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(6) MEASUREMENTS OF ANTENNA CURRENT AND TELEPHONE INFLUENCE FACTOR AT THE U.S. NAVY'S WISCONSIN ELF COMMUNICATIONS TEST FACILITY

Prepared for

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FOREWORD

This report presents data and observations from IITRI's Telephone Influence Factor (TIF) measurement activities conducted at the U.S. Navy's ELF Communications Test Facility in Wisconsin in June 1977. It may be considered a companion to IITRI Technical Report No. 8, "Voice Telephone Interference Due to Seafarer Generated Harmonics." The report is divided into two separate parts; these cover antenna current measurement experience using the Wilcom T132B Test Set together with (1) a clamp-on current probe, and (2) a test coil.

This document was prepared for the Special Communications Project Office of the U.S. Naval Electronic Systems Command, by IIT Research Institute, as part of Contract N00039-76-C-0141. The effort reported supports development of the Navy's ELF Communications System and was carried out at the direction of Lt. Cdr. W.S. Phillips (PME 117-214).

Respectfully submitted,

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TABLE OF CONTENTS

PART 1

ELF TRANSMITTER CURRENT HARMONICS
MEASURED WITH A CLAMP-ON CURRENT PROBE

1. INTRODUCTION

ELF harmonic measurements were made on the Wisconsin Test Facility (WTF) transmitter current by means of a current probe clamped onto the antenna cable (pair) going to the west leg of the east-west antenna. The measurements had the following objectives:

- Gain familiarity with the use of the Wilcom T132B test set and the T272 clamp-on probe for measuring the RMS current and the telephone influence factor (TIF) of the current in an insulated conductor.
- Determine harmonic content and TIF for the WTF transmitter when operating either single frequency or modulated (MSK).

Part 1 of this report describes the current-probe tests and presents the measurement results.

2. CONCLUSIONS

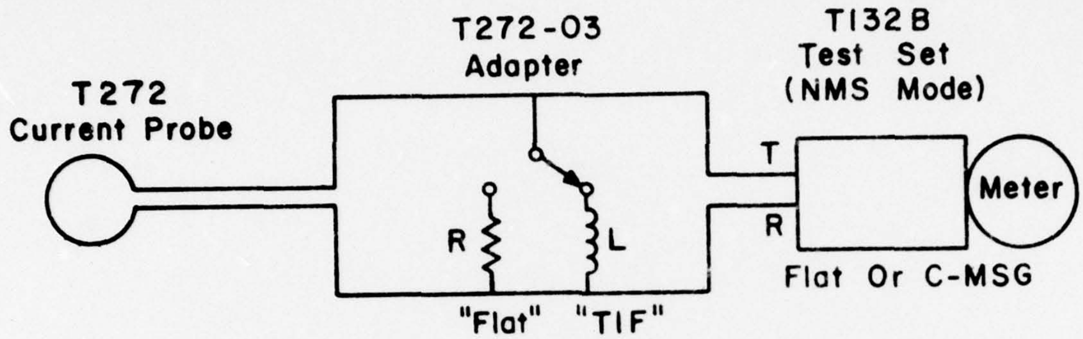
For both single frequency and MSK operation of the WTF transmitter only the first few harmonics were detectable, and these were approximately 70 dB below the fundamental in amplitude. Due to these extremely small values for all the harmonics, the calculated value[1] for TIF of the modulated transmitter current was found to be equal to the TIF for single frequency 76 Hz signal, namely, 1.27. Thus, an antenna current of 295 amperes RMS has a calculated I·T product of 375.

Directly measured values of the I·T product were somewhat higher than the indirectly determined value, due to overloading of the TIF meter at this high value of antenna current.

3. DESCRIPTION OF INSTRUMENTATION

The Wilcom T272 Clamp-On Current Probe, the T272-03 Adapter, and the T132B Spectrum Analyzer and Noise Measuring Set are used for measuring either total RMS current I, in a conductor, or the I·T product for the current. As shown in Figure 1, the T272-03 adapter consists of two components -- a resistor and an inductor -- either of which can be switched so as to shunt the T132B test set input, depending on the type of measurement desired.

The clamp-on current probe acts as a transformer between the current carrying conductor (antenna cable) and the measuring instrument. For each frequency component of current flowing in the conductor, the probe develops a voltage proportional to the magnitude (I) and the frequency (f) of that



R = 0.275 Ohm

L = 263 Millihenry

Setting For	T272-03	T132B
I	Flat	Flat
I·T	TIF	C-Msg

Figure 1 USE OF T272-03 ADAPTER IN MEASUREMENT OF I AND I·T USING T132B IN BROADBAND MODE

component. In addition, the frequency response of the T132B noise measuring set (NMS Mode) can be selected to have C-message weighting. This weighting,[1] usually denoted by p_f, plus the probe response, gives an overall response proportional to Ifp_f. At any single frequency f the TIF, or T, is defined as $T \equiv 5\ fp_f$. Thus, for a single frequency, the test set, with its appropriate scale factor, provides a measurement of I·T. For a complex current waveform consisting of components at several frequencies, the test set determines the root-sum-square of all the (weighted) components in the waveform and indicates the value of I·T for the composite waveform.

As shown in Figure 2, one meter reading, designated as M1, is used for obtaining a direct measurement of the I·T product for the magnitude and waveform of the current. The meter reading M2, derived from the unweighted frequency response, is used for direct measurement of I, the RMS magnitude of total current flowing in the conductor, even if it contains more than one frequency component. The value for the waveform TIF can be found by taking the quotient I·T/I.

The T132B test set can also operate in a spectrum analyzer mode with a 3 dB bandwidth of approximately 16 Hz. Hence, individual harmonics of the transmitter can be measured.

4. TEST PROCEDURES AND RESULTS

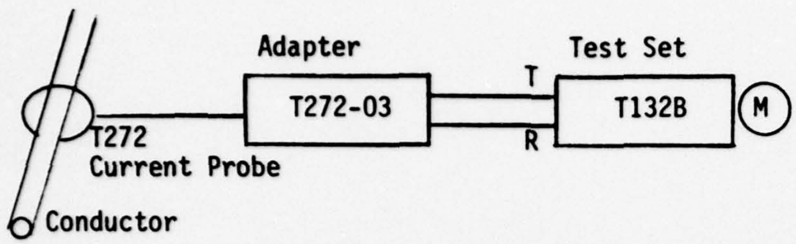
After the WTF transmitter and the output filter in the WTF Capacitor Room were de-energized, the T272 probe was clamped onto the pair of cables going to the west leg of the east-west antenna. The probe was placed on the cable pair just ahead of the point where the cables exit from the Capacitor Room. A long twisted-wire pair of test leads were used to connect the probe output to the T272-03 adapter and T132B test set, which were located in the hallway on the floor outside the door of the Capacitor Room.

Measurements of current, harmonics, or TIF were then made for either single frequency or modulated (MSK) transmitter operation at desired current levels requested of the transmitter console operating engineer.

Results are presented in Table 1.

4.1 Transmitter Harmonics

Currents at the transmitter fundamental and harmonics were measured using the T132B test set in the spectrum analyzer mode (see Table 1). Measured data



M is sum of (1) Black (dBrn) setting on LEVEL switch, and
(2) Black (dBrn) reading on METER

Settings

T132B			T272-03	T = TIF I = RMS Total Current
Function	Weighting	Operating Mode		
BRDG 600	CMSG	NMS	TIF	Read M as M_1 $(I \cdot T)_{dB > 1\ ampere} = M_1 - 20$ $I \cdot T = 10^{\left(\frac{M_1 - 20}{20}\right)}$ amperes
BRDG 600	FLAT	NMS	FLAT	Read M as M_2 $(I)_{dB > 1\ ampere} = M_2 - 20$ $I = 10^{\left(\frac{M_2 - 20}{20}\right)}$ amperes
				$T = \frac{I \cdot T}{I} = 10^{\left(\frac{M_1 - M_2}{20}\right)}$

Figure 2 MEASUREMENT OF I·TIF USING CLAMP-ON CURRENT PROBE[2]

TABLE 1

WTF CURRENT MEASUREMENTS WITH CLAMP-ON PROBE

Date	Transmitter		T132B Spectrum Analyzer Mode						T132B NMS mode				
	Mode	I(amp)	Harmonic	Freq.	M2	I(amp)	I·T	T	M2	I_{rms}	M1	I·T	T
6/14	SF	277							69.4	295	85.3	1840	6.2
			1	76	69.4	295							
			2	152	≃ - 4	0.06							
			3	228	≃ - 1	0.09							
			4	304	≃ - 7	0.04							
			5	380	≃ - 6	0.05							
			6	456	< -10								
			> 6	None up to 4 kHz			375	1.27					
	MSK	197							66.8	218	80.5	1059	4.9
			1	76	66.8	218							
			2	152	≃ - 2	0.08							
			3	228	≃ - 5	0.06							
			4	304	< -10								
			> 4	None up to 4 kHz			277	1.27					
	SF	197							66.6	214	80.5	1059	5.0

SF = nominal single frequency (76 Hz)

MSK = modulated { 72 Hz low frequency; 80 Hz high frequency; 16 Hz chip rate } are given in the first column labeled M2. From these values the current, I, in amperes, was calculated separately for each harmonic using the equation for I as given in Figure 2. Then, values for C-message weighting (p_f) were used for calculating the I·T product for the composite waveform. Lastly, the calculated value of I·T was divided by the measured value of I to determine T, the TIF of the waveform.

The conclusions drawn from the spectral analysis measured are:

1) Only a few harmonics are large enough to be detectable, and these are approximately 70 dB below the fundamental both for single frequency and MSK operation.

2) The calculated value of T (or TIF) based on the measurements of the individual harmonics was 1.27 for both single frequency and MSK operation. In both cases only the fundamental was significant in these calculations, and thus the resultant value of T is the value for a single frequency signal of 76 Hz.

4.2 Direct Measurement of I·T

With the T132B test set operating in the NMS (noise measuring set) mode (see Table 1), values of the RMS total current and of the I·T product were determined directly by measurements M_2 and M_1, respectively, using the methods of Figure 2. Then, T was determined by division.

The results for the I·T products and for T as obtained from measurements in the NMS mode disagree with the results obtained from spectral analysis, namely, 4.9, 5.0, and 6.2 vs. 1.27. This was due to a slight overloading of the T132B test set in the NMS mode when measuring high currents. Direct measurement of I·T using a current probe could be accurately made if the coupling factor of the probe were reduced or a voltage attenuator network were used to preclude overloading the test set.

REFERENCES

1. "Voice Telephone Interference Due to Seafarer Generated Harmonics," Technical Report No. 8, IIT Research Institute for U.S. Naval Electronic Systems Command, June 1977.

2. "Model T132B Spectrum Analyzer and Noise Measuring Set," Wilcom Products, Inc., Laconia, New Hampshire, August 1973.

PART 2

ELF WTF TRANSMITTER CURRENT HARMONICS
MEASURED WITH A PROBE COIL UNDER THE WTF ANTENNA

1. INTRODUCTION

Spectral measurements of the ELF communications transmitter at the WTF had shown all harmonics to be at least 70 dB below the fundamental, as described in Part 1 of this report. Those measurements were made in the transmitter building using a Wilcom T132B test set with a current probe on the antenna cable (pair) going to the west leg of the east-west antenna.

Subsequently, measurements of the antenna current TIF[1] were performed at three locations along the antenna, using the Wilcom test set with a probe coil positioned beneath the (overhead) antenna. This part of the report describes the probe-coil tests and presents the results of those measurements. Some qualitative comparisons are made of the relative merits of a broadband measurement set (e.g., Wilcom T132B) and a narrowband wave analyzer (e.g., HP3581) for making these types of measurements. Lastly, some comments are made on the possible use of this method for making similar measurements on a buried antenna.

2. CONCLUSIONS

For a uniform current flowing along the antenna, the measured values of I and T (and therefore also I·T) should be the same for all three test sites and for all values of antenna-to-coil separation. The MSK data show this to be the case, within a small experimental error. Measured values of current ranged from 234 to 262 amperes; I·T products from 317 to 338; and TIF values from 1.3 to 1.4, with an overall average of 1.32. This average value agrees well with the expected value of 1.27 for a single-frequency current at 76 Hz, i.e., the ELF transmitter fundamental frequency in the absence of harmonics.

Harmonics were found to be 65 dB below the fundamental in amplitude, substantially agreeing with the result of 70 dB previously determined from measurements with a clamp-on current probe.

The single frequency (SF) data, taken at one site, are similar to the MSK data taken at all three sites.

No measurements were attempted in the vicinity of a buried antenna cable, but measurements of I and TIF could probably be performed in this situation if cable location is known to a reasonable accuracy.

3. DESCRIPTION OF INSTRUMENTATION

In general, a conductor carrying an alternating current produces an alternating magnetic field in the surrounding space. A probe coil immersed in that magnetic field will have an induced voltage proportional to current and frequency, and dependent on coil dimensions, orientation, and distance from the conductor. Such a probe coil was used in conjunction with the Wilcom T132B Test Set to make measurements which indicate the total RMS current flowing in the WTF antenna and also the I·T product for that current.

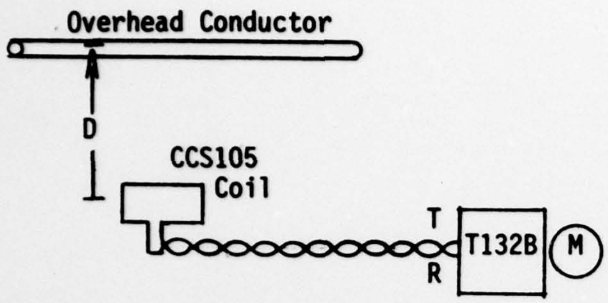
Figure 1 shows the basic elements of the test procedure. A Wilcom CCS105 test coil is placed a selected distance, D, beneath the overhead conductor (WTF ELF communications antenna), with the coil oriented in a vertical plane passing through the conductor. Two readings are taken on the Wilcom T132B test set. The meter reading designated as M_1 is used for obtaining a direct measurement of the I·TIF (or I·T) product for the particular magnitude and waveform of current flowing in the antenna. The meter reading M_2 is used for obtaining a direct measurement of the RMS magnitude of the total current, I, flowing in the antenna, even if it contains more than one frequency component. In both cases a distance factor of $20 \log_{10} D$ and appropriate calibration constants must be used in converting the measurements to values of current.

The value for the antenna waveform TIF can be obtained by simply dividing the I·T product by I.

4. TEST PROCEDURES AND RESULTS

The test coil was attached to one end of a portable fiberglass telescopiing mast ("hot stick"). With the base of the mast resting on the ground beneath the antenna, the mast height was adjusted in increments, providing several values of spacing between antenna and probe coil.

As indicated in Figure 2, measurements were performed at three locations along the west leg of the east-west antenna -- at points where the antenna crosses Forest Roads 173, 176, and 204. These points are approximately 1/3, 1-1/3, and 6 miles from the transmitter, respectively. At the third site (FR204) measurements were made using the Hewlett-Packard 3581 Wave Analyzer, in addition to the Wilcom test set.



M is sum of (1) Black (dBrn) setting on LEVEL switch, and
(2) Black (dBrn) reading on METER.

T = TIF; I = RMS Total Current
D = Distance in Feet

T132B Setting			
Function	Weighting	Operating Mode	
BRDG 600	CMSG	NMS	Read M as M_1 $(I \cdot T)_{dB > 1\ ampere} = M_1 + 20 \log_{10} D - 6.5$ $I \cdot T = 10^{\left(\frac{M_1 + 20 \log_{10} D - 6.5}{20}\right)}$ amperes
BRDG 600	20/f	NMS	Read M as M_2 $(I)_{db > 1\ ampere} = M_2 - 40 + 20 \log_{10} D - 6.5$ $I = 10^{\left(\frac{M_2 - 40 + 20 \log_{10} D - 6.5}{20}\right)}$
			$T = \frac{I \cdot T}{I} = 10^{\left(\frac{M_1 - M_2 + 40}{20}\right)}$

Figure 1 MEASUREMENT OF I·TIF, I, TIF USING WILCOM CCS105 COIL[2,3]

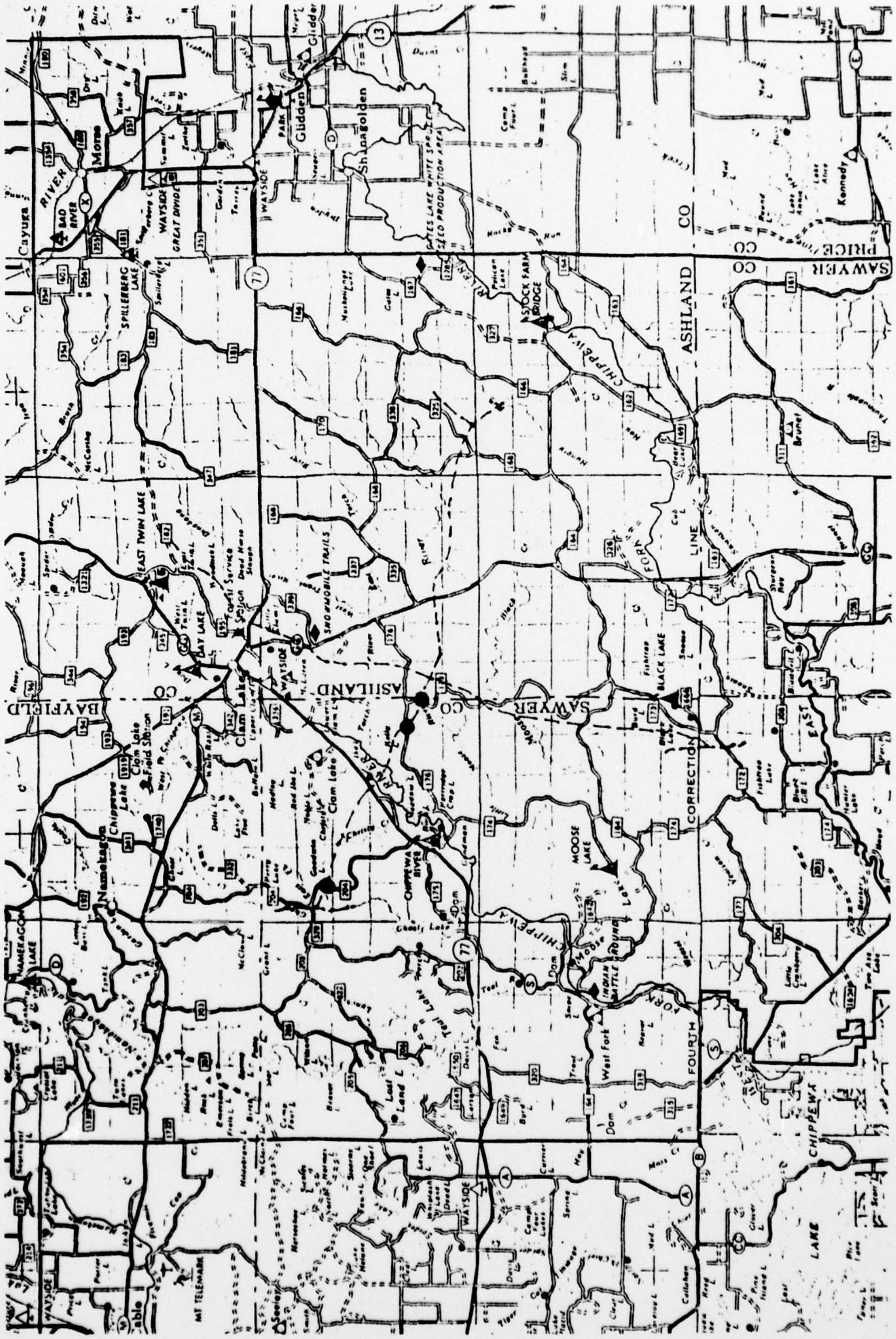


Figure 2 THREE TEST SITES ALONG WEST LEG OF E-W ANTENNA

Test results are given in Tables 1, 2, and 3. The data have the following significance:

- A = antenna height above ground.
- h = coil height above ground.
- D = A-h = spacing between antenna and coil center.
- M = mutual inductance between antenna and coil (used only at Site 3 for reducing data from HP3581 measurements).
- C = $20 \log_{10} D - 6.5$ = coupling factor for reducing data from T132B measurements.
- M_1 and M_2 are the T132B measurement data.
- M_1 + C (and M_2 + C) is the sum of the measured data and the coupling factor for use in determining I·T (and I) as indicated in Figure 1.
- I·T = the I·TIF product. (Note: A multiplying factor of 1.4 has been included to correct for a -3 dB error previously found in the C-message weighting network in this particular Wilcom T132B measuring set -- measured at 60 Hz).
- I = RMS total current in the conductor as determined from T132B measurement.
- I_{3581} = RMS current in the conductor as determined from HP3581 measurement (here assumed to be the fundamental only).

Results are reasonably consistent for the various heights of the test coil as well as for the three sites. Due to possible errors in estimating the height of the antenna cable above the ground, it is believed that the measurements obtained with the largest values of coil height (h) are subject to the greatest errors since the spacing (D) will be subject to the largest percent error for these cases. If one considers only the data taken with D > 10 ft, the averages of the measurements are as shown in Table 4.

TABLE 4

AVERAGES OF TEST DATA FOR D > 10 FT

	T132B			HP3581
Site	I·T (amp)	I (amp)	T	I(amp)
1	317	245	1.29	-
2	338	262	1.29	-
3	323	234	1.38	242
all	325	247	1.32	-

TABLE 1

ANTENNA DATA AT SITE 1

Test Location: Forest Road 173 and West Leg of Antenna — Date: 15 June 1977

A = Antenna Height Above Ground 25 ft — Antenna Current(1) 300 amperes

Trans. Mode	H = Coil Height	D = A-h (feet)	M (henry)	C(2) (dB)	M_1 CMSG	M_1+C	I·T(3)	M_2 20/f	M_2+C	I	T
SF	21.75	3.25		3.7	41.5	45.2	257	82.4	86.1	202	1.27
	17.5	7.5		11.0	35.4	46.4	295	76.6	87.6	239	1.23
	13.25	11.75		14.9	32.0	46.9	312	72.8	87.7	242	1.29
	9.25	15.75		17.4	29.2	46.6	302	70.1	87.5	237	1.27
	6.0	19.0		19.0	27.7	46.7	305	68.8	87.8	246	1.24
MSK	9.25	15.75		17.4	30.5	47.9	351	70.7	88.1	253	1.39
	6.0	19.0		19.0	28.0	47.0	316	68.8	87.8	246	1.28

(1) As read on panel meter at transmitter console.

(2) $C = 20 \log_{10} D - 6.5$

(3) Includes multiplication by 1.4 to correct for -3 dB error in Wilcom T132B C-Message weighting curve (measured at 60 Hz).

TABLE 2

ANTENNA DATA AT SITE 2

Test Location: Forest Road 176 and West Leg of Antenna   Date: 15 June 1977

A = Antenna Height Above Ground 28' 6"   Antenna Current(1) 300 amperes

Trans. Mode	H = Coil Height	D = A-h (feet)	M (henry)	$C^{(2)}$ (dB)	M_1 CMSG	M_1+C	$I \cdot T^{(3)}$	M_2 20/f	M_2+C	I	T
MSK	21.75	6.75		9.9	40.0	49.9	442	79.3	89.3	291	1.52
	17.5	11.0		14.2	34.0	48.2	363	74.7	88.9	278	1.30
	13.25	15.25		17.1	30.5	47.6	339	71.5	88.6	268	1.26
	9.25	19.25		19.2	28.3	47.5	335	69.2	88.4	263	1.27
	6.0	22.5		20.5	26.5	47.0	316	67.1	87.6	239	1.32

(1) As read on panel meter at transmitter console.

(2) $C = 20 \log_{10} D - 6.5$

(3) Includes multiplication by 1.4 to correct for -3 dB error in Wilcom T132B C-Message weighting curve (measured at 60 Hz).

TABLE 3

ANTENNA DATA AT SITE 3

Test Location: Forest Road 204 and West Leg of Antenna   Date: 15 June 1977

A = Antenna Height Above Ground 27' 8"   Antenna Current(1) 300 amperes

Trans. Mode	H = Coil Height	D = A-h (feet)	M (henry)	C(2) (dB)	M_1 CMSG	M_1+C	I·T(3)	M_2 20/f	M_2+C	I	T	HP3581 VRMS	I_{3581}
MSK	21.75	6.1	$6.7(10)^{-6}$	9.2	37.0	46.2	289	77.7	86.9	221	1.31	0.75	235
	17.5	10.2	$4.0(10)^{-6}$	13.7	33.5	47.2	324	73.5	87.2	229	1.41	0.47	241
	13.25	14.4	$2.8(10)^{-6}$	16.6	31.0	47.6	339	70.5	87.1	226	1.50	0.32	236
	9.25	18.4	$2.2(10)^{-6}$	18.8	28.0	46.8	309	68.8	87.6	239	1.29	0.26	240
	6.0	21.7	$1.9(10)^{-6}$	20.2	26.9	47.1	319	67.5	87.7	242	1.32	0.23	250

(1) As read on panel meter at transmitter console.

(2) $C = 20 \log_{10} D - 6.5$

(3) Includes multiplication by 1.4 to correct for -3 dB error in Wilcom T132B C-Message weighting curve (measured at 60 Hz).

All the measurements discussed above were made with the T132B test set operating in the broadband or noise measuring set (NMS) mode. At Site 1 the test set was briefly operated in its spectrum analyzer mode to measure the magnitude of the fundamental current and the harmonics with the transmitter operating at a single frequency (nominally 76 Hz). The measurements were taken at only one coil height, 21-3/4 ft. The meter readings, M_2, were 82.4, 17 and 16 at 76 Hz, 152 Hz, and 228 Hz, respectively, which convert to currents of 202 amperes at 76 Hz, 0.11 amperes at 152 Hz, and 0.10 amperes at 228 Hz. No other harmonics could be detected. These measurements indicate the harmonics are 65 dB below the fundamental. This result is in reasonable agreement with the result of 70 dB previously determined from measurements with a clamp-on current probe.

5. POSSIBLE MEASUREMENTS ON A BURIED ANTENNA

No measurements were attempted in the vicinity of a buried antenna cable, but measurements of I and TIF could probably be performed if the cable location is known to a reasonable accuracy and if no other current carrying conductors are nearby. For accurate measurement of I and I·T, accurately known coupling between the antenna and the probe coil is required. Location and orientation of the underground antenna could be determined by first orienting the probe in a vertical plane and then positioning it to maximize the induced voltage.

The antenna burial depth may not be known accurately, but the error from the uncertainty in antenna-to-coil spacing, and hence uncertainty in coupling factor, can be minimized if the probe coil is mounted on a tall portable mast above the buried antenna. To estimate the possible error from this source, assume a 20-foot mast, i.e., the coil is 20 feet above the surface of the ground. Consider that the antenna burial depth is unknown except that it is between 3 feet and 6 feet. Assume it to be 4½ feet deep, resulting in an antenna-to-coil spacing of $24\frac{1}{2} \pm 1\frac{1}{2}$ feet. The coupling factor would be 21.2 ± 0.6 dB, so the maximum error in I or I·T from this uncertainty would be 0.6 dB.

The measurement of T will not be subject to this same error. If the coil is held in a fixed position while both I and I·T are measured with the T132B, the same relative error (due to antenna-to-coil spacing error) will occur in the measurement of both I and I·T, so the error will be eliminated when the ratio is taken to determine T. If a narrowband wave analyzer such as the

HP3581 is used, again, inaccuracy in the estimated value of the coupling factor (or mutual inductance between antenna and coil) will not introduce an error in T as long as the coil is held in a fixed position for the induced voltage measurements of all frequency components in the antenna.

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1. "Voice Telephone Interference Due to Seafarer Generated Harmonics," Technical Report No. 8, IIT Research Institute for U.S. Naval Electronic Systems Command, June 1977.

2. "Model T132B Spectrum Analyzer and Noise Measuring Set," Wilcom Products, Inc., Laconia, N.H., August 1973.

3. "Instruction Manual for Model CCS105 Exploring Coil," Wilcom Products, Inc., August 1977.

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The harmonic components of the ELF antenna current at the Navy's Wisconsin Test Facility were measured using both a clamp-on current probe on the antenna and a probe coil positioned beneath the antenna. Only harmonics up to the sixth were detectable, and all were at least 70 dB below the magnitude of the 76 Hz fundamental. The Telephone Influence Factor (TIF) for the composite waveform was 1.27, the same value as for a pure 76 Hz signal without harmonics.

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