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FINAL REPORT

VLF Radio Field Strength Measurement Of Power Line Carrier System In San Diego, California

EMACO Report No. 8101-10
15 October 1981

FINAL REPORT
VLF Radio Field Strength Measurements Of Power Line Carrier System In San Diego, California

Prepared for:

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Under Contract No.: 955952

"Very Low Frequency Radio Field Strength Measurements"

"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by Department of Energy through an agreement with the National Aeronautics and Space Administration."

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TECHNICAL CONTENT STATEMENT

ABSTRACT AND SUMMARY

The radio frequency interference (RFI) potential was evaluated for a Powerline Carrier (PLC) system installed in San Diego which monitors the performance of an electrical power system. The PLC system generated 30 amperes at 5.79 kHz. The RF radiations were measured to be (typically) 120 dBuV/m at the beginning of the 12 kV powerline and 60 dBuV/m at the end of the powerline. The RF fields varied inversely as the distance squared.

Measurements were also performed with a 45 kHz PLC system. The RF fields were of similar amplitude.

ACKNOWLEDGMENTS

This engineering measurements study was made possible by an extraordinary cooperative effort of the following team:

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The above addresses and telephone numbers are presented in the event the reader requires further clarification of this report.

LIST OF DATA RECORDS SHOWN IN SECTION 7

ABBREVIATIONS AND SYMBOLS

AS&E	American Science and Engineering, Inc.
CISPR	French Initials of: International Special Committee for Radio Frequency Interference
dB	deci-Bel
dBuA	dB above one Micro-ampere = log (E/1uA)
dBuA/m	dBuA per meter. Unit of Magnetic Field Strength
dBuV	dB above one microvolt = 20 log (E/1uV)
dBuV/m	dBuV per meter. Unit of Electric Field Strength
DOE	Department of Energy
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference (Same as RFI)
EPRI	Electric Power Research Institute
JPL	Jet Propulsion Laboratory
PLC	Power Line Carrier System
PSK	Phase-Shift-Keying
RFI	Radio Frequency Interference
SCU	Substation Control Unit
SDG&E	San Diego Gas and Electric Company
VLF	Very Low Frequency

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1. INTRODUCTION

1.1 Scope and Purpose

This final report documents the measurement procedures, data, conclusions and recommendations for the radio frequency environment caused by a 5790 Hz Power Line Carrier (PLC) system. This PLC system is used for bi-directional communication for electrical power load management, deferral and measurement by the San Diego Gas and Electric Company (SDG&E) in its Murray Substation in San Diego.

The "Very Low Frequency (VLF) Radio Field Strength Measurements" study and investigation was performed by EMACO, 7562 Trade Street, San Diego, CA 92121 and was funded by Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, under Contract No.: 95592. The contract period of performance was February 12, 1981 to October 15, 1981.

The purpose of the measurement study and this final report is to measure and document the electric and magnetic field strength of Very Low Frequency (VLF) fields produced by the 5790 Hz Power Line Carrier (PLC) system located in the Lake Murray Substation and distribution system of the San Diego Gas and Electric Company in the area of Northeast San Diego and La Mesa, CA.

The investigation was performed in accordance with the contract statement of work and as modified per the measurement findings. The required tasks and findings are summarized in Table 1.

TABLE 1: SUMMARY OF MEASUREMENT TASKS AND FINDINGS

	Measurement Tasks	Measurement Findings	See Sec. No.
1	Conduct a preliminary field strength survey making exploratory measurements in and around the Murray Substation distribution area, leading to contour maps showing electromagnetic field parameters.	Substation injected current harmonics were 50 dB below fundamental. E-Field was 120 dBuV/m 20 feet from 12 kV powerlines.	(2.3.1) (2.4.1) (2.4.2)
2	Determine criteria for measurement location.	Difficulties were experienced in finding an isolated powerline.	(2.4.3.5)
3	Determine the approximate limiting distance around the distribution system where measurements of the electric and magnetic fields can no longer be distinguished from atmospheric and man-made noise.	Was 500 feet with sensitivity of .1 uV in 10 Hz bandwidth. Amplitude is inversely proportional to distance squared.	(2.4.3.5)
4	Determine the approximate upper and lower bounds on the magnitude of the electromagnetic field at selected sites inside and outside the distribution area. Variations are expected to be both random and cyclic.	Maximum was 120 dBuV/m Minimum was 60 dBuV/m	(2.4)
5	Determine the length of time necessary for an individual measurement to appropriately quantify the temporal variation in field strength.	Amplitude was constant as a function of injected PLC current.	(2.4)
6	Determine the appropriate frequency range over which measurements are necessary.	Harmonics were not generated by system. Only fundamental was measurable.	(2.3) (2.4.1)
7	Determine the equipment to be used in making further measurements.	Narrowband field strength meter EATON/AILTECH NM 7A plus loop antenna.	(2.4.3.1)
8	Select procedures for final measurements.	Use Pilot PLC Signal, field strength meter and loop antenna.	(2.4.3)
9	Perform measurements and submit reports.	Three test plans and reports were submitted to JPL.	(2.2)
10	Measure 5790 Hz current at low and high voltage side of PLC injection transformer.	31.6 and .631 A (50:1) 3.16 A and .05 A (63:1)	(2.3.2)
11	Measure 5790 Hz RF fields with 30 and 3 amperes injected.	Linear relationship exists. RF fields were 20 dB lower with 3 amperes. Falloff = $1/d^2$.	(2.4.3.6)
12	Determine and install the hardware to change the PLC frequency to 45 kHz.	Used signal generator and 400 watt IFI amplifier.	(2.2.4) (2.3.2)
13	Measure 45 kHz current at low and high voltage side of PLC injection transformer.	3.16 A and .07 A (44:1)	(2.3.2)
14	Measure 45 kHz RF fields with 3 amperes injected and at the same location as in 11 above.	The 45 kHz field was 6 dB lower than equivalent 5.79 kHz field because of line losses: Falloff = $1/d^2$.	(2.4.3.7)

1.2 Format of This Report

The format of this report follows the JPL Report No.: 1030-26 Rev C, "Specification for Research and Advanced Development Technical Reports Prepared by JPL Contractors."

The format is as follows:

Section 2 contains the principal technical discussion.

Section 2.1 describes the planned and actually used instrumentation.

Section 2.2 presents all measurement procedures.

Section 2.3 presents the data for all PLC injection current measurements for Phases I, II, and III.

Section 2.4 presents the data for all RF radiation measurements for Phases I, II, and III.

Section 3 contains the conclusions.

Section 4 contains the recommendations.

Since there are numerous Data Records in the form of tables, graphs and photographs and since the text might be hard to find between the Data Records, the following sequence of presentation is used:

Figures and Tables follow the text where they are first referenced. This pertains to Sections 1, 2.1, 2.2.

Data Records are presented in sequence at the end of the report in Section 7 "Supporting Data." This pertains to Sections 2.3 and 2.4.

1.3 Background for the VLF Measurement Study

1.3.1 The Need for the Study

The need for communication systems that are capable of performing load management and distribution system automation function has increased quite dramatically in recent years. The increasing need for higher reliability in the electrical distribution system comes in part from the growing dependence on electricity as the primary source of energy for vital user functions. Reliability also becomes a greater factor in system design as higher distribution voltages become necessary. One potential method of improving reliability is to automate the functions of system fault indication and fault isolation. Operation of tie switches to provide alternative emergency power delivery routes and the ability to serve loads routinely from alternative feeders also increase reliability, as well as system loading capability. Such automation requires a reliable two-way communication system.

Load management as a tool to reduce system peak load through direct control, peak load pricing and energy storage, etc., has also directed attention to the need for economical and effective two-way communication channels. There are methods of load management that do not require sophisticated communication systems but these implementation methods often suffer from their limitations and inflexibility. Today, a need is apparent for better technical information on alternative communication links.

Impressing a carrier frequency signal onto the distribution feeders is a method of communication that many feel offers the most hope of solving system problems of the future. Experimentation on distribution systems has taken place for several years and small scale carrier systems have been implemented at several utilities as a trial demonstration of its potential. Numerous problems are as yet unresolved and work continues in several areas that will help to determine more completely the limitations and capabilities of such systems.

The Electric Power Research Institute (EPRI) and the Department of Energy (DOE) are jointly sponsoring a major demonstration program, "Field Demonstrations of Communications Systems for Distribution Automation" whose objective is "to test and evaluate bi-directional distribution communication systems in large field installations." Some of the systems to be evaluated will be distribution line carrier systems, and it is expected that this program will develop more understanding of the capabilities of such systems. The present plan is for these systems to be fully operational for the period of 1 July 1979 to 1 July 1980. Other large scale systems are in the offing stimulated by the utility commissions of the various states. The potential for proliferation of these systems appears to be enormous.

Other types of systems (e.g. navigational beacons) operate using radiated electromagnetic energy at frequencies near, or harmonically related to these power-line carrier frequencies. A mutual interference potential appears to exist.

This experimental study is an effort to map one set of PLC fields for use in beginning to assess the actual interference problem.

The desired result from this task is an accurate geographical assessment of the radiated field strength from the PLC system (contours of constant field strength as a function of geographical location), some reasonable assessment of the magnitude and nature of temporal variations in field strength, and knowledge of the radiated frequency spectrum.

1.3.2 Description of the PLC System to be Measured

The bi-directional distribution PLC system measured has been installed by SDG&E at its Murray Substation in La Mesa, CA. The purpose of the system is to test its performance with a number of SDG&E's residential and commercial customers. The system will investigate distribution automation, perform load management by use of load deferral techniques, test multipart rates, and collect load survey data. The SDG&E test program is one of five bi-directional communication projects sponsored by DOE and EPRI. The objective of the measurement study is to determine the interference potential of the PLC system to other systems that occupy the same (or harmonically related) very low frequency (VLF) spectrum.

The PLC system installed by SDG&E was manufactured by American Science and Engineering, Inc. and is shown in the diagram in Figure 1. The PLC equipment is installed on sixteen 12-kV feeders served from SDG&E Murray and El Cajon Substations. However, only the Murray Substation distribution system and equipment will be evaluated as part of this study.

The Murray Substation is located near El Paso Avenue and Lake Murray Avenue. Eleven circuits with the PLC are in operation. Each circuit is 7 to 8 miles long.

The general PLC system layout is shown in Figure 1. (Note: the following information was obtained from Reference 1). The carrier system uses a frequency of 5790 Hz in a bi-directional mode over the 12-kV distribution network. Operational control is via the Data Dispatch Controller (DDC), a dedicated minicomputer, located in the Mission Control Center. Communication between the DDC and the Substation Control Unit (SCU) are over leased telephone lines at a 300 baud data rate. The SCU generates the 5790 Hz carrier signal which is transformer-coupled to the 12-kV Substation bus. Data and control commands are transmitted to individual transponders, located at house meters or other points of secondary service. Data transmission is made via phase-shift-keying (PSK).* Both the carrier pilot tone and data rate are locked to the power line 60 Hz.

The transponder contains the receive and transmit logic, metering data collection and load control outputs. Each transponder, as shown in Figure 2, can accept serialized data and can control up to seven switchable loads and accept data from kwh meters. The signal conditioner, demodulator, decoder, and address selector determine the required task. The data transmission logic and transmitter return the data to the SCU. Each transponder transmits a 2 amps RMS signal from its internal power supply.

It should be noted that the transponder may also be a source of radio frequency interference (RFI) to the consumer since the transponder is the unit that is physically the closest to the consumer and electronic equipment. Therefore, the RFI characteristics of the transponder were also evaluated.

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*PSK is a form of phase modulation in which the modulating function shifts the instantaneous phase of the modulated wave between predetermined discrete values.

Phase modulation causes the angle of a carrier to depart from its reference value by an amount proportional to the instantaneous value of the modulation function.

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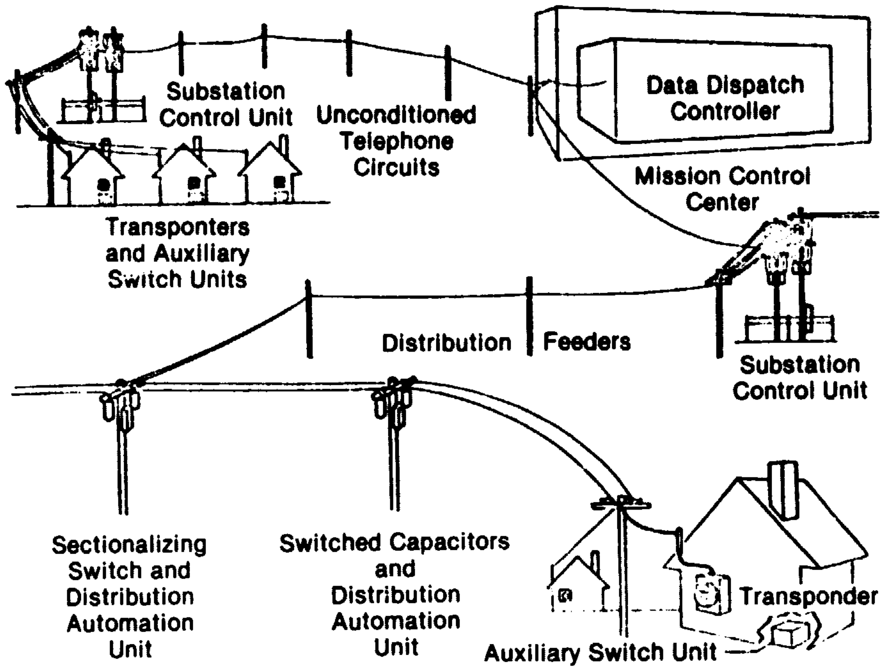


FIGURE 1 Sketch of Power Line Carrier System

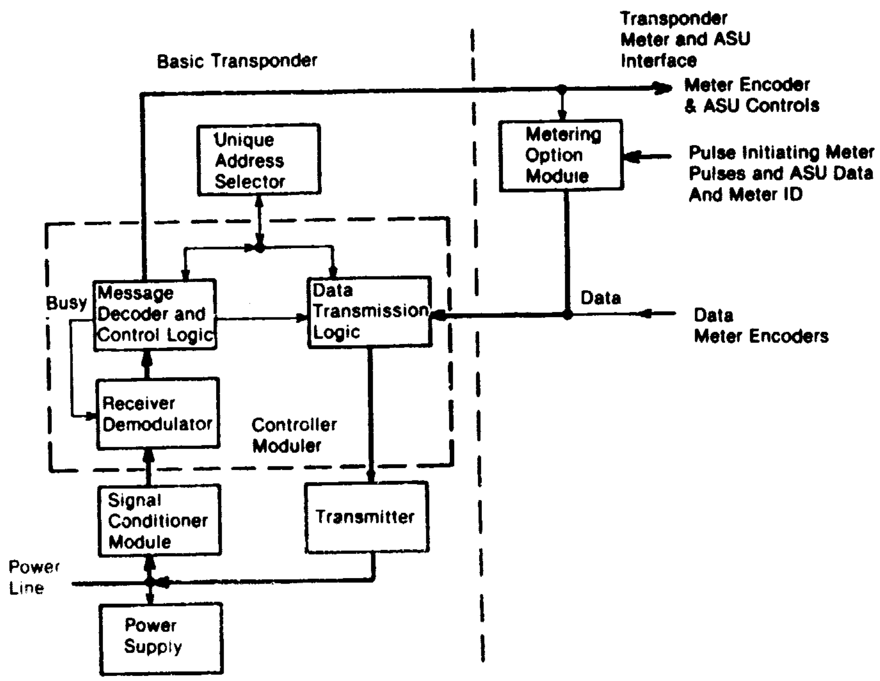


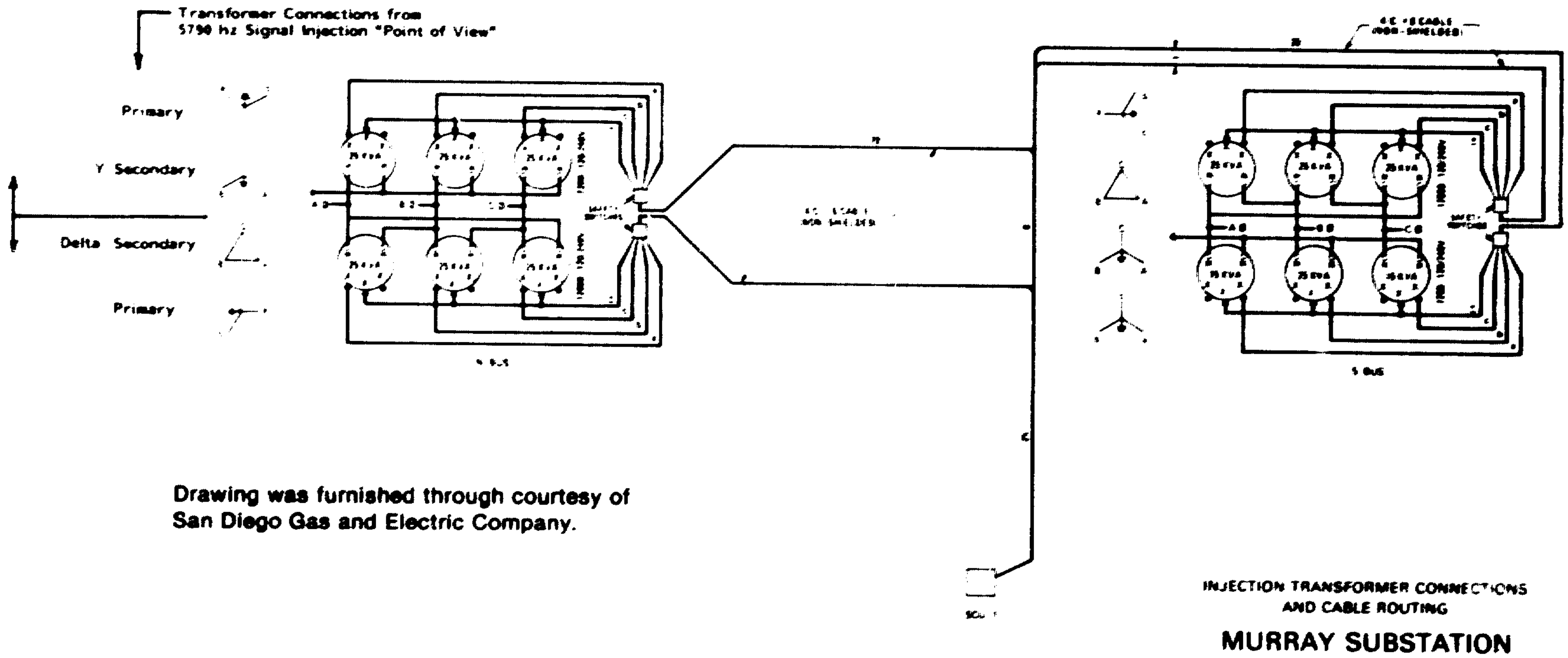
FIGURE 2 Block Diagram of Transponder Located at Each Power Load

—Primary Operational Signal Frequency

The PLC system of Figure 1 uses a frequency of 5790 Hz. This carrier frequency was chosen by American Science and Engineering since the signal propagates easily on power lines. In addition, the frequency is not severely attenuated by distribution transformers to reduce the need for bypass and repeater equipment. To reduce the signal loss of the power factor correction capacitors, the capacitors are reactively compensated with series inductors to present a high impedance at 5790 Hz. The carrier frequency is generated by the Substation Control Unit (SCU) by a high power tuned output audio amplifier.* Standard power distribution transformers are used to couple the single phase carrier signal to the 12-kV bus. The SCU amplifier is tuned to resonate with the inductance of the 120 Volt transformer secondary and the injected signal is stepped up and appears on the primary bus. Both line-to-line and line-to-ground coupling were proposed. If these methods are still optional, the VLF measurements should be performed with both coupling modes.

To obtain access to all transponders connected to a Substation, the SCU steps through each phase of the bus in turn. The time required to select a phase and transmit a one-way load deferral message is approximately 2 seconds. Bi-directional communications require approximately 3 seconds. The overall injection scheme is shown in Figure 3.

*The SCU also contains a receiver; however, the receiver is of secondary interest in the measurement study.



Drawing was furnished through courtesy of San Diego Gas and Electric Company.

FIGURE 3 Murray Substation: Injection Transformer Connections and Cable Routing

2. TECHNICAL DISCUSSION

2.1 Instrumentation System

The Equipment utilized and the system configuration for the measurement of radiated emission from the PLC system is summarized in Figure 4 and tabulated in Table 2. The following is a brief description of each major equipment.

—Mobile Radio Frequency Shielded Laboratory

The mobile RF shielded laboratory is shown in Figure 4 and has the following features:
—Double shielded room 17.7 x 7.2 x 7.3 ft. high
—On-board power: 115/208 V, 5 kVA, 60 Hz (diesel)
—Air Conditioning: 2 HP, 60 Hz, 208 V, 3 Ø
—EMI Filters: 60 Hz, 4 @ 50 A, Filtron FSR-104
—Lighting: Incandescent
—Vehicle: Chevrolet Van 27 x 7.7 x 12 ft. high
—Roof Platform: 18 x 7.5 ft.

—Spectrum Analyzers

The spectrum analyzer is a receiver that is automatically tuned over a wide frequency range. Any measured signals are stored on a cathode ray tube or digital memory. For the proposed measurements a low-frequency analyzer Hewlett Packard Model 3580 A and a medium frequency unit Hewlett Packard Model 141 T/8552B/8553B was used.

The HP 3580A is used for measurements up to 50 kHz. The unit has digital memory and adaptive sweep digital storage makes it possible to store one or two traces. When two are stored, both may be simultaneously displayed for easy comparison. Adaptive sweep makes it possible to reduce the measurement time by looking only for desired signals above a threshold.

—Field Intensity Meter

Field Intensity Meters are normally used for RFI measurements. These meters are similar to spectrum analyzers with one very important difference: pre-selector filters. Consequently, signals can be measured where a high ambient exists near the signal under observation.

For the measurements the Electro-Metrics EMC-10, EMC-25 and AILTECH NM 7 were used.

—Recording Equipment

Data from the measurements was recorded manually, by camera, and by strip chart recorder. The spectrum analyzer was photographed for short duration measurements.

—Calibration Equipment

All measurements were calibrated against a sine-wave signal generator by the substitution measurement. In addition, the field intensity meters were used for calibration.

—Antennas

When measuring electromagnetic fields, such as electromagnetic interference, an antenna of some type is necessary to intercept the radiated signal. The antenna is connected to a receiver or spectrum analyzer which measures the output voltage from the antenna. By knowing the antenna conversion factor and the cable losses, the measured voltage can be converted to units of magnetic (A/m) or electric (V/m) fields. The antenna factors are usually calibrated for the far field only. Consequently, the measurements in the near field of a source are often inaccurate. By varying the distance to the source an accurate field plot may be obtained.

The Electro-Metrics ALP-10 was the primary antenna used for the measurements. The frequency dependent conversion factor is shown in Table 3.

—Current Probes

The measurement of RFI current on a wire can be accomplished by use of a clamp-on current probe. Several different models are available from manufacturers of RFI measuring equipment. The sensitivity of a current probe is expressed in terms of transfer impedance which is the ratio of secondary voltage (across a 50 ohm load) to the primary current ($Z_s = Es/Ip$). Since this value is expressed in ohms the transfer impedance is usually given in dB relative to one ohm, or in logarithmic form $Z_T = 20 \log (Z/1 \text{ ohm})$. The transfer impedance for the current probes used is given in Figure 5.

The current probes are used in this study to measure the PLC injection current.

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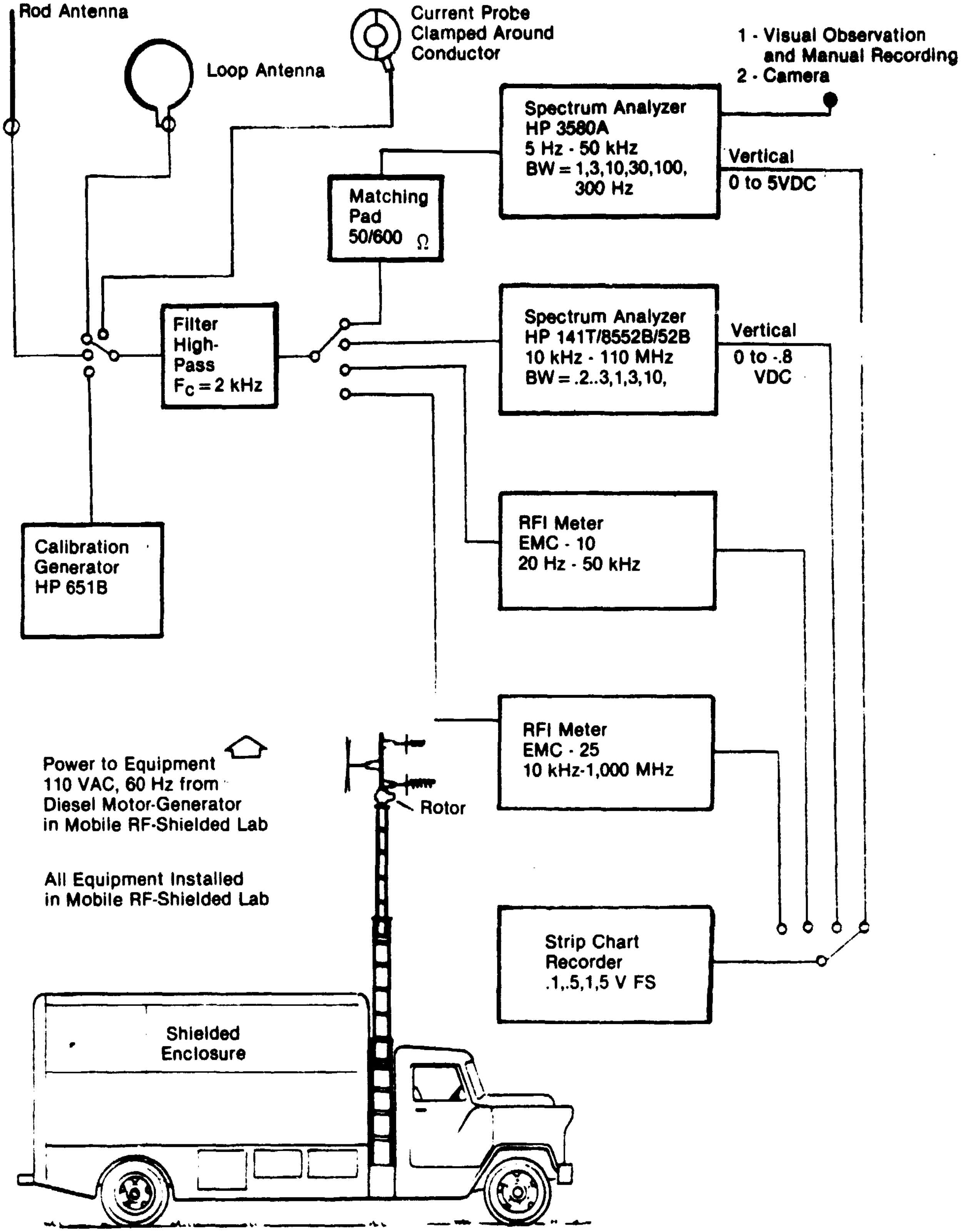

FIGURE 4 Block Diagram for Instrumentation System for Measurement of RF Radiations from VLF PLC System.

TABLE 2. EQUIPMENT LIST

Item No.	Equipment Description
1	Mobile RF Shielded Enclosure with Internal 60 Hz Diesel Generator, EMACO No. 1
2	Spectrum Analyzer, HP 3580A, 5 Hz-50 kHz
3	Spectrum Analyzer, HP 141 T/8552B/8553B, 10 kHz-110 MHz
4	Field Intensity Meter, Electro-Metrics EMC-10, 20 Hz-50 kHz
5	Field Intensity Meter, Electro-Metrics EMC-25, 10 kHz-1000 MHz
6	Strip Chart Recorder, HP 680
7	Camera, HP 197B
8	Signal Generator, Calibration, HP 651B, 10 Hz to 10 MHz
9	Antenna Loop
10	Antenna Loop
11	Antenna Rod
12	Current Probe, Electro-Metrics, 20 Hz-100 MHz
13	Filter, High Pass, 2 kHz-110 MHz
14	Attenuator, Matching 50 to 600 ohms
15	Field Intensity Meter, AILTECH NM7, 20 Hz-50 kHz

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TABLE 3. ANTENNA CONVERSTION FACTORS

From SAE AIR 1509: "Antenna Factors"

Algebraically add the indicated value to convert from ↓ to ⟶	dbuV/m	dB Gauss	dBpt	dBuA/m	dBWb/m2
0 dB microvolts-per-meter =	0	−209.5	−49.5	−51.5	−289.5
0 dB gauss (1) =	+209.5	0	+160	+158	−80
0 dB picotesla =	+49.5	−160	0	−2	−240
0 dB microempere-per-meter =	+51.5	−158	+2	−238	
0 dB weber per-square meter(2) =	+289.5	+80	+240	+238	0

NOTES:
(1) One gauss and one oersted are equivalent and may be interchanged.
(2) One weber-per-square meter and one tesla are equivalent and may be interchanged.
(3) Decibel values are "rounded off" to the nearest 0.5 dB.

FAIRCHILD ALP-10, 20 Hz to 50 kHz, LOOP

Frequency (Hz)	AF (dB)	Frequency (Hz)	AF (dB)
20	62	1000	26
30	56	1200	25
40	54	1400	24
50	52	1600	22
60	50	2000	21
70	49	2400	19
80	48	2800	18
90	47	3200	16
100	46	3600	15
120	45	4000	14
140	43	4800	13
170	42	5600	12
200	40	6200	11
230	39	7000	10
260	38	8000	9
300	36	9000	8
350	37	10,000	7
400	35	13,000	6
450	33	20,000	5
500	32	30,000	4
550	31	50,000	3
699	30		
700	29		
800	28		
900	27		

Note 1: Meter reading (dBuV) + Antenna factor (dB) = Field intensity (dBuA/m).

Note 2: To read the E-field (Far Field), add 51.5 dB to the dBuA/m value to get dBuV/m.

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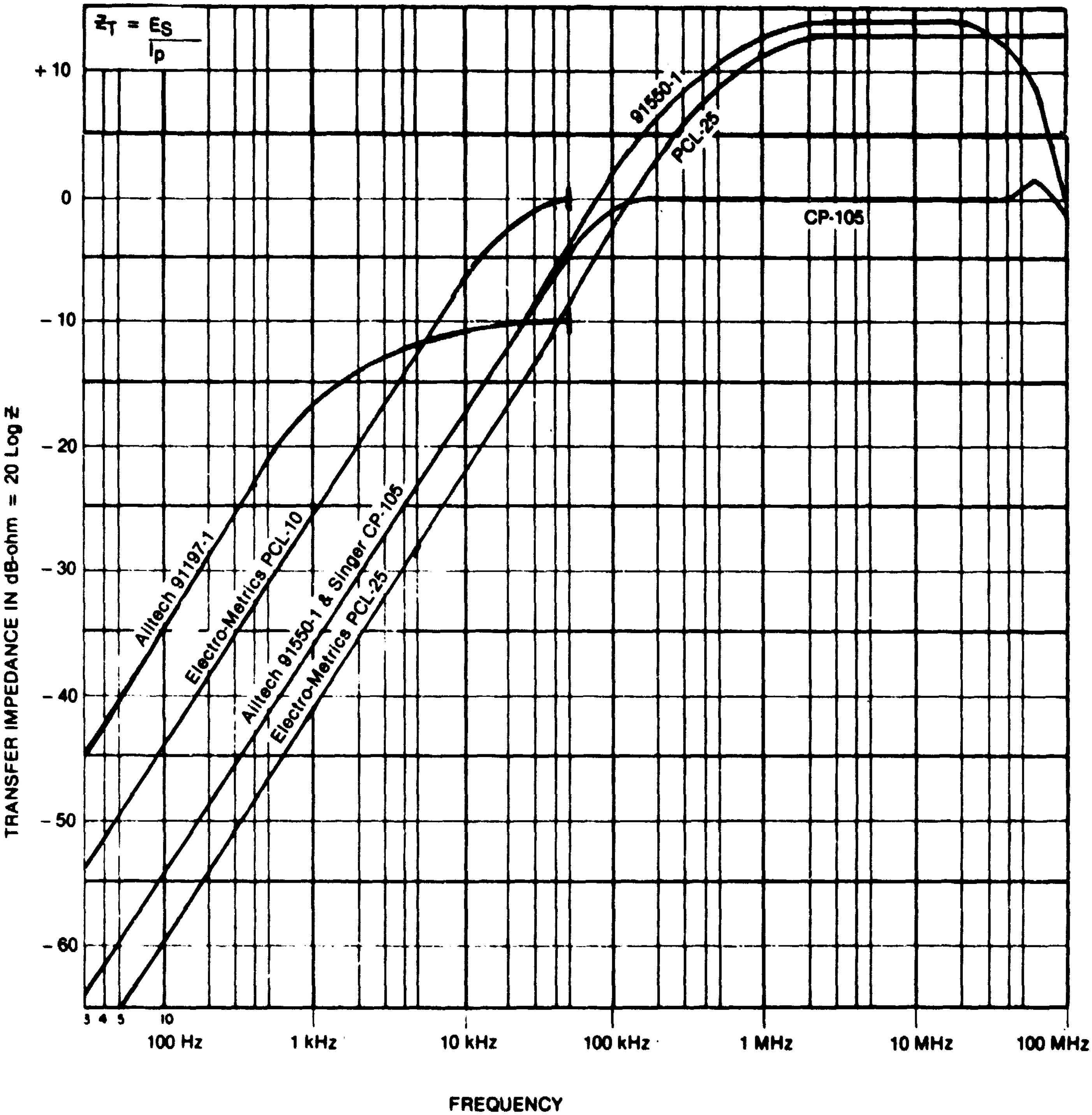

FIGURE 5 Transfer Impedance of Current Probes

2.2 Measurement Procedures

2.2.1 Summary

Prior to each measurement phase, a test plan was prepared to familiarize all personnel involved in the test with the overall approach. The measurements were performed in essentially three phases:

Phase I. Initial familiarization and detailed evaluation of injection current and radiated fields along typical powerlines. Measurements were performed on April 13 to 16 and June 22 to 23, 1981.

Phase II. Determine the relationship between PLC input current and radiations from the powerline. Monitor the injection transformer input and output current. Measurements were performed on September 8-10, 1981.

Phase III. Determine the radiation amplitudes from the powerline when the PLC signal frequency is increased to 45 kHz. Monitor the injection transformer input and output current. The measurements were performed during the same period as Phase II measurements.

2.2.2 Phase I Measurement Procedure

2.2.2.1 Initial Measurement Procedures

The measurements were performed to familiarize the test personnel with the spectrum signature of the 5790 Hz Powerline Carrier PLC signal while the signal is under the direct control of the test personnel. The objective of these measurements was to obtain a "feeling" for the measurability of the PLC signals while at the same time proofing the proposed instrumentation. This information was used to enhance the test plan preparation for the detailed measurement program.

The following measurements were performed:

1. Measure continuous pilot tone PLC current at Substation Control Unit, i.e. at output of 5790 Hz transmitter.

2. Measure continuous pilot tone PLC current at Injection Transformer Disconnect Switch.

3. Measure normal operational and modulated signal current at Injection Transformer Disconnect Switch.

4. Measure the H and E Field radiated from a pilot tone near the Murray Substation.

5. Perform some measurements near a 12 kV feeder signal while a continuous pilot tone is sent.

The test equipment for this test was as shown in Figure 4 and Table 2.

The measurement procedure was as follows:

1. Calibrate the test equipment by use of the calibration generator HP 651 B and compare to the internal calibration of the RFI receivers. Calibration must compare within 2 dB.

2. Clamp the current probe around one conductor between the generator filter and the phase relays within the SCU equipment. Start with the South-Y Injection Phase A.

3. Obtain readings for the 5790 Hz fundamental and any measurable harmonic that is 10 dB above instrumentation noise. Measure with a 300 Hz to 1 kHz bandwidth. Record "Peak" values.

4. For the initial measurements use the EMC-10 and EMC-25 RFI receivers.

5. Repeat Steps 3 and 5 with the HP 3580 A and HP 8552 B Spectrum Analyzers. Obtain photographs of the display. Record all data.

6. Divide the voltage by the current probe transfer impedance to obtain current: $I = E/Z_T$ or in logarithmic form $dBuI = 20 \log E - 20 \log Z_T$.

7. Repeat Step 5 with the current probe clamped around conductors to the following relays:

INJECTION MODE	INJECTION MODE
South-Y, Phase B	South-Delta, Phase A
South-Y, Phase C	South-Delta, Phase B
	South-Delta, Phase C
North-Y, Phase A	North-Delta, Phase A
North-Y, Phase B	North-Delta, Phase B
North-Y, Phase C	North-Delta, Phase C

Observe spectrum analyzer display and compare with the photographs obtained during Step 5. If there is any significant change (i.e. readings are 6 dB higher or lower or spectrum shape is different), photograph the display.

8. Move the clamp-on current probe to the South-Y Injection Transformer Disconnect Switch. Clamp the current probe around the following wires in turn

South-Y Injection	Phase A
South-Y Injection	Phase B
South-Y Injection	Phase C

Observe the spectrum display and compare with the photos obtained in Steps 5 or 7. If there is any significant change repeat the measurements for all phases of the

South-Delta Injection
North-Y Injection
North-Delta Injection

9. Mount the loop antenna 6 ft. above the roof of the Mobile Laboratory (total height above ground is 18 ft.).

CAUTION: STAY AT LEAST 10 FEET AWAY FROM ANY POWER CONDUCTOR!

Move the Mobile Laboratory to any convenient measurement location within the fence of the Substation.

10. Measure the magnetic field associated with the PLC signal. Correlate any measurable signal with the PLC signal by turning it off and on. Rotate the loop antenna for maximum pick-up. Use the EMC instrumentation as appropriate. As a minimum, record values at the following frequencies:

Fundamental	5.79 kHz
1st harmonic	11.58 kHz
2nd harmonic	17.37 kHz
3rd harmonic	23.16 kHz
4th harmonic	28.95 kHz
5th harmonic	34.74 kHz

Any other signal that is correlatable to the PLC signal.

11. Observe the spectrum to at least 250 kHz. Note any changes with PLC signal off and on. Record all data.

12. Mount the E-field antenna 6 ft. above the roof of the Mobile Laboratory. (Total height is 18 ft.). Repeat Steps 10 and 11.

13. Move the Mobile Laboratory along Circuit 401, 12 kV overhead line outside of the Substation as shown in Figure 6, Location A. Coordinate with SDG&E personnel to ensure that a continuous pilot tone is on that particular overhead line (North-Y, Phase A). Repeat Steps 10, 11 and 12 for that measurement location.

14. Move Mobile Laboratory to a location near a capacitor load bank with compensating coil (Location B of Figure 6). Repeat Step 13.

15. Repeat Steps 13 and 14 with a normal operational signal being sent to the overhead line being measured. Record all data. Take photographs of all measurement locations. Reduce data. Plot data if it will help to understand it. Prepare a report with conclusions and recommendations.

2.2.2.2 Detailed Measurement Procedures

This set of measurements was a follow-up of the initial measurements that were performed on 13 and 16 April 1981. The initial measurements showed that the harmonic content of the 5790 Hz PLC signal is a minimum of 50 dB below the fundamental. Consequently, only the radiations at 5790 Hz were measured.

The objective of these measurements was as follows:

—Demonstrate a 20 dB more sensitive instrumentation system than the 10dBuV sensitivity reported for the initial measurements at a frequency of 5790 Hz.

—Measure the 5790 Hz field intensity at a location previously measured (Boulder Lake and Navajo Blvds.).

—Measure the 5790 Hz field intensity variation along and under a powerline run.

—Measure the 5790 Hz field intensity attenuation as a function of distance at a right angle to the powerline.

Because of the data evaluation of the initial measurements the instrumentation was simplified as shown in Figure 7. This simplified measurement setup, as compared to Figure 4, allowed the use of a smaller 3/4 ton van which enhanced mobility in residential streets and rough terrain.

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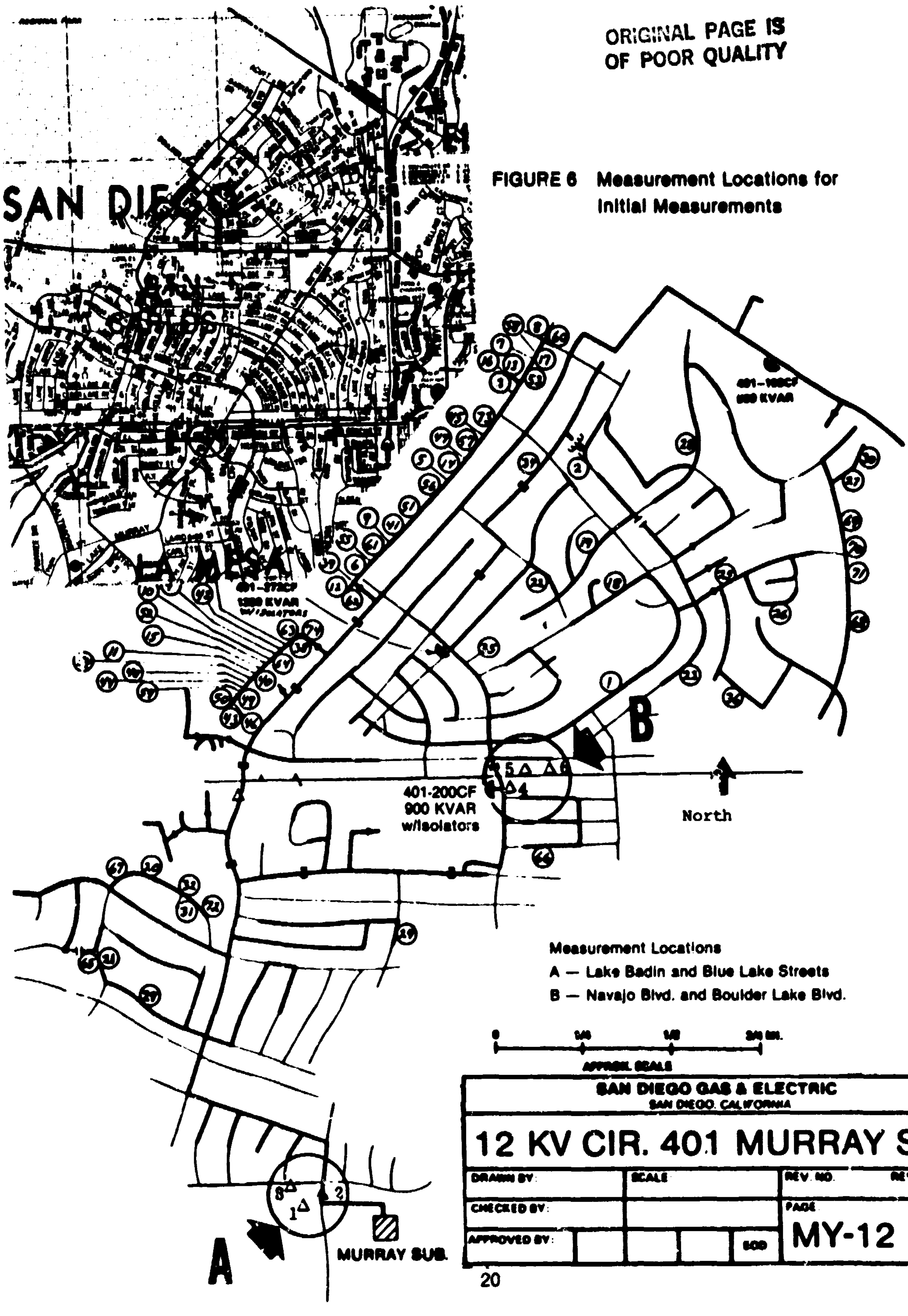
FIGURE 6 Measurement Locations for Initial Measurements



Measurement Locations
A — Lake Badin and Blue Lake Streets
B — Navajo Blvd. and Boulder Lake Blvd.

0 1/4 1/2 3/4 MI.
APPROX. SCALE

SAN DIEGO GAS & ELECTRIC
SAN DIEGO, CALIFORNIA

12 KV CIR. 401 MURRAY SUB.

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The NM- 7 was the RFI meter used for the measurements. The instrument is battery-operated. It has a sensitivity of −40 dBuV (.01 uV) in its 10 Hz bandwidth. The HP 651B signal generator was used for frequency calibration and to confirm the amplitude calibration of the NM- 7. The EMC-10 RFI meter was only a backup unit in case the NM- 7 would fail. The ALP-10 loop antenna was used. It was installed on top of the van at a height of 14 feet above ground. The antenna mast was turnable from the inside of the van. The ALP-10 antenna factor is 12 dB at 5790 Hz. This factor must be added to the meter reading to obtain dBuA/m. To obtain dBuV/m another 51 dB (20 log 377 ohms) must be added.

The PLC signal was transmitted continuously from the Substation Control Unit (SCU) at Murray Substation. At prearranged times the PLC signal was manually turned off for positive identification. On the first measurement day the signal intervals were "ON" for 5 minutes and "OFF" for 1 minute. On the second measurement day the signal intervals were "ON" for 14 minutes and "OFF" for 1 minute.

The 5790 Hz signal from the SCU was injected into the North "Y" Phase Injection Transformer which is connected to Circuit 401 from the Murray Substation. A schematic of the injection transformers is shown in Figure 3. A map of the measurement locations and Circuit 401 is shown in Figure 8. Circuit 401 was selected by SDG&E, JPL, and EMACO personnel as the most representative and easily accessible circuit served from the Murray Substation. Measurement locations were at the following locations:

—Boulder Lake and Navajo

—Boulder Lake and Pershing Junior High School

—Along Regner from Jackie to Barker

—Along Grossmont Drive to Fanita

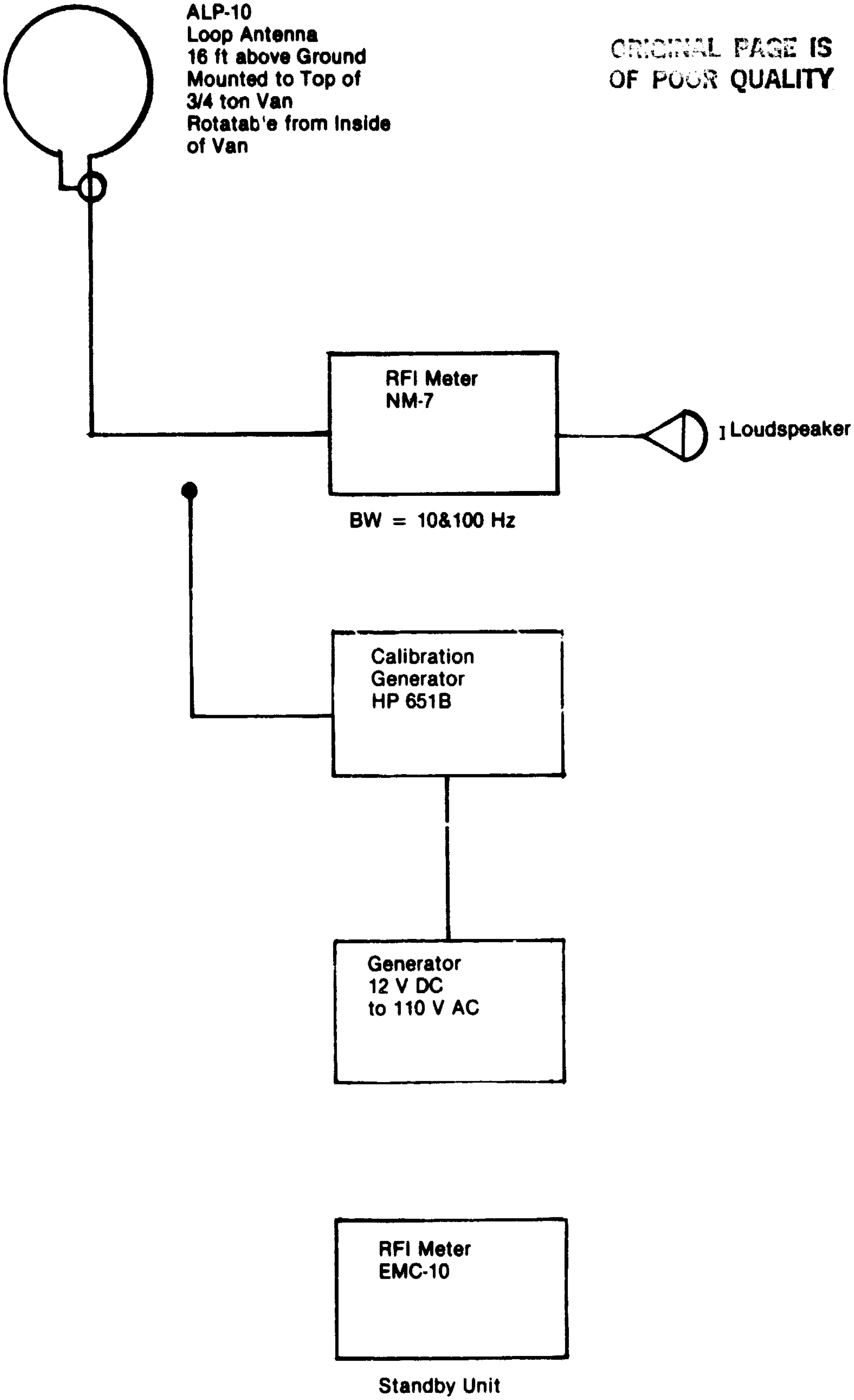


FIGURE 7 Instrumentation Used for Phase I Detailed Measurements

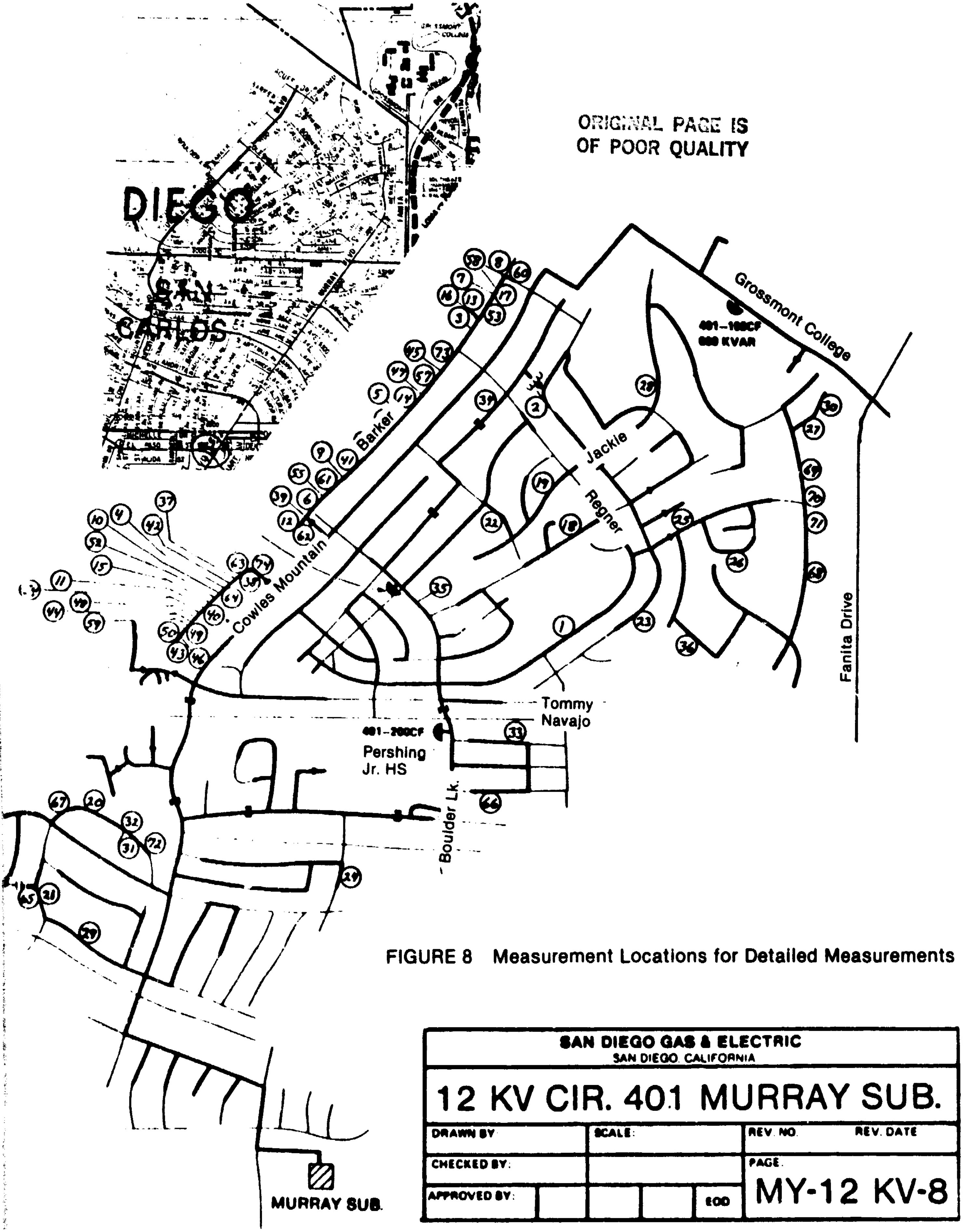


FIGURE 8 Measurement Locations for Detailed Measurements

2.2.3 Phase II Measurement Procedures

The objective of the Phase II measurements was to determine the relationship between the 5.79 kHz PLC input current and radiations from the powerline. The injection transformer input and output current were monitored. The schematic for the current measurements was as shown in Figure 9. The procedure was as follows:

1. Install insulated jumper on high voltage side of injection transformer on North-Y Phase A (Circuit 401).

2. Clamp current probe around insulated jumper and also around wire on input side (i.e. Phase A of North-Y).

3. Adjust PLC current at 5.79 kHz to obtain 30 amps on input side. Record transformer input and output current.

4. Perform radiation measurements on Boulder Lake Blvd. near playground entrance steps of Pershing Junior High School with 30 amps input current.

5. Perform measurements at slant ranges of 50, 100, 150, 200, 250, 300, 400 and 500 feet from powerline.

6. Reduce input current to 3 ampere input while measurement antenna is in place at Boulder Lake Blvd. Repeat measurements of Step 5.

7. Measure injection transformer output current with 3 ampere input current.

8. Repeat Steps 4 and 5 with 3 ampere input current.

2.2.4 Phase III Measurement Procedures

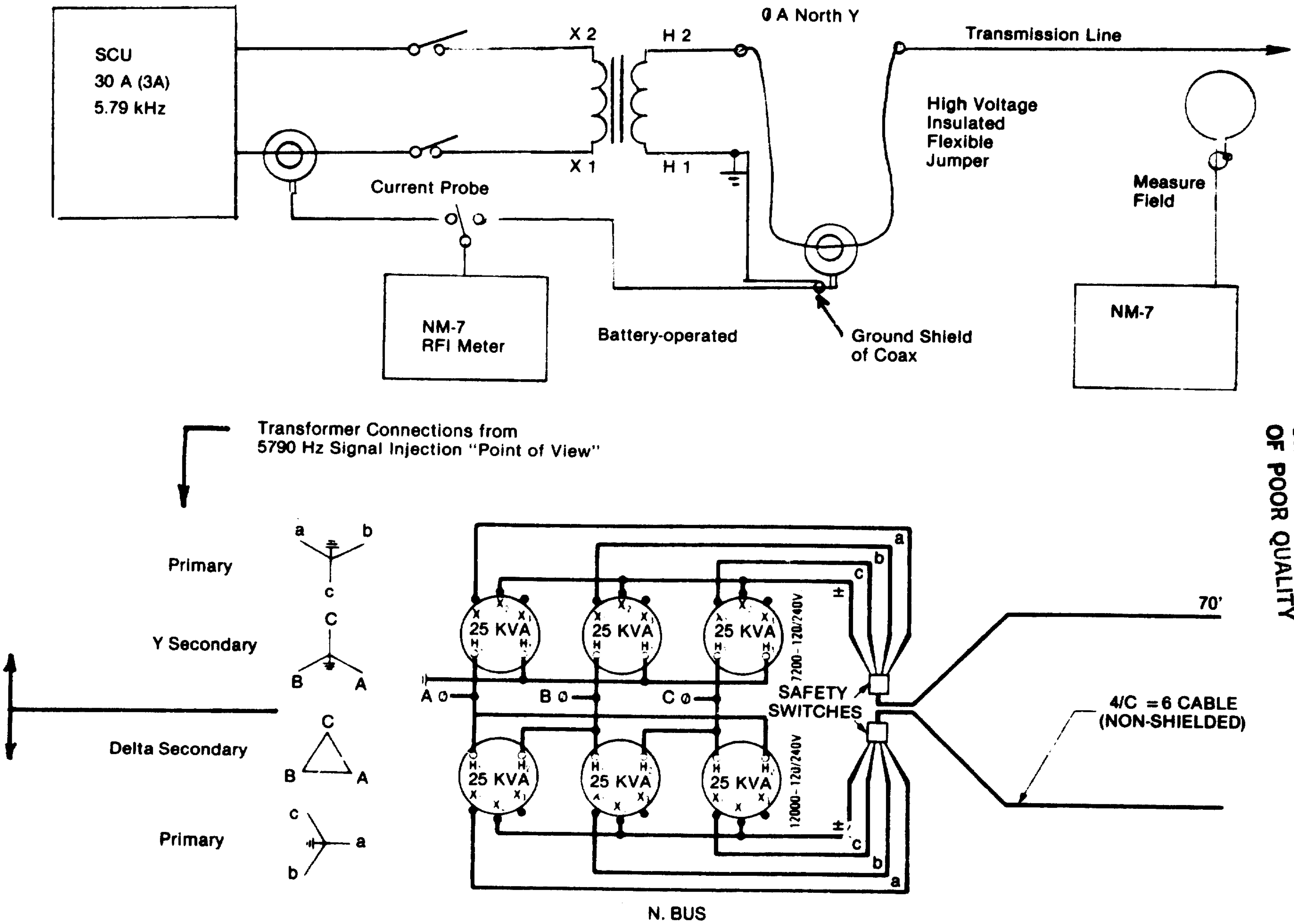
The objective of the Phase III measurements was to determine the radiation amplitudes from the powerline when the PLC signal frequency is increased to 45 kHz. The injection transformer input and output current was monitored.

The schematic for the 45 kHz current measurements was as shown in Figure 10. The procedure was as follows:

1. Disconnect power factor capacitors from Circuit 401 (since the resonating coil characteristics are not known at 45 kHz).

2. Connect the 400 watt amplifier to the injection transformer disconnect switch via coupling capacitors of 1 uF. Adjust frequency to 45 kHz and current to maximum. (NOTE: The 1 uF capacitor has a 45 kHz reactance of 3.5 ohm and a 60 Hz reactance of 2,650 ohm).

FIGURE 9 Phase II Current Measurements at 5.79 kHz



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3. Clamp current probe around insulated high voltage jumper and between amplifier and input to injection transformers. Record transformer input and output current.

4. Repeat steps 3 through 7, except that current should only be 3 ampere. (NOTE: The 400 watt amplifier will not be able to generate 30 ampere.)

5. Repeat Step 8 of Section 2.2.3 with 45 kHz and 3 ampere injection current.

2.3 PLC Current Measurement Data

2.3.1 Measurement of PLC Current at SCU and Transformer Disconnect Switch

The current was measured with the current probe clamped around the wire carrying the pilot tone current from the Substation Control Unit (SCU) to the injection transformers as shown in Data Record 1* and Figure 3. Initial measurements were performed with current injected into Phase B of the South-Y connected injection transformer. The PLC-10 current probe was used to 40.53 kHz and the CP-105 current probe was used for measurements of 46.32 kHz and higher. (Later measurements utilized only the CP-105 probe). The transfer impedance of these current probes in dB above one ohm is shown in Figure 5 and in the data tabulation of Data Record 2. The injection transformer connections are shown in Figure 3. The terms "Y" or "Delta" injection pertain to the transformer secondary connections as shown in Figure 3.

The current was measured with the EMC-10 and EMC-25 Analyzer. In addition, the current was also measured with the HP 3580A and HP 141/8552B/8553B Spectrum Analyzers.

The measured current is tabulated in Data Record 2 and is plotted in Data Record 3. The spectrum analyzer display photographs are shown in Data Record 4. It should be noted, that the spectrum analyzer data is only the indicated voltage. To obtain current amplitudes the frequency-dependent current probe factors, shown in Figure 5 must be added at each frequency. All readings were calibrated with the HP 651B signal generator.

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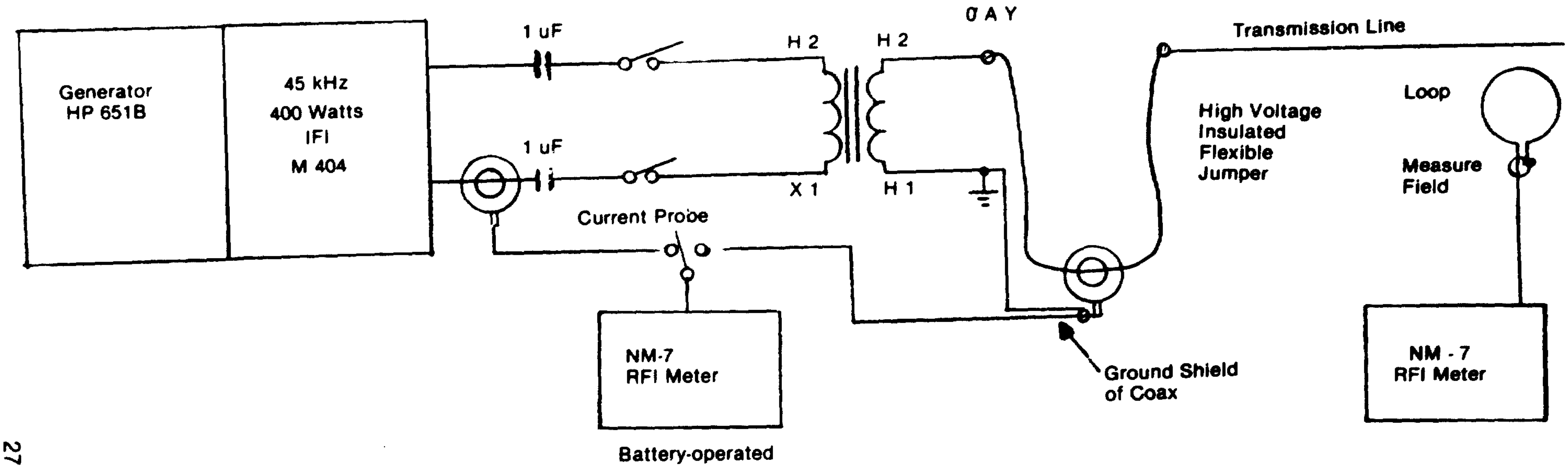
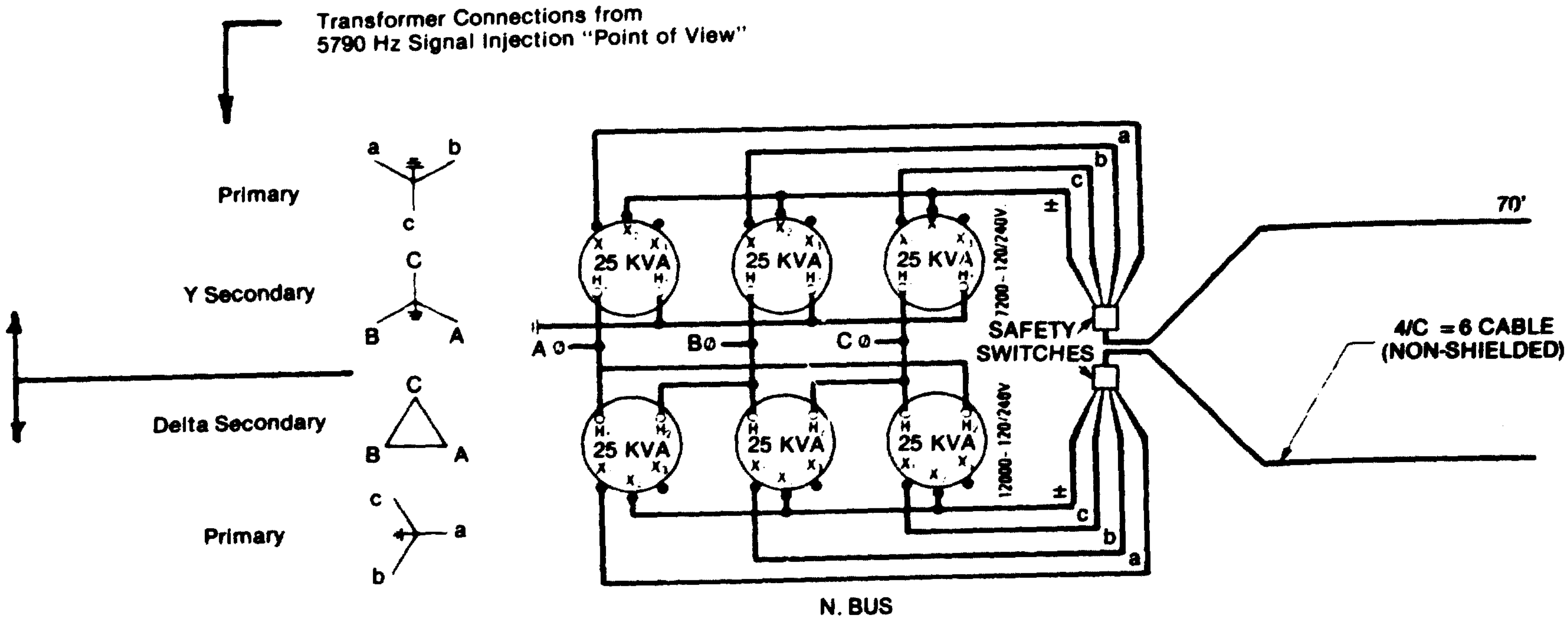
*Please note that Data Records are in sequence at the end of this Report. Figures and Tables are within the text.

FIGURE 10 Phase III Current Measurement at 45 kHz





After completing the South-Y, Phase B, injection measurements; the other phases were also measured. It was noted that the readings were approximately the same at all locations. The photographs of the spectrum display are shown in Data Records 5. The SCU current measurements are summarized as follows:

Injection Points	Notes
South-Y, Phase B	Data Record 4, Data Record 5 (Photo 1A)
South-Y, Phase A	Photo 3, Second Harmonic is 10 dB higher
South-Y, Phase C	Current is the same as for South-Y, Phase B
South-Delta, Phase A	Current is the same as for South-Y, Phase B
South-Delta, Phase B	Current is the same as for South-Y, Phase B
South-Delta, Phase C	Photo 2, Noise is higher
North-Y, Phase A	Current is the same as for South-Y, Phase B
North-Y, Phase B	Current is the same as for South-Y, Phase B
North-Y, Phase C	Current is the same as for South-Y, Phase B
North-Delta, Phase A	Current is the same as for South-Y, Phase B
North-Delta, Phase B	Current is the same as for South-Y, Phase B
North-Delta, Phase C	Current is the same as for South-Y, Phase B
South-Y, Phase B	Photos 8 and 9, While operational signal was sent to subscriber. No change from amplitude originally obtained for South-Y, Phase B shown in Data Record 4.

Transformer Disconnect Switch Measurement

Injection Point	Notes
South-Y, Phase A	Photo 4
South-Y, Phase B	Photos 5 and 6
South-Y, Phase C	Current is the same as Photo 5

Conclusions

The fundamental current of 5.79 kHz is sufficient to give a measurable radiated field, that is approximately 40 dB above the EMC-10 sensitivity in a 200 Hz bandwidth. The second, third and higher harmonic currents are however at least 40 dB lower. Consequently, they may not be measurable as radiations.

Analysis of the current data shows that the characteristics of the signal injected is independent of Y or Delta injection, and the current is only slightly attenuated between the SCU and the Transformer Disconnect Switch. The harmonic content is low. The third harmonic is the highest, but it is 40 to 48 dB below the fundamental. Current measurements to 100 MHz were performed with the spectrum analyzer and the current probe. The SCU generator had no measurable output above 250 kHz. The system sensitivity was 10 micro-ampere.

Additional photographs of the current measurements are shown in Data Record 5.

The overall measurement accuracy was ±2 dB. Consequently, in injection current that was measured as 28.18 ampere could be 30 ampere. Since the maximum output current of the SCU is rated at 30 ampere, the subsequent reference to the maximum SCU current is 30 ampere.

2.3.2 Measurement of 5.79 kHz, and 45 kHz Current at Injection Transformer Primary and Secondary

These measurements were part of measurement Phase II and III; however for completeness they are repeated in this section.

The current amplitudes were measured twice during the day. The same indicated readings were obtained. At 5.79 kHz the SCU current was varied until the primary current was 30 amperes (or 3 amperes). The corresponding secondary current ratio was slightly different at the 30 ampere and at the 3 ampere injection. This is possible due to instrumentation accuracy which is ±2 dB. The attenuator setting of the NM-7 required changing between the 30 ampere and the 3 ampere injection. If the 3 ampere secondary reading would be 2 dB higher, the transformer current ratio would also be 50:1.

The transformer current ratio was 44:1 at 45 kHz injection. This was somewhat surprising since it is lower than at 5.79 kHz. One would expect that the Eddy current losses in the transformer would be higher at 45 kHz to give a lower secondary current than at 5.79 kHz. Photographs of the primary and secondary current measurement test instrumentation are shown in Data Records 8 and 9.

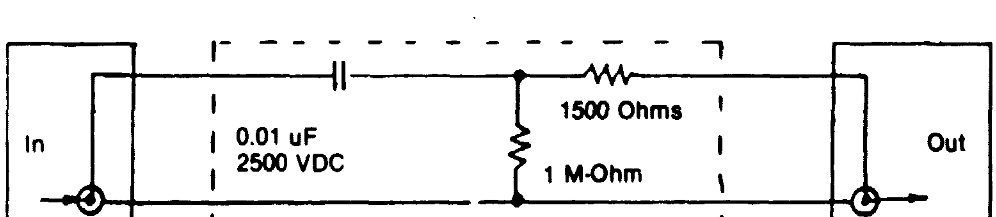
The data for the primary (120 V side of injection transformer) and secondary (12,000 V side) current measurements were as follows:

Frequency	Primary dBuA	Primary A	Secondary dBuA	Secondary A	Transformer Current Ratio
5.79 kHz	150	31.6	116	.631	50:1
5.79 kHz	130	3.16	94	.05	63:1
45.0 kHz	130	3.16	97	.0708	44:1

Sample calculation for 5.79 kHz and 3 amp at the transformer secondary:

A—Meter Reading = 72 dBuV
B—Current Probe Factor = 12 dB
C—Attenuator = 10 dB
Total current = A + B + C = 94 dBuA

At the 30 amp, 5.79 kHz injection the injection voltage was also measured at the Phase A to neutral low voltage terminal and was found to be 11.22 volts. The voltage measurement was made via a CISPR Line Probe with schematic as follows:



The insertion loss of this probe is 30 dB in a 50 ohm system and at 5.79 kHz. The NM-7 meter reading was 111 dBuV giving a total of 141 dBuV = 11.22 volts.

2.3.3 Measurement of 5.79 kHz Crosstalk Between Phases

Although not directly related to the measurement objective, a special crosstalk test was performed as follows:

1. Clamp current probe to South-Y, Phase B, at Transformer Disconnect Switch.

2. Connect current probe output to calibrated spectrum analyzer.

3. Inject signal into South-Y, Phase A, and measure signal on South-Y, Phase B.

4. Measure signal on South-Y, Phase A.

5. Subtract the current value of Step 3 from Step 4.

Results—The signal on Phase B was 70 dB lower than signal injected into Phase A.

2.3.4 Transponder RFI Evaluation

The transponder, located at each data collection point, contains the receive and transmit logic. Since the transponder could be a source of RFI, it was evaluated for powerline conducted noise (i.e. noise that could feed continuously to a subscriber's wiring). The noise was found to be approximately 30 microvolts peak over the 0.45 to 1.6 MHz frequency range and 10 microvolts peak over the 1.6 to 30 MHz frequency range. Measurements were performed with a 10 kHz bandwidth. These amplitudes are below the 250 microvolt "B" limits of FCC, Volume II, Part 15 J, RFI Requirements for Data Processing Equipment. (Reference 3).

2.4 RF Radiation Measurements

Most RF radiation measurements were performed with 30 ampere injected into the North-Y, Phase A to Circuit 401. Other current values were used for special correlation tests. This will be reported in the specific section.

2.4.1 Initial RF Radiation Measurements at Murray Substation

As part of the familiarization mesurements at Murray Substation the RF radiation was also measured near the injection transformers. The signal was injected into the South-Y, Phase A. The measurement location is shown in the photograph of Data Record 10. The ALP loop antenna was approximately 30 feet from the switchgear. The data for these measurements was as follows:

	Frequency	Reading	A.F.* H-Field	A.F.E.-Field	H-Field	E-Field
1	5.79 kHz	69 dBuV	12 dB	12 + 51 dB	81 dBuA/m	132 dBuV/m
2	11.58	12 dBuV				
3	17.37	<10				
4	23.16		Noise Level of Receiver ≈ 3 uV			
5	28.95					
6	34.74					
7	40.53					
8	46.35					

*A.F. = Antenna Correction Factor

When the signal was injected into the South-Delta, Phase A, the reading at 5.79 kHz was 35 dBuV, giving an H-Field of 47 dBuA/m and an E-Field of 98 dBuV/m. However, this data is not conclusive since the wire orientation in the Substation is very complex and the fields may cancel each other.

Since the loop antenna is relatively insensitive, an active rod (Singer 95010-1) antenna was also used when the signal was injected into South-Y, Phase A. Since the active rod will easily overload to strong fields, such as 60 Hz, it was located 200 feet from any switch-gear. The reading at 5.79 kHz was 54 dBuV plus the antenna factor of 8 dB gave an E-Field of 62 dBuV/m. The reading at the second and third harmonic was 11 and 12 dBuV/m, respectively. During the radiated measurements the frequency range of 30 Hz to 110 MHz was scanned. Since the normal broadcast activity existed, the measurements were performed first with the SCU generator "off" and then "on." No spectrum changes were noted above the second harmonic of 11.58 kHz.

2.4.2 Initial RF Radiation Measurements Along Circuit 401

As part of the initial familiarization measurements, RF radiation data were taken under the 12-kV lines of Circuit 401.

Measurements were performed with the ALP-10 loop antenna and the EMC-10 receiver. The pilot tone was being sent in a sequence of 2-minute "on" and 2-minute "off" per synchronized watches. A map of Circuit 401 is shown in Figure 6. Only the 5.79 kHz fundamental was measurable. The antenna was rotated for maximum pickup. The data shown are with the detector in the "Peak" mode.

The photographs of the measurement locations are shown in Data Records 11 through 15. A summary of the data is as follows:

Location	**Amplitude**
Lake Badin and one-half block south of Blue Lake, 50 feet from Powerline.	45 dBuV, 108 dBuV/m
Lake Badin & Blue Lake, under Powerline	57 dBuV, 120 dBuV/m
Blue Lake, 300 feet from Circuit 401	28 dBuV, 91 dBuV/m
Boulder Lake & Navajo, under isolator.	38 dBuV, 101 dBuV/m
Navajo, 100 feet East of Boulder Lake.	18 dBuV, 81 dBuV/m
Navajo, 300 feet East of Boulder Lake.	14 dBuV, 77 dBuV/m

Conclusions

The initial familiarization measurements showed that the 5.79 kHz pilot tone is measurable as radiated H-Field along the overhead powerlines. However, the fields are very weak at a distance of 300 feet from the powerline. Harmonics of the PLC pilot tone are not measurable with instrumentation sensitivity of one microvolt.

For measurement of the H-Field a loop antenna with a field strength meter, such as the Electro-Metrics EMC-10 or Ailtech NM-7 must be used to obtain maximum sensitivity.

2.4.3 Detailed RF Radiation Survey

The detailed RF radiation survey was planned after the initial survey was completed. The test procedure is given in Section 2.2.2.2 of this report. All measurements were performed on Circuit 401. For completeness, the Phase II and III measurements that were a follow-up of the detailed survey are also repeated in this section (2.4.3). A summary of the measurement objectives is as follows:

1. Demonstrate a 20 dB more sensitive instrumentation system than the 20 dBuV sensitivity reported for the initial measurements at a frequency of 5790 Hz.

2. Measure the 5790 Hz field strength at a location previously measured (Boulder Lake and Navajo Blvds.).

3. Measure the 5790 Hz field strength variation along and under a powerline run.

4. Measure the 5790 Hz field strength near the end of a typical circuit.

5. Measure the 5790 Hz field attenuation as a function of distance at a right angle to the powerline.

6. Measure the 5790 Hz field strength with 30 amperes and 3 amperes of SCU current injected (Phase II).

7. Replace the 5790 Hz signal with a 45 kHz oscillator and amplifier. Measure the 45 kHz field strength attenuation as a function of distance from the powerline with 3 amperes of 45 kHz current injected into the injection transformer.

2.4.3.1 Demonstration of Instrumentation Sensitivity

The instrumentation sensitivity was verified at the Murray Substation and adjacent to the North Injection Transformers.

The following data was obtained for the NM-7 RFI meter at 5.79 kHz:

Bandwidth		
100 Hz dBuV	10 Hz dBuV	NOTES
– 38	– 40	Receiver sensitivity with antenna disconnected
60	59	With antenna connected and tuned to 5.79 kHz
– 5	– 30	Ambient noise with antenna connected, tuned to 5.79 kHz, and SCU signal "OFF."

This demonstrated that the sensitivity was -40 dBuV (.01 uV) which is 50 dB more sensitive than reported for the initial survey.

2.4.3.2 Repeat of Initial Survey Measurements

Initial radiated measurements of Circuit 401 were primarily made at Navajo and Boulder Lake Blvds. The same measurement location was selected to repeat the measurements. The previous data reported in Section 2.4.2 was 38 dBuV (raw data) which is equivalent to 50 dBuA/m or 101 dBuV/m (with a 100 Hz bandwidth).

The repeat data readings obtained were 36 dBuV (raw data), 48 dBuA/m, 98 dBuV/m with a 100 Hz bandwidth. This is 2 dB lower than previously measured, but within the tolerance of the instrumentation. It was observed that with the PLC signal "Off" the background noise was 25 dBuV. With the antenna disconnected the receiver indicated −38 dBuV with a 100 Hz bandwidth. Subsequently, the Substation was visited to verify that the PLC signal was completely turned "off." The next measurement was performed with the osillator power "off." The same reading of 25 dBuV was obtained; therefore, it was concluded that the background noise was high directly under the powerline and near the capacitor bank on Boulder Lake Blvd. This was confirmed by performing a RFI survey with the PLC signal "off" and measuring the frequency range of 40 Hz to 50,000 Hz at the same location (under the capacitor bank). This data is shown in Data Record 16.

The PLC signal as a function of distance was then measured in a direction West of Boulder Lake Blvd. along the North side of Navajo Blvd. This data is shown in Data Record 17. The plotted readings are for the 10 Hz bandwidth.

It must be noted that the initial measurement is directly under the powerline and is approximately 40-16 ft. = 24 feet from the powerline. Some of the return current in the overhead line may also cancel the measured fields. In one measurement it was noted that as the antenna moved away from directly under the powerline, the reading increased by 6 dB.

The data obtained along the North side of Navajo Blvd. was somewhat influenced by the powerline that runs on Tommy Drive, that is one block North of Navajo Blvd. This is especially noticeable at the 800, 900, and 1,000 feet distances where the antenna was 45° from the 0° position. (Parallel to powerline = 0°).

The measurement van was driven the entire length of Tommy Drive. The amplitudes measured varied from 15 to 20 dBuV.

To verify the validity of the close-in readings, the measurements were repeated at the South side of Navajo Blvd. giving approximately 150 feet more separation from Tommy Drive. The South side of Navajo Blvd. borders on the playing field of Pershing Junior High School, where no powerlines are located. The same readings for the 100, 200, and 300 feet distances shown in Data Record 17 were obtained.

Data Record 18 shows photographs of the measurement location under the capacitor bank on Boulder Lake and Navajo Blvds.

2.4.3.3 Measurements Under a Typical Powerline

A set of data was obtained for a portion of Circuit 401 along a residential street with a mix of 12-kV and 120/240 volt lines. The measurements were started at the intersection of Jackie Drive and Regner Road and was continued for 1600 feet along Regner Road and in a Northwest direction. The data is shown in Data Record 19.

Additional readings were also tak... ...o 300 feet intervals along Cowles Mountain Road while driving in a Southwest direction from Regner Road to Navajo Blvd. The following readings were obtained: 21, 26, 32, 21, 50, 40, 35, 38 dBuV. The reading of 50 dBuV was obtained near Cowles Mountain and Boulder Lake where a high voltage cable goes underground to supply Barker Way. Along Barker Way, where power is underground, readings were 30 to 40 dBuV.

Photographs of the measurements along Regner Road are shown in Data Record 20.

2.4.3.4 Fields Near the End of a Circuit

The 5790 Hz RF fields were also measured at the end of circuit 401 near Grossmont College Drive, Griffin, and Fanita Streets as shown in Data Record 21. Between Griffin and Fanita Streets amplitudes of −3 dBuV were measured. Within the lighted parking lots of Grossmont College the field was constant at −13 dBuV.

Apparently, the underground wiring carried some 5790 Hz signals.

2.4.3.5 Field Attenuation as a Function of Distance

Several attempts were made to measure the 5.79 kHz field attenuation as a function of distance from and perpendicular to the powerline. However, variations occured when the distance from the powerline under investigation was increased, other powerlines of the same circuit were approached which caused the field to increase again. Near the end of Circuit 401, the fields were too weak (−3 dBuV under the powerline) to investigate the attenuation with distance.

An open area was finally located in the playing field of Pershing Junior High School. This open field is directly West of Circuit 401 and borders the West side of Boulder Lake Blvd. between Navajo and San Carlos Drive. The measurements were performed in the 6500 block of Boulder Lake Blvd. where only the 12-kV lines were carrying PLC current. A 120/240 line was also on the power poles. However, it was inactive and carried no current. A crossection of the measurement location is shown in Data Record 22 and photographs are shown in Data Record 23.

The entire playing field is surrounded by a 10 foot chain link fence. During initial measurements it was noted that the 5.79 kHz field fluctuated widely near the fence. During subsequent Phase II and III tests it was observed that a steel waterpipe was on top of the fence for the entire length. Apparently, a signal is induced into the waterpipe. When the loop antenna was laid adjacent to and centered with the waterpipe the meter reading went down 30 dB as compared to when the loop was above the waterpipe. The current flowing in the waterpipe was measured with the current probe and found to be 49 dBuA (approximately 0.3 mA) when the injected PLC current was 30 A at 6.79 kHz. Photographs of these measurements are shown in Data Record 24. The waterpipe apparently is a new source when compared to the low amplitude fields from the powerline. The measurement distances were in 10 foot increments to 200 feet from the powerline and in 50 foot increments to 500 feet from the powerline. The antenna was kept at 12 feet above ground. The antenna height above ground was not critical. The variation from 12 feet to 1 foot above ground was 0.5 to 1 dB at distances of 120 feet from the powerline (44 ft. from fence).

The measured data is tabulated in Data Record 25. The data is plotted in Data Record 26. The following analysis of the data is made:

1. The close-in data from 31 feet to 62 feet falls off at a rate of 12 dB, i.e. $1/d^2$.

2. The difference of the radiated data between 30 ampere and 3 ampere injection of 5.79 kHz at the SCU is 21 dB for distances up to 65 feet slant range. Above 100 feet, the difference is typically 24 dB. However, a change of 20 dB was expected. The error was possibly introduced by the low voltages measured and a possible cancellation of low-level fields.

3. The unanticipated confounding variable is the fence with the waterpipe on top. The current in the waterpipe was measured to be 0.3 mA. The waterpipe is located 76 feet West of the powerline with a slant distance of 78.3 feet. Consequently, the reading No. 9 of Data Record 24 at 80 feet West is high since the waterpipe is a strong source compared to the powerline (which is 80 feet distant) and all data beyond 80 feet is probably due to the 5.79 kHz flowing in the waterpipe.

4. The source of the current in the waterpipe appears to be induction from the powerline since the fence runs parallel to the powerline for 3 blocks or approximately 1,000 feet. The entire fence is over 5,000 feet long. The current was measured along several points of the fence as follows:

At Stairway	:	0.3 mA
On South side near San Carlos Blvd.	:	0.158 mA
At Vertical Feedline (1)	:	0.013 mA
At Vertical Feedline (2)	:	0.030 mA

The current was highest in the horizontal waterpipe on top of the fence near where the measurements were made.

5. The data record was replotted with data point 10 of Data Records 25 as the starting point, which is 14 feet from the waterpipe source. All other distances from the powerline were corrected by subtracting 76 feet which is the slant range from powerline to the fence. This data is plotted in Data Record 27. The field falls off at varying rates depending upon the distance from the pipe. For each doubling of the distance the following data is obtained:

Distance Change	30 A 5.79 kHz	3 A 5.79 kHz	3 A 45 kHz
14 to 28 feet	2.5 dB	2.5 dB	2.5 dB
30 to 60 feet	2 dB	3 dB	2.5 dB
50 to 100 feet	4.5 dB	5 dB	5 dB
100 to 200 feet	7 dB	7 dB	7.5 dB
200 to 400 feet	7.5 dB	8 dB	9 dB

From 50 feet to 400 feet the field decreased 18 dB. This shows that the field decreases as the inverse of the distance (i.e. 6 dB for each doubling of distance).

6. When the sketch of the measurement layout of Data Record 22 and various photographs are examined it is noted that the low voltage lines are 6 feet beneath the high voltage lines. However, these low-voltage lines did not carry any current. Consequently, only the current flowing on the high voltage lines set up the fields measured.

7. Reference (2) gives equation 8 which indicates that for vertically stacked powerline conductors (i.e. the low voltage lines) the field decreases as the inverse square of the distance from the powerline. This is equal to 12 dB for each doubled distance.

8. Reference (2) also gives equation 10 which indicates that for horizontally arranged conductors (i.e. the high voltage lines) the field decreases as the inverse of the cube of the distance from the powerline. This is equal to 18 dB for each doubling of distance. However, further explanations in Reference (1) of equation 10 (on page 533) shows that when the currents in the horizontally arranged conductors are not equal, the field also decreases as the inverse square of the distance.

9. Reference (2) also gives equation 5 for a single wire transmission line which is the case for the current in the waterpipe. The field decreases as the inverse of the distance from the single wire line. This is equivalent to 6 dB for each doubling of distance.

10. With reference to points 7, 8 and 9 above, the data shown in Data Records 5 and 6 corroborates with the theoretical equations:

    a. The field from the powerline decreases at a rate of 12 dB for each doubling of distance.

    b. The field from the waterpipe on top of the fence decreases at an approximate rate of 6 dB for each doubling of distance.

2.4.3.6 Fields with 30 and 3 Ampere of SCU Current

As part of the Phase II measurements the RF field was evaluated as the current was reduced from 30 amperes to 3 amperes. The data is presented as part of Section 2.4.3.5 and in Data Records 25, 26 and 27. The difference of the radiated data between 30 amperes and 3 amperes injection of 5.79 kHz at the SCU is 21 dB for distances up to 65 feet slant range. Above 100 feet, the difference is typically 24 dB. However, a change of 20 dB was expected. The error was possibly introduced by the low voltages measured and a possible cancellation of low level fields.

2.4.3.7 Fields with 3 amperes of 45 kHz Current

As part of the Phase III measurements the RF field was evaluated as the PLC frequency was changed from 5.79 kHz to 45 kHz.

The data for radiated fields at the injected frequency of 45 kHz are shown in the tabulation and graphs of Data Records 25, 26 and 27 for ease of comparison with the 5.79 kHz data. The 45 kHz injected current was 3 amperes which was the same as the low current injection at 5.79 kHz. Although the secondary current was 3 dB higher at 45 kHz, direct comparison of the two lower curves of Data Records 26 and 27 can still be made. By comparing these curves the following analysis is made:

1. The 45 kHz fields are typically 5 to 6 dB lower than the equivalent 5.79 kHz fields. This indicated that the line losses are 8 to 9 dB higher by considering the 3 dB higher secondary current.

2. The 45 kHz fields attenuate at the same rate as the 5.79 kHz fields.

It was also observed that the noise environment at 45 kHz is much lower than at 5.79 kHz. The radiated measurements were easier to perform at 45 kHz.

Measurements at 45 kHz were also performed along Circuit 401, Boulder Lake, San Carlos, Cowles Mountain, Topaz Lake and Lake Badin. The readings were 0 to 20 dBuV (54.5 to 74.5 dBuV/m). At Lake Badin (near the Substation) a reading of 26 dBuV (80.5 dBuV/m) was obtained. The harmonic content of the 45 kHz generator was considerably higher than the 5.79 kHz generator. To obtain some cursory data, the following measurements were made:

Measurement Type	45 kHz	90 kHz	135 kHz	180 kHz
Current at Substation	130 dBuA	113	95	93
Radiation at Mt. Badin	26 dBuV	16	25	13

The fields do not drop off as rapidly as the injected current. There could be some non-linearities in the line to generate the third harmonics. However, conclusions can not be made until the generator is filtered and a more controlled experiment is established. The 45 kHz (or higher frequency) PLC signal poses a higher threat to the AM broadcasts since the 12th harmonic is in the AM Band.

3. CONCLUSIONS

The conclusions of this PLC measurement study are as follows:

3.1 PLC Current Measurements at 5.79 and 45 kHz

The fundamental current injection at 5.79 kHz is 30 ampere. This is sufficient to give a measurable radiated field, that is approximately 60 dB above typical RFI instrumentation sensitivity.

The second, third and higher harmonic currents are however at least 40 dB lower. Consequently, they were not measurable as radiations in the high ambient fields from normal powerline noise.

The primary/secondary current injection was as follows:

5.79 kHz	31.6 A/.631 A	50:1 Ratio
5.79 kHz	3.16 A/.05 A	63:1 Ratio
45 kHz	3.16 A/.07 A	44:1 Ratio

This indicates that the injection transformers can be used for higher PLC frequency injection. In addition, the 3 amp current values at 5.79 kHz and 45 kHz were used as a relative control for the subsequent radiation measurements.

3.2 Radiation Measurements

The 5790 Hz PLC signal is measurable as a radiated H-Field under the powerlines. The amplitude of the PLC signal is approximately 15 dB above the normal powerline noise measurable under the powerline. Typical amplitudes are 50 dBuV (123 dBuV/m) at the Substation and 0 dBuV (63 dBuV/m) at the end of a powerline circuit. The radiations are directly related to the amount of PLC current flowing in the powerline. For measurement of the H-Field a loop antenna with a field strength meter, such as the Alltech NM-7 must be used to obtain maximum sensitivity. A spectrum analyzer may be used; however, a preselector must be connected in front of the analyzer to prevent overloads from strong 60 Hz fields.

The fields from the powerline decrease as the inverse of the distance squared. The fields from the powerline are directly proportional to the injected current. From an injected current of 31.6 amperes to 3.16 amperes the fields decreased a proportional 20 dB. The fields are very weak at a distance of 200 feet from the powerline.

Secondary fields can be generated by current induced into parallel conductors, such as waterpipes and fences. Re-radiation from these structures can significantly alter the radiation patterns since the re-radiation fields decrease only as the inverse of the distance.

The fields from the powerline from a simulated 45 kHz PLC signal decrease the same as at the 5.79 kHz PLC frequency. The radiated fields were typically 5 dB lower at 45 kHz than for the equivalent 5.79 kHz current injection (3.16 amperes) even though the 45 kHz secondary current was 3 dB higher than the 5.79 kHz secondary current. This indicates that the losses from the Substation to the 5600 block of Boulder Lake were a total of 8 dB higher than for the 5.79 kHz frequency. The interference potential of a 45 kHz PLC signal is greater since the 12th harmonic falls within the AM broadcast band and also since the ambient noise environment is considerably (20 to 40 dB) lower at 45 kHz than at 5.79 kHz.

4. RECOMMENDATIONS

4.1 General Discussion

The utilization of power control systems via carrier frequencies impressed on electrical distribution wires will find widespread use in the future. The interference potential of these carrier frequencies appears to be great if improperly implemented. This practical measurement study showed that with a 5.79 kHz PLC signal and approximately 30 amperes injection current the interference potential is low. The fields from the overhead powerlines decrease as the inverse of the distance squared. This corroborates with theory.

What remains to be done is to establish a model for the typical USA power distribution network. To establish this model, the PLC current and voltages in the overhead powerline at the point of radiated measurements must be known. These measurements should be performed for each high and low voltage overhead wire and for the different delta or wye injection modes.

In addition, measurements should also be performed of currents flowing in any nearby metallic structure, such as building entries of gas and water lines, telephone cables, fences, antenna masts, and lead-ins to determine how much PLC current is inductively coupled to nearby structures that could have a potentially harmful effect on communication systems and electronic equipment.

Once the currents are known, a model can be made to accurately predict (and also corroborate) the radiated measurements. From a PLC implementation and verification point of view this model could then also be used to determine the amount of current flowing on the powerline on the basis of radiated measurements. This could be used as a trouble-shooting technique and also to verify PLC current division along a particular circuit network.

When higher PLC frequencies are used the interference potential to communication networks increases. Harmonic generation within the power distribution network may be significantly greater than at 5.79 kHz. To verify this, a "clean" PLC generator where second and higher harmonics are suppressed by 60 dB should be connected to the power distribution network. The current on the high voltage circuit should then be measured to determine harmonic generation in the network.

From a practical point of view the high voltage line PLC current and voltage measurements could be accomplished by use of "Hot Stick" current and voltage probes. The RF receiver should be battery-operated, and the entire measurement system (including test personnel) should be insulated from ground for redundant safety.

In addition, it must be noted that the measurements were performed in San Diego where the precipitation is low and powerline insulators are relatively clean. Similar measurements should also be performed in an environment where corona and insulation breakdown occurs frequently. These nonlinearities are generally the cause for harmonic generation.

4.2 Specific Recommendations

To further quantify the interference potential and prediction of PLC systems the following measurements and analysis should be performed:

1. Measure PLC current and voltage in each wire of a high/low voltage powerline while performing radiation measurements at the same point.

   Data Application: The data is required to accurately predict the RF fields from a typical USA power network. The model would be used to:
   A—predict the RF fields from a known PLC current;
   B—predict the PLC current in the powerline from a RF field which is easier to measure than the current in a (for example) 12-kV line. This could be used as a tool to evaluate the PLC system.

2. Measure current at PLC frequency in nearby metallic structures.

   Data Applications: The data is required to define any confounding variables in the model to be established. If a waterline runs parallel to a powerline, a current will be induced. The fields from this induced current may be stronger than from the powerline.

3. Perform measurements with a higher frequency (PLC) generator connected to the powerline. The harmonic output of the generator must be suppressed by 60 dB. Measure the harmonics, current, voltage, and radiations generated by the power network.

   Data Application: When higher frequency PLC systems are to be used, the interference potential of the PLC system is greater. The data would be used to predict the interference potential of the system as a function of injection current.

4. Perform a PLC system evaulation in an adverse environment, such as Seattle or Florida.

   Data Application: The harmonic generation of the PLC signal may be greater when non-linearities caused by insulation breakdown occur. The data would be used to refine the model for those locations.

5. Develop a real-time (Bootstrap) RF monitoring system that is monitored by the PLC system. Essentially, a fixed-tuned RF receiver with loop antenna would be installed in the PLC system to provide real-time data of the radiation during any environmental condition. Several channels could be used to measure the fundamental and harmonic frequencies. Each channel would be addressed the same as any other data point in the PLC system.

   Data Application: A—The system would be used to evaluate the interference potential of the PLC system over a long period of time. It could be installed on any new system for evaluation and be removed once the system is proven.

   B—The RF monitoring system could also be used to indirectly measure the PLC current with varying load conditions. Essentially, a previously established model could be used to correlate RF radiations with powerline PLC current. As an alternate measurement, the loop antenna would be replaced with a current probe that is clamped around the powerline wire to measure PLC current directly.

6. Develop a limit for permissible RFI levels from PLC system operation for overhead and underground powerlines. There is no uniform limit at present. Several national regulations exist (Reference 7) which range from 50 uV/m to 1000 uV/m and at a frequency of 500 kHz or 1 MHz.

   Data Application: The limit should be imposed upon any PLC system installation to insure that the PLC system is installed properly and does not cause interference with communication networks.

5. NEW TECHNOLOGY

Not applicable. New technology was not developed as part of this contract.

6. REFERENCES

1. "SDG&E to Test Power Line Carrier for ADS," by Ronald W. Williamson, SDG&E, published in Transmission and Distribution, pp. 44, 46, 48, and 70, May 1978.

2. "The Calculated Electromagnetic Fields Surrounding Carrier Bearing Power Line Conductors," F. D. Pullen, C.E.R.L. Leatherhead England, IEEE Trans on Power Apparatus and Systems, Vol. PAS-94, No. 2, March-April 1975, pp. 530-537.

3. Rules and Regulations, Volume II, Part 15 J, Computing Devices, Federal Communications Commission, Washington, DC 20554.

4. IEEE Standard Procedures for the Measurement of Radio Noise from Overhead Powerlines, IEEE Standard 430-1976, The Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, NY 10017.

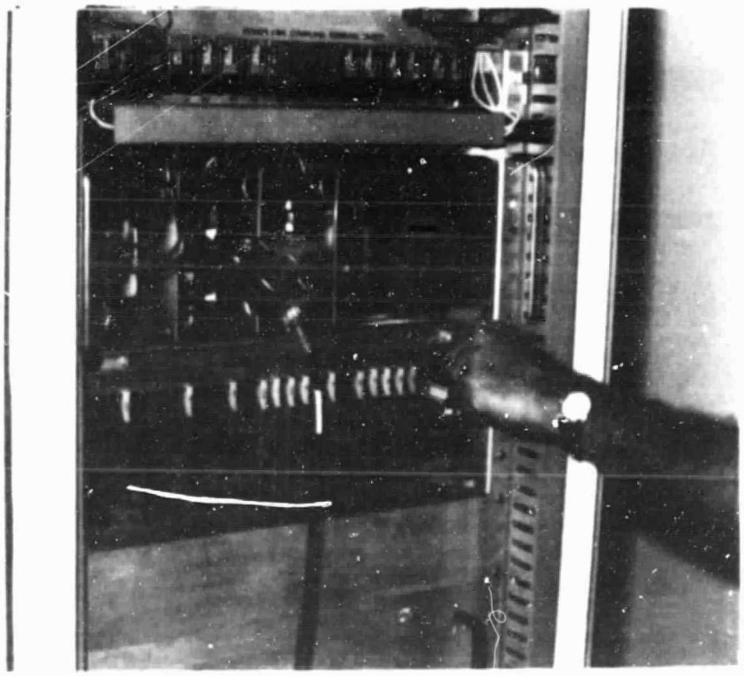
5. IEEE Recommended Practice for Measurement of Electrical Noise and Harmonic Filter Performance of High-Voltage Direct-Current Systems, IEEE Standard 368-1977.

6. The Location, Correction and Prevention of RI and TVI Sources from Overhead Powerlines, IEEE Tutorial Course Text 76 CH 1163-5-PWR, IEEE Power Engineering Society.

7. Limits of Radio Interference and Leakage Currents According to CISPR and National Regulations, IEC/CISPR Publication 9, Central Office of the IEC, 1 Rue de Varembe, Geneva, Switzerland.

7. SUPPORTING DATA

This section contains Data Records 1 through 25.



Data Record 1. Location of Current Probe in SCU Cabinet.

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Harmonic Number	Frequency kHz	Amplitude		Current Probe Factor in dB	Total Peak		
		RMS	Peak		dBuA	Amp	
1	5.79	—	137	12	149	28.18	
2	11.58	—	88	6	94	0.05	
3	17.37	—	95	4	99	0.09	
4	23.16	—	76	3	79		
5	28.95	—	88	2	90	0.031	
6	34.74	—	78	1	79	0.09	
7	40.53	—	84	1	85	0.017	
8	46.32	64	72	5	77	0.0071	
9	52.11	73	74	4	78	0.0079	
10	57.9	52	58	3	61	0.0011	
11	63.69	63	64	3	67	0.0022	
12	69.48	52	60	2	62	0.0013	
13	75.27	63	64	2	66	0.002	
14	81.06	54	62	2	64	0.0016	
15	86.85	60	62	1	63	0.0014	
16	92.94	50	58	1	59	890 uA	
17	98.43	54	56	1	57	708 uA	
18	104.22	41	49	1	50	316 uA	
19	110.01	51	54	1	55	562 uA	
20	115.80	46	53	1	54	501 uA	
21	121.59	48	52	0	52	398 uA	
22	127.38	48	54	0	54	501 uA	
23	133.17	46	51	0	51	355 uA	
24	138.96	41	46	0	46	200 uA	
25	144.75	40	46	0	46	200 uA	
26	150.54	38	46	0	46	200 uA	
35	200	29	36	0	36	63 uA	
43	250	20	28	0	28	25 uA	

Notes: 1 — PCL-10 Current Probe to 40.53 kHz
CP-105 Current Probe from 46.32 kHz

2 — Measurements were made to 100 MHz. The SCU had no measurable output above 250 kHz. The measurement system sensitivity was 10 micro ampere.

Data Record 2. PLC Current Measurements, South-Y, Phase B Murray Substation.

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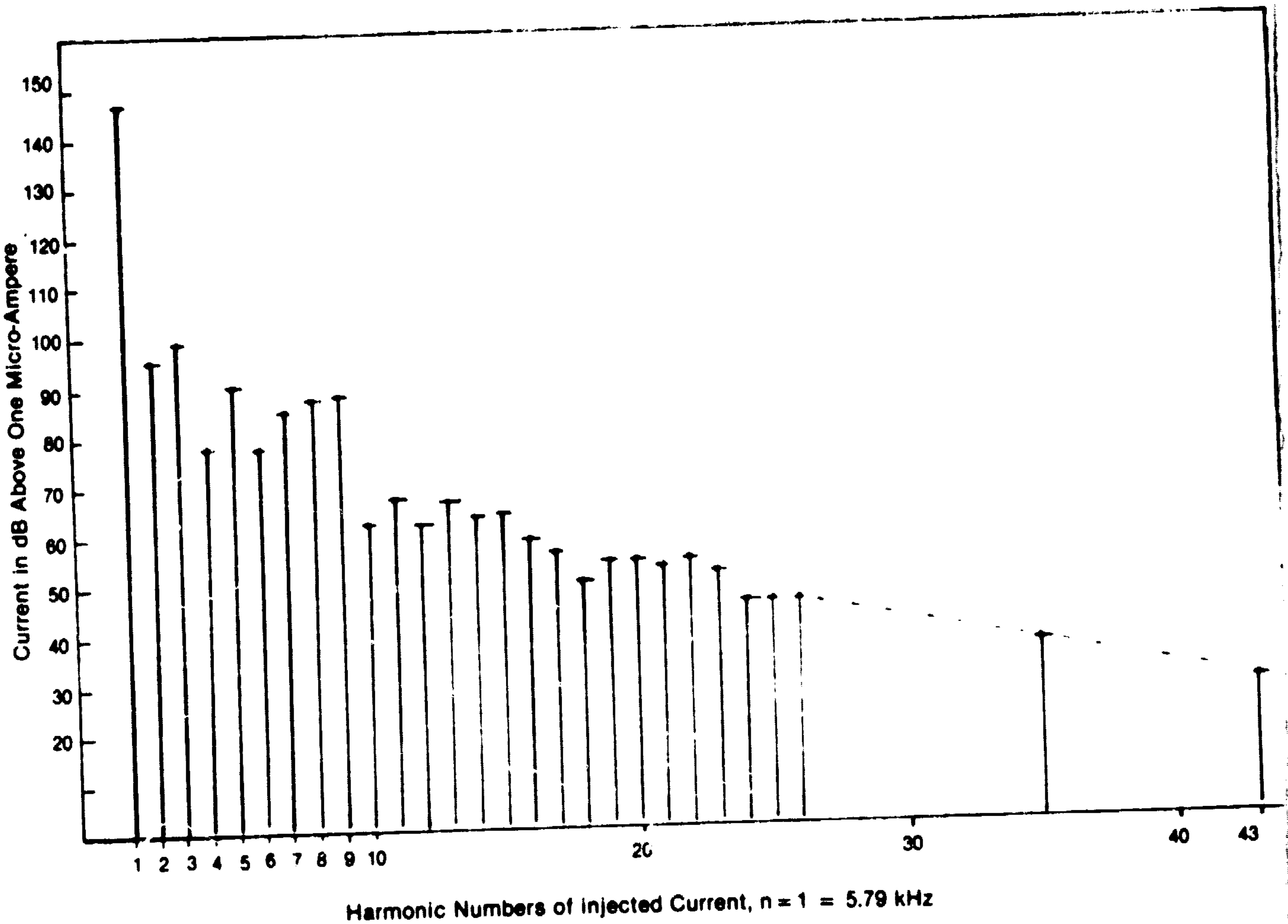
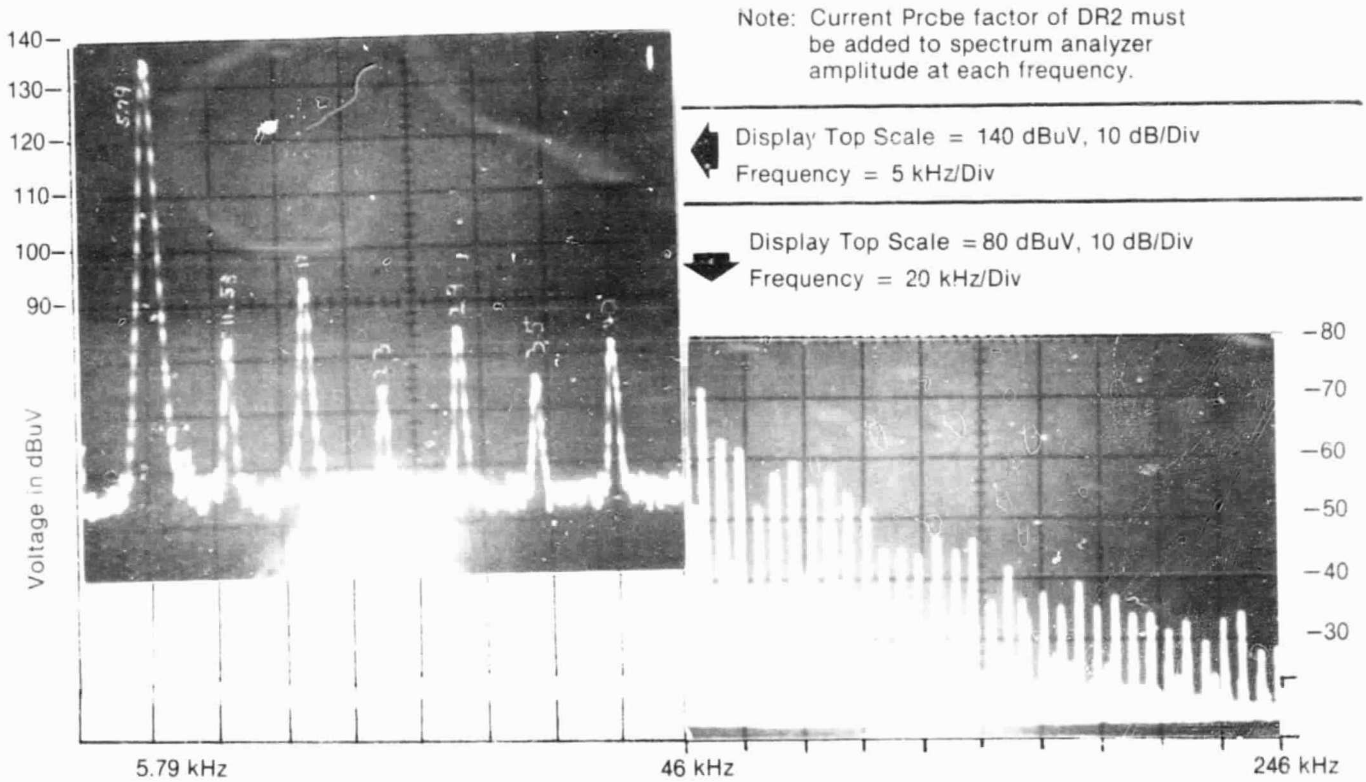


Data Record 3. Measured Current at SCU Injection.



Data Record 4. Fundamental and Harmonic Current as Displayed on Spectrum Analyzer.

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Data Record 5. Spectrum Displays of SCU Currents.

Photograph shown in
Data Record 4 of Report

PHOTO NO. 1 DATE: 4-13-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Y, Phase B
SENSOR: Current Probe PCL-10
NOTES: At Filter/Relay in SCU Cabinet Current Probe Factor is:

Freq, kHz	dB
5.79	12
11.58	6
17.37	4
23.16	3
28.95	2
34.74	1
40.53	1

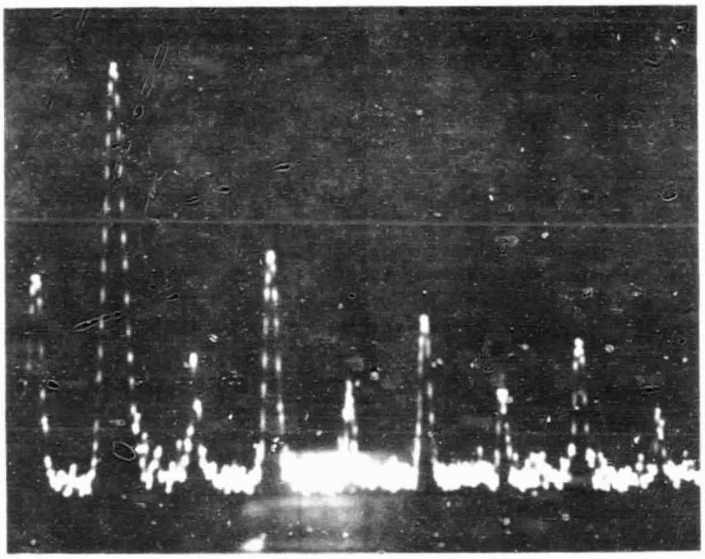

PHOTO NO. 1A DATE: 4-14-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: Same as Photo No. 1
SENSOR: Current Probe CP-105
NOTES: Data is the same as photo No. 1 except current probe factor is higher.

Freq, kHz	dB
5.79	25
11.58	14
17.37	11
23.16	9
28.95	7
34.74	6
40.53	5

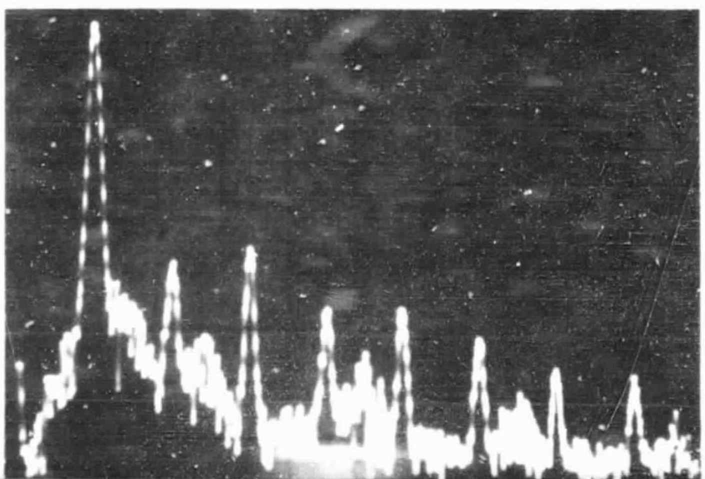

PHOTO NO. 2 DATE: 4-13-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Delta, Phase C
SENSOR: PCL-10
NOTES: Control settings are the same as Photo No. 1. The 2nd harmonic is higher. Noise between fundamental and 2nd harmonic is higher.

Data Record 5. Cont'd. Spectrum Displays of SCU Currents.

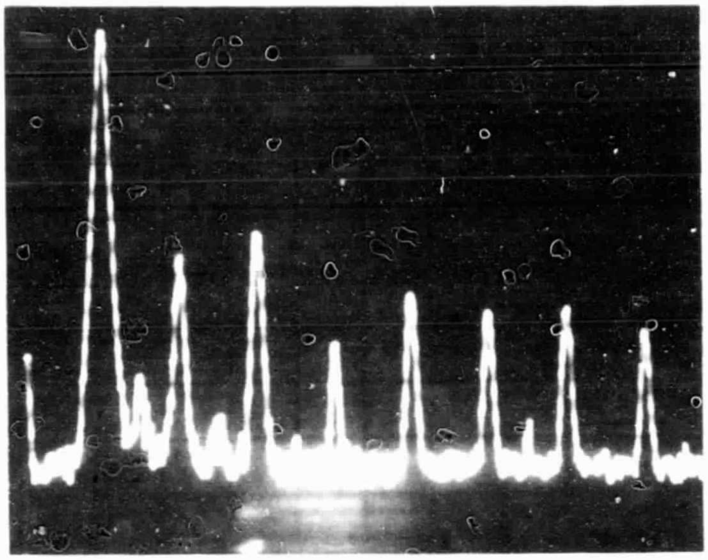

PHOTO NO. 3 DATE: 4-13-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Y, Phase A
SENSOR: Current Probe PCL-10
NOTES: 2nd harmonic is 10 dB higher than in Photo No. 1

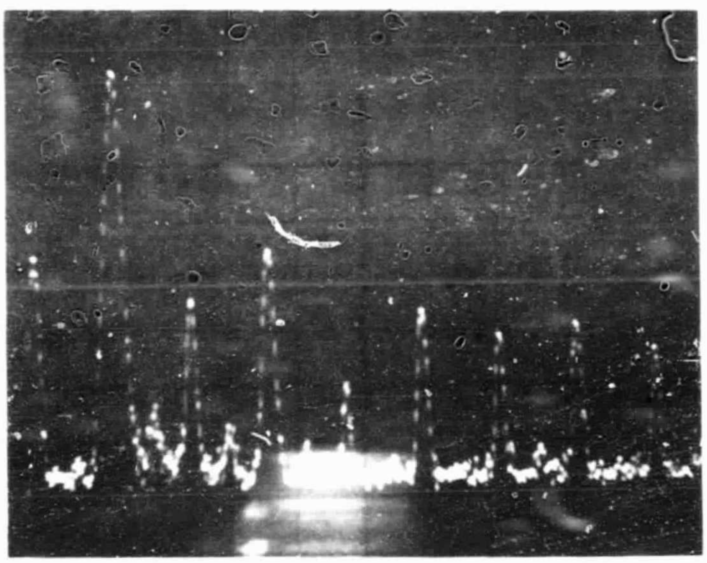

PHOTO NO. 4 DATE: 4-14-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Y, Phase A
SENSOR: Current Probe CP-105
NOTES: Measured at Injection Transformer Disconnect Switch. This is the same current as in Photo No. 3 except that a CP-105 Current Probe is used.

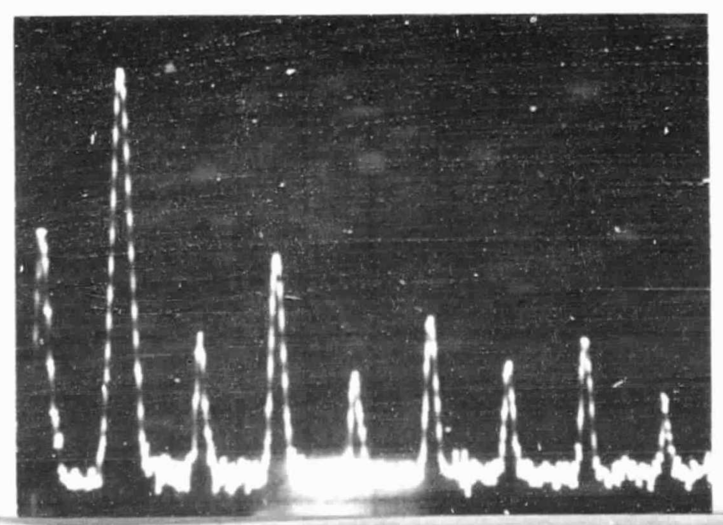

PHOTO NO. 5 DATE: 4-14-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Y, Phase B
SENSOR: Current Probe CP-105
NOTES: Measured at Injection Transformer Disconnect Switch.

Data Record 5. Cont'd. Spectrum Displays of SCU Currents.

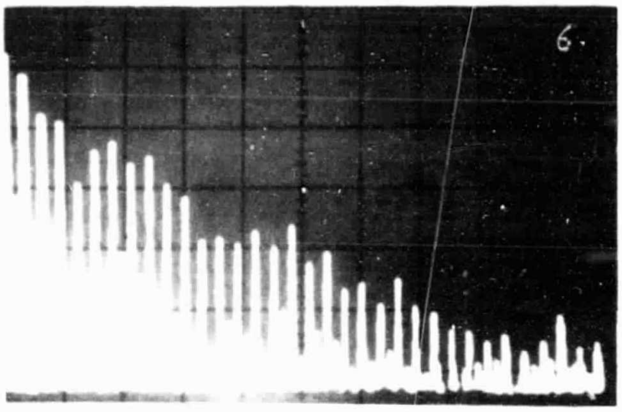

PHOTO NO. 6 DATE: 4-14-81
AMPLITUDE: 0 dB = 80 DBUV
CENTER FREQUENCY: 146 k HZ
SCAN WIDTH : 20 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 10 SEC/DIV.
LOCATION: South-Y, Phase B
SENSOR: Current Probe CP-105
NOTES: Measured at Injection Transformer Disconnect Switch. Frequency: 46 - 246 kHz

PHOTO No. 7 in Data Record 4 of the Report. Dial settings were the same as for Photo No. 6, except that Measurement was made at South-Y, Phase B in SCU Cabinet.

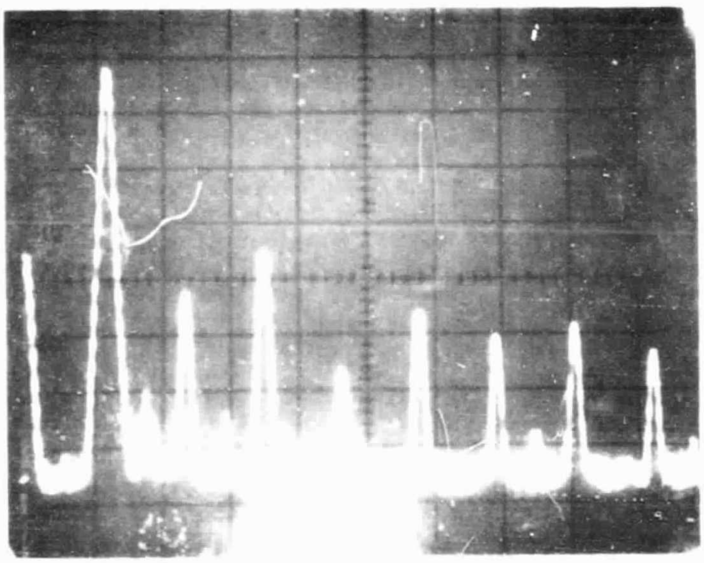

PHOTO NO. 8 DATE: 4-15-81
AMPLITUDE: 0 dB = 140 DBUV
CENTER FREQUENCY: 25 k HZ
SCAN WIDTH : 5 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 5 SEC/DIV.
LOCATION: South-Y, Phase B
SENSOR: Current Probe CP-105
NOTES: Measurement was made at Filter/Relay in SCU Cabinet while opertional signal Was Sent to subscriber.

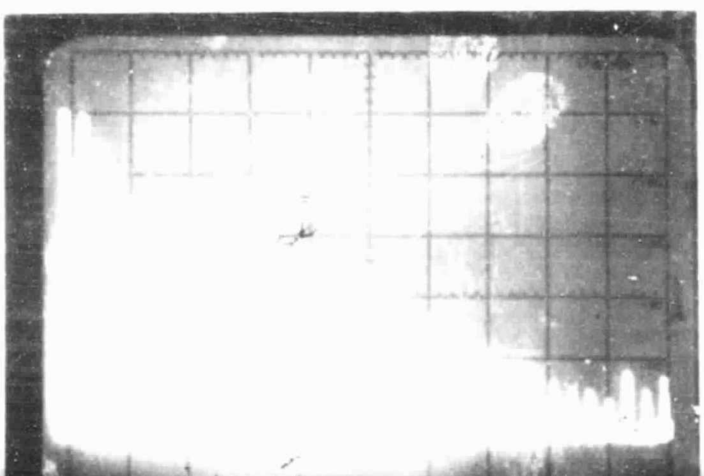

PHOTO NO. 9 DATE: 4-15-81
AMPLITUDE: 0 dB = 80 DBUV
CENTER FREQUENCY: 146 k HZ
SCAN WIDTH : 20 k HZ/DIV.
BANDWIDTH : 0.3 KHZ
SCAN TIME : 10 SEC/DIV.
LOCATION: South-Y, Phase B
SENSOR: Current Probe CP-105
NOTES: Same as for Photo No. 9.

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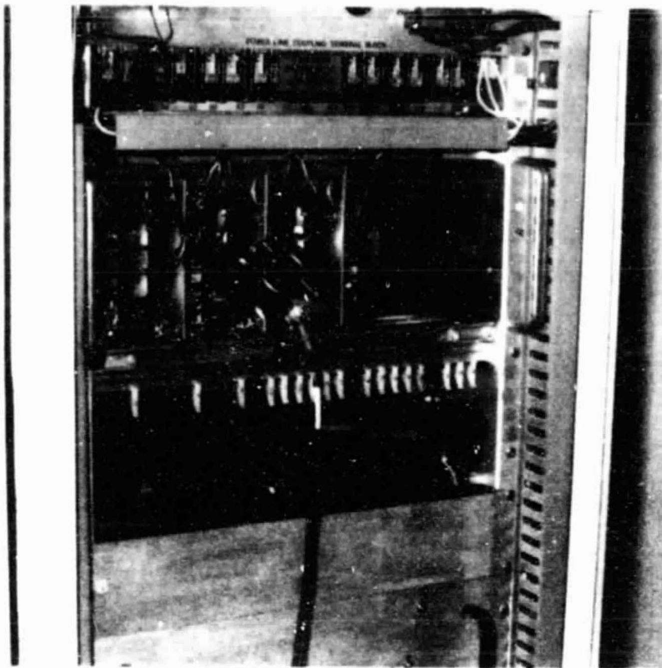
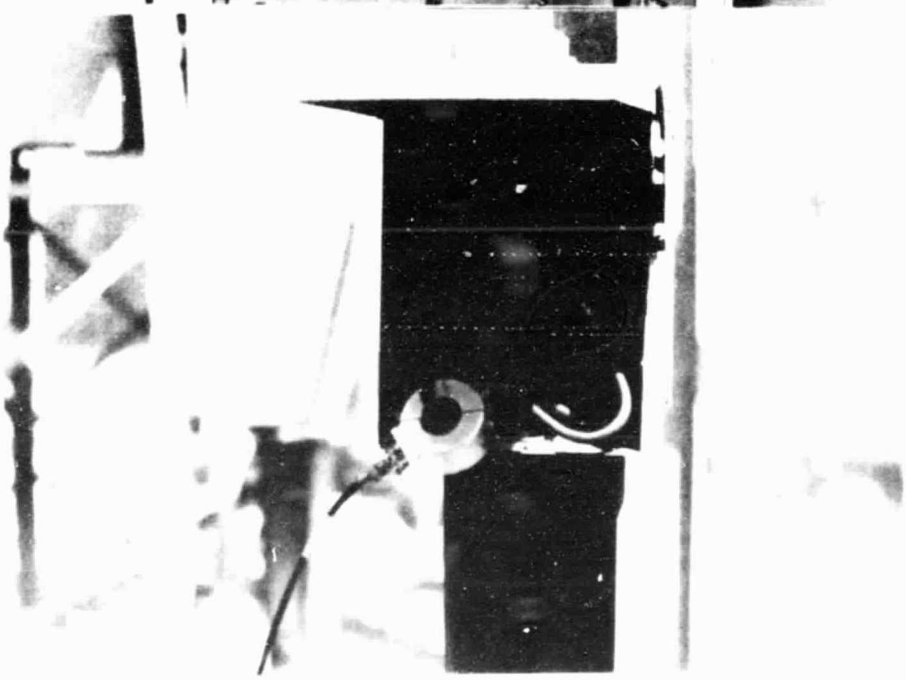
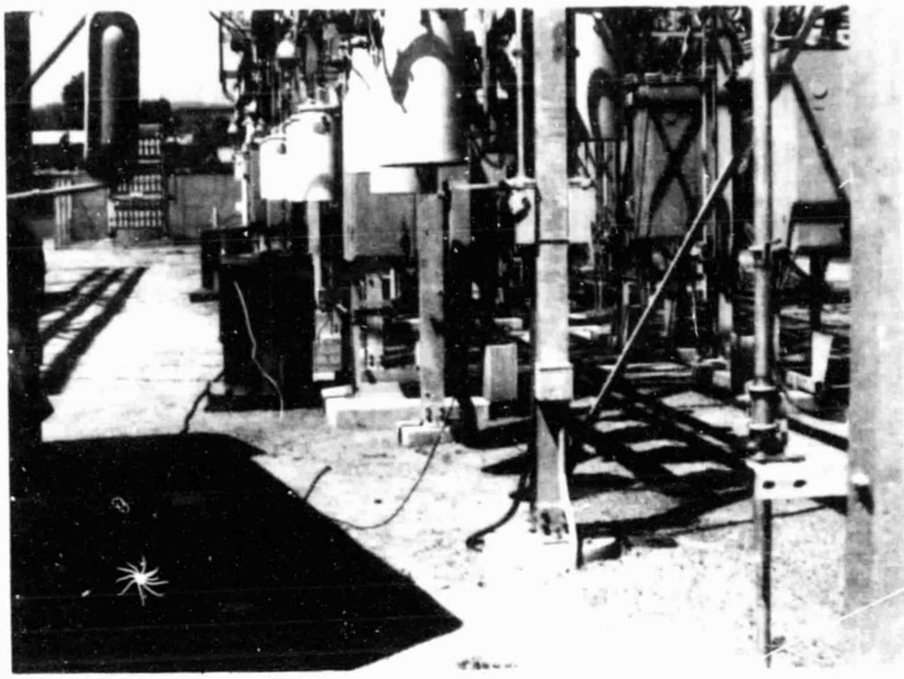


Current probe at SCU

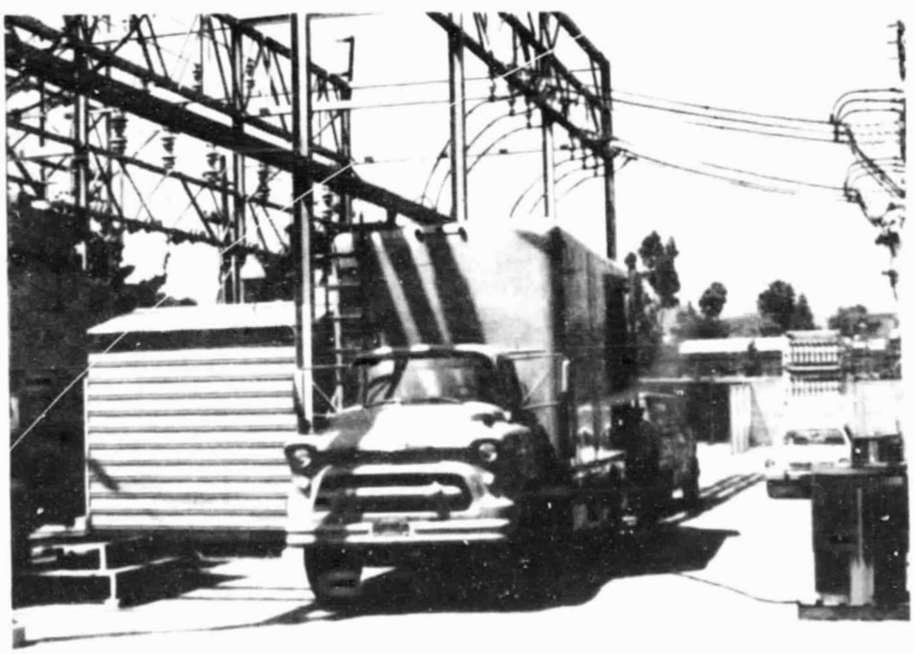


Current probe at South Injection Transformer Disconnect Switch

Data Record 6. Photographs of PLC Current Measurements.

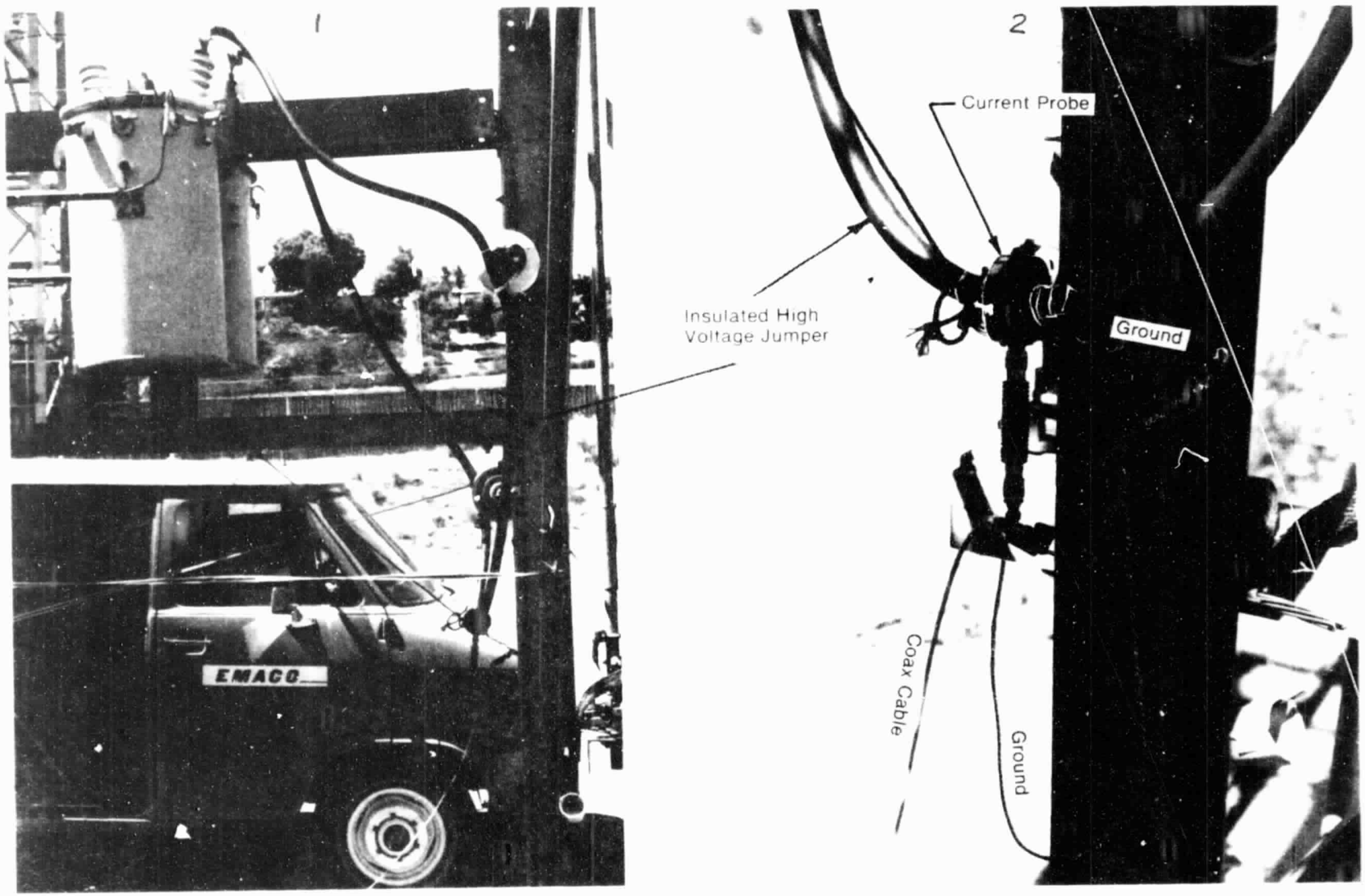


South-Y Injection Transformer Disconnect Switch and Injection Transformers



Mobile RF-Shielded Laboratory at Murray Substation

Data Record 7. Photographs of Murray Substation PLC Equipment.



Data Record 8. Measurement of PLC Current on High Voltage Side.

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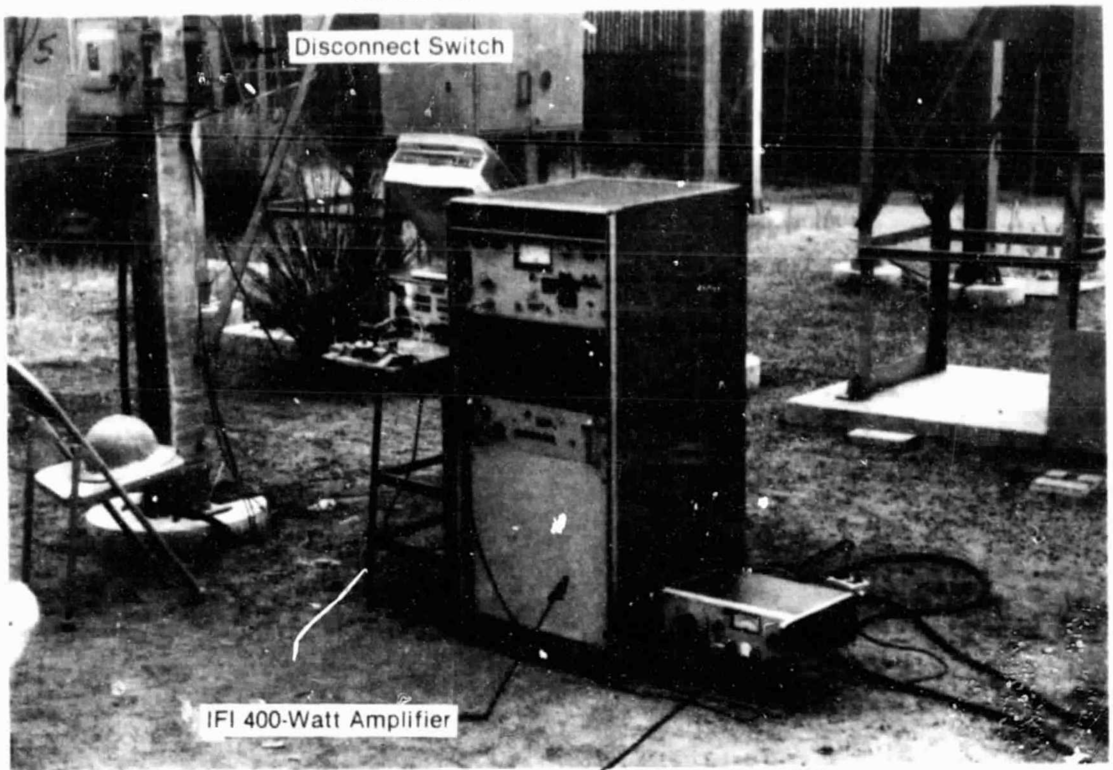
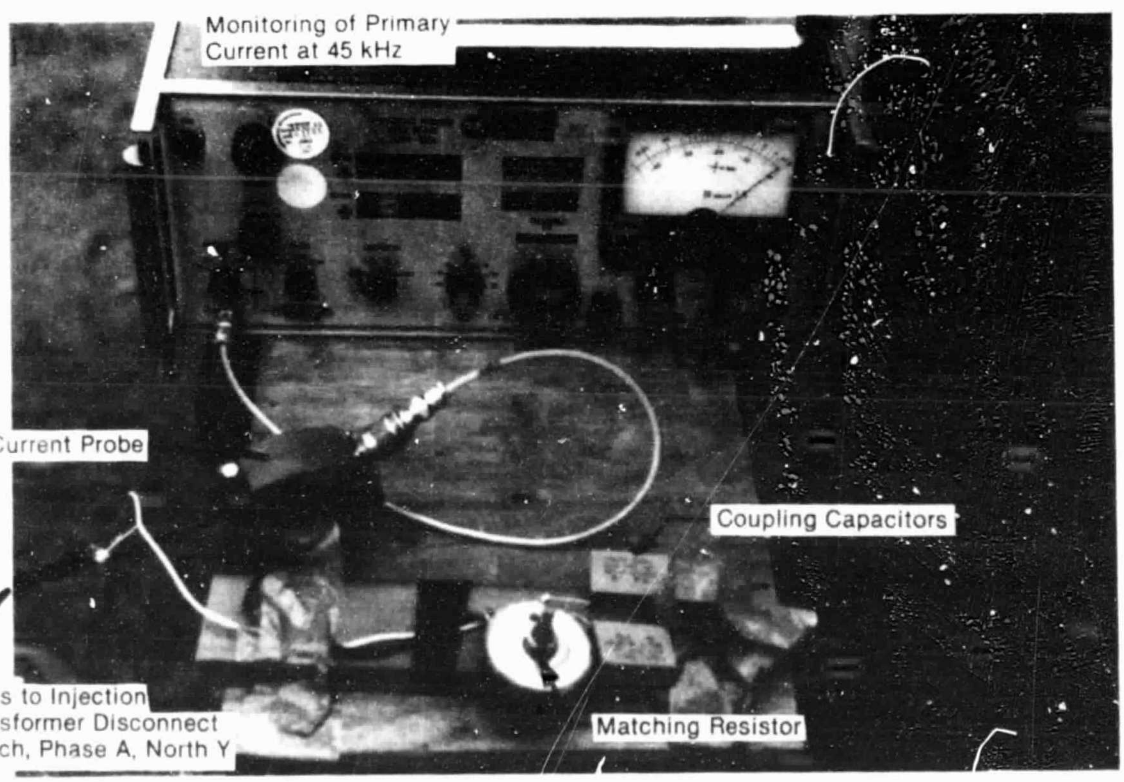
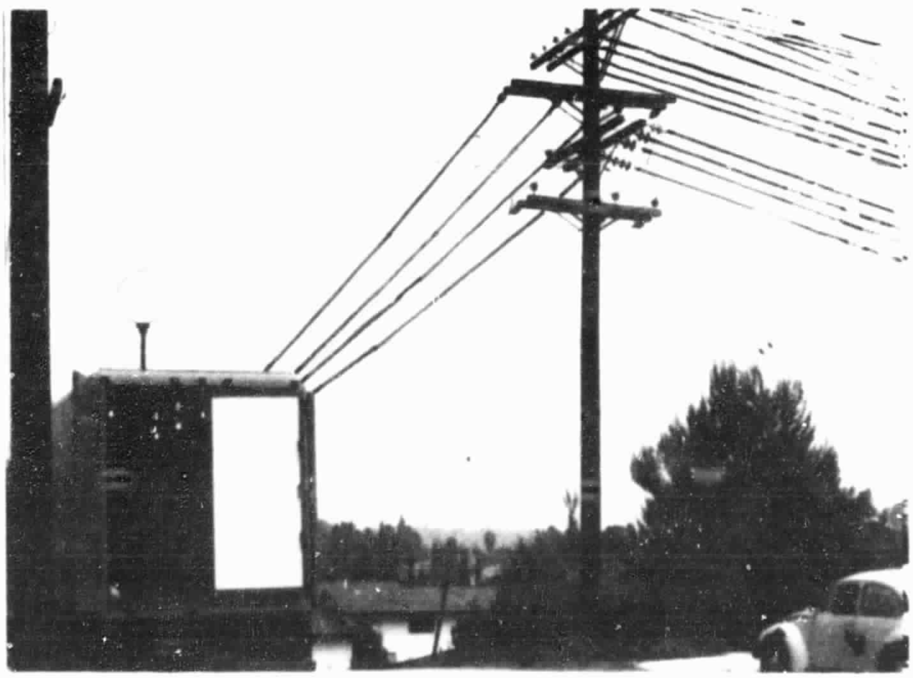




Data Record 9. Generation of 45 kHz PLC Signal.

Data Record 10. Loop Antenna Measurement at Murray Substation.

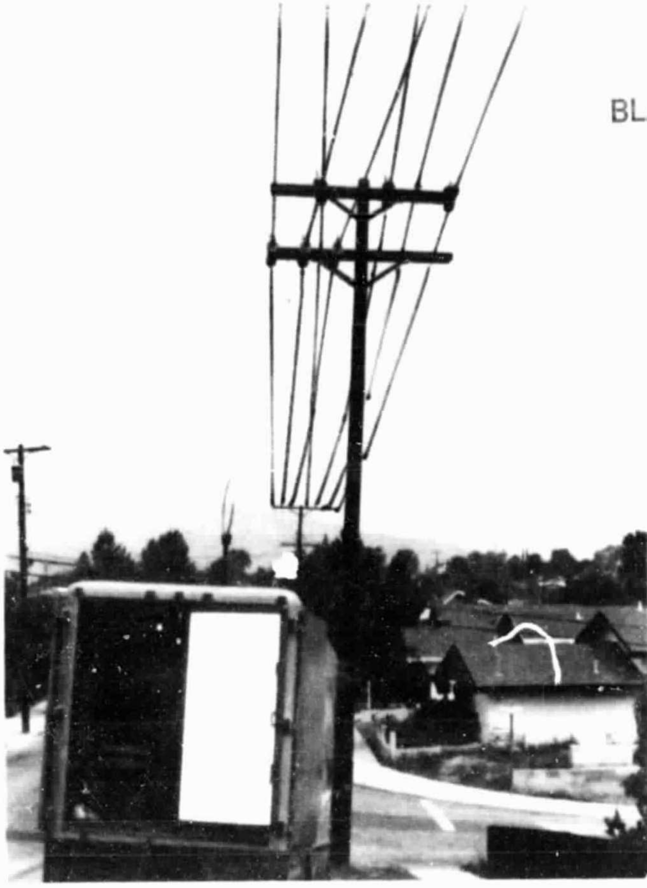


At Lake Badin and one-half block South of Blue Lake across Road and 50 feet from Powerline. Loop in maximum reading position.

45 dBuV
57 dBuA/m
108 dBuV/m

Note: This is at the border of San Diego and La Mesa. Lake Badin is in San Diego, Kimberly Drive is in La Mesa.

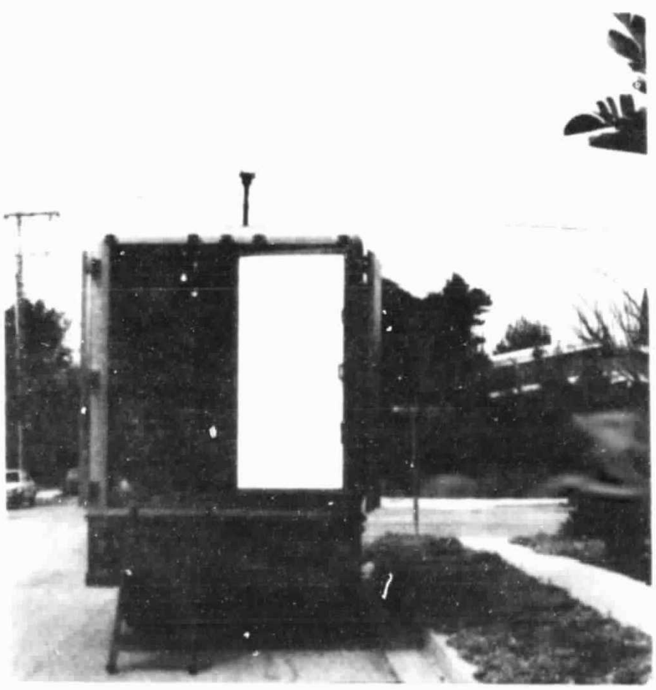
Data Record 11. Initial Measurements at Lake Badin Street.



At Lake Badin and Blue Lake under powerline.

57 dBuV
69 dBuA/m
120 dBuV/m

Data Record 12. Initial Measurements at Lake Badin and Blue Lake Streets.

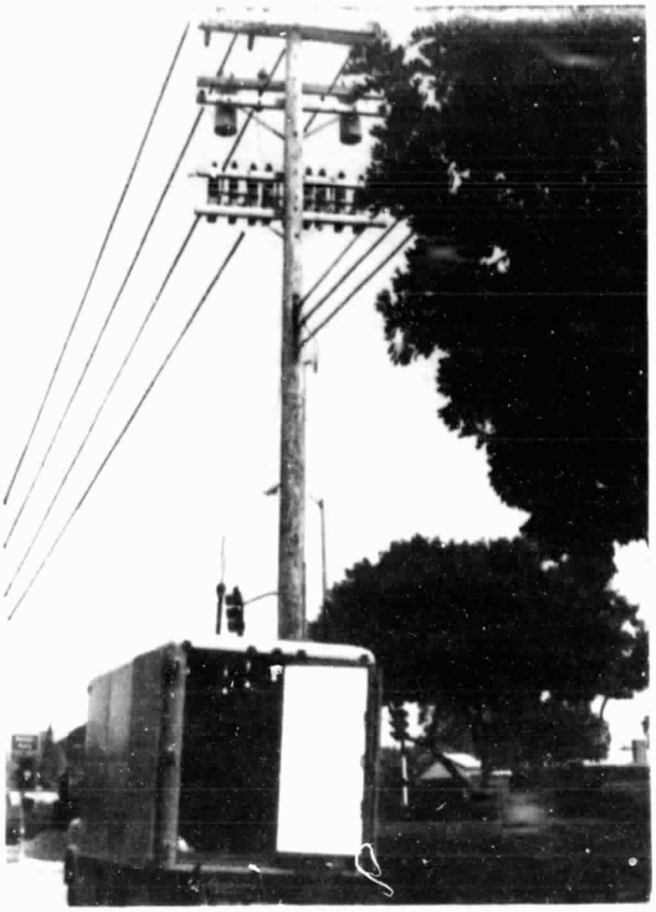


300 feet West of Lake Badin and away from Circuit 401 along Blue Lake.

Note: Powerlines showing are not Circuit 401.

28 dBuV
40 dBuA/m
91 dBuV/m

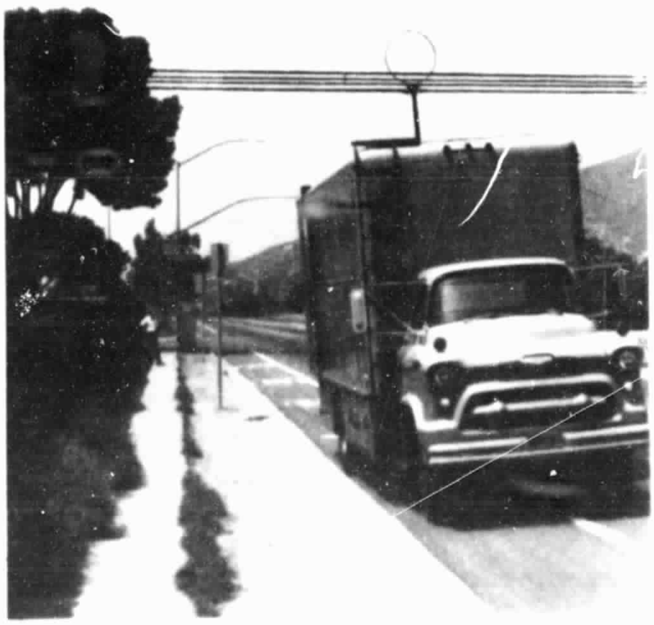
Data Record 13. Initial Measurements 300 Feet West of Lake Badin.



Near Intersection of Boulder Lake Blvd. and Navajo Blvd. and under Isolator/Capacitor. (Just south of Navajo Blvd.) A

38 dBuV
50 dBuA/m
101 dBuV/m

Data Record 14. Initial Meas.,rements at Boulder Lake and Navajo Blvd.



100 Feet East of Boulder Lake Blvd. Along Navajo Blvd. Antenna is Pointing Northwest or Southeast to Another Powerline. A

18 dBuV
30 dBuA/m
81 dBuV/m

Data Record 15. Initial Measurements 100 Feet West of Boulder Lake on Navajo.

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Freq. kHz	B.W. 10 Hz dBuV	B.W. 100 Hz dBuV	B.W. 1000 Hz dBuV	Antenna Factor dB	B.W. 10 Hz dBuV/m	B.W. 100 Hz dBuV/m	B.W. 1 kHz dBuV/m
.040	5	—	—	54 + 51	110	—	—
.060	53	54	62	50 + 51	154	155	163
.120	20	48	62	45 + 51	116	144	158
.180	45	47	60	41 + 51	137	138	152
.240	15	40	60	39 + 51	105	130	150
.300	30	40	60	37 + 51	127	128	188
.360	22	37	60	36 + 51	109	133	147
.420	40	40	60	34 + 51	126	125	185
.480	17	38	58	32 + 51	100	121	141
.540	38	38	57	31 + 51	120	120	139
.600	13	20	55	30 + 51	94	101	136
.780	32	33	54	28 + 51	111	112	133
.820	11	27	52	28 + 51	90	106	131
1	25	27	47	26 + 51	102	104	124
1.5	23	25	38	23 + 51	97	99	112
2	27	27	40	21 + 51	99	99	112
3	21	23	40	17 + 51	89	91	108
4	23	25	40	14 + 51	88	90	105
5	15	22	41	13 + 51	79	86	105
5.8	25	28	44	12 + 51	88	91	107
5.9	24	25	42	12 + 51	87	88	105
6	25	26	42	11 + 51	87	88	104
7	25	25	41	10 + 51	86	86	102
8	20	24	40	9 + 51	80	84	100
9	25	25	40	8 + 51	84	84	99
10	24	25	40	7 + 51	82	83	98
15	18	22	35	6 + 51	75	79	92
20	12	13	31	5 + 51	68	69	87
30	14	15	28	4 + 51	69	70	83
37	15	22	23	4 + 51	70	77	78
40	5	6	6	4 + 51	60	61	61
44	4	4	6	3 + 51	58	58	60
50	-15	-7	9	3 + 51	39	47	63

0830: Start Time
0845: Finished Survey

Data Record 16. Powerline Noise Survey with SCU Off at Boulder Lake and Navajo Location.

Data Record 17. Measurements Along Navajo Blvd. and West of Boulder Lake Blvd.

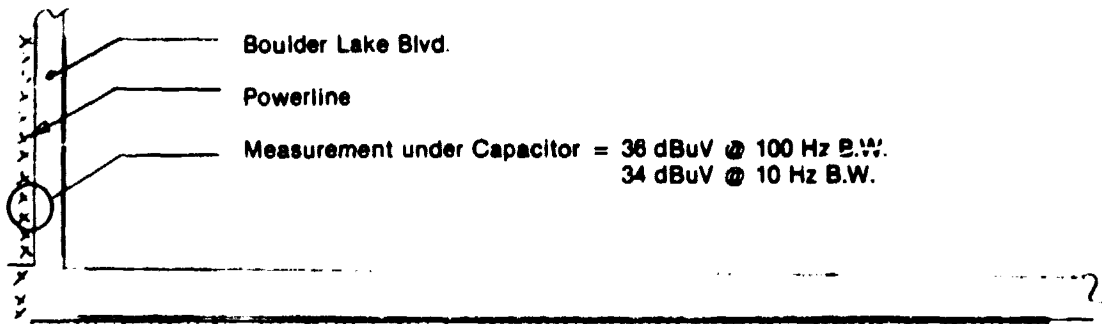
	Bandwidth		
Distance from Line	100 Hz dBuV	10 Hz dBuV	Antenna Orientation
24'	36	34	0°
100'	22	22	0°
200'	13	13	0°
300'	9	9	0°
400'	5	5	0°
500'	1	1	0°
600'	-2	-2	0°
700'	-3	-4	0°
800'	0	-9	45°
900'	0	0	45°
1000'	0	0	45°

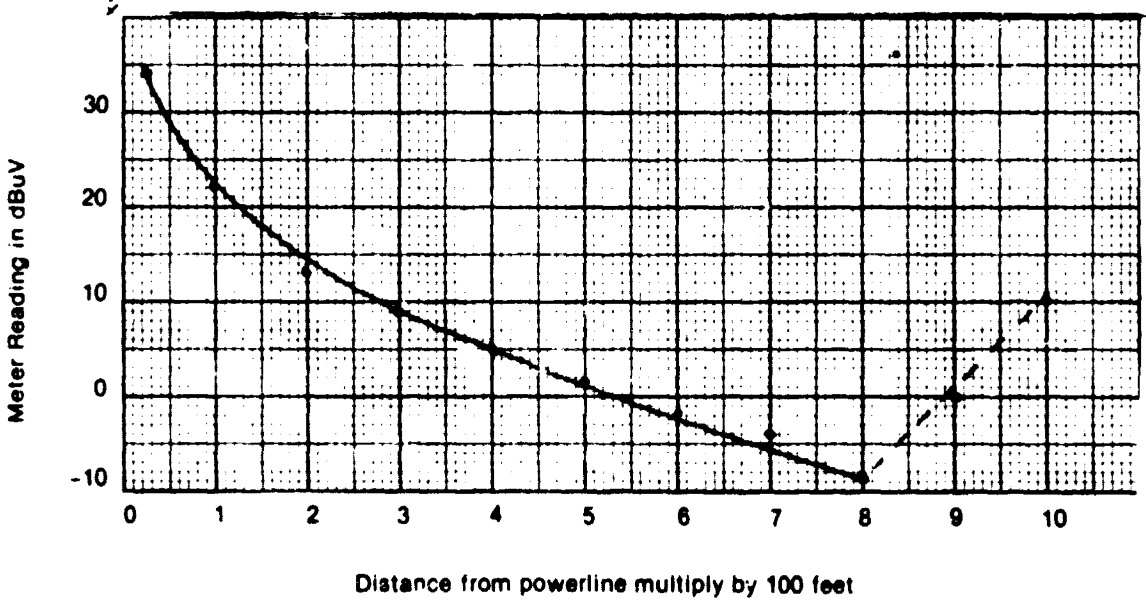
NOTE: For normalized Units antenna factors must be added Sample Calculation for 50' dBuA/m = 34 + 12 = 46

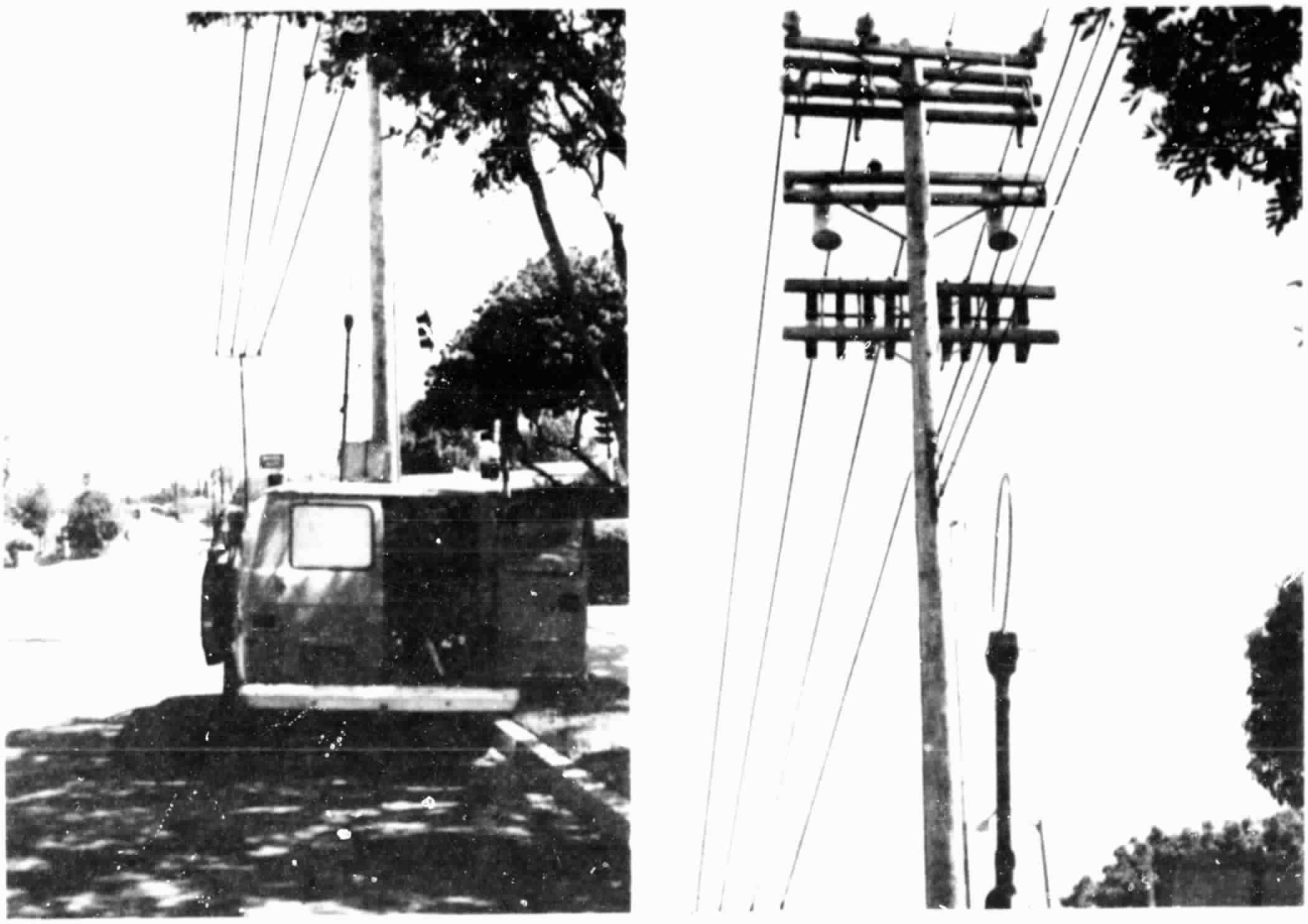
dBuV/m = 46 + 51 = 97

Loop Factor = 12 dB

A/m to V/m = 51 dB







Data Record 18. Measurements at Boulder Lake and Navajo Blvds. Location

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Data Record 19. Measurements Along Regner Road and Northwest of Jackie Drive.

Distance and Location	Bandwidth 100 Hz dBuV	10 Hz dBuV	Antenna Orientation (2)	NOTES
-Jackie Drive	6	3	90°	Under high and low voltage lines
100'NW	4	3	90°	Low voltage lines
200'NW	4	2	90°	Low voltage lines
-Gain				
300'NW	10	4	90°	Low voltage lines
400'NW	10	3	90°	Start of line
500'NW	8	4	90°	H V line
-Harwell				
600'NW	14	7	90°	
700'NW	16	9	90°	
800'NW	16	11	45°	
900'NW	16	15	45°	
-Ballinger				
1000'NW	20	19	0°	Middle of street, Two HV Lines
1020'NW	30	29	0°	Under HV line. 10'Off (1)
1100'NW	20	19	0°	
1200'NW	16	15	0°	
-Cowles Mtn.				
1300'	17	16	0°	
1400'	8	6	0°	
1500'	7	6	0°	
-Barker				
1520'	22	22	0°	Underground HV Vault
1590'	13	12	0°	Power is underground End of Regner Road

(1) Reading was 6 dB higher when antenna was 10 ft to NW of HV line

(2) 90° = Antenna is parallel to Regner Road
0° = Perpendicular to Regner Road

Data Record 20. Measurement Location Along Regner Road.

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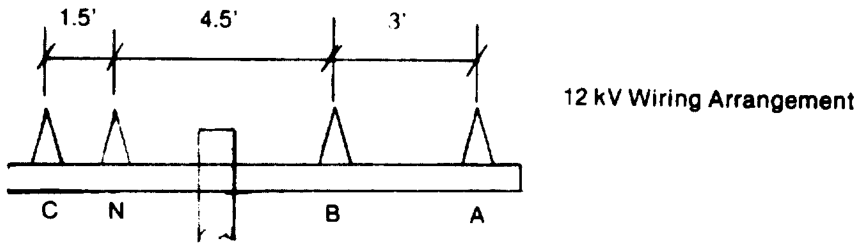
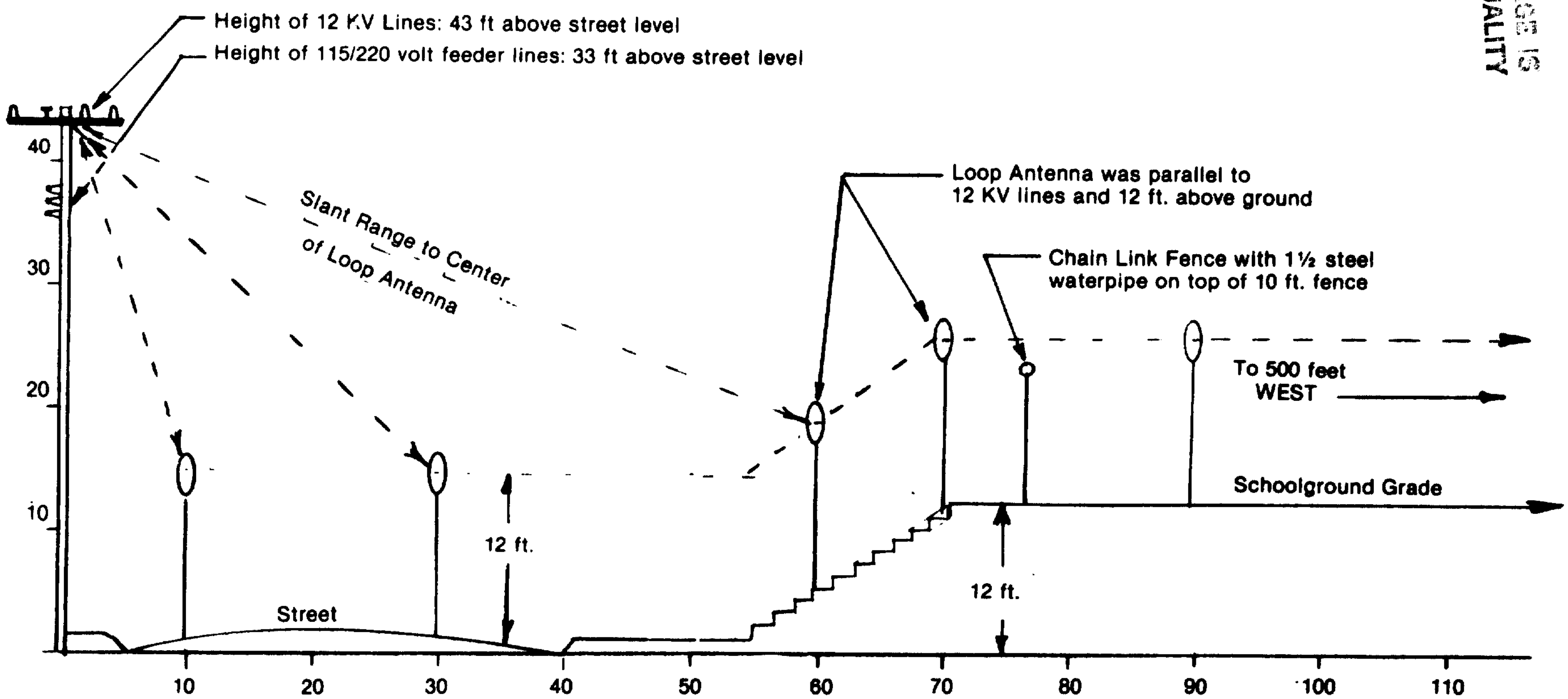
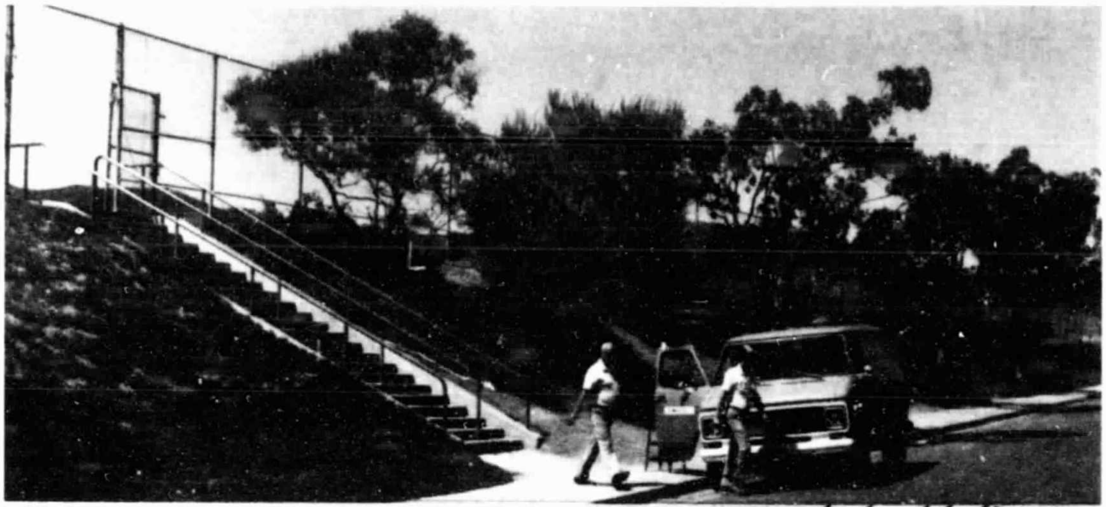
Data Record 21. Measurement Location Near Grossmont College and Griffin Street.

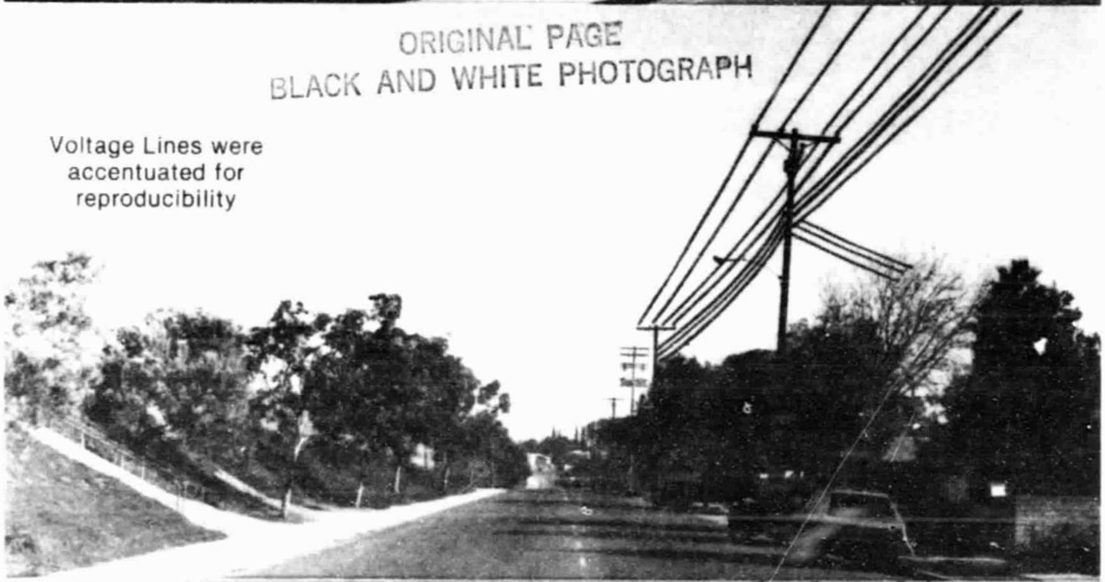
Data Record 22. Sketch of Crossection of Boulder Lake Blvd. (6500 Block) and Pershing Junior High School.

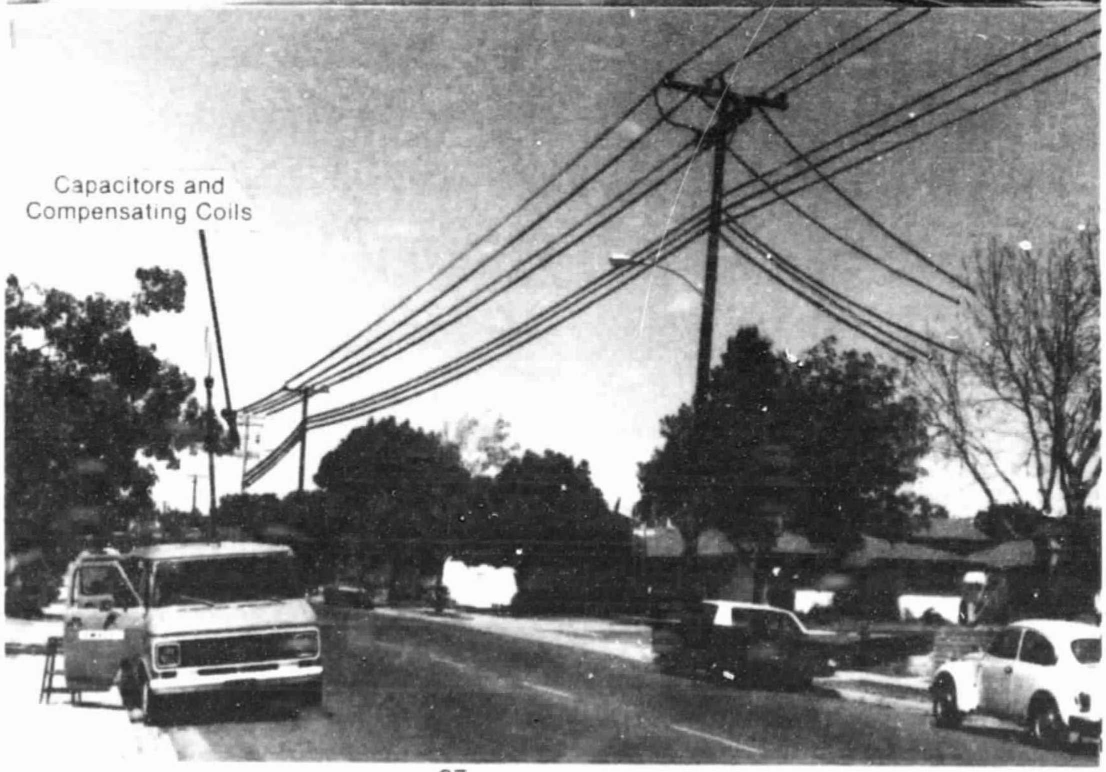


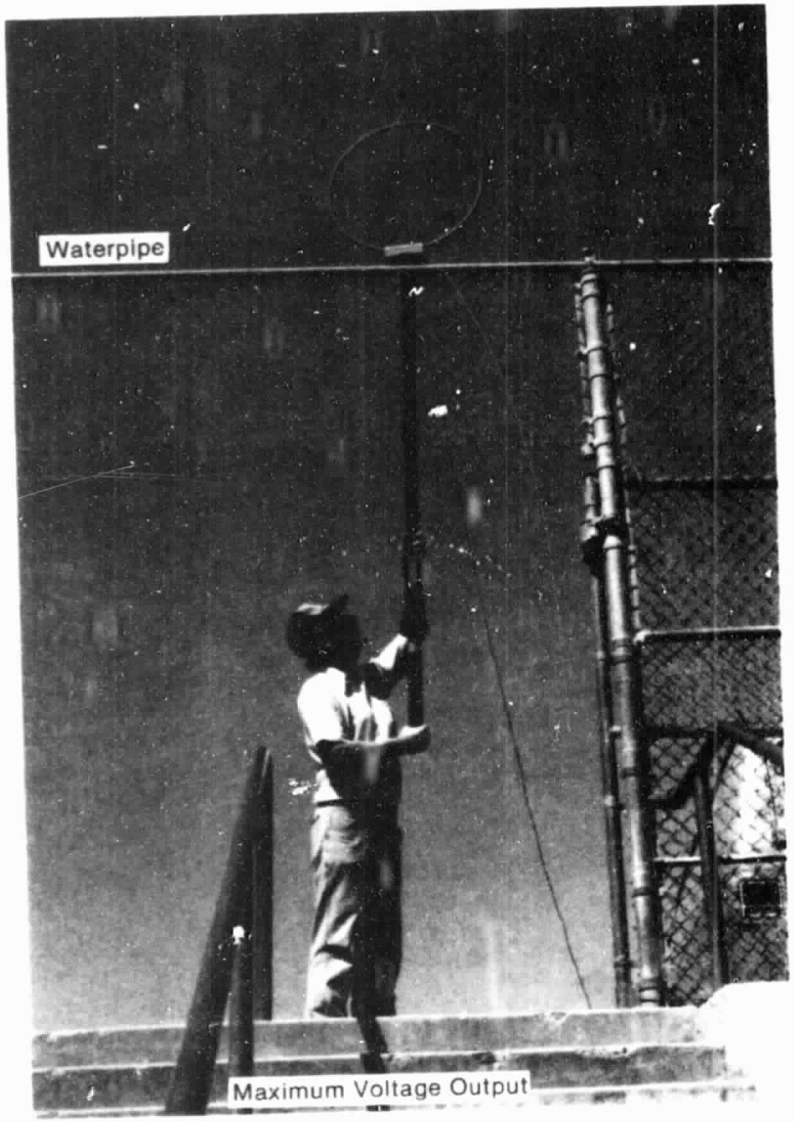


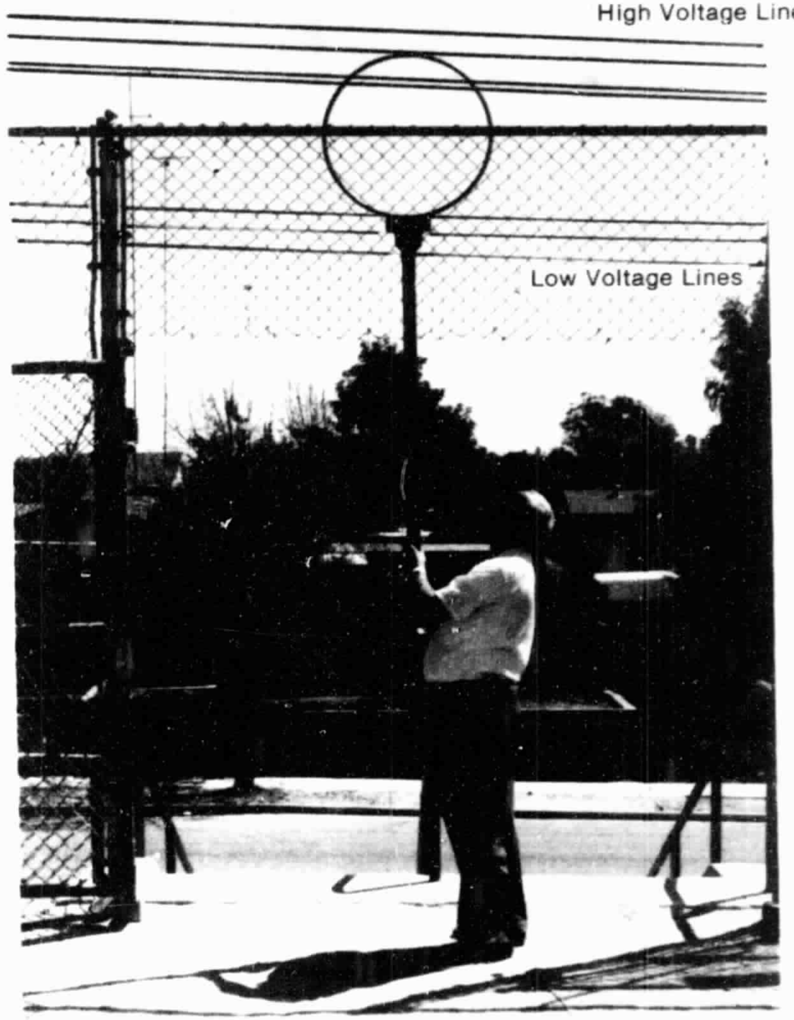
Data Record 23. Photographs of Pershing Junior High School Measurement Area.











Data Record 24. Photos of Loop Antenna Measurements Near Waterpipe on Top of Fence.

Data Record 25. Tabulation of Field Strength Versus Distance from Powerline.

	Distance, Feet		NM-7 Readings, dBuV			Antenna Factor		Field Strength		dBuV/m
1 Data Point	2 West	3 Slant	4 30A 5.79 kHz	5 3A 5.79 kHz	6 3A 45 kHz	7 dB/m 5.79 kHz	8 dB/m 45 kHz	9 30 A 5.79 kHz	10 3 A 5.79 kHz	11 3 A 45 kHz
1	0	31	35	13.5	18	63.5	54.5	98.5	77	72.5
2	10	33	34	13	17			97.5	76.5	71.5
3	20	37	33.5	12	15			97	75.5	69.5
4	30	43	30.5	9	12.5			94	72.5	67
5	40	51	28.5	6	10			92	69.5	64.5
6	50	59	25	3	7			88.5	66.5	61.5
7	60	65	22.5	- 1	4			86	62.5	58.5
8	70	73	20	- 3	3			84	60.5	57.5
9	80	82	36	13	5			99.5	75.5	59.5
10	90	92	20	- 1	1			83.5	62.5	55.5
11	100	102	18	- 3	- 1			81.5	60.5	53.5
12	110	112	17.5	- 4	- 2			81	59.5	52.5
13	120	122	17	- 5	- 2.5			80.5	58.5	52
14	130	131	16.5	- 6	- 3.5			80	57.5	51
15	140	141	15.5	- 7	- 4			79	56.5	50.5
16	150	151	14.5	- 8	- 5			78	55.5	49.5
17	160	161	14	- 8.5	- 6			77.5	55	48.5
18	170	171	13.5	- 9.5	- 7			77	54	47.5
19	180	181	12.5	-10	- 7.5			76	53.5	47
20	190	191	11.5	-10.5	- 8.5			75	53	46
21	200	201	11	-11.5	- 9.5			74.5	52	45
22	250	250	7.5	-15	-13.5			71	48.5	41
23	300	300	5	-18	-16			68.5	45.5	38.5
24	350	350	2.5	-20	-18.5			66	43.5	36
25	400	400	0	-23	-20.5			63.5	40.5	34
26	450	450	-1	-25	-23			62.5	38.5	31.5
27	500	500	-2	-26	-25			61.4	37.5	29.5

NOTE: See Data Record 25 A for Further Explanations of Columns.

Data Record 25A. Explanation of Column Entries for Data Record 25.

Column	Explanation of Entry
1	Row Number
2	Horizontal distance to West of powerline
3	Slant range from high voltage line to center of instrumentation loop antenna
4	NM-7 meter reading in dBuV with 30 A/5.79 kHz injected at Substation
5	NM-7 meter reading in dBuV with 3 A/5.79 kHz injected at Substation
6	NM-7 meter reading in dBuV with 3 A/45 kHz injected at Substation
7	Antenna correction factor includes 12 dB/A plus 20 log 377 = 51.5 dB for conversion to V/m at 5.79 kHz
8	Antenna correction factor for 45 kHz = 3 dB + 51.5 = 54.5
9	Sum of columns 4 + 7
10	Sum of columns 5 + 7
11	Sum of columns 6 + 8

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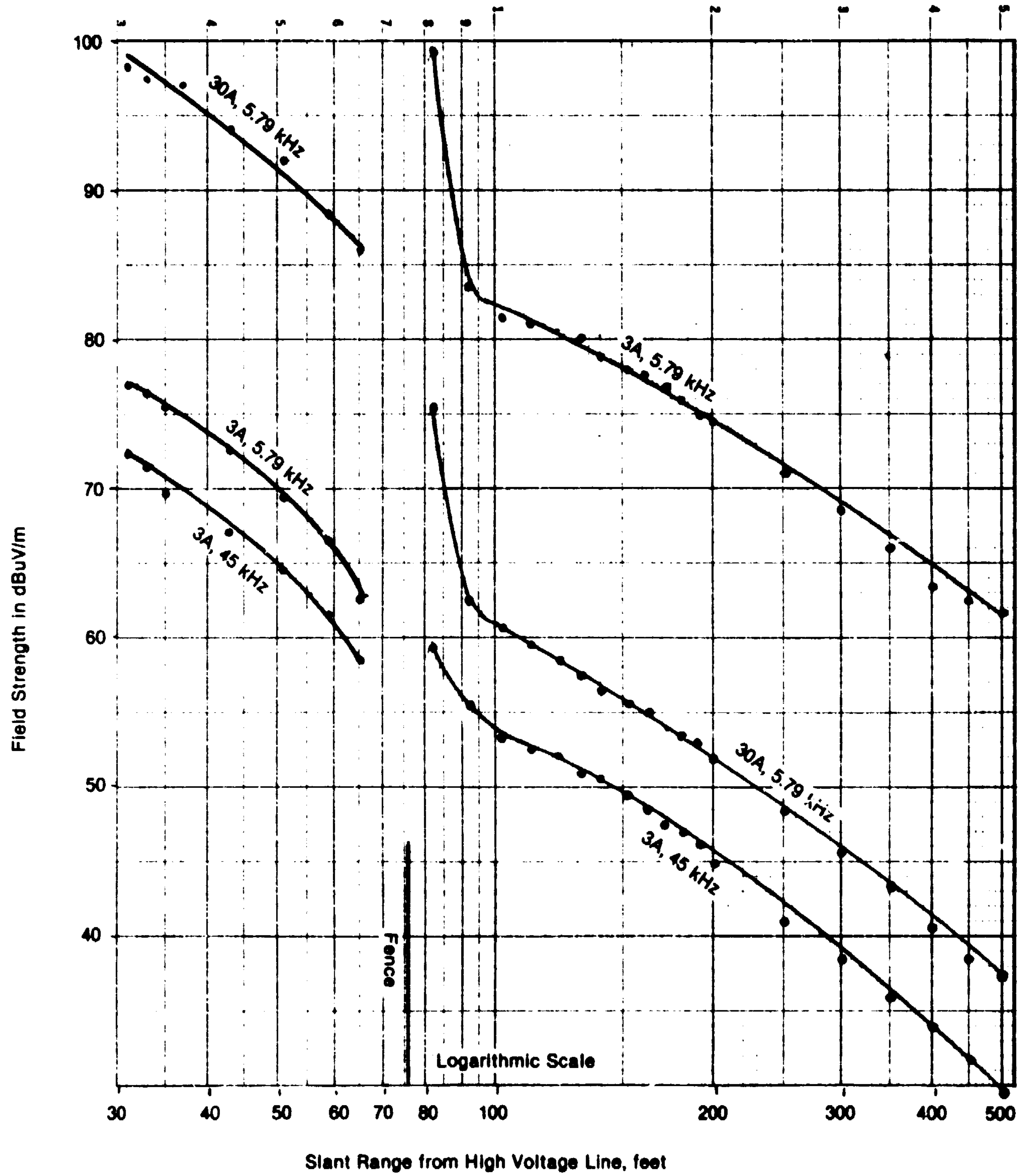
Data Record 26. Field Strength as a Function of Slant Distance from High Voltage Line.



Data Record 27. Field Strength as a Function of Distance from Waterpipe and Fence.