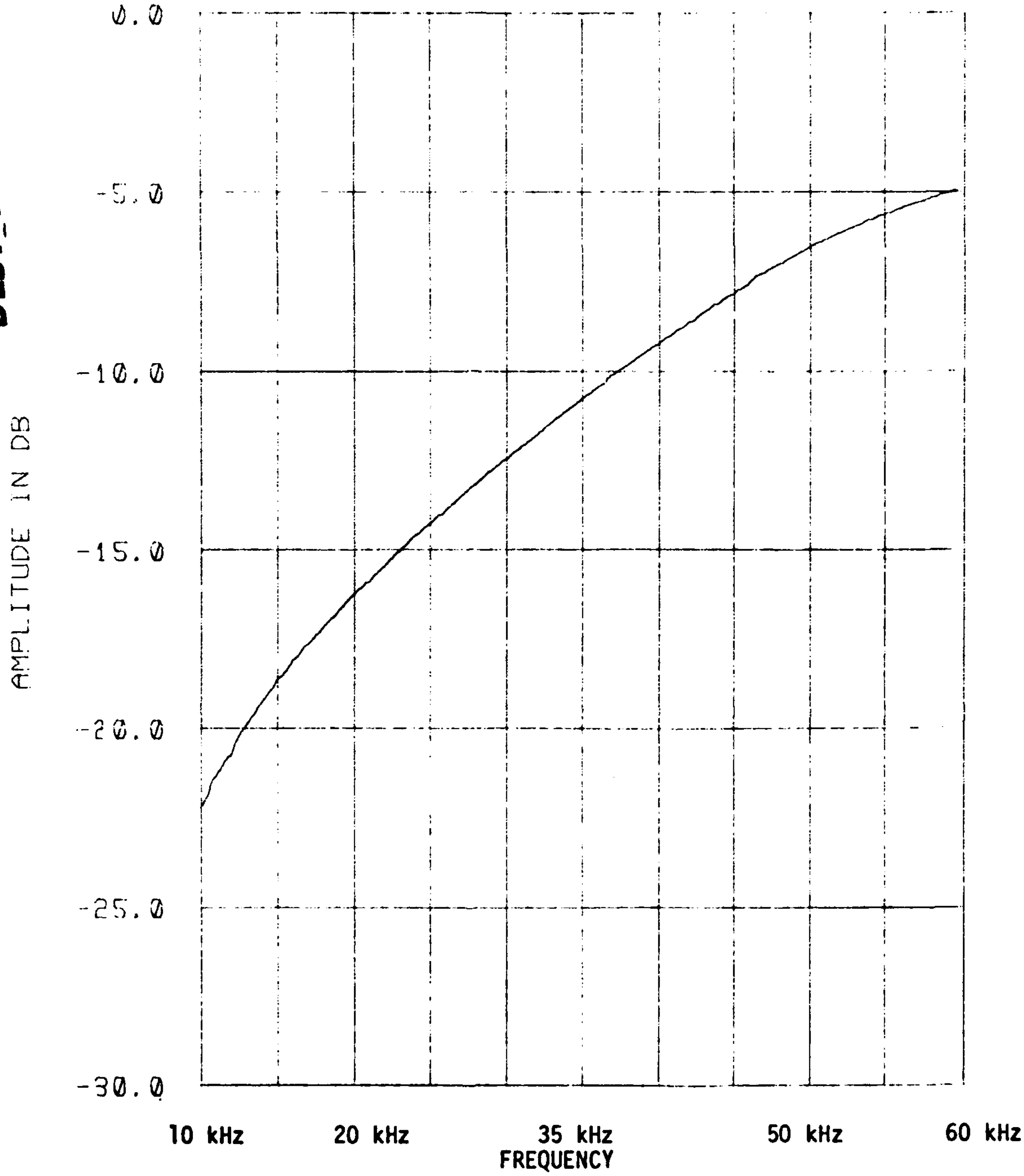
ANTENNA SYSTEM CONFIGURATIONS

There are two main VLF receive antenna systems on KC-135 #125 which are of concern in this report.

The Air Force has a crossed-loop antenna on the belly of the aircraft. The loops are oriented at 45° angles to the structure. Both loops are summed to form an omnidirectional receive pattern. The power to the pre-amp/summer is supplied by two 28 volt batteries tapped for + and -15 volts. The combination pre/amp and summer has an overall gain of 50 dB. The antenna is tuned to a peak at approximately 31 kHz.

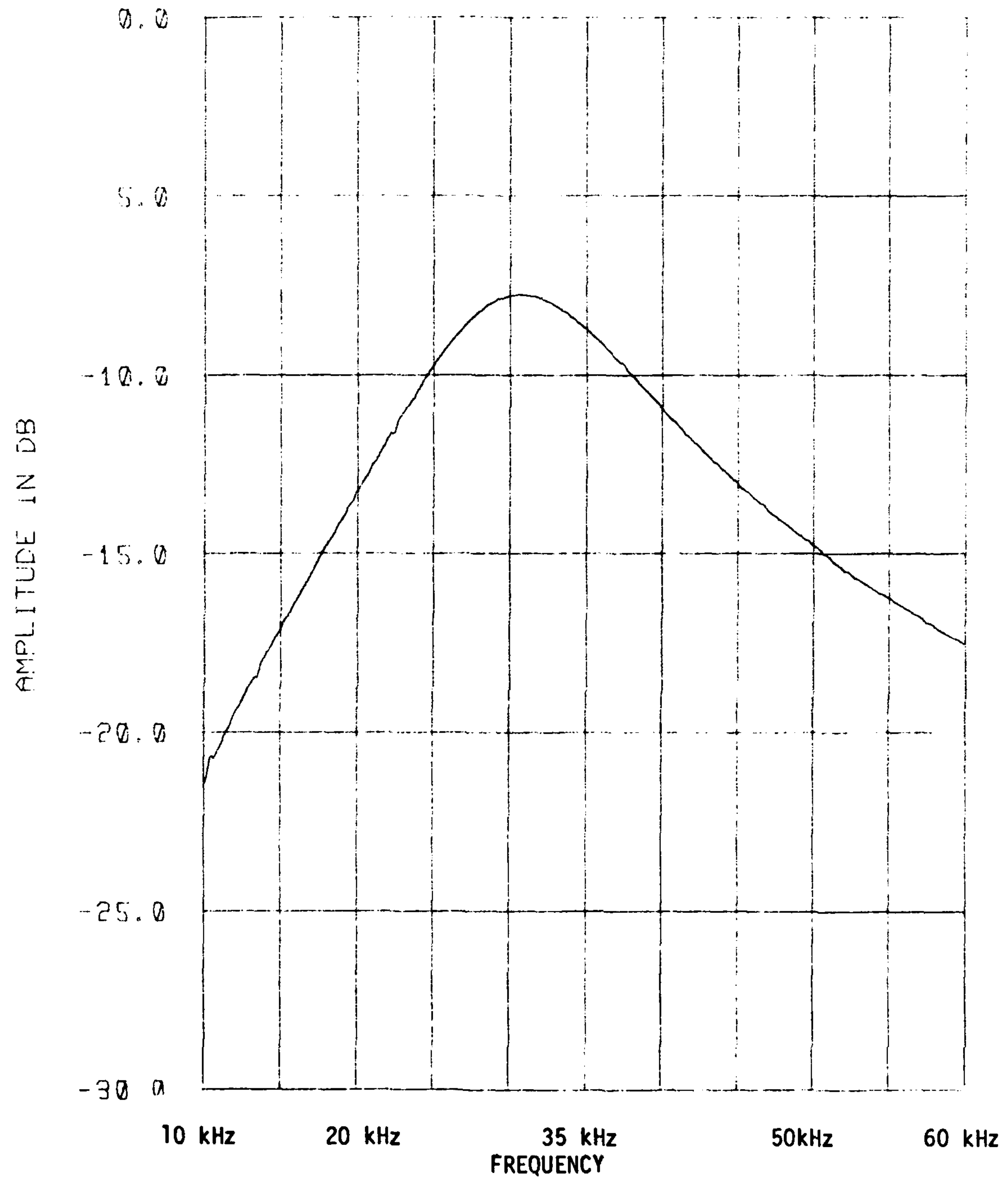
The Navy has a crossed-loop antenna mounted on the boom of the aircraft. One loop has a vertical orientation, the other horizontal. The loops feed a 50 dB gain pre-amp and then, in turn, a multi-coupler. The power to the pre-amp and multicoupler is supplied by two 28 volt power supplies. The loops are tuned to a peak at approximately 65 kHz.

Both the Navy and Air Force's crossed-loop antennas were designed and built by Megatek Corporation (Calif.). The Air Force's crossed-loop antenna was originally tuned to 65 kHz, but was retuned by RADC engineers to be more responsive to Air Force frequencies. (See Figures 2 and 3).



ORIGINAL TUNING AIR FORCE ANTENNA

FIGURE 2



FINAL TUNING AIR FORCE ANTENNA

FIGURE 3

DESCRIPTION OF INTERFERENCE

Aircraft interference, on both Navy and Air Force Antennas, has been examined in the frequency and time domains. Measurements were made using an oscilloscope and a 3040A Network Analyzer. All measurements were made in the hangar at a time when the aircraft was in for repairs. All access doors and panels were open or off at the time of these measurements. A slight increase in interference was noted; in comparison to preliminary measurements made on an earlier date. The following photos and graphs display the interference as seen on KC-135 #125.

Photo #1 was taken with the oscilloscope connected to a URM-6 loop antenna. This antenna was positioned directly below (but not in contact with) the aircraft structure as near as possible to the Air Force Loops. Photo #2 is a time reduction of the waveform seen in Photo #1.

Photo #3 displays the time domain waveform taken with the oscilloscope connected to the Air Force antenna. Photo #4 displays the time domain waveform of the Navy's vertical loop. Comparison of these two waveforms shows that the interference on the Air Force loops is approximately 40 times greater in peak voltage than the Navy loop on the boom (2.5V P-P versus .03V P-P).

Photo #5 displays the same waveform as Photo #4 with the time expanded to show the 60 cycle component.

Photo #6 displays the waveform as measured on the Navy's horizontal loop.

Figures 4 and 5 display the aircraft noise spectrum from 16 kHz to 18.5 kHz on the Air Force loop and the Navy vertical loop, respectively. Figures 6 and 7 display the spectrums from 35-37.5 kHz on the respective antennas.

It can be seen that the Navy antenna, on the boom, has approximately 30 dB less average noise. The transmission from Cutler, Maine on 17.8/17.850 kHz can be distinguished in Figure #5.

Comparison of Photos 7 and 8 demonstrates the effect of the 60 Hz converters on the Air Force Antenna's Interference. Figures 8 and 9 display a 20 dB drop in average interference level when the 60 Hz converters are off and project equipment on 60 Hz ground (hangar) power (compared to Figures 4 and 6).

Photos 9 and 10 display the effect of 60 Hz converters (Photo 9 converters ON, Photo 10 converters OFF) in the time domain as seen on the Air Force Antenna Calibration Loop (Cal. Loop does not go through pre-amp/summer).

Photo 11 displays the interference which appears on the Air Force Antenna with all project power off (this includes the +/-15 volts DC to pre-amp/summer).

Photo
#1

.05 volts/cm

. 5 ms/cm

URM-6 Antenna Pickup of 60 cycle Converter Noise

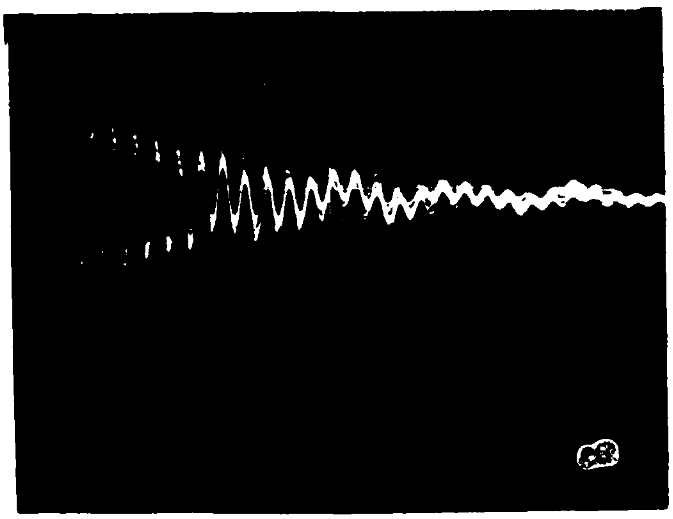


Photo
#2

.05 volts/cm
10μs /cm

expansion of Photo #1

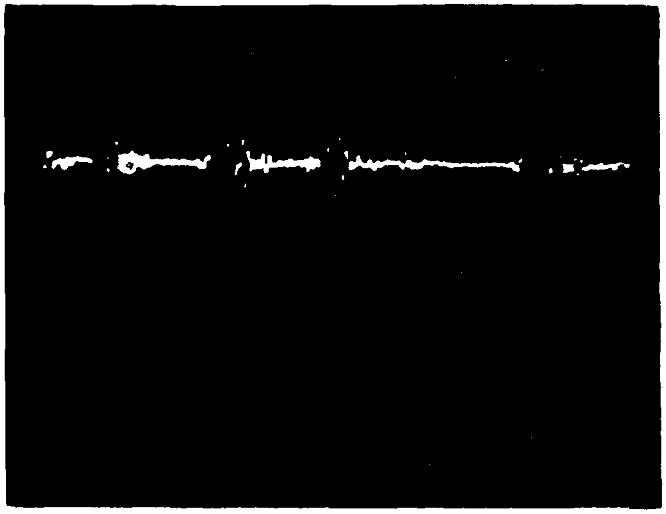


Photo
#3

1. volt/cm
.5 ms/cm

Air Force Antenna
Interference

Photo
#4

.02 volts/cm
. 5 ms/cm

Navy's Vertical Loop
Interference

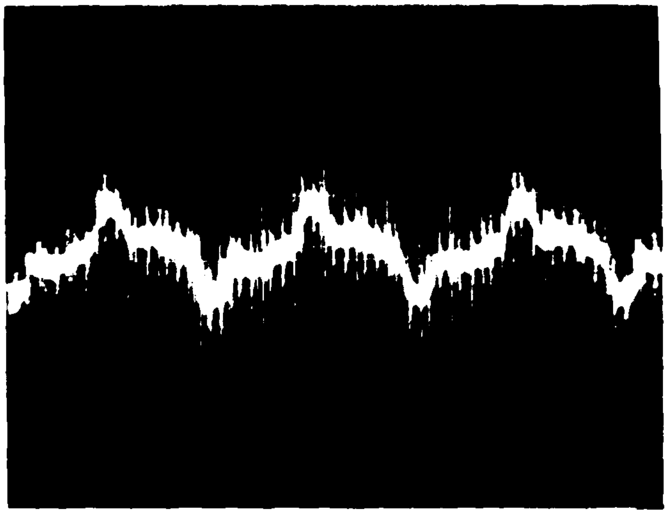


Photo
#5

.02 volts/cm
5.0 ms/cm

Navy's Vertical Loop
Interference

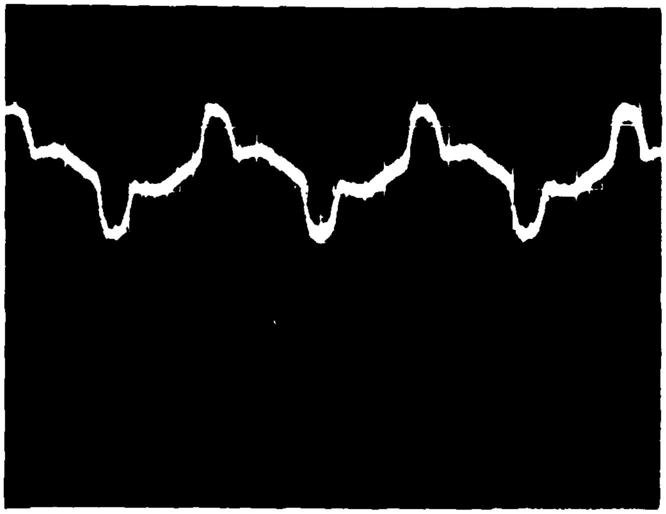


Photo
#6

.02 volts/cm
5.0 ms/cm

Navy's Horizontal Loop
Interference

Photo
#7

2 volts/cm
.5 ms/cm

Air Force Antenna
Interference 60 Hz
Converters ON

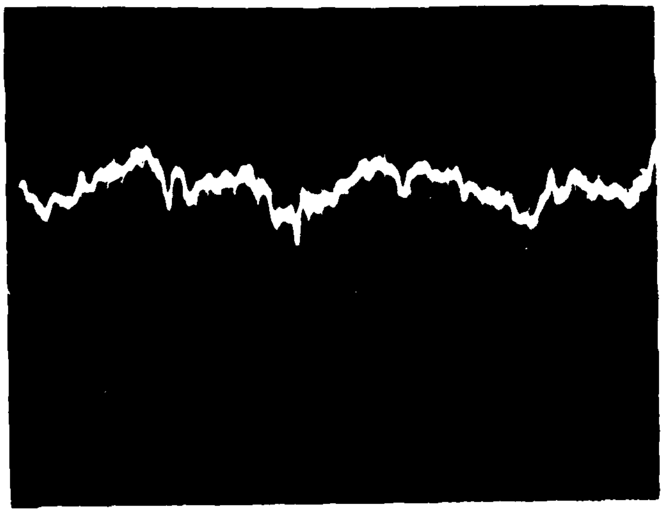


Photo
#8

.02 volts/cm
.2 ms/cm

Air Force Antenna
Interference 60 Hz
Converters OFF

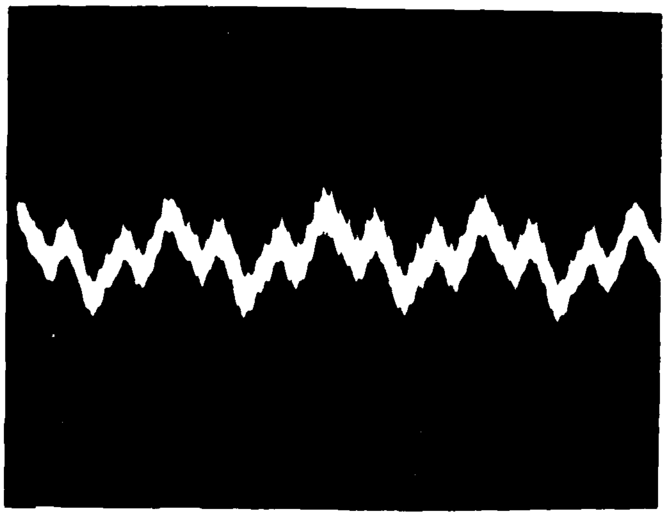


Photo
#9

.01 volts/cm
1.0 ms/cm

Air Force Calibrate
Loop 60 Hz Converters
OFF

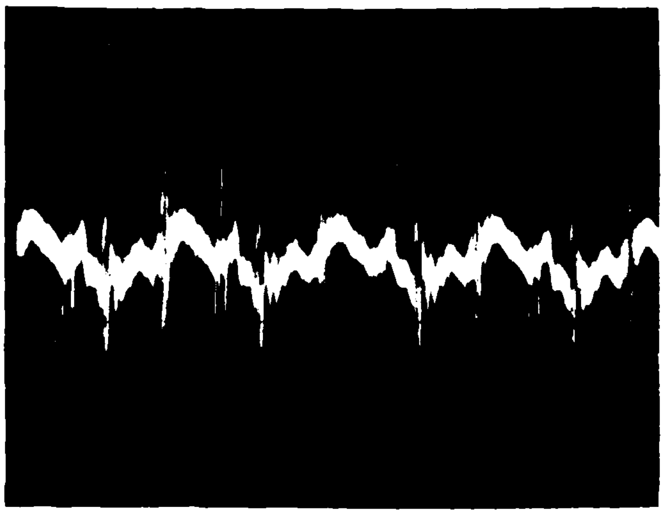


Photo
#10

.02 volts/cm
1.0 ms/cm

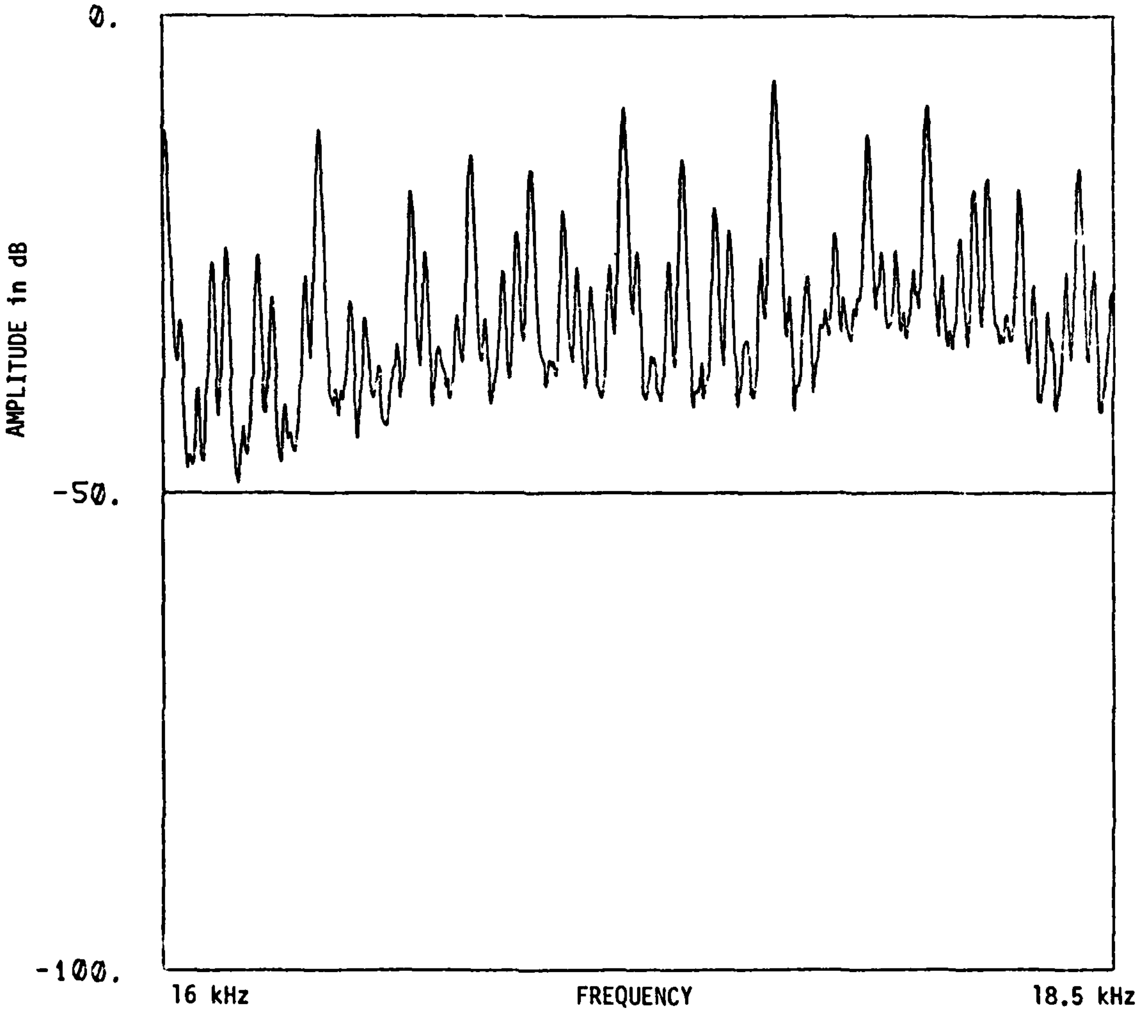
Air Force Calibrate
Loop 60 Hz Converters
ON

Photo
#11

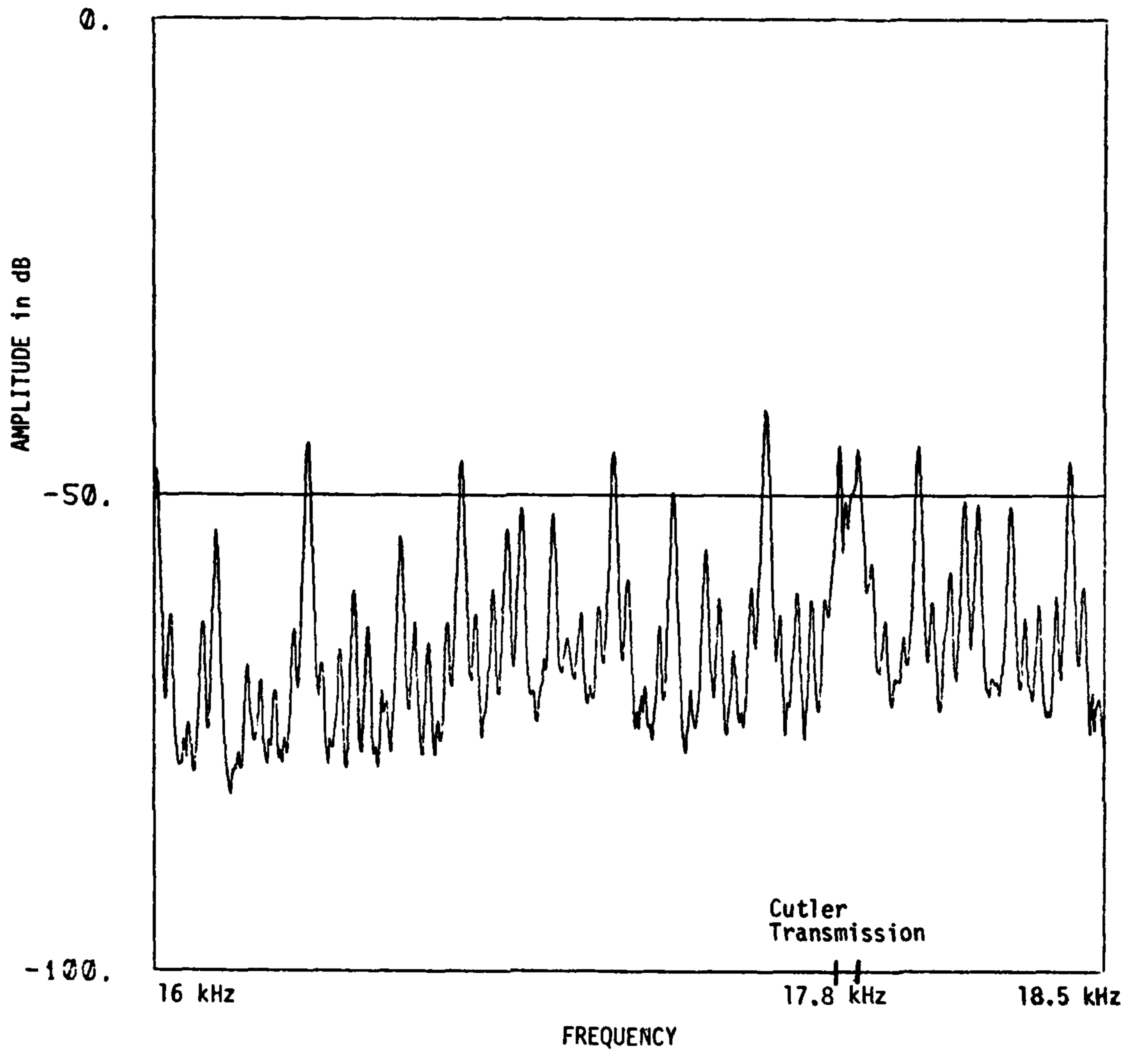
.005 volts/cm
1 ms/cm

Air Force Antenna All Project Power OFF

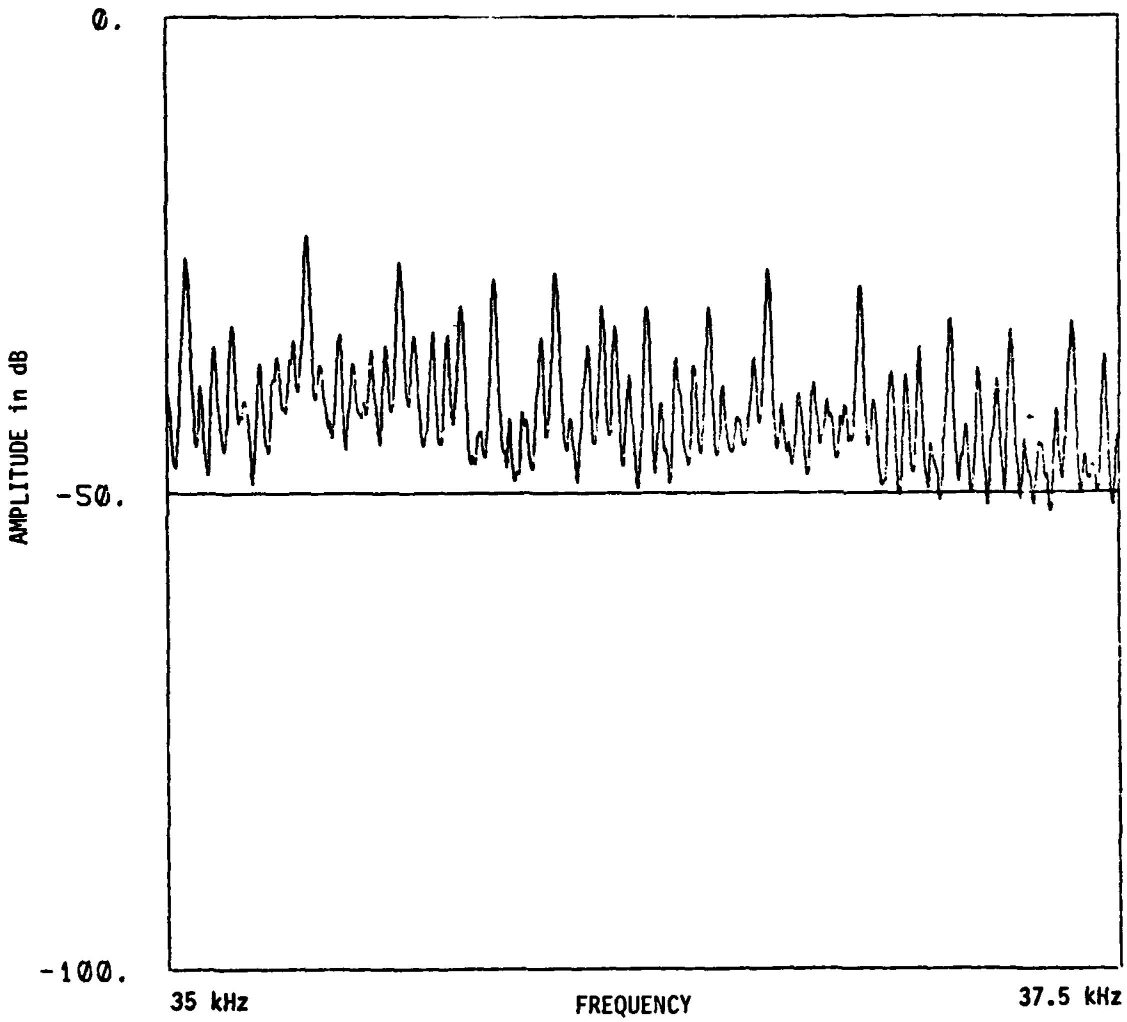
(+/-15 volts to pre-amp/summer OFF)



AIR FORCE'S CROSSED LOOP
FIGURE 4

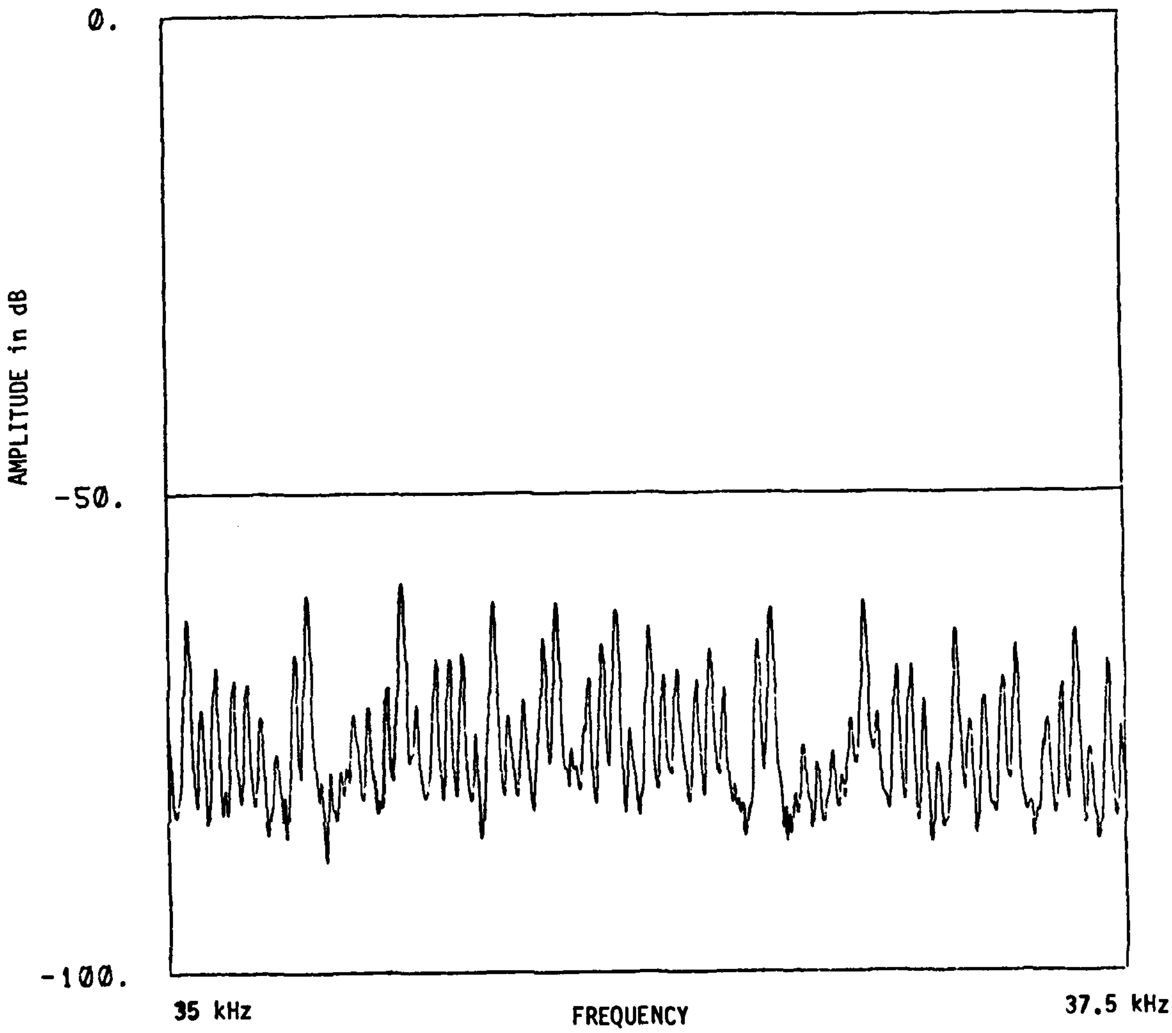


NAVY'S VERTICAL LOOP
FIGURE 5



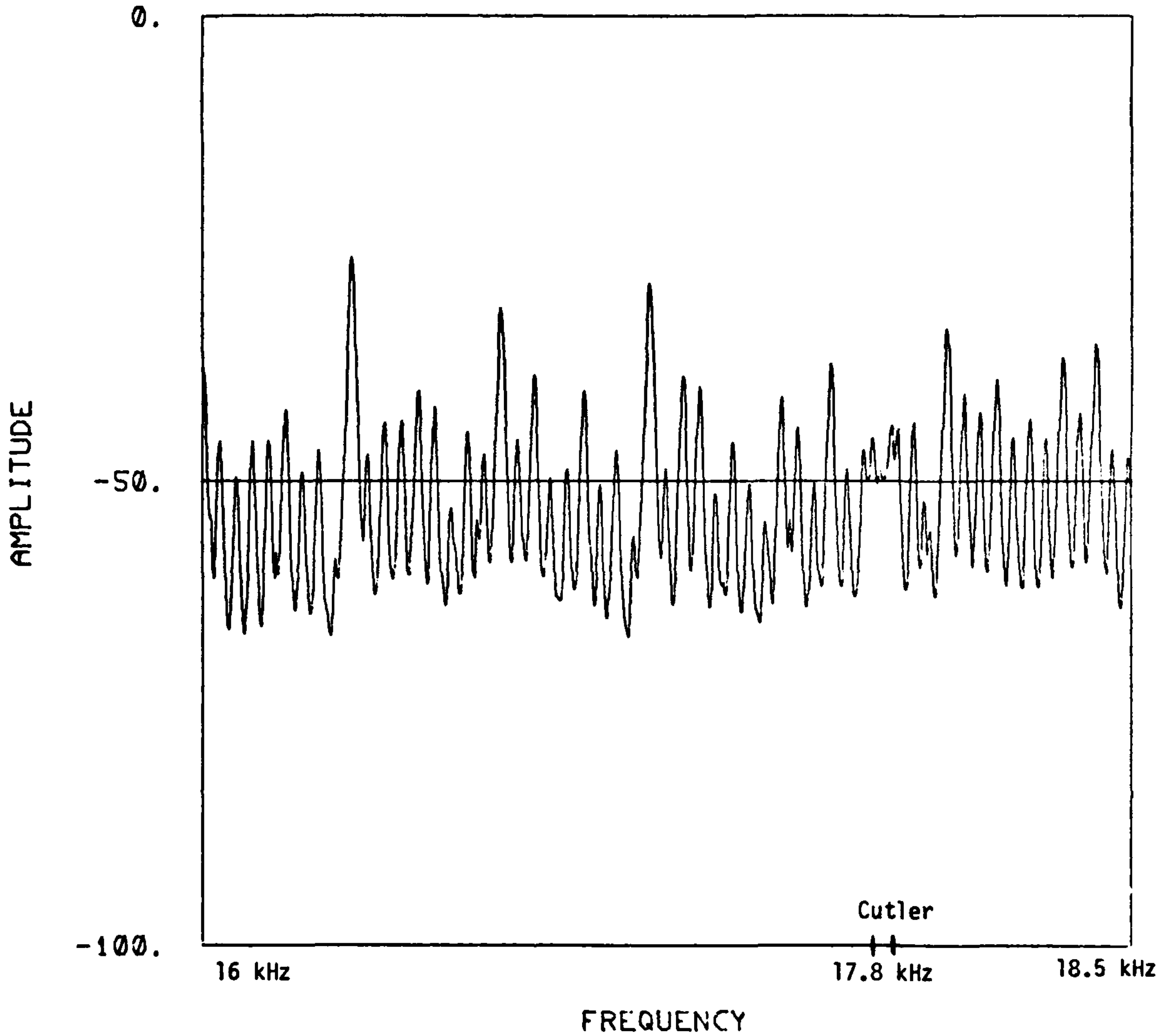
AIR FORCE'S CROSSED LOOP

FIGURE 6

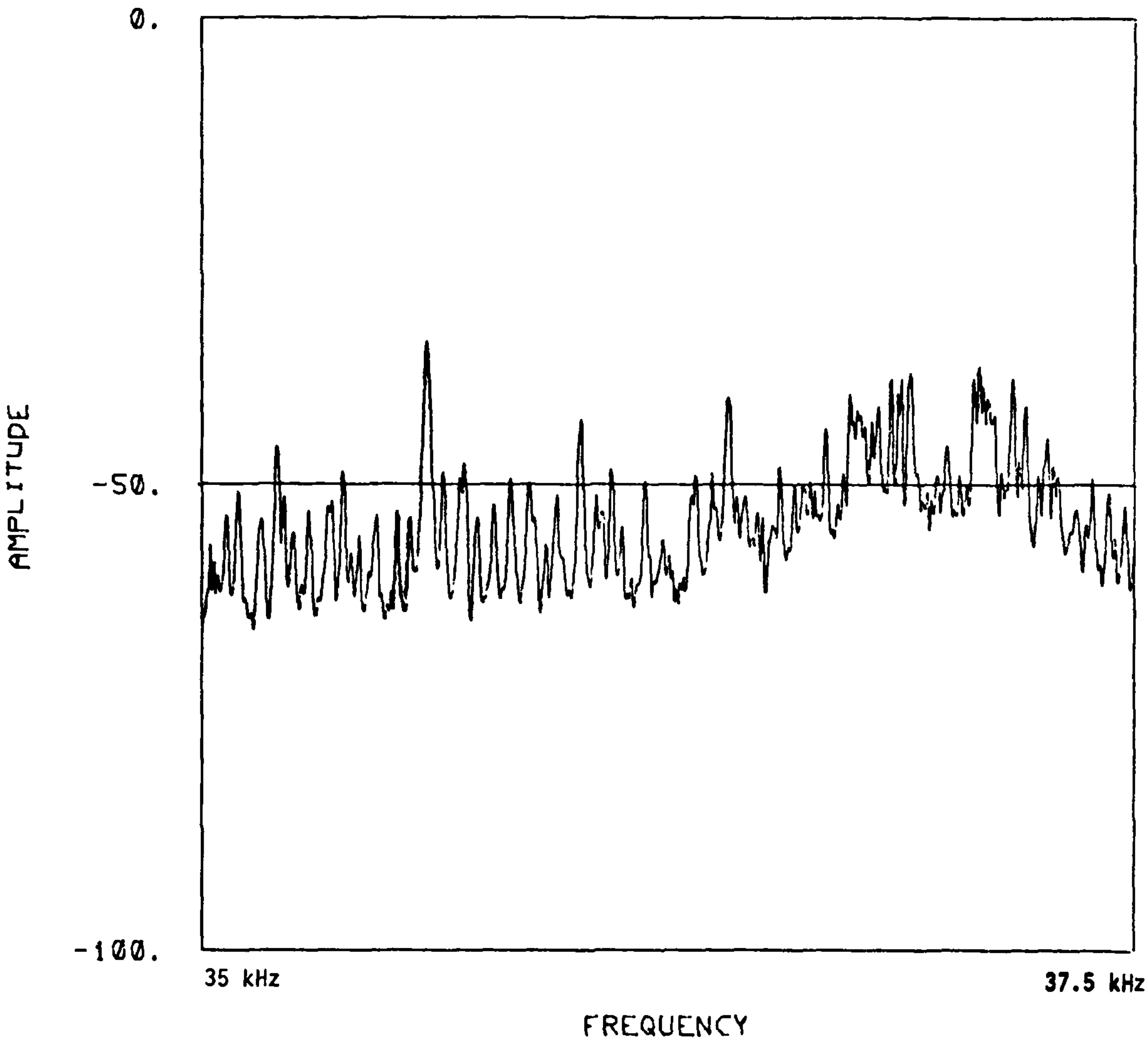


NAVY'S VERTICAL LOOP

FIGURE 7



AIR FORCE ANTENNA 60 Hz CONVERTER OFF
FIGURE 8



AIR FORCE ANTENNA 60 Hz CONVERTER OFF

FIGURE 9

SUMMARY

From all the measurements made on and around the aircraft, both in and out of the hangar, and under both ground and aircraft power, it is concluded that the KC-135's boom is the most advantageous position for a VLF antenna. The farther from the frequency converters and the body of the aircraft, the less the interference. Battery power would reduce some of the 60 cycle noise as seen on the Navy loops, however, it has been determined that the single most obliterating interference is caused by the 60 cycle converters which are needed to supply the 60 cycle, 115V power to all the project equipment. These converters cause the large ($\approx$ 300 kHz) bursts at a 400 cycle rate which can be seen in Photos #1,2, 3 and 4.

There has been some investigation of spatial filtering in the time domain but no experiments or recommendations have been made in this area.

Unfortunately, the Navy's antenna has only a single vertical loop and is therefore, directional. Any changes in the aircraft's orientation with respect to transmitted signals produce amplitude fluctuations in reception. RADC flight engineers are reluctant to place another vertically oriented loop onto the aircraft's boom in apprehension of severe structural stress.

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METRIC SYSTEM

BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

SUPPLEMENTARY UNITS:

Quantity	Unit	SI Symbol	Formula
plane angle	radian	rad	...
solid angle	steradian	sr	...

DERIVED UNITS:

Quantity	Unit	SI Symbol	Formula
Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
electric potential difference	volt	V	W/A
electric resistance	ohm		V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m/s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

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