E-248

BURGLAR ALARM SYSTEM

POWERLINE TEST REPORT

CONTRACT NO. 44368-V

AUGUST 1976

Prepared for
THE AEROSPACE CORPORATION

SECURITY SYSTEMS DEPARTMENT

RECONNAISSANCE ELECTRONIC WARFARE
ELECTRO-OPTICS

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BURGLAR ALARM SYSTEM POWERLINE TEST REPORT

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Prepared for the Aerospace Corporation under Contract 44368-V

Report Number E-248

August 1976

This project was supported by Contract Number J-LEAA-025-73 awarded by the Law Enforcement Assistance Administration, U. S. Department of Justice, under the Omnibus Crime Control and Safe Streets Act of 1968, as amended. Points of view or opinions stated in this document are those of the author(s) and do not necessarily represent the official position or policies of the U. S. Department of Justice.

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ABSTRACT

This document is a report of the powerline testing conducted during the Burglar Alarm System (BAS) program funded by the Aerospace Corporation through a primary contract with the Law Enforcement Assistance Administration. The purpose of the powerline tests was to empirically augment a theoretical study on powerline usage for BAS previously conducted during Phase I of this program. The testing was designed to obtain necessary data in a real environment before a final selection of a powerline communications technique was made. A powerline communications technique was subsequently chosen and specified.

CHAPTER I. INTRODUCTION

This document is a report of the powerline testing done during the Burglar Alarm System (BAS), Contract Number 44368-V with the Aerospace Corporation, under prime contract to the Law Enforcement Assistance Administration. Powerline testing was done to provide empirical support of a previously conducted study to determine the best powerline communication technique to be applied to BAS. A variety of tests were conducted, and the data analyzed, and specifications for the communications link were determined.

Chapter II is an executive summary of the powerline test effort. The test objectives are defined in Chapter III, while Chapter IV discusses the methodology for implementing the tests. The test conduct itself is discussed in Chapter V and Chapters VI and VII discuss the test results and the application of those results to the BAS communications design, respectively.

CHAPTER II. EXECUTIVE SUMMARY

The overall requirements for the BAS data transmission system had previously been derived during Phase I of the BAS program. It was highly desirable however, to augment the study with empirically derived data pertaining to spectral noise distribution, bit errors versus bit rates, phase stability, and the evaluation of different detection schemes. A methodology was formulated by which this data could be determined. It was required that a special BAS test set be fabricated to be used during the conduct of the tests. The test set consisted of a digital FSK transmitter and receiver with parameters which could be varied. The variable parameters included frequency, power output of the transmitter, transmission bit rate, and two different bit detection schemes, namely a sample and hold, and integrate and dump. In addition, the test set allowed the direct measurement of bit errors by comparing the transmitted bits with the received bits. In addition, the receiver was capable of obtaining its clocking information either directly from the powerline frequency or by generating a clock from the transmitted bit stream itself. The test set was subsequently used both in the laboratory tests and the field tests.

Prior to conducting tests in the field, laboratory tests were conducted to determine worst case noise levels on powerlines and conduct bit error tests under controlled noise conditions with the two different types of detection schemes. The amplitude of the noise spectrum was observed in a variety of buildings and under a variety of conditions at GTE Sylvania in Mountain View, California. Because of the industrial environment, it was considered that these noise tests represented more of a worst case condition than would be experienced in a residential area. After the completion of the noise tests bit error tests were conducted under controlled conditions with filtered powerlines in a shield room with a variety of noise producing devices and varying bit transmission rates. In addition, two different types of detection schemes were employed to determine their relative merits. As a result of these tests, it was determined that a bit transmission rate of 60 bps should be used with an integrate and dump detection scheme for either a FSK or PSK modulation technique. The remaining tests were conducted in the field.

A total of four field sites were selected, comprised of two single family residences and two apartments. In each of these locations the electrical distribution system was mapped out as a first step. This included determining the number of circuits, the location of each outlet on each particular circuit, and their relative phases. The initial tests were conducted to determine bit error rate and phase stability. Because of the relatively high dynamic range of the BAS communications system, powerline attenuations great enough to force a measurable bit error rate could not be achieved. Tests were conducted over a six day period at a single location without observing a single bit error. A Hewlett-Packard Model 3575A gain phase meter was used to determine the phase stability of the powerlines. It was found that the phase was highly unstable as a function of various loads being switched on and off the powerlines. This subsequently ruled out the use of PSK as a viable BAS modulation technique. Tests were then conducted at each of the locations to determine powerline attenuation characteristics from phase to phase within phase and at large variety of different points within the power distribution system. The maximum path loss observed in testing the four different locations yielded a figure of 36.5 dB cross phase with no coupling between phases. An overall average in the apartment locations, including like phases and unlike phases, was 14.5 dB while the same figure for single family dwellings was 25.6 dB. Overall averages for all measurements taken was approximately 20 dB.

As a result of the powerline tests and the previous analysis, it was determined that a digital FSK split-phase code should be employed for BAS powerline communications. A frequency of 170 kHz was selected with the transmitter power output of 50 mw into a 20 Ω load. It was determined that the best bit detection scheme would be an integrate and dump technique with a bit transmission rate of 60 bps. Details of the powerline tests and their results are given in the following chapters.

CHAPTER III. TEST OBJECTIVES

The overall requirements for the BAS data transmission system had been derived in a study previously performed during Phase I of the BAS program. A summary of these requirements is given below.

a. 30 binary bits of data per transmission
b. Single frequency operation is very desirable
c. 60 dB path loss maximum is sufficient
d. Minimize false alarm probability
e. Maximize probability of detection
f. Minimum cost in high volume production.

In order to implement these requirements a preliminary data transmission system was designed based on the results of research GTE Sylvania conducted in 1973 on the characteristics of data transmission on powerlines.[1] The results of the preliminary design were:

a. Impulse noise on lines is the worst problem
b. *Transmitter power levels of 10 to 100 mw would be sufficient
c. *Frequency range of 100 to 500 kHz (160 to 190 kHz would be best)
d. *Angle modulation should be used, either FSK or PSK.
e. Binary modulation format should be used
f. *30 or 60 bps data rate
g. Split phase encoding for ease of bit synchronization
h. *Integrate and dump detection should be used
i. PLL demodulation would be easiest to implement
j. Message duration qualification should be used
k. Frequency stabilities of ± 2% are feasible
ℓ. Frequency deviations of ± 5% to be compatible with realizable stabilities and filter bandwidths.

---

*Indicates items where the final determination must be made by field test results.

[1] Powerline Alarm Transmission System Phase I Report, GTE Sylvania, August 1973; D.L. Hardison, K.M. Duvall.

The objectives of the test program are to gather sufficient data to allow a decision to be made on each of the five areas in question. Items b and c require a quantitive power level and specific frequency while items d, f, and h require only a binary decision as to the optimum solution.

In order to make these determinations the following tests were conducted. They are listed in their order of importance.

a. Noise distribution in amplitude, time and frequency
b. Bit error versus bit rate
c. Evaluate detection schemes; integrate and dump versus sample
d. Phase stability of paths
e. Coupling attenuation, phase to phase
f. House to house attenuation (apartment to apartment)
g. Line attenuation
h. Line impedance.

The testing methodology employed for obtaining the above information is given in Chapter IV.

CHAPTER IV. TEST METHODOLOGY

4.1 TEST PLAN

The following represents the test plan generated for use during the BAS powerline testing. It should be noted that there are tests conducted in the laboratory and the field. The tests will be discussed in this same sequence in Chapter V of this report.

BAS TEST PLAN FOR POWERLINE CIRCUITS

Major tests to be conducted (in order of importance)

a. Noise distribution in amplitude, time and frequency
b. Bit error versus bit rate
c. Evaluate detection schemes; integrate and dump versus sample
d. Phase stability of paths
e. Coupling attenuation, phase to phase
f. House to house attenuation (apartment to apartment)
g. Line attenuation (verify)

Test Equipment Required:

1 each HP 7004 X-Y Recorder
1 each HP 3575A gain Phase Meter
1 each HP 208A Oscillator
1 each General Purpose Scope
1 each HP 427A Voltmeter
1 each HP 456A Current Probe
1 each HP 467A Power Amplifier
1 each Sylvania BAS Test Set
1 each Sylvania 170 kHz Bandpass Filter
1 each Sylvania Power Unit Coupler
1 each Screen Room with good powerline filters
Assorted noise sources for powerline
- Drill motor
- SCR power supply
- SCR light dimmer
- Any other bad noise generators available

4.1 (Continued)

2 each Sylvania Powerline Couplers - GFE

1 each Test Set - Sylvania CDE-1

1 each Filter Set, BW= 3 kHz, double pole, f_o = 170, 320, 450 kHz

Assorted samples of various wiring (romex, conduit, etc.)

Tests

a. Outside screen room in laboratory environment
Look at narrowband amplitude noise on powerlines through the narrowband 170 kHz filter. This is also checked in building 5 near the computer. Of particular interest is amplitude distribution and duration.

b. Inside screen or shield room with good powerline filtering
(1) Evaluate amplitude noise on lines with same filter used above. Ambient levels should be substantially less than indicated above.
(2) Attempt to simulate the noise environments of paragraph a with available noise generators such as drill motors, heaters, SCR supplies and speed controllers, etc. Record and compare with paragraph a.
(3) Compare bit sync schemes by measuring bit erros as a function of transmitter power on the line for hardwired clock versus recovery from data stream.
(4) Evaluate bit detection schemes, integrate and dump versus sample, at the best rate found in paragraph 5 below. Use several low TX power levels.
(5) Run bit error versus bit rate measurements as a function of all noise sources, and power level on the line (pad the TX output).
(6) Measure the phase variations on the line as a function of switching loads, and the noise sources used above.

c. Lab testing in Sylvania complex (outside screen room)
(1) Set up test power lines and verify attenuation and impedance comparable with previous measurements.
(2) Set up circuits in laboratory on existing internal wiring and perform attenuation and impedance measurements. Perform bit error versus TX power at best rate found in paragraph a.
(3) Locate 2 circuits which are on opposite phases of transformer. Measure attenuation phase to phase with and without coupling capacitor across phases.

4.1 (Continued)

d. Field Testing

(1) Line attenuation on circuits, with and without phase to phase coupling. Use as many load variations as possible to find worst case.

(2) House to house attenuation when both on same secondary of power transformer.

(3) Bit error measurements as a function of TX power and worst load variation on the lines.

(4) Line impedance for worst case loads available.

e. Repeat paragraph d at various sites.

4.2 SITE SELECTION

In order to augment data taken in the laboratory it was necessary to take data in the field under real operating conditions. It has empirically been determined that measurements made in the laboratory at GTE Sylvania are far more representative of a worst case condition. This is because of the severe loads being switched on and off of the powerline as well as a very large variety of test equipment and emitters which are present. This is valuable since it does represent the extreme environment which one may encounter when attempting to communicate on the powerlines.

It was desired that the selected field sites be representative of typical apartments and single family dwellings. In reviewing budget allocations it was determined that a total of two apartments and two residences could be tested. A great deal of test equipment had to be set up at each field location and the complete power distribution system for each location had to be mapped. Site coordination had to be such that either vacant residences had to be found or the cooperation of the resident had to be solicited. Three of the test units consisted of residences of GTE Sylvania employees and the fourth was a vacant apartment owned by an employee. The characteristics of the selected sites are given in Table 4-1. More detailed information for each of these sites is given in the sections describing the test conduct at each of these locations.

Table 4-1. Characteristics of the Four Selected Field Test Sites

	Apartment 1 Tri-Terrace	Apartment 2 Cherry Wood	House 1 Cupertino	House 2 San Jose
Construction	Frame/Stucco	Frame/Stucco	Frame/Stucco	Frame/Stucco
Type	2 Bedroom 1 Bath	1 Bedroom 1 Bath	3 Bedroom 2 Baths	3 Bedroom 2 Baths
Age	15 years	2 years	12 years	10 years
Approximate square feet	912	600	1650	1400
Meter to apartment service type	2 wire conduit	3 wire conduit	N/A	N/A
Wiring scheme	Centralized	Centralized	Centralized	Centralized
Inter unit wiring	2 conduit Romex	3 conduit Romex	2 conduit Romex	3 conduit Romex

4.3 SPECIAL TEST EQUIPMENT PREPARATION

Prior to the beginning of any test activity an analysis was conducted to determine the most probable specifications for a BAS powerline data link. The output of this analysis was summarized in Section 3 of this report. There were a number of parameters that required emperical verification through tests conducted in the laboratory and in the field. Because of the nature of these tests it became mandatory that special test equipment must be designed and fabricated which would provide flexibility in changing and measuring various parameters. These parameters included the following:

a. Allow direct measurement of bit error rate.

b. Have the capability for changing bit transmission from 30 to 60 to 120 bits per second and possess the capability for the detection of same.

c. Have the capability for changing carrier frequency.

d. Have the capability for changing the detection technique from sample and hold to integrate and dump and visa versa.

e. Have the capability for recovering bit synchronization from the transmitted signal or from the powerline frequency.

4.3 (Continued)

Equipment was subsequently designed and fabricated which met the above conditions. A block diagram of the BAS Test Set is given in Figure 4-1. Test words are generated in the block at the top of the diagram and subsequently are converted from a Non-Return to Zero (NRZ) format to a biphase level format and are then used to modulate the RF transmitter. The output of the transmitter is passed through an attenuator and powerline coupler. The attenuator is used to determine dynamic range limitations to achieve various bit error rates. This signal is then transmitted over the test path (powerline) to a receiver which has a line coupler front end built into it. The pre-selected signal is amplified and sent to the bit detector which can sample and hold or integrate and dump detect. Furthermore the detector can obtain its bit synchronization clock from either the powerline frequency or the clock recovery circuitry which uses the bit stream itself for regeneration of clock data. The detected bit stream is in an NRZ format and can subsequently be directly compared with the transmitted signal in the word generator and bit comparator. The output of the bit comparator can be used to drive an electronic or electromechanical counter. Provisions were also made in the system to allow the variation of bit transmission rates and transmission frequency. This test equipment was used both in the laboratory tests and the field tests. Schematics of each of these blocks can be found in Appendix A of this report.

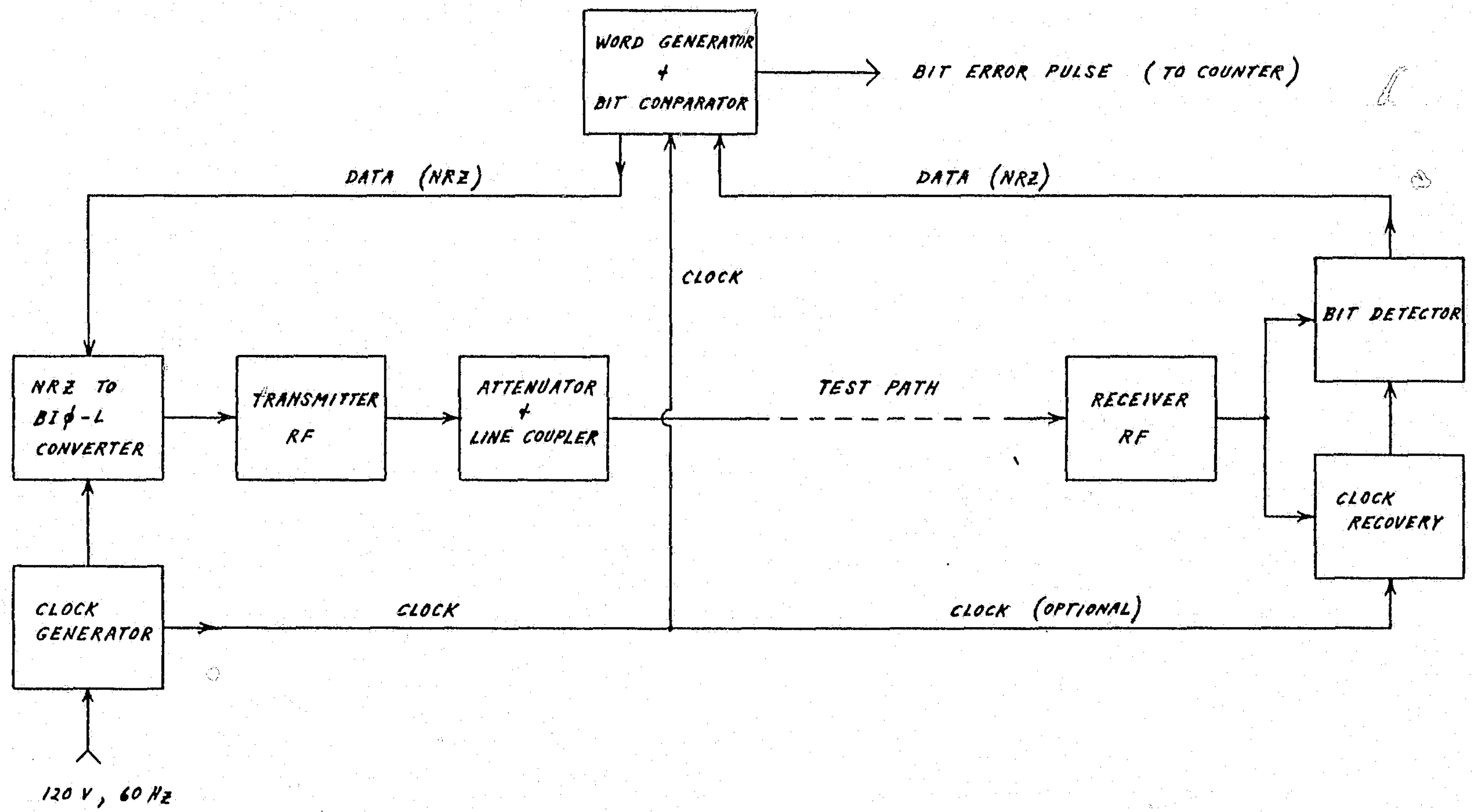


Figure 4-1. Block Diagram of BAS Test Set

CHAPTER V. TEST CONDUCT

5.1 GENERAL

Many tests were conducted during the Powerline Test Phase of the BAS program. The tests fell into two broad categories - laboratory tests and residential field tests. The purpose of the laboratory tests were to: (1) checkout the test equipment, (2) determine worst case noise levels on powerlines and (3) conduct bit error tests under "controlled" noise conditions with two types of detection schemes, two types of synchronization schemes and variable bit transmission rates. These preliminary tests, because of their nature, were all conducted in the laboratory. As a result of the preliminary tests it was possible to choose an optimum bit detection scheme. The prime remaining question to be answered by the residential field tests was the dynamic range required in the powerline link for very reliable performance.

Both sets of these tests and their results are discussed in the following sections.

5.2 LABORATORY TESTS

5.2.1 Ambient Line Noise Measurements

These measurements were accomplished by outfitting a mobile cart with the test equipment as shown in Figure 5-1. The equipment consisted of a Tektronix model 549 oscilloscope with 1A7A high gain plug-in, a Polaroid camera, and the 170 kHz bandpass filter test aid which was built for these measurements. The frequency response characteristics of this filter is given in Figure 5-2. It will be noted that frequency response characteristics of two other filters are given in the figure. One is centered around 320 kHz and the other around 450 kHz. These filter characteristics correspond to the design parameters given as the last schematic in Appendix A. The 320 kHz and 450 kHz filter design were never used. The purpose of the test was to record the normal and worst case noise signatures which are found at this GTE Sylvania complex. Particular attention was given to testing at locations which had been known previously to have had electrical service with high ambient noise levels.

The first recordings were made in the engineering laboratory area and are indicated by the group of photos in Figure 5-3. The next recordings were made throughout

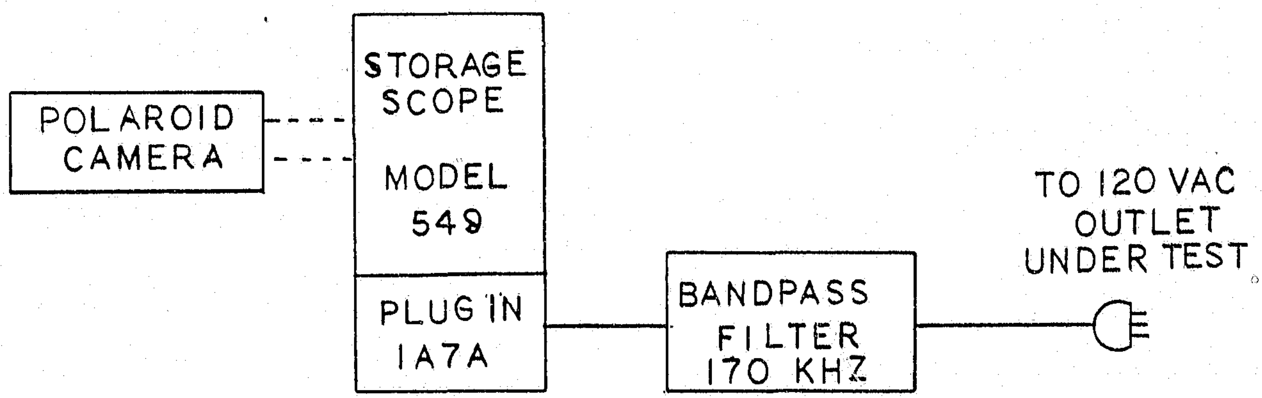


Figure 5-1. Test Setup for Mobile Line Noise Recording

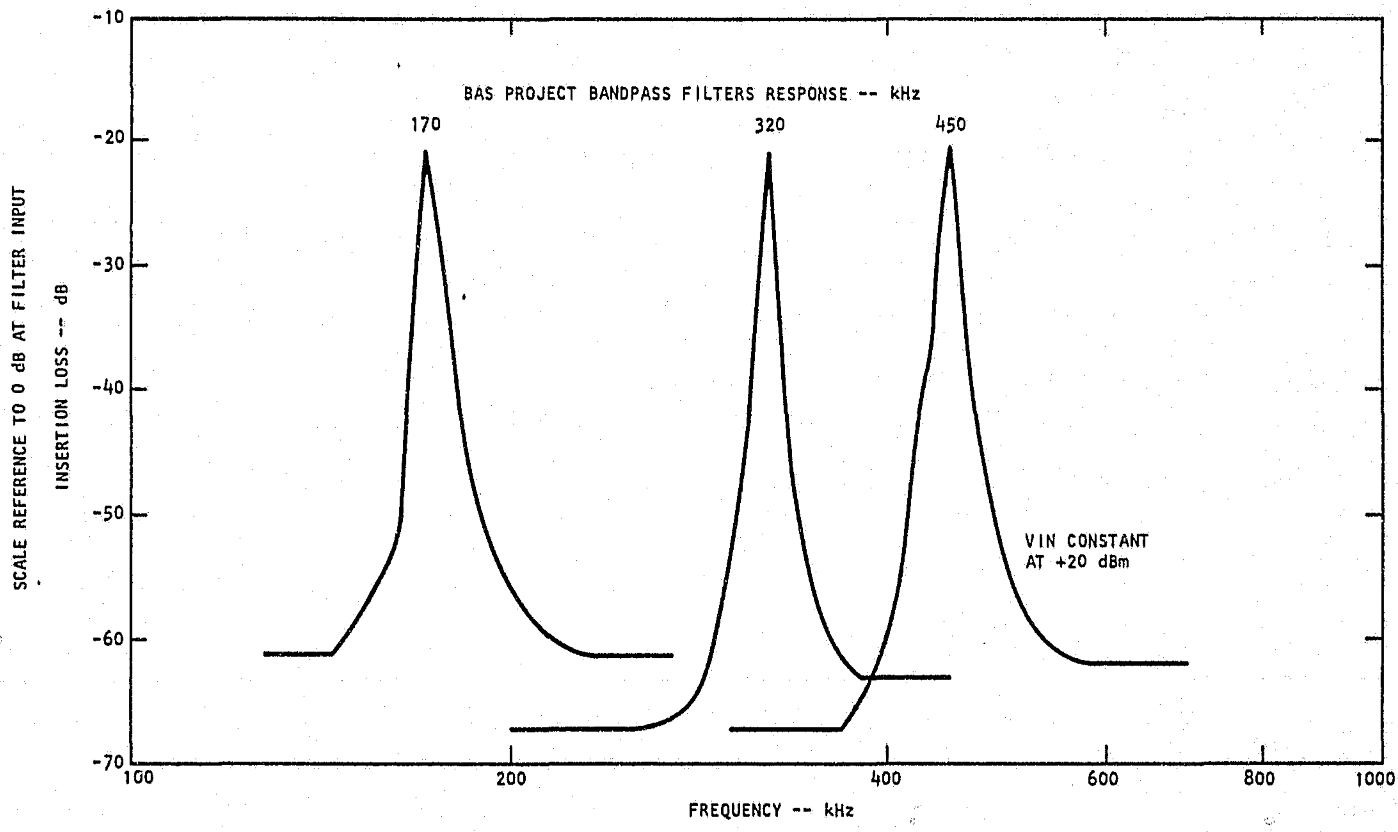


Figure 5-2. Frequency Response Characteristics of 170 kHz, 320 kHz, and 450 kHz Bandpass Filters

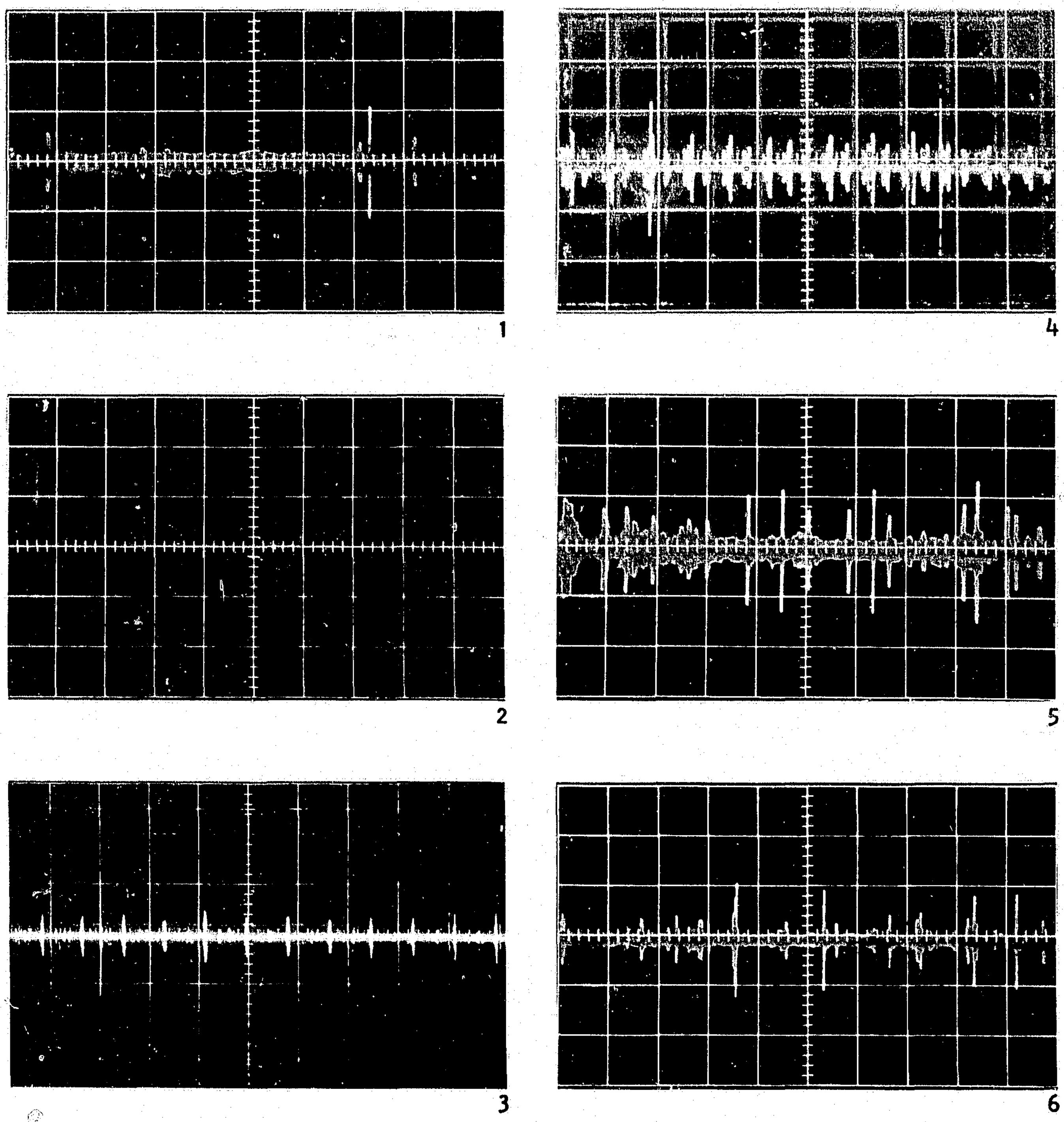
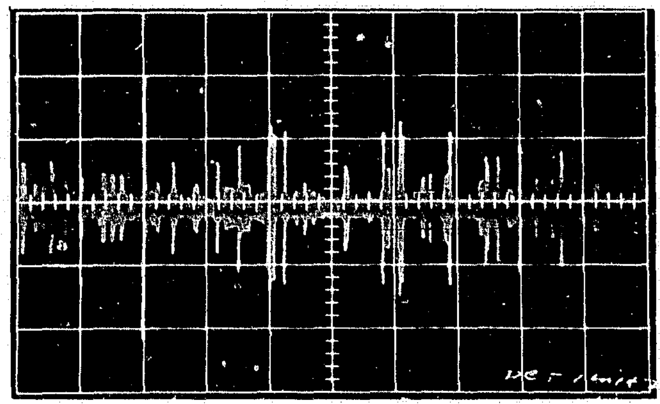


Figure 5-3. Line Noise Measurements in Building 4 Laboratory



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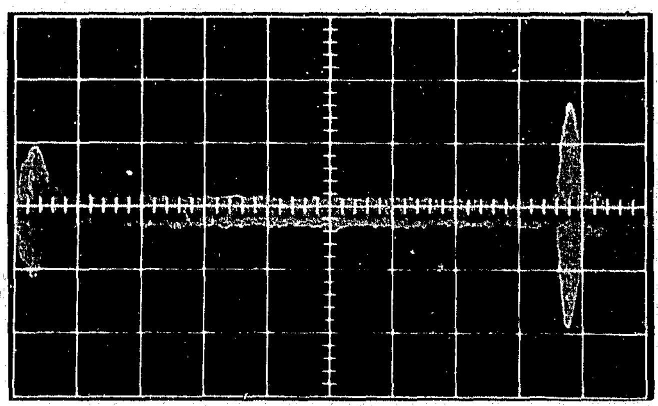

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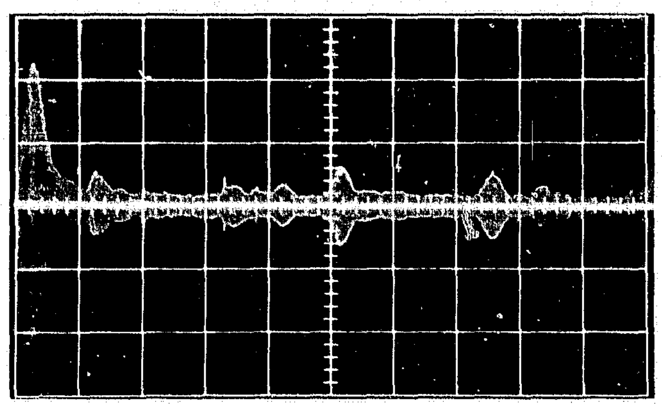


9

Figure 5-3 (Continued)

5.2.1 (Continued)

the other buildings and these results can be seen in the photos in Figure 5-4. The third group of photos in Figure 5-5 were taken in the Security Systems Laboratory screen room and represent the ambient line noise level found there. The final photos in Figure 5-6 consists mainly of the signatures of devices that might be found in a home or small business and could be considered a threat to BAS system performance. The averaged and summarized data from this series of photographs appear in Tables 5-1, 5-2, 5-3, and 5-4, respectively.

5.2.2 Shield Room Measurements of Bit Error Rate

5.2.2.1 General

Previous studies conducted during Phase I of the BAS effort identified the need for transmitting digital data and furthermore to use either FSK (frequency shift keying) or PSK (phase shift keying) as a modulation technique. Amplitude shift keying (ASK) was ruled out because of its suceptibility to impulsive noise commonly found on powerlines. PSK was subsequently ruled out because of the lack of phase coherence on a powerline distribution system. The power system is continuously subject to the switching on and off of a variety of reactive loads. Because of this the phase characteristics of the powerlines are not predictable and are extremely time varient.

During the empirical testing it was desired to determine FSK transmission bit errors as a function of dynamic range, different detection techniques and bit synchronization techniques and bit transmission rate. Two detection techniques were identified as possible candidates for BAS application: integrate and dump, and sample and hold. In the first technique the entire bit period is integrated and only at the end of the period is a binary decision made. The energy is then dumped and the next bit period is integrated. In the second technique the bit period is sampled during a small increment of time in order to make the binary decision. The first technique appears to have the advantage of being able to integrate through 60 Hz transient noise (such as that caused by SCR controlers, etc.). If a sampling technique was used and synchronization occurred between the sample time and the transient noise time all information could theoretically be lost.

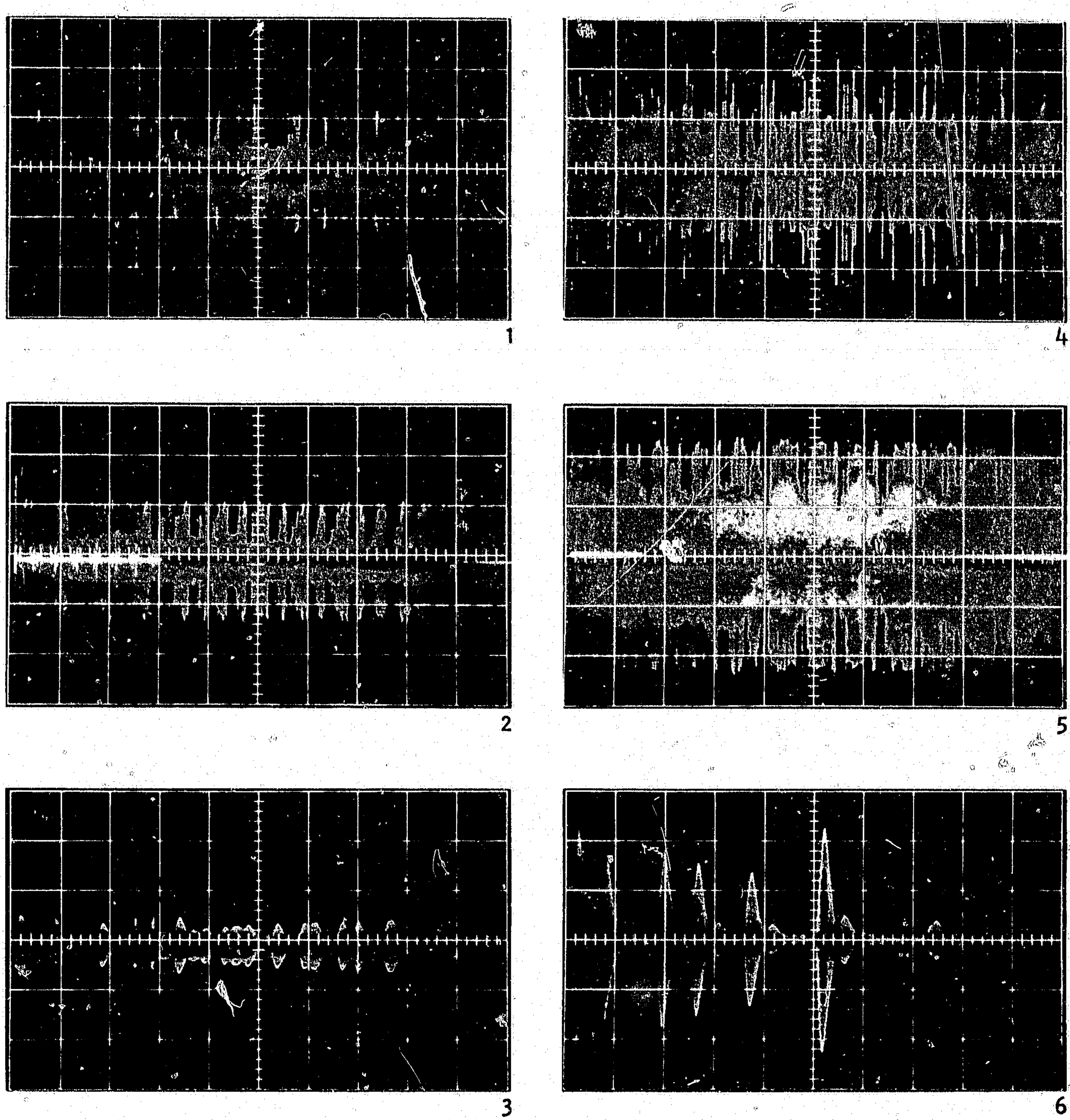


Figure 5-4. Line Noise Measurements of Buildings 3 and 5

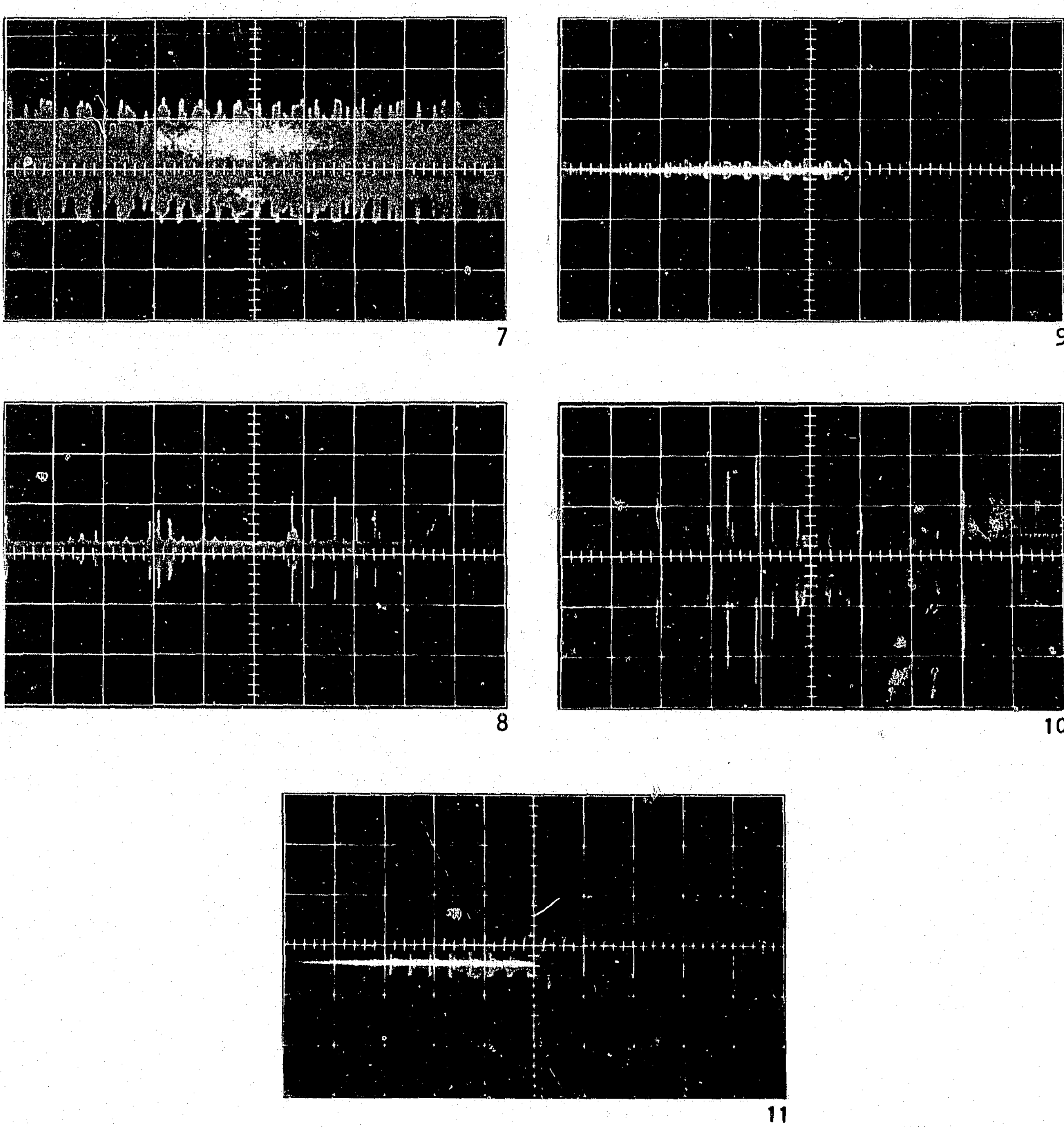


Figure 5-4 (Continued)

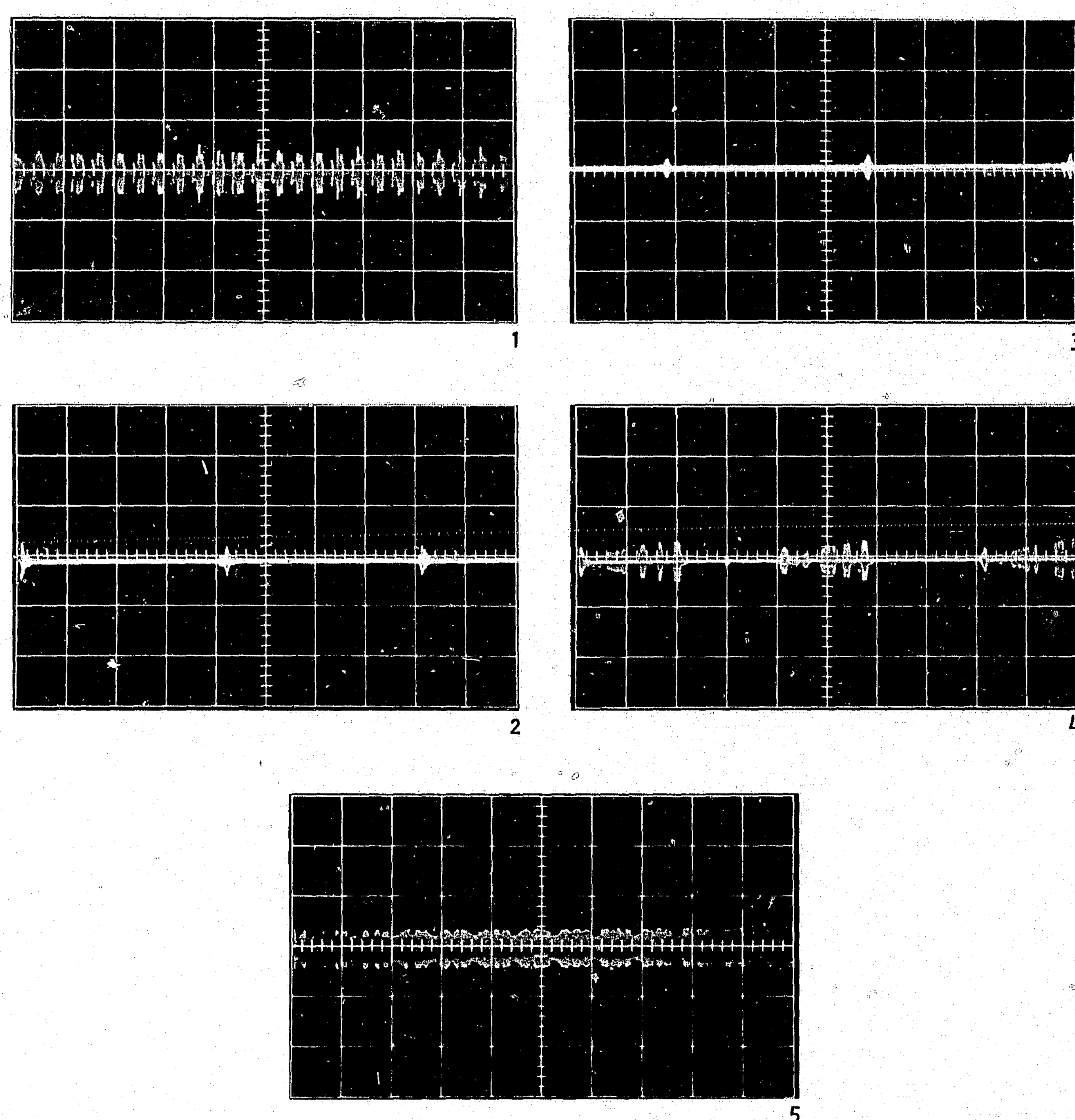


Figure 5-5. Line Noise Measurements in Shield and Screen Rooms, Building 4

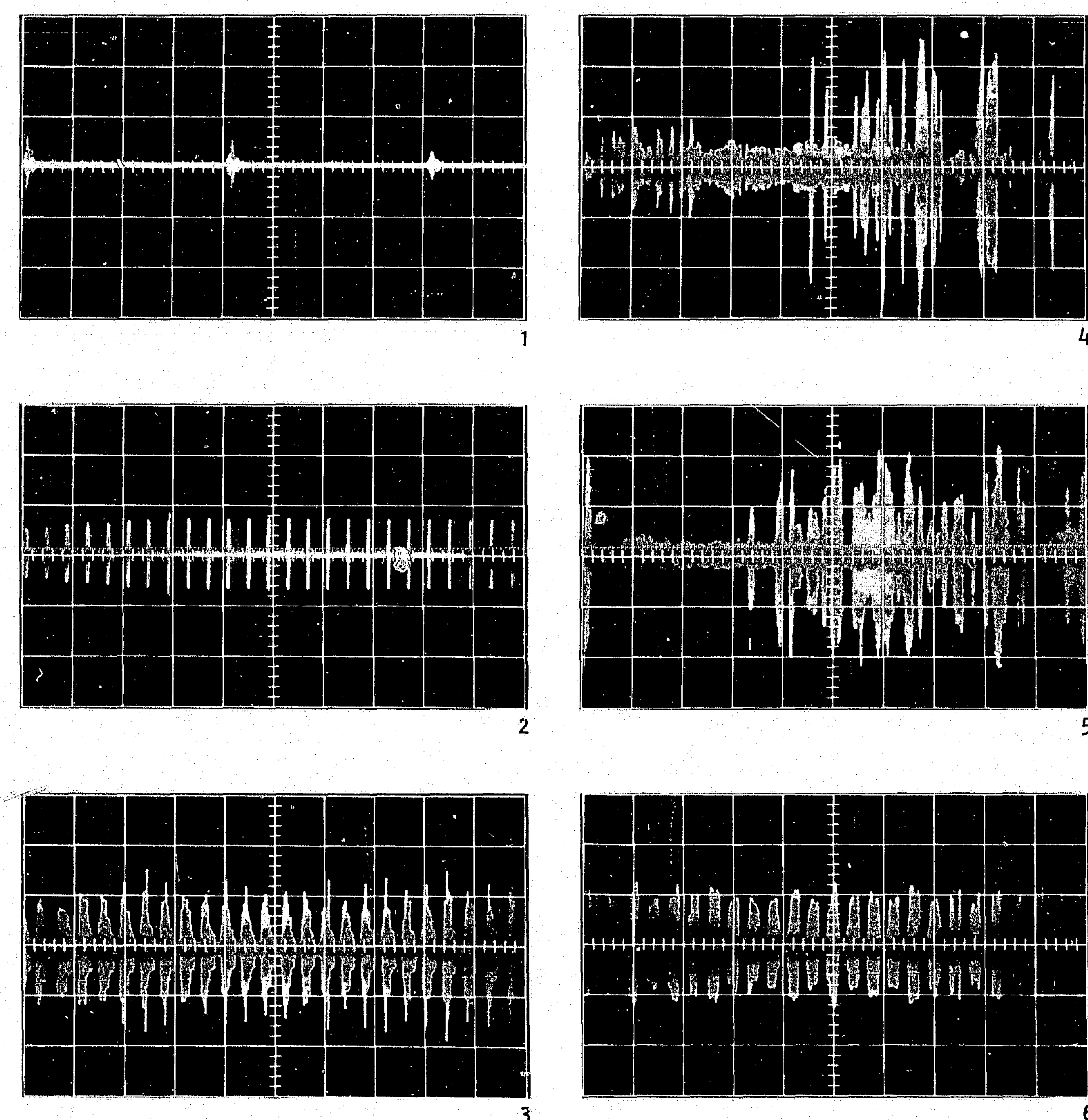


Figure 5-6. Line Noise Measurements with Known Noise Sources

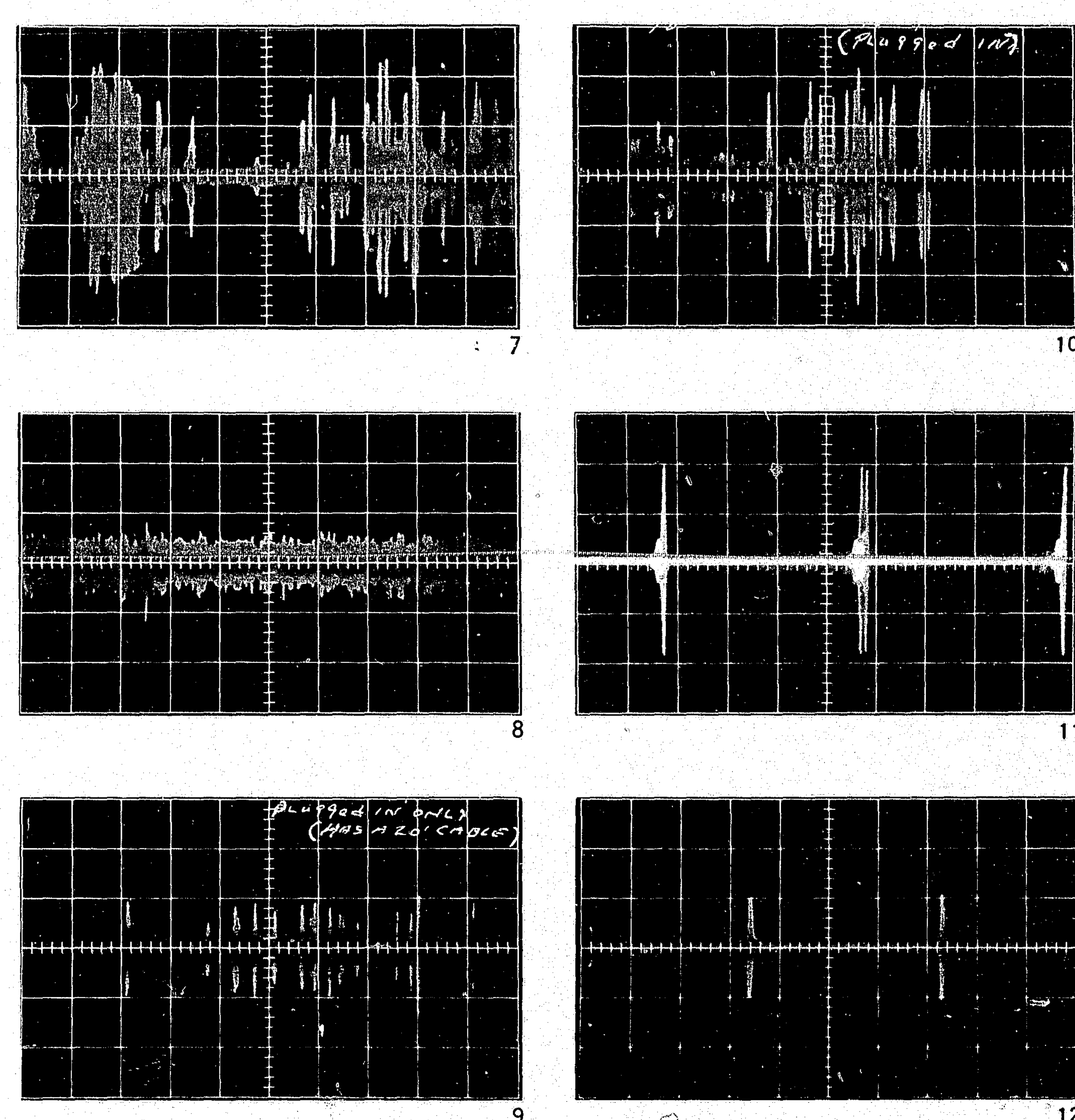


Figure 5-6 (Continued)

Table 5-1. Tabulated Noise Results of Building 4 Laboratory

PHOTO IDENTIFICATION NUMBER	1	2	3	4	5	6	7	8	9
DATE	8-4-75	8-4-75	8-4-75	---	8-4-75	8-4-75	8-4-75	8-4-75	8-5-75
TIME	---	---	---	---	1525 HRS	1535 HRS	1540 HRS	1545 HRS	0830 HRS
VERTICAL SENSITIVITY/CM	5 MV	1 MV	0.5 MV	1 MV	5 MV	5 MV	5 MV	5 MV	5 MV
HORIZONTAL SWEEP SPEED/CM	20 MS	20 MS	10 MS	20 MS	20 MS	20 MS	20 MS	0.5 MS	0.5 MS
SINGLE SWEEP/FREE RUN	FR	SS	SS	FR	FR	FR	FR	FR	FR
RECORDING DURATION	60 SEC	20 MS	10 MS	30 SEC	5 MIN	5 MIN	15 MIN	90 SEC	3 MIN
P/P MAXIMUM NOISE	12 MV	3.5 MV	0.5 MV	NG	14 MV	12 MV	13.5 MV	18 MV	23 MV
AVERAGE P/P NOISE	3 MV	0.5 MV	0.2 MV	NG	3.5 MV	3 MV	3 MV	3 MV	4 MV

Table 5-2. Tabulated Noise Results of Buildings 3 and 5 Laboratories

PHOTO IDENTIFICATION NUMBER	1	2	3	4	5	6	7	8	9	10	11
DATE	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75	8-5-75
TIME	1400 HRS	1405 HRS	1408 HRS	1410 HRS	1420 HRS	1425 HRS	1440 HRS	1505 HRS	1525 HRS	1550 HRS	1555 HRS
BUILDING AND OUTLET	BLDG 3/5 RIWL5	BLDG 3/5 RIWL5	BLDG 3/5 RIWL5	BLDG 3 NEAR HI-VOLTAGE TRANS-FORMERS	BLDG 3 NEAR HI-VOLTAGE TRANS-FORMERS	BLDG 3 NEAR HI-VOLTAGE TRANS-FORMERS	BLDG 5 COMPUTER ROOM	BLDG 3/5 ENVIRON-MENTAL TEST LABORATORY	BLDG 2 NEAR LARGE POWER TRANS-FORMERS	BLDG 2 VENDING MACHINE AREA	BLDG 2 ELECTRICAL ASSEMBLY AREA
VERTICAL SENSITIVITY/CM	5 MV	5 MV	5 MV	20 MV	20 MV	20 MV	10 MV	5 MV	5 MV	5 MV	5 MV
HORIZONTAL SWEEP SPEED/CM	20 MS	20 MS	0.5 MS	20 MS	20 MS	0.5 MS	20 MX	20 MS	20 MS	20 MS	20 MS
SINGLE SWEEP/FREE RUN	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR
RECORDING DURATION	5 MIN	5 MIN	30 SEC	60 SEC	5 MIN	10 SEC	5 MIN	5 MIN	5 MIN	5 MIN	5 MIN
P/P MAXIMUM NOISE	31 MV	17 MV	5.5 MV	95 MV	100 MV	95 MV	24 MV	11 MV	2 MV	24 MV	9 MV
AVERAGE P/P NOISE	7 MV	7 MV	3 MV	---	---	10 MV	---	2 MV	1 MV	3 MV	2 MV

Table 5-3. Tabulated Noise Results of Shield and Screen Rooms in Building 4

PHOTO IDENTIFICATION NUMBER	1	2	3	4	5
DATE	8-6-75	8-6-75	8-6-75	8-6-75	8-6-75
TIME	1350 HRS	1400 HRS	1415 HRS	1420 HRS	1430 HRS
BUILDING AND OUTLET	SHIELD ROOM	SHIELD ROOM	SCREEN ROOM	SCREEN ROOM	SCREEN ROOM
VERTICAL SENSITIVITY/CM	1 MV	1 MV	1 MV	1 MV	1 MV
HORIZONTAL SWEEP SPEED/CM	20 MS	2 MS	2 MS	2 MS	20 MS
SINGLE SWEEP/FREE RUN	FR	SS	SS	FR	FR
RECORDING DURATION	5 MIN	2 MS	2 MS	10 SEC	5 MIN
P/P MAXIMUM NOISE	1 MV	0.5 MV	0.4 MV	0.8 MV	0.8 MV
AVERAGE P/P NOISE	0.1 MV	0.1 MV	0.1 MV	0.05 MV	---

Table 5-4. Tabulated Noise Results with Known Noise Sources

PHOTO IDENTIFICATION NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
DATE	8-6-75	8-6-75	8-7-75	8-7-75	8-7-75	8-7-75	8-7-75	8-8-75	8-8-75	8-8-75	8-8-75	8-8-75
TIME	1615 HRS	1625 HRS	0845 HRS	0900 HRS	1005 HRS	1025 HRS	1020 HRS	0850 HRS	0950 HRS	0955 HRS	1615 HRS	1650 HRS
BUILDING AND OUTLET	SCREEN	SCREEN	SCREEN	SEARS VAR SPEED START/STOP 3/8" DRILL MOTOR SCREEN ROOM	START/STOP 3/8" B&D DRILL MOTOR SCREEN ROOM	WIRE WRAP GUN SCREEN ROOM	CV 53 HEAT GUN SCREEN ROOM	DEFEC-TIVE, GE MIX-MASTER SCREEN ROOM	SEARS 3/8" VAR SPEED DRILL WITH WIRE WRAP GUN SCREEN ROOM	SEARS 3/8" VAR SPEED DRILL MOTOR ONLY SCREEN ROOM	SCR CONTROL WITH PARTIAL 200 W LOAD SCREEN ROOM	SCR CONTROL WITH 50% 360 W LOAD SCREEN ROOM
VERTICAL SENSITIVITY/CM	1 MV	1 MV	1 MV	50 MV	50 MV	50 MV	50 MV	50 MV	50 MV	50 MV	50 MV	200 MV
HORIZONTAL SWEEP SPEED/CM	2 MS	20 MS	20 MS	20 MS	20 MS	20 MS	20 MS	20 MS	2 MS	20 MS	2 MS	2 MS
SINGLE SWEEP/FREE RUN	SS	FR	FR	FR	FR	SS	FR	SS	FR	FR	SS	SS
RECORDING DURATION	2 MS	5 MIN	5 MIN	5 SEC	10 SEC	20 MS	10 SEC	20 MS	5 SEC	5 SEC	2 MS	2 MS
P/P MAXIMUM NOISE	1 MV	1.4 MV	3.5 MV	300 MV	225 MV	115 MV	240 MV	100 MV	115 MV	250 MV	190 MV	400 MV
AVERAGE P/P NOISE	0.1 MV	0.1 MV	---	15 MV	---	50 MV	25 MV	2.5 MV RMS	20 MV	25 MV	7.5 MV RMS	11 MV RMS

5.2.2.1 (Continued)

Two bit synchronization schemes were proposed: utilize the same synchronization source at the receiver as that generated for the transmitter (i.e., use 60 Hz line frequency), or recover the transmitted clock rate from the signal itself. The first technique would work fine as long as there was no power failures while the second technique would work at any time but with the possibility of some degraded performance. It was desired to empirically determine the magnitude of this degradation.

Finally, it was desired to determine bit error rates as a function of bit transmission rate. After analysis it was determined that a nominal transmission rate of 60 bps was optimum for BAS use. A large amount of transient noise is synchronous with 60 Hz and may be represented by a very high amplitude transient over a small percentage of the 60 Hz period. If an integrate and dump detection scheme is used one may integrate over an entire period and therefore integrate the transient out. If a higher rate is used, less integration time with respect to the noise is obtained and bit errors will increase. On the other hand if a lower bit rate is used a greater length of time is required to transmit a given message which increases the probability of message interference.

5.2.2.2 Test Conduct

It was necessary to determine the bit error rate of the following combinations of bit detection and receiver clock generation schemes:

a. Utilize the transmitter clock with intergrate-dump detector
b. Utilize the transmitter clock with sample detector
c. Recover the clock with intergrate-dump detector
d. Recover the clock with sample detector.

Because bit errors are a direct function of powerline noise, accelerated measurements of bit error rate versus line noise could be conducted using the following noise sources:

a. a quarter-inch SCR controlled hand drill
b. a SCR lamp dimmer with a 600 watt load
c. a large "Shop-Vac" vacuum cleaner
d. a wire wrapping gun.

The tests were conducted in a shield room, chosen because of extremely quite powerline noise, particularly in the band around 170 kHz. At a 60 Hz bit rate, reasonable bit error rates could be found by counting the number of bit errors that occurred

5.2.2.2 (Continued)

per time period, as follows:

$$BER = \frac{\text{bit errors}}{\text{total number of bits}} \times 100\%$$

In order to accelerate the time required to make BER measurements, powerline loss (attenuation) was added such that the BER ratio yields the desired rate (expressed here in orders of magnitude starting at 0.5 and decreasing to 1×10^{-4}, or 1 bit error in 10,000 bits). Notice that the highest possible BER is 0.5 because the "random" distribution of ones and zeros are equal. Thus, if infinate attenuation is inserted between the transmitter and receiver, the eventual number of bit errors will equal 50% of the total number of bits.

At a bit rate of 60 Hz, a BER = 10^{-4} will then require one bit error in 10,000 bits, or at 16.7 ms per bit, 167 seconds. This is a reasonable time period. In order to obtain a good curve of BER versus line attenuation (dB), the following rates were determined:

a. 5×10^{-1} BER (to "just give" that rate)
b. 3.2×10^{-1} BER
c. 1×10^{-1} BER
d. 3.2×10^{-2} BER
e. 1×10^{-2} BER
f. 1×10^{-3} BER
g. 1×10^{-4} BER

Figure 5-7 shows the physical layout of the shield room along with the electrical blocks showing the powerline distribution system with its associated filters. Figure 5-8 shows the test block diagram.

A special BAS test transmitter and receiver had previously been designed and fabricated and was described in Section 4.3. These test instruments allowed the use of the two different detection schemes, the two different synchronization schemes, change of bit transmission rate, and the measurement of bit errors and total bits received.

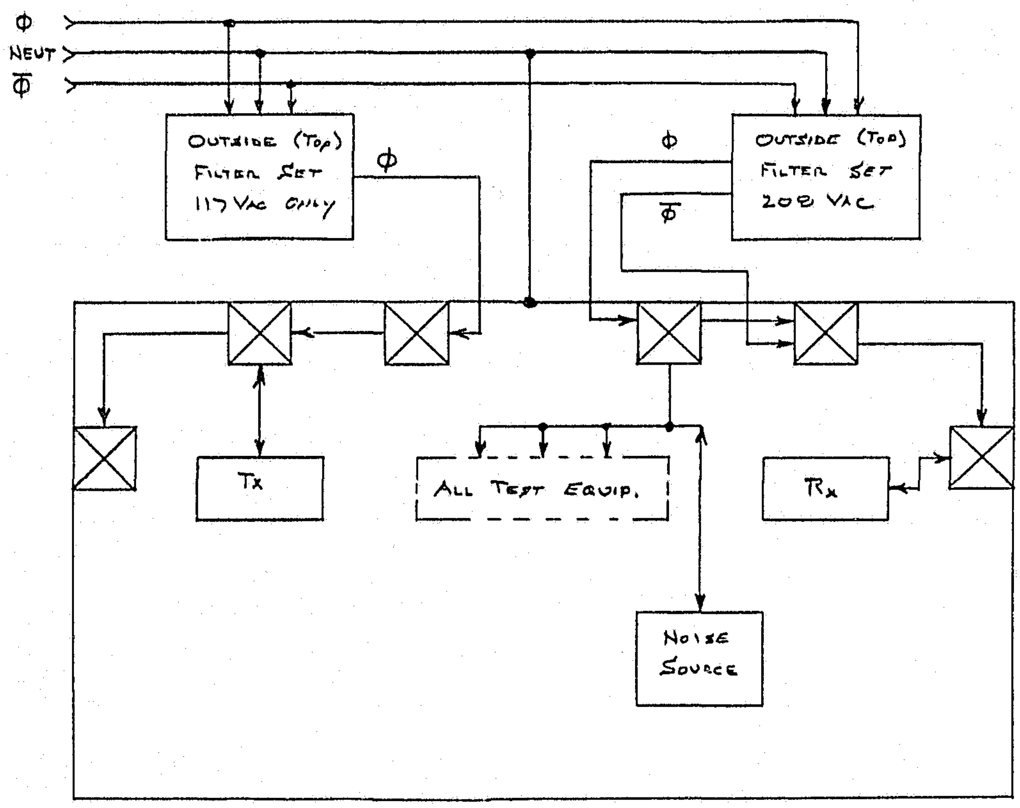


Figure 5-7. Shield Room Power Distribution

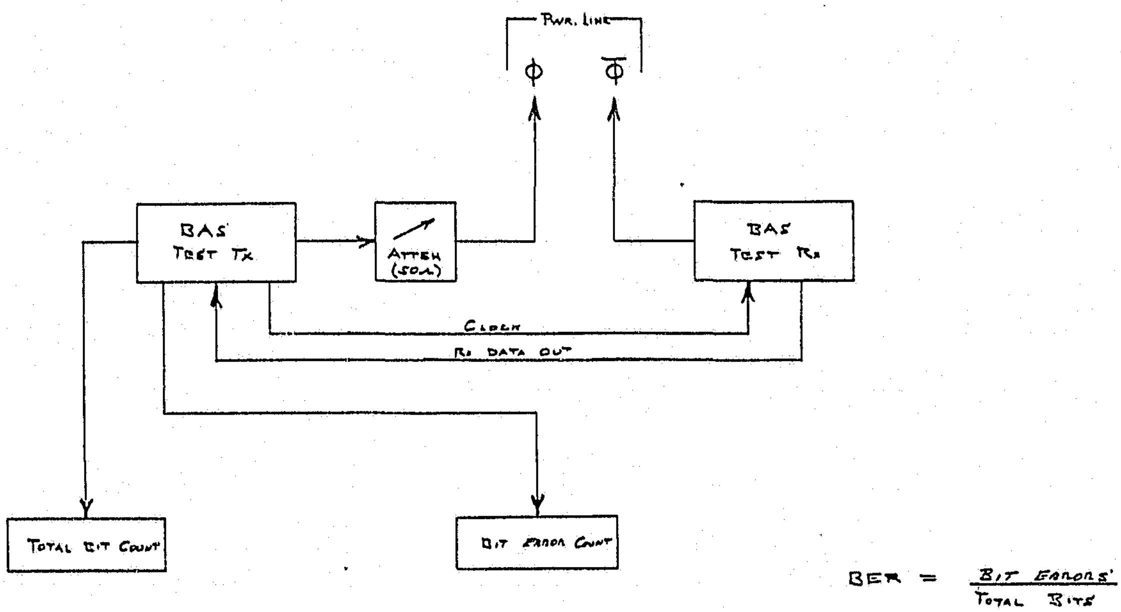


Figure 5-8. BAS Bit Error Rate Block Diagram

5.2.2.3 Test Results

The resulting bit error rate curves for the various samples are shown in Figures 5-9, 5-10, and 5-11. Notice that these curves were all run at a bit rate of 60 Hz. All results followed the predicted trend.

Bit error rates were also run at 30 Hz (see Figures 5-12 and 5-13) and 120 Hz (see Figure 5-14). Again, as predicted the results improved with lower bit rate.

In all cases, regardless of noise source, the results indicated that best performance is obtained with an intergrate/dump detector using the "hard-wired" transmitter clock. However, recovering the clock using the intergrate/dump type detector show only a marginal decrease in performance. Use of the sampling type of detector was found to be not recommended.

5.3 RESIDENTIAL FIELD TESTS

5.3.1 General

The first step taken at each site was the mapping of the electrical circuits. The main circuit breaker box was located and each circuit breaker was assigned a number. A "home base" location was chosen within the dwelling (a location where equipment could easily be operated). The electrical phase of the nearest receptacle was then termed "Phase A". All opposite phased receptacles and outlets were termed "Phase B".

A floor plan sketch was drawn to scale so that relative distances would be evident. Conventional symbols were used to show:

a. Receptacles (wall plugs): 

b. Outlets (wall or ceiling mounted lights): 

c. Wall switches: △

A number was then placed adjacent to each symbol indicating:

a. The circuit number (that circuit breaker which turns off that particular receptacle or outlet).

b. The number of that particular receptacle or outlet (in sequence as mapped) on that circuit.

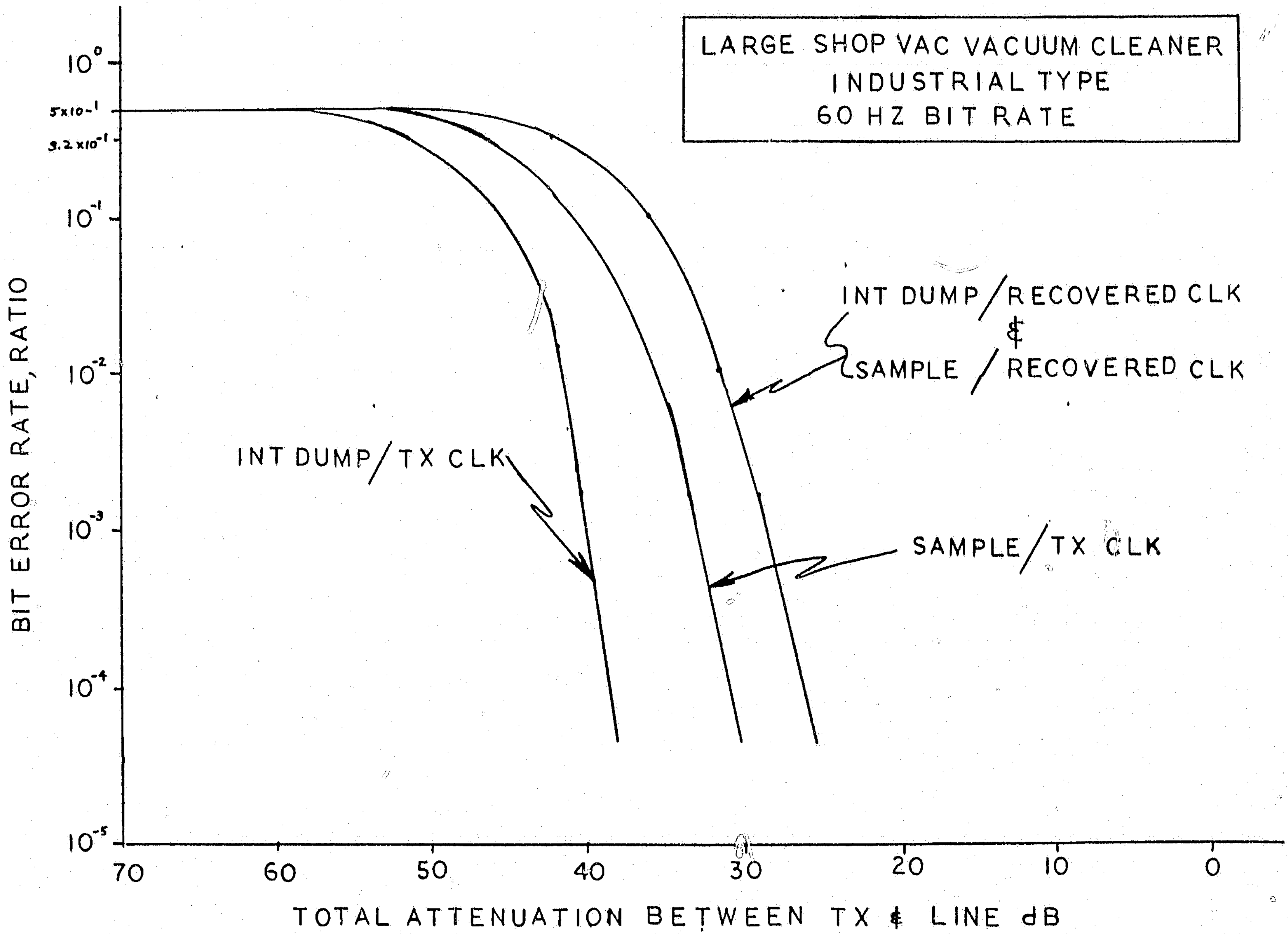


Figure 5-9. Bit Error Rate for Shop Vac Vacuum Cleaner - 60 bps

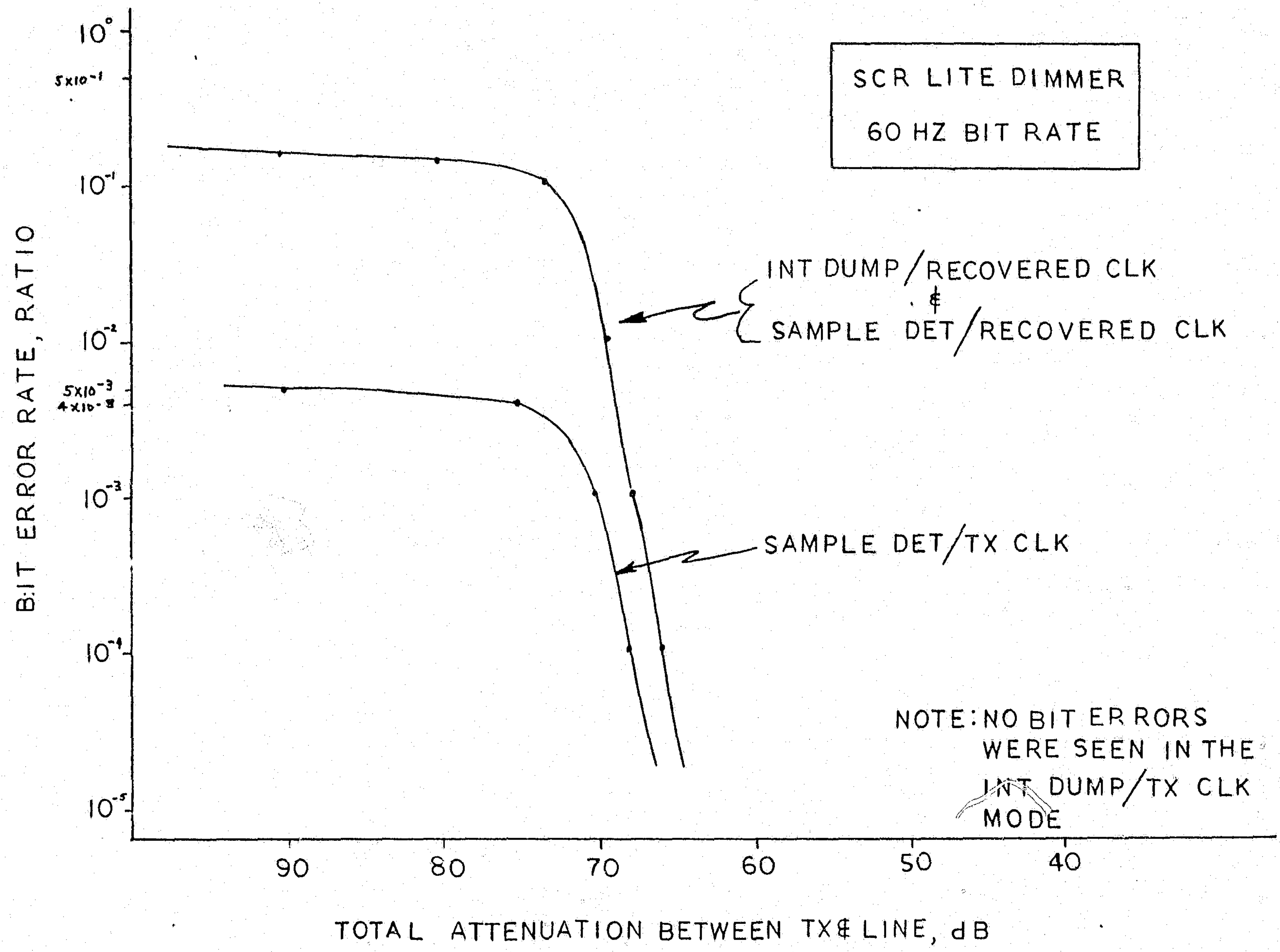


Figure 5-10. Bit Error Rate for SCR Lite Dimmer - 60 bps

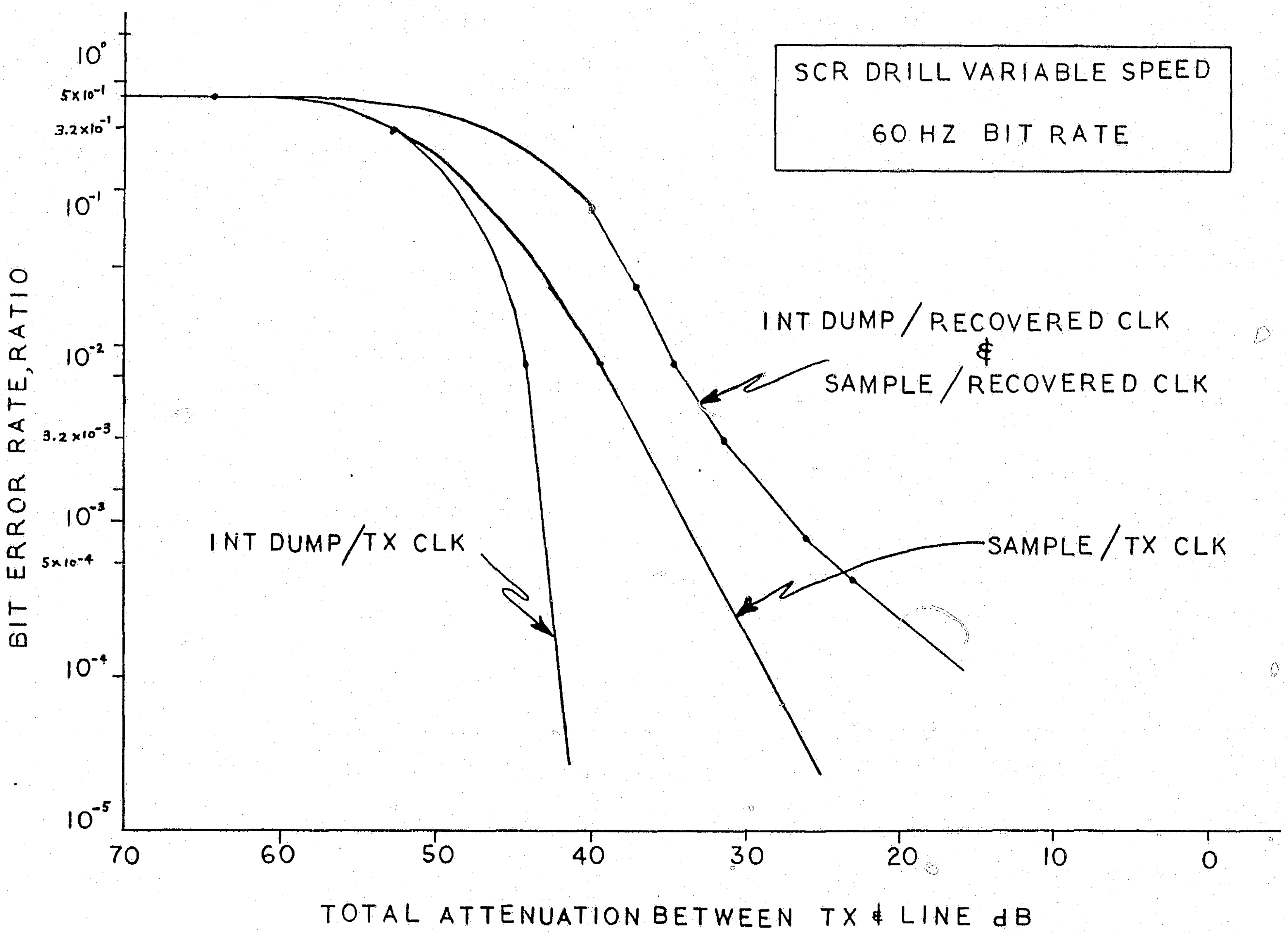


Figure 5-11. Bit Error Rate for SCR Variable Speed Drill - 60 bps

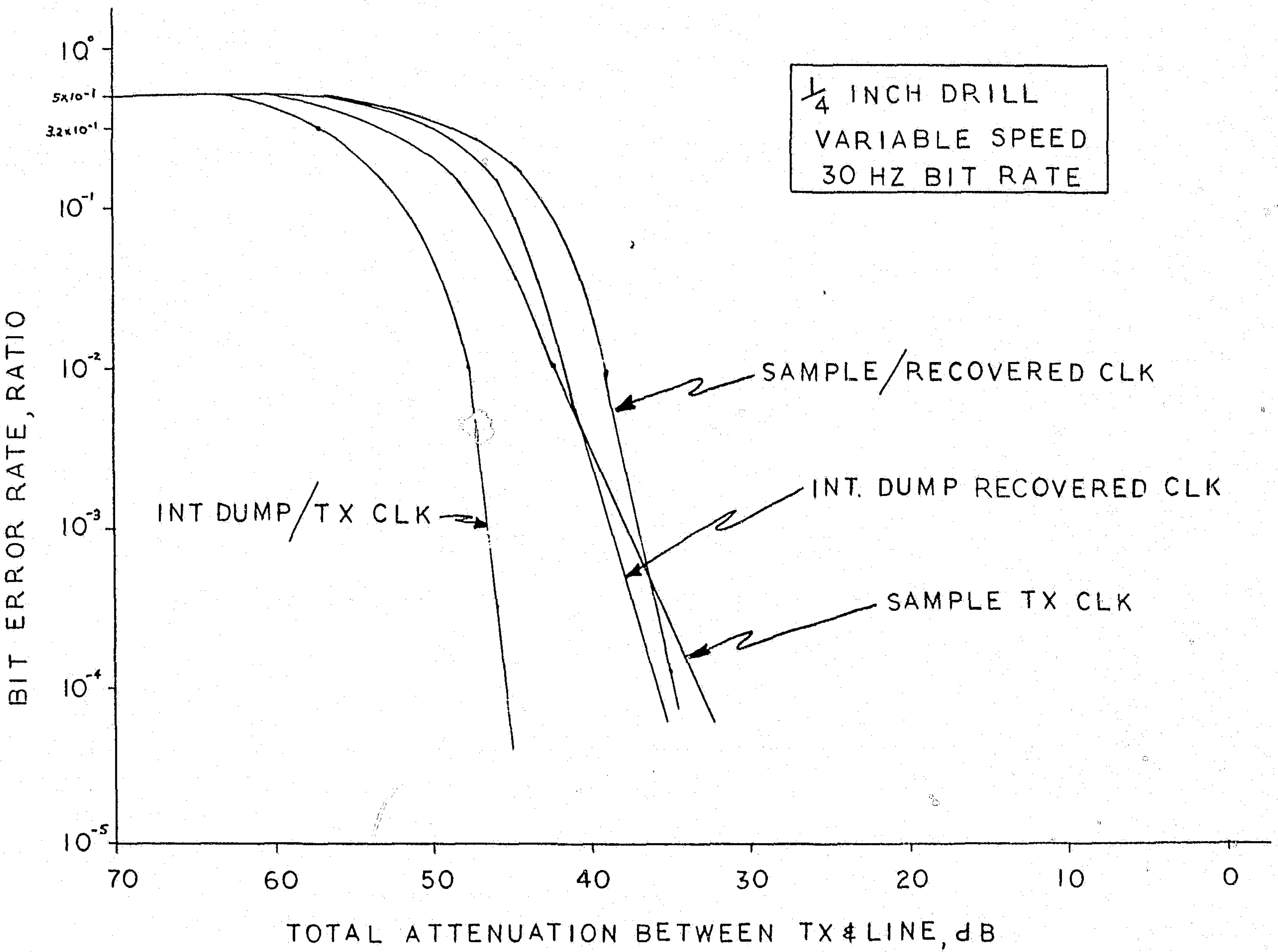


Figure 5-12. Bit Error Rate for 1/4 inch Variable Speed Drill - 30 bps

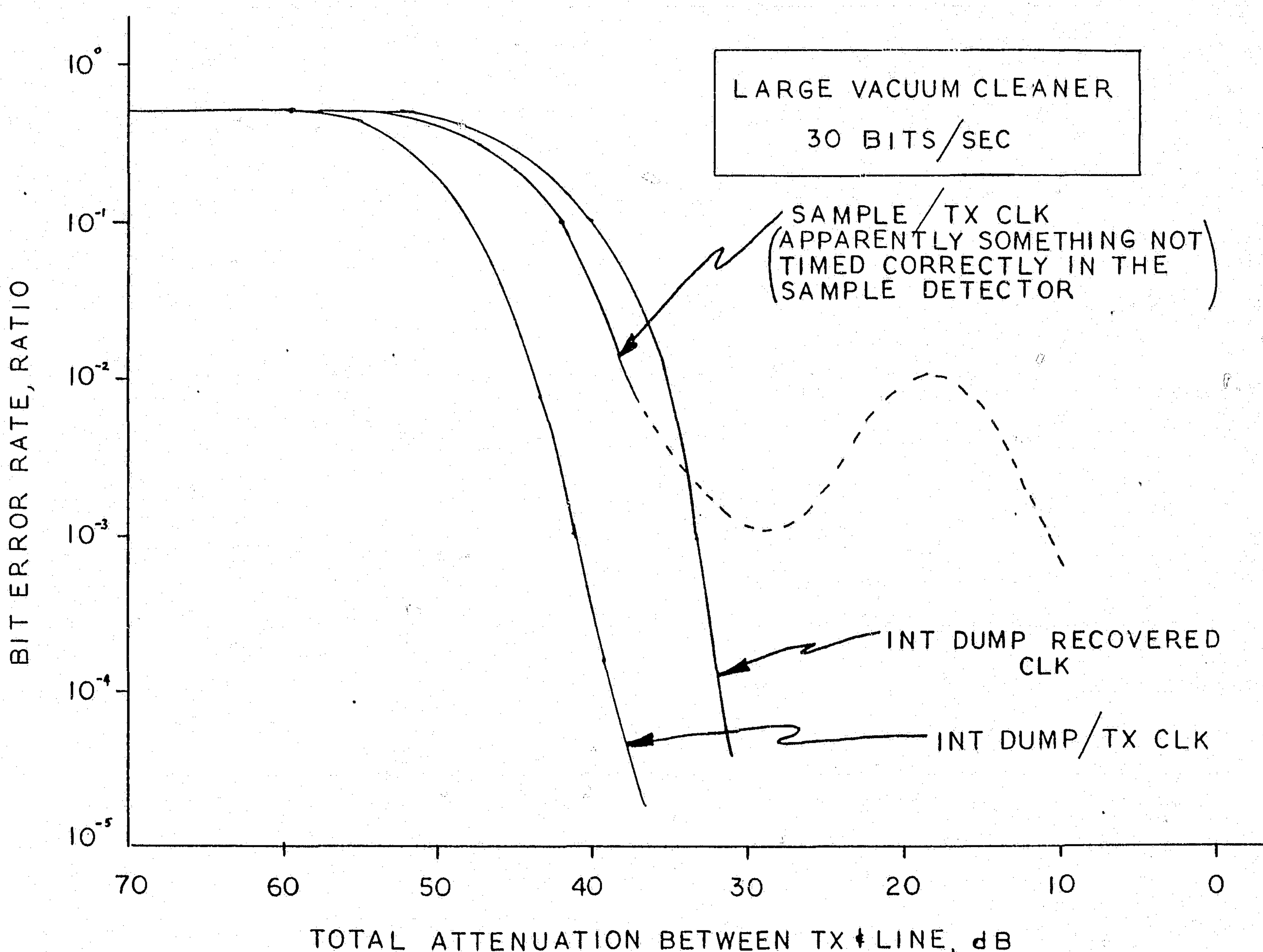


Figure 5-13. Bit Error Rate for Large Vacuum Cleaner - 30 bps

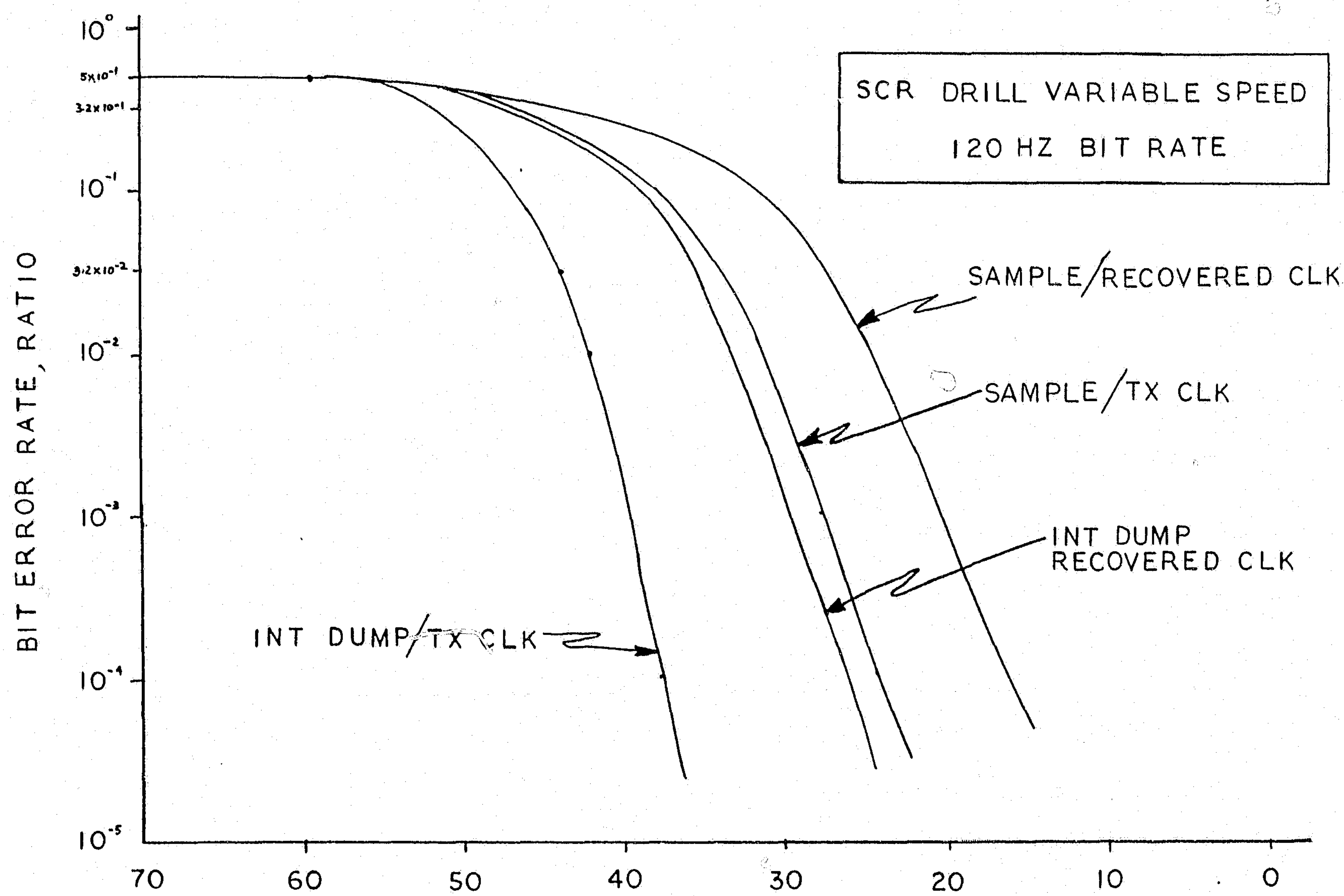


Figure 5-14. Bit Error Rate for SCR Variable Speed Drill - 120 bps

5.3.1 (Continued)

After mapping, a table was placed on the plan showing the relative phase of each circuit (Phase A or B). Figure 5-15 shows the simple method used for determining the relative phase (with respect to the "home base" location) of each receptacle or outlet. The individual circuits were assigned nomenclatures as follows:

a. Lamps do not light indicates Phase A.

b. Lamps do light indicates Phase B.

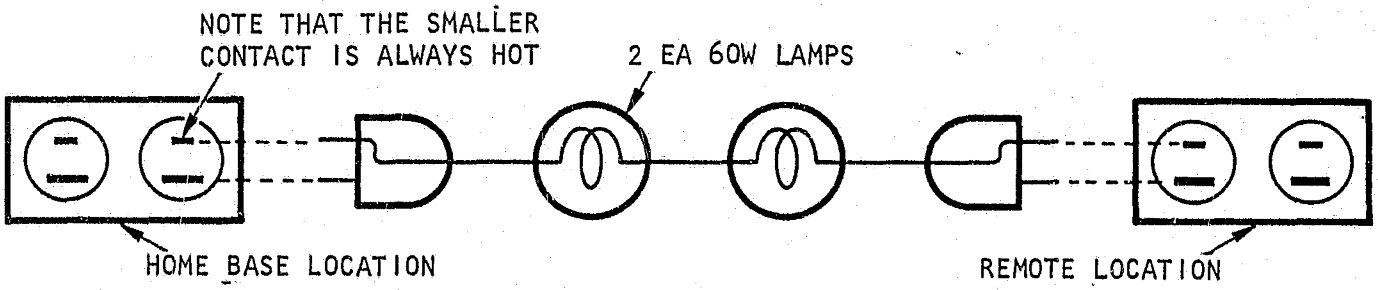


Figure 5-15. Relative Phase-Determining Method

The primary tests conducted at the field sites utilized the test set-up shown in Figure 5-16. This test allowed a measurement of powerline signal attenuation as well as the phase stability of the transmission path. A 170 kHz test signal was generated in the HP208A oscillator and amplified via an HP467A power amplifier. This signal is split and is coupled to the powerline via the Sylvania powerline coupler as well as to the HP3575A gain/phase meter as a phase reference "A". The signal is transmitted over the powerline under test, passed through the 170 kHz bandpass filter at the other end of the test line and sent to the "B" input of the gain/phase meter. The primary purpose of the gain/phase meter was to be able to determine the phase stability as well as the attenuation characteristics of the line. The phase stability was checked to emperically determine whether PSK could be used in a BAS powerline communications system. PSK enjoys the same technical advantages of FSK but is easier to implement. It was determined quite rapidly that the transmission path's phase stability was practically nonexistent. The phase varied considerably with many loads being switched on and off the line.

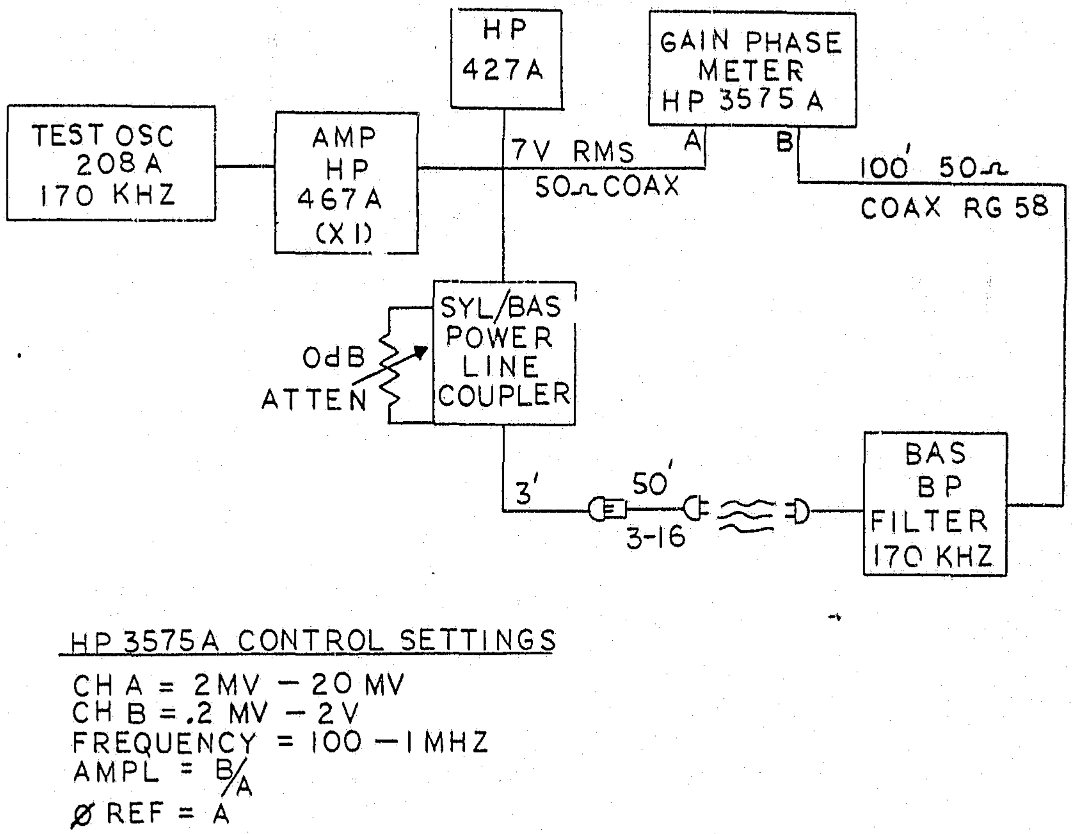


Figure 5-16. Narrow Band Signal Attenuation Test Set Up

5.3.1 (Continued)

A second test set up was employed in the field which was illustrated in Figure 4-1 (Section 4.3, BAS Test Set). This was done to measure bit error rate in a real environment as a function of various loads being switched on and off the line. Representative loads which were used were ovens, vacuum cleaners, 1/4" drills, SCR drivers, etc. Under the existing normal line attenuations no bit errors could be induced, not even during a 144 hour test period (6 days). The dynamic operating range of the BAS receiver and transmitter (~ 65 dB) appeared to be more than adequate.

Because of the outcome of the phase stability tests (no stability) and the bit error tests (no errors) the prime variable to report upon for the field tests was that of attenuation. These results are described in the following sections for each of the test sites.

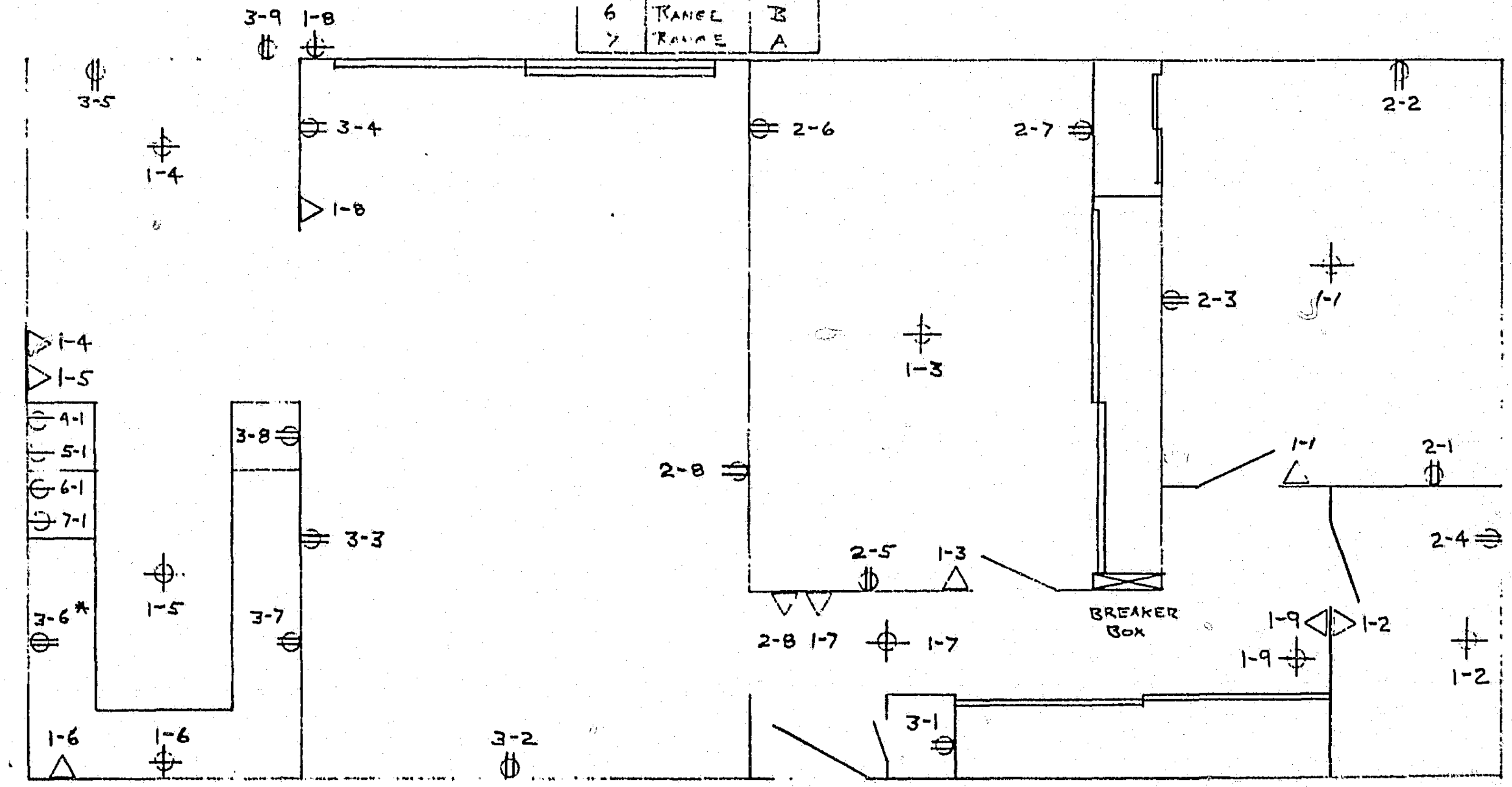
5.3.2 Apartment No. 1, Sunnyvale Site Description

The floor plan for apartment No. 1 is shown in Figure 5-17. It is a garden-type, 2 bedroom apartment, wood frame construction with a stucco exterior, and 15 years old. The living area is 912 square feet which is large for a 2 bedroom apartment, but still considered a medium income dwelling because of its age. The electrical service within the apartment is a centralized wiring system where one circuit breaker panel distributes the electricity to the various load centers via 2-conductor Romex unshielded cable. Phases A and B are provided to the range and oven for 220v service, and also are distributed evenly among the other loads to provide even loading on the input transformer.

The apartment is located on the second floor within a "U" shaped group of 28 other units. Electricity is brought to the unit from the meter in the rear carport area, approximately 167 feet away. This service is a 2-conductor Romex cable which is shielded by thin wall conduit. The outside site layout and service feed information are provided in Figure 5-18. Service to the meter is by an aerial drop from a utility pole at the back of the property line. This pole also contains the high voltage transformer which is used solely for these units.

Prior to taking attenuation measurements of the electrical service within the apartment, a map was made (see Figure 5-17) which identified the phase and circuit number of each circuit load location. The attenuation measurements were then taken from each circuit load location to other load locations of the same or opposite phase. After these tests, a 0.1 microfarad capacitor was connected from Phase A to B at the remote meter location. Because of the distance involved, a measurable reduction in signal attenuation could not be detected and therefore was not included in the test results. The averaged and summarized data for this location appears in Table 5-5.

BKR No.	LOCATION	REL. φ
1	[illegible]	A
2	RECPT	B
3	RECPT	A
4	OVEN	B
5	OVEN	A
6	RANGE	B
7	RANGE	A



* "HOME-BASE" LOCATION

Figure 5-17. Apartment No. 1, Sunnyvale Test Site

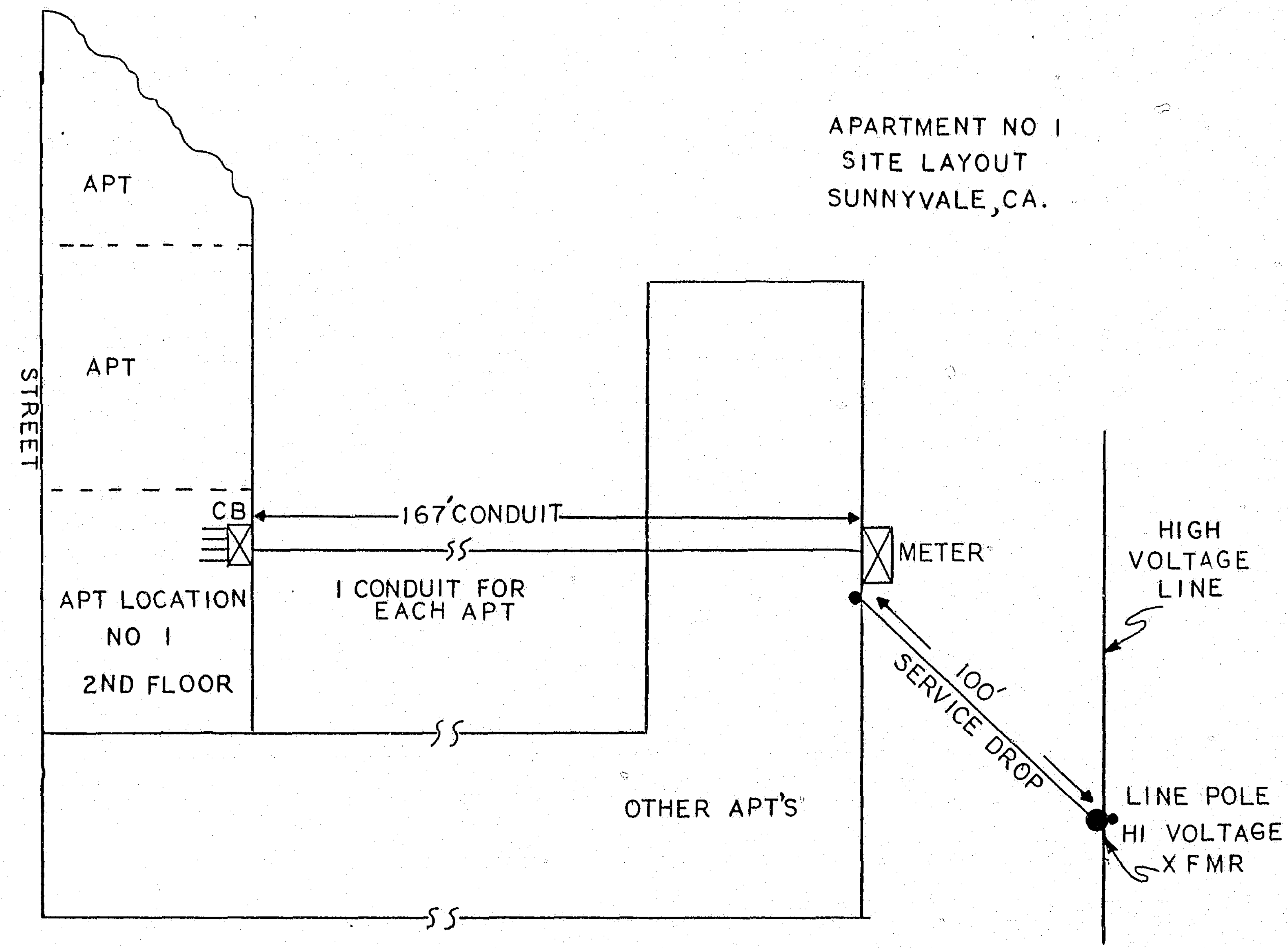


Figure 5-18. Apartment No. 1 Site Layout, Sunnyvale

Table 5-5. Apartment #1 Test Site Results Summary

Circuit (Home-Base is 3-6)	Respect to "Home-Base" In Phase Attenuation (dB)	Respect to "Home-Base" Out of Phase Attenuation (dB)	Miscellaneous Notes
1-1	4.9		
1-2	13.7		Sw. On ? ?
1-3	5.1		
1-4	5.9		
1-7	5.3		
1-8	5.8		
2-1		13.8	No phase coupling
2-2		12.7	No phase coupling
2-3		12.7	No phase coupling
2-4		13.7	No phase coupling
2-5		13.3	No phase coupling
2-6		15.2	No phase coupling
2-7		14.4	No phase coupling
2-8		15.3	Sw. Recpt.
3-2	1.9		
3-3	1.2		
3-4	0.3		
3-5	0.2		
3-6	(9.2)		Insertion Loss
3-7	0.8		
Average Loss dB	3.1	13.9	Very Quiet Line (S/N High)

5.3.3 Apartment No. 2, Union City Site Description

This site is a modern two year old apartment complex of wood frame and exterior stucco construction. An apartment building plan for the building housing the apartment is shown in Figure 5-19. It is a single bedroom unit with 600 square feet of living area. It is a downstairs unit and shares a garden cluster setting with seven other similar units, which could all be considered in the medium income range. It has a centralized wiring system similar to apartment No. 1, but was wired with the modern unshielded 3-wire Romex cable. Phases A and B are both provided to the range and oven for 220v service and also are distributed evenly among the other circuit load points to provide a balanced load to the input transformer. The site physical layout and electrical service information can be seen in Figure 5-20. These apartments were supplied with underground electrical service. It was not possible to determine the location of the high voltage transformer because it was also underground. (Most community codes require this modern system.) The electrical service from the outside meter box to the apartment unit circuit breaker panel is a 3-wire Romex cable within thin wall metal conduit.

After mapping out the phases and circuit numbers within the apartment, the 170 kHz attenuation measurements were made. These measurements were made from each circuit load location to other locations of the same as well as to the opposite phase. In addition, these measurements were also taken with respect to the two phases of adjacent apartments. These measurements were again repeated with a 0.1 microfarad coupling capacitor phase-to-phase at the meter. The averaged and summarized data for this location appears in Table 5-6.

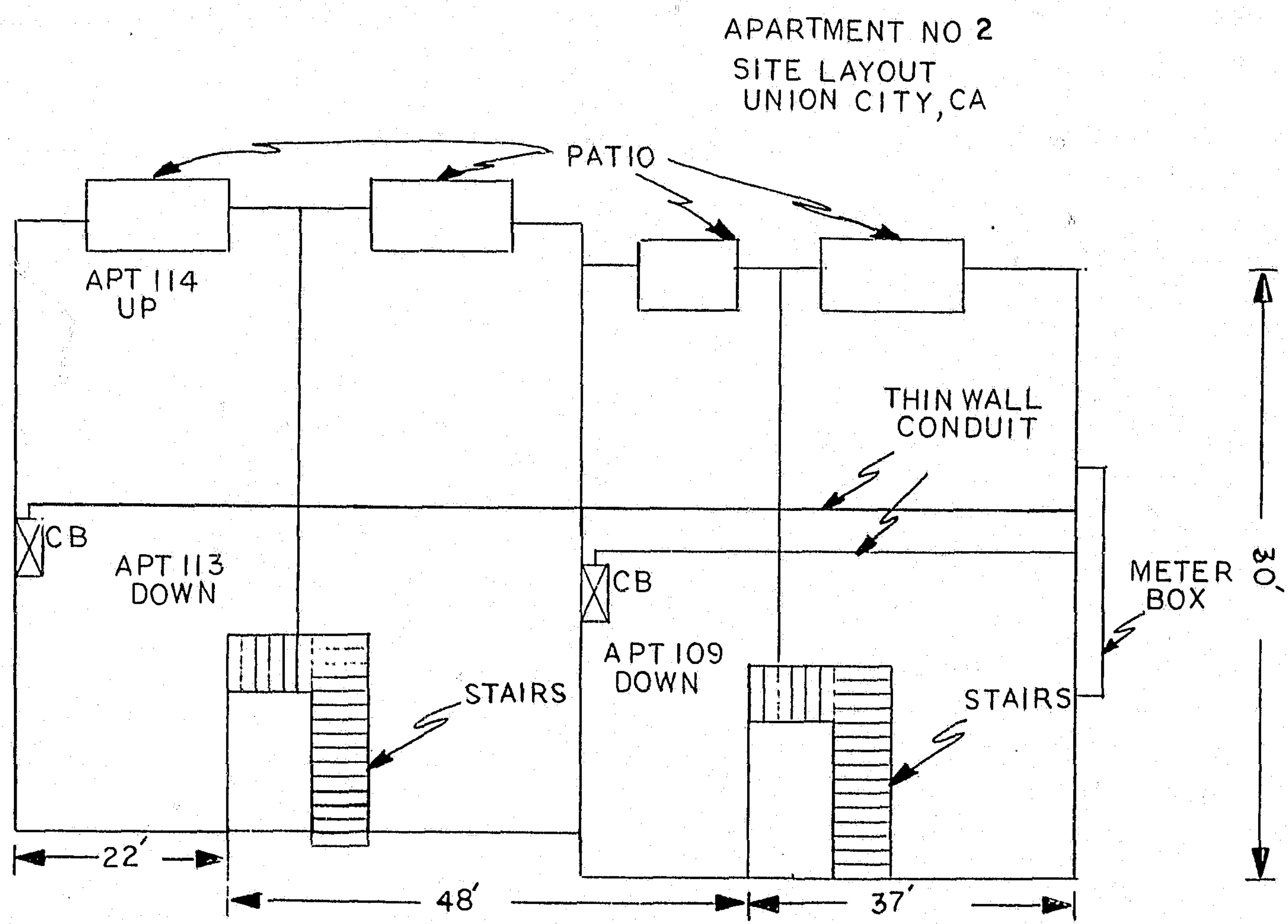
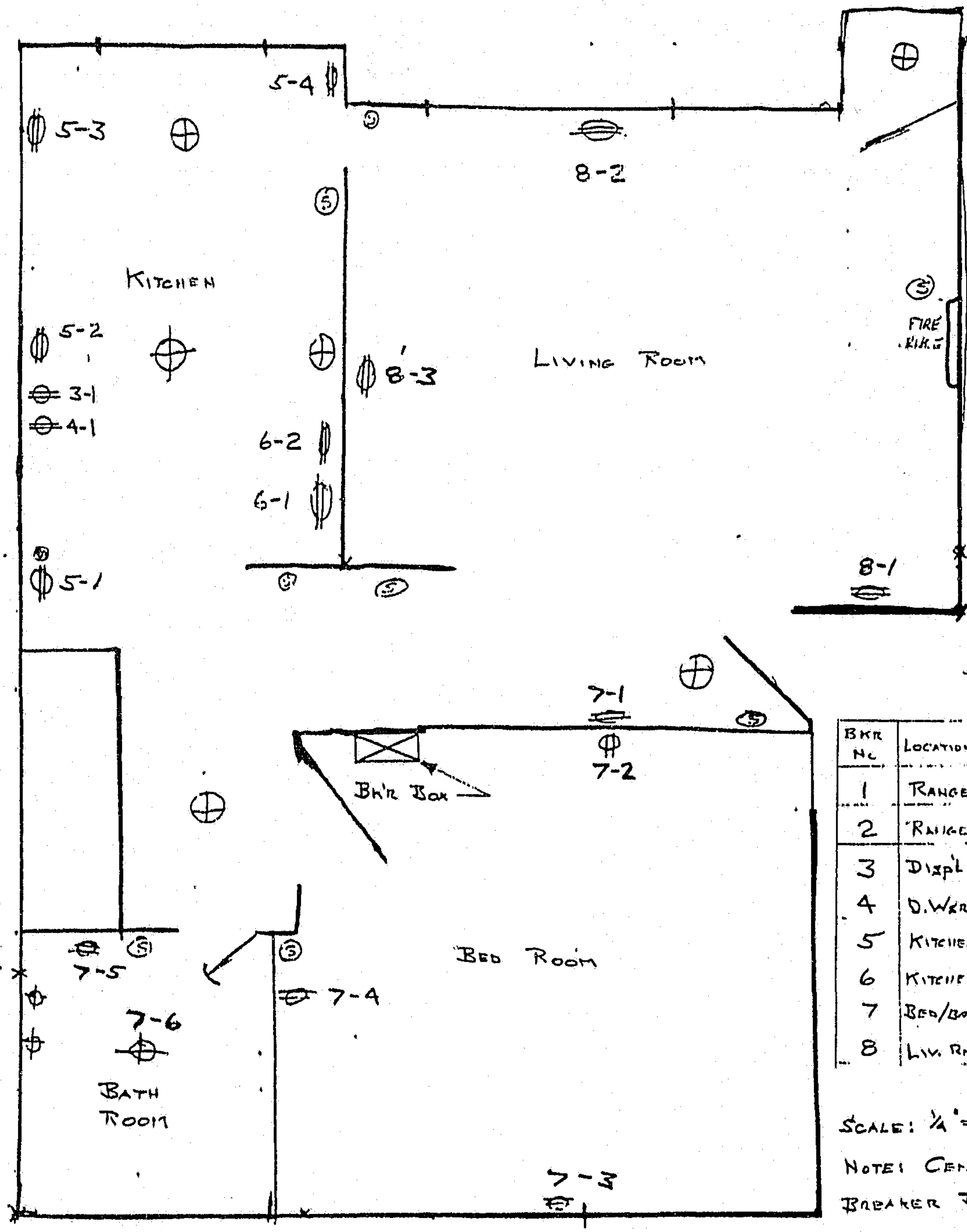


Figure 5-19. Apartment No. 2 Site Layout, Union City



BKR No	LOCATION	REL Φ
1	RANGE	B
2	RANGE	A
3	DISP'L.	B
4	D.WSR.	B
5	KITCHEN	A
6	KITCHEN	A
7	BED/BATH	B
8	LIV. RM.	B

SCALE: 1/4" = 1 FT

NOTE: CENTERAL BREAKER BOX IS APPROX 100' AWAY.

Figure 5-20. Apartment No. 2, Union City Test Site

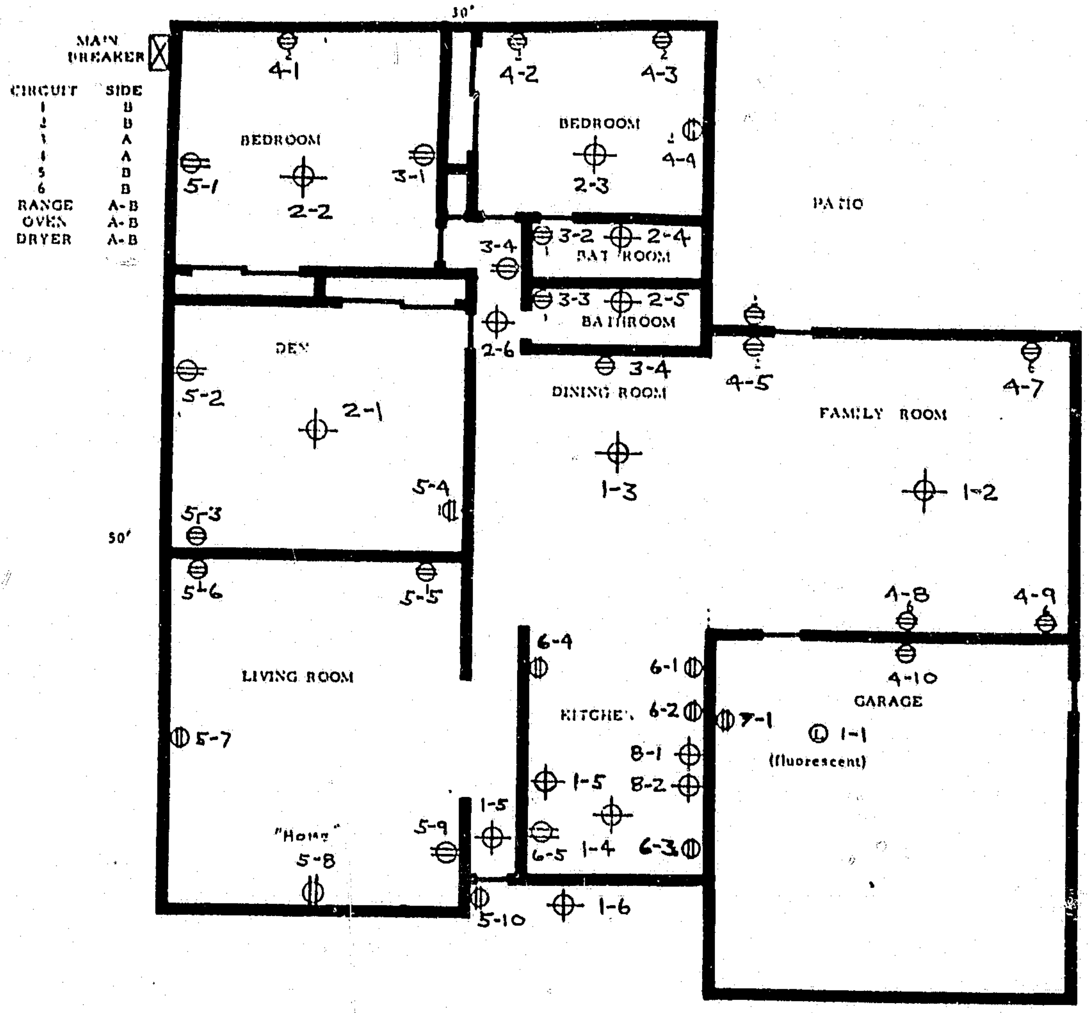
Table 5-6. Apartment No. 2 Test Site Results Summary

Circuit (Home-Base is 5-1)	Respect to "Home-Base" In Phase Attenuation (dB)	Out of Phase Attenuation (dB)	Miscellaneous Notes
6-1	6.7		
3-1		25.5	No phase coupling
4-1		26.5	No phase coupling
7-5		26.5	No phase coupling
8-2		21.5	No phase coupling
4-1		21.5	Phase Coupling
Apt/Adj Apt		23.2	No phase coupling
Apt/Adj Apt	14.6		
Apt/Adj Apt		18.7	No phase coupling
Apt/Adj Apt	11.3		
Apt/Adj Apt	12.3		Phase Coupling
Apt/Adj Apt		17.6	Phase Coupling
Apt/Adj Apt	14.2		Phase Coupling
Apt/Adj Apt		18.2	Phase Coupling
Apt/Upper Apt	14.0		No phase coupling
Apt/Upper Apt		22.5	No phase coupling
Apt/Upper Apt	10.6		No phase coupling
Apt/Upper Apt		17.7	No phase coupling
Apt/Upper Apt		16.8	Phase Coupling
Apt/Upper Apt	12.5		Phase Coupling
Apt/Upper Apt		17.9	Phase Coupling
Apt/Upper Apt	13.7		Phase Coupling
Average Loss dB			Within Apt
	6.7	25.0	No phase coupling
		21.5	Phase Coupling
Average Loss dB			Apt/Apt
	12.9	20.5	No phase coupling
	12.9	17.6	Phase Coupling

5.3.4 House No. 1, Cupertino Test Site Description

A floor plan for test house No. 1 is shown in Figure 5-21. It is a single story 3 bedroom frame and stucco residence and has a living area of approximately 1600 square feet. This home is typical of the medium income homes which are located in the San Francisco bay area. The house is 12 years old and was wired with 2-conductor unshielded Romex wire. A combination power meter and circuit breaker panel is located at the back wall of the house and it serves as the hub of the centralized wiring system where the two phases are distributed among multiple circuits to provide a balanced transformer loading. AC power (220v) is provided to the range, oven, and electric clothes dryer by providing Phases A and B to the appliances. Electricity is provided to the residence by an aerial utility pole type distribution system. In this system a single high voltage transformer serves 10 residences. Figure 5-22 provides outside service feed physical information.

Before attenuation measurements were made, each of the outlets within the residence were tested for circuit phase and a complete electrical site layout was made. Attenuation measurements were then made from each circuit to another circuit location of the same phase, and to one of an opposite phase. These same measurements were again taken with a 0.1 microfarad capacitor connected from Phase A to B at the meter box circuit breakers. The purpose of the coupling capacity was to determine how much improvement could be made in reducing the phase-to-phase attenuation. The data which was taken for each of the measurement situations were averaged and summarized and can be seen in Table 5-7.



BKR No.	LOCATION	REL. Φ
1	OUTLETS	A
2	OUTLETS	A
3	RECPT	B
4	RECPT	B
5	RECPT	A
6	RECPT	A
7	WASH.	B
8	DISP.	B
9	RANGE	B
10	RANGE	A
11	[illegible]	B
12	[illegible]	[illegible]
13	DRYER	A
14	[illegible]	A

SCALE: 1/8" = 1 FT.

Figure 5-21. House No. 1 Test Site, Cupertino

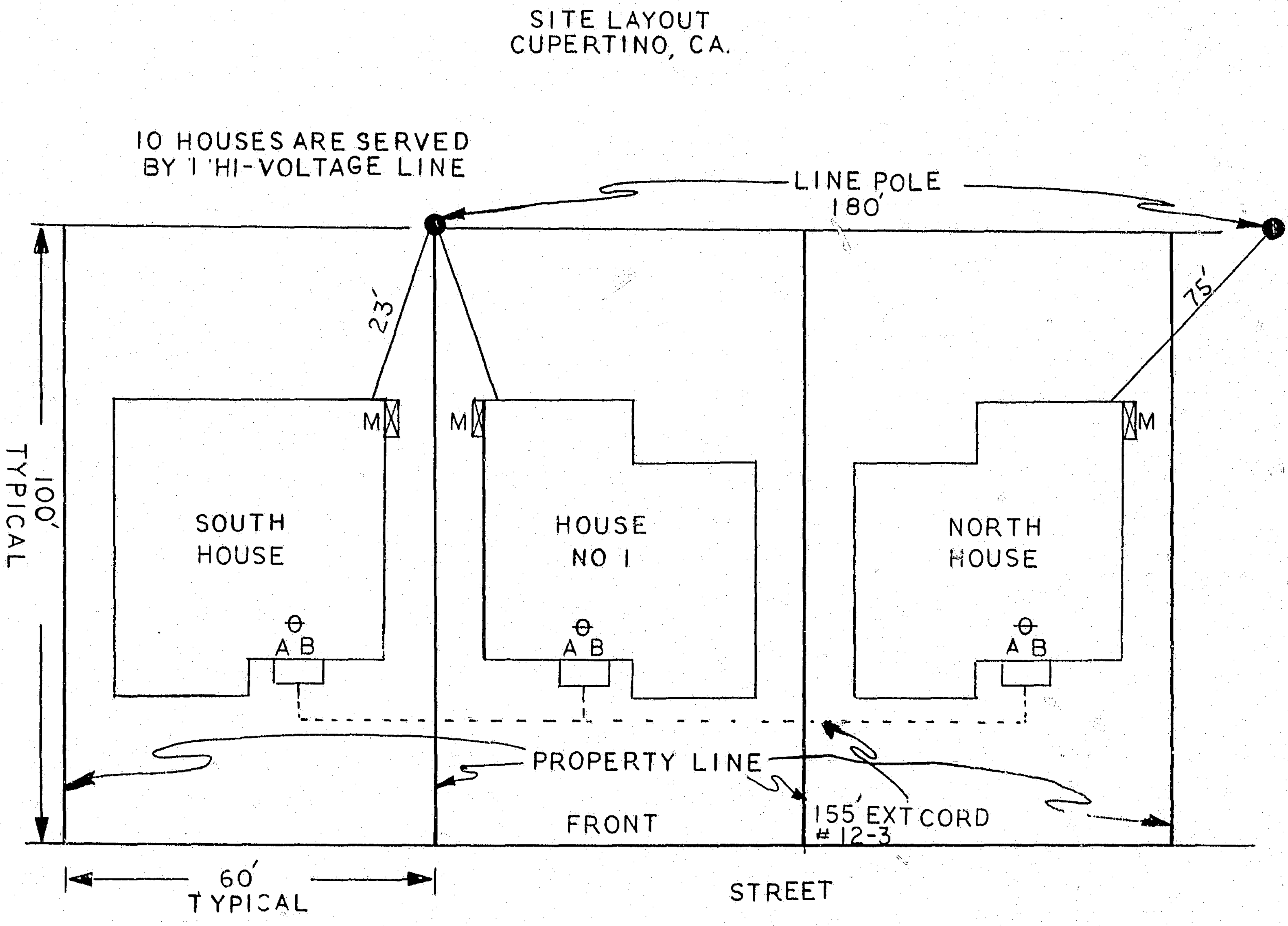


Figure 5-22. House No. 1 Site Layout, Cupertino

Table 5-7. House No. 1 Test Site Results Summary

Circuit (Home-Base is 5-8)	Respect to "Home-Base" In Phase Attenuation (dB)	Out of Phase Attenuation (dB)	Miscellaneous Notes
1-1	11.2		
1-5	10.7		
2-6	9.4		
3-1		20.1	No phase coupling
3-3		21.7	No phase coupling
4-1		20.5	No phase coupling
4-9		24.9	No phase coupling
5-5	8.8		
5-9	13.0		
6.2	8.7		
6.4	9.7		
7.1		22.9	No phase coupling
8.1		23.5	No phase coupling
3-1		16.6	Phase Coupling
4-4		18.1	Phase Coupling
4-4		23.1	No phase coupling
8-1		18.4	Phase Coupling
House/South House		30.8	Phase A/Phase B
House/South House	13.5		Phase B/Phase B
House/South House	5.6		Phase A/Phase A
House/South House		29.2	Phase B/Phase A
House/South House	16.4		Phase A/Phase A
House/South House		36.6	Phase B/Phase A
House/South House	34.7		Phase B/Phase B
House/North House		43.3	Phase A/Phase B
Average Loss dB	10.2	22.4 17.7	Within House No phase coupling Phase Coupling
Average Loss dB	17.6	35.0	House to House

5.3.5 House No. 2, San Jose Test Site Description

House No. 2 has a floor plan which is shown in Figure 5-23. It is also a single story 3 bedroom frame and stucco residence of approximately 1400 square feet. It is 10 years old and is a typical medium income home. The service is more modern than house No. 1, it was wired with 3-conductor unshielded Romex cable. The third conductor is used to provide a safety ground at each load location. Most codes today require a 3-conductor system. This house also has a centralized wiring system where the combination meter and circuit breaker panel are located at the back of the house. Except for the 3-conductor wiring system, the electrical service is identical to house No. 1. The outside electrical service feed configuration is shown in Figure 5-24. The electrical test data measurements were taken as previously described for house No. 1. The results for this test site are given in Table 5-8. The overall averaged results for all field test sites are given in Table 5-9.

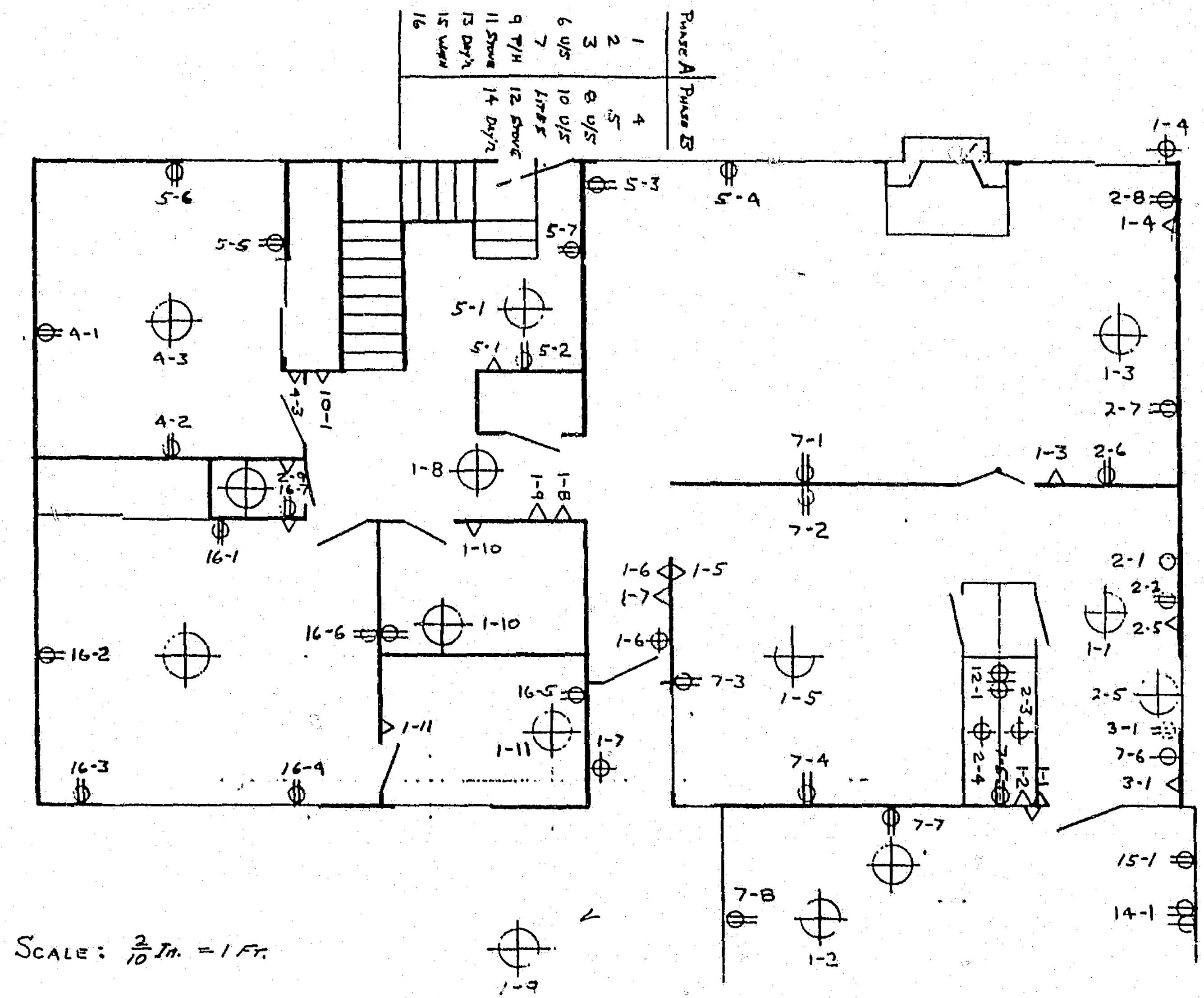


Figure 5-23. House No. 2 Test Site, San Jose

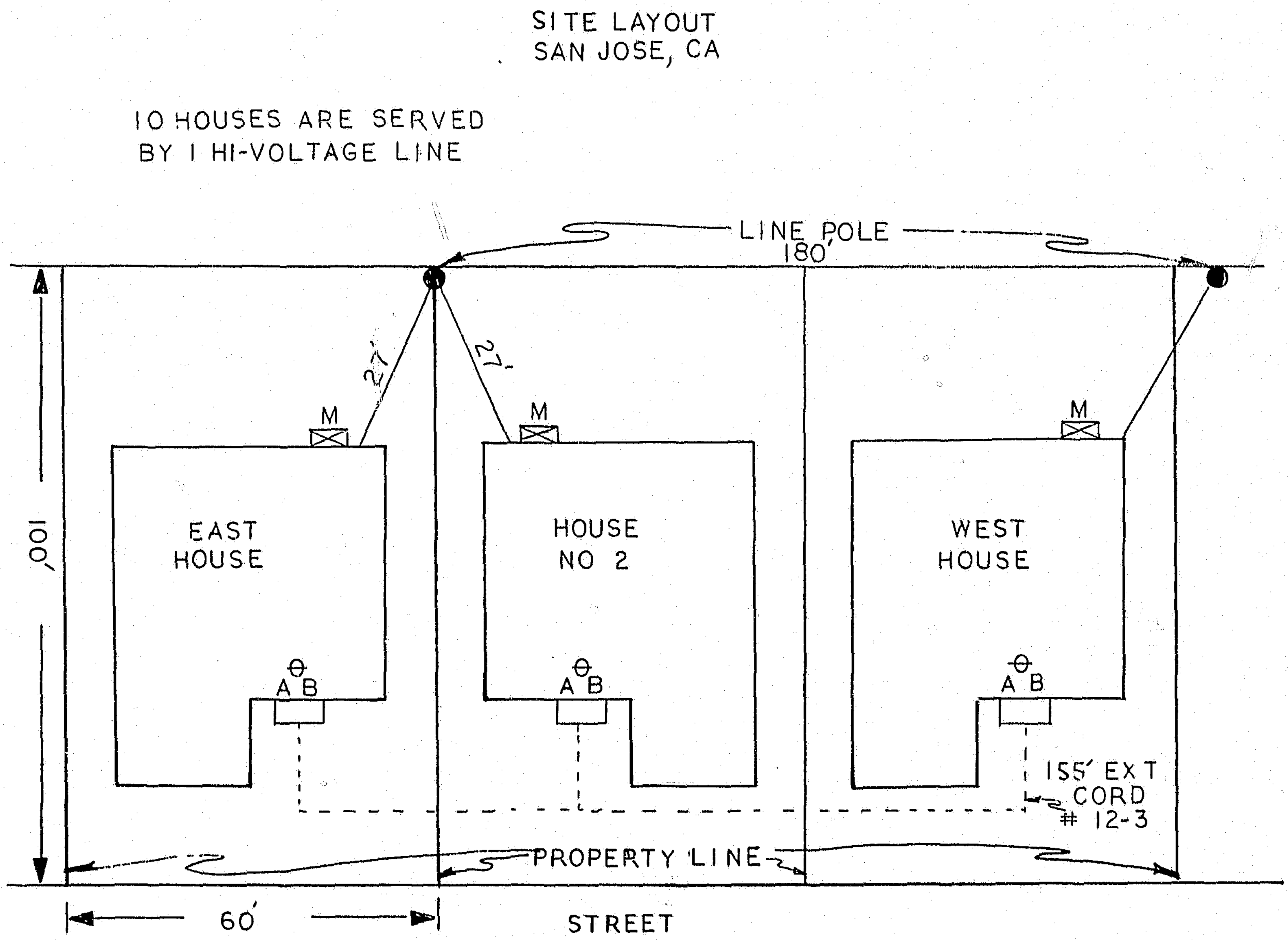


Figure 5-24. House No. 2 Site Layout, San Jose

Table 5-8. House No. 2 Test Site Results Summary

Circuit (Home-Base is 7-7)	Respect to "Home-Base"		Miscellaneous Notes
	In Phase Attenuation (dB)	Out of Phase Attenuation (dB)	
1-2	17.2		
2-8	16.3		
4-2		24.2	No phase coupling
5-4		26.9	No phase coupling
5-4		18.6	Phase Coupling
6-1	25.9		
7-6	5.1		
8-1		36.5	No phase coupling
15-1	15.7		
16-5	15.5		
5-7		28.2	
House/West House		30.7	Phase A/Phase B
House/West House	20.0		Phase A/Phase A
House/West House	27.8		Phase B/Phase B
House/West House		27.1	Phase B/Phase A
House/East House		56.0	Phase A/Phase B
House/East House	41.3		Phase B/Phase B
House/East House		50.0	Phase B/Phase A
House/East House	45.1		Phase A/Phase A
Average Loss dB	16.0	29.0 18.6	Within House No phase coupling Phase Coupling
Average Loss dB	33.6	41.0	House to House

Table 5-9. Averaged Results for All Attenuation Tests

OVERALL ATTENUATION, dB							
APARTMENT				HOUSE			
Within Apartment		Apartment/Apartment		Within House		House/House	
Like Phase	Unlike Phase	Like Phase	Unlike Phase	Like Phase	Unlike Phase	Like Phase	Unlike Phase
4.9 dB	19.5 dB	12.9 dB	20.5 dB	13.1 dB	25.7 dB	25.6 dB	38 dB
12.2 dB		16.7 dB		19.4 dB		31.8 dB	
14.5 dB				25.6 dB			
20 dB							

CHAPTER VI. TEST RESULTS

6.1 PATH

An anlysis of the worst case data attenuation within a single building shows a maximum path loss of 36.5 dB if no phase to phase coupling is used. The use of a 0.1 μf coupling capacitor across phases reduces this maximum loss by 8 dB to 28.5 dB maximum.

6.2 OPERATING FREQUENCY

Our earlier testing has revealed that the noise levels on the powerlines is a minimum between 100 and 500 kHz; with the least noise occurring at the lower end of the band. There are Marine Navigation systems below 130 kHz, and Air Navigation systems above 200 kHz. The FCC will allow higher emitted radiation limits for our application in the 160 to 190 kHz band (Regulation Part 15.202). Finally, we will have better shielding at the lower frequencies due to normal twist of wires. Therefore, we selected 170 kHz as the nominal operating frequency.

6.3 MODULATION TYPE

Our previous testing and analysis had eliminated any consideration of Amplitude Modulation as a signaling technique on powerlines. On the basis of bit error versus signal to noise ratio curves for gaussian noise as shown in Figure 6-1, both PSK and FSK have a clear advantage over ASK. PSK is not superior to FSK on powerlines, however, where there are large phase instabilities in the transmission path as shown in the testing.

Preliminary laboratory testing of the phase noise on the powerlines indicated 20 to 30 degrees noise at the input of a 170 kHz phase detector while various loads were switched on and off the lines. A frequency demodulator differentiates these phase changes and thus produces only a transient output. Therefore, FSK was selected as the optimum modulation technique for this application.

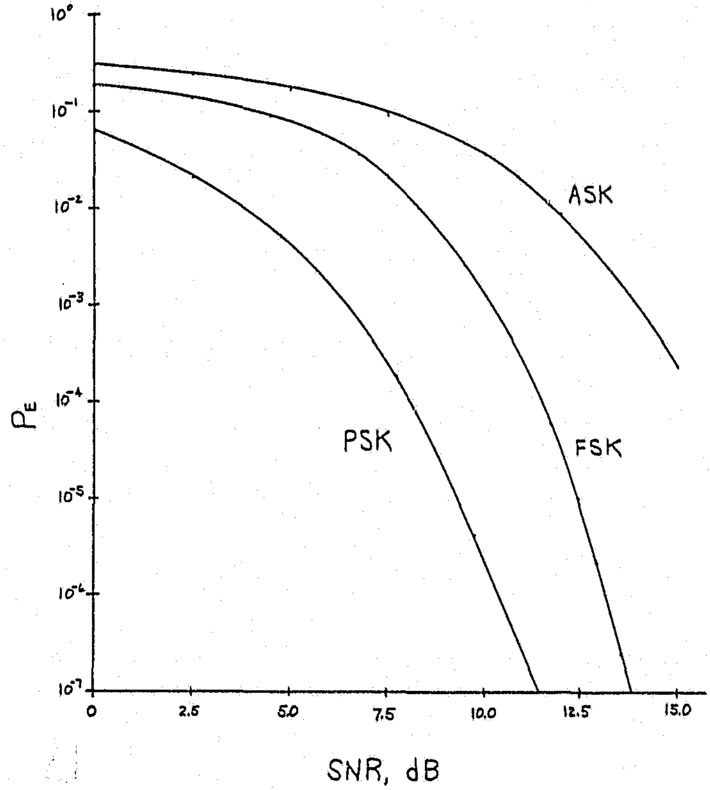


Figure 6-1. Bit Error Rate versus SNR for Gaussian Noise

6.4 BIT RATE SELECTION

In order to desensitize the powerline transmission system to noise transients which are phase coherent with the powerline frequency, such as SCR controllers, it is desirable to be able to integrate the detector output over at least 1 complete cycle of the 60 Hz line frequency. In order to evaluate this philosophy we ran bit error measurements at 30, 60, and 120 Hz bit rates. There was no basic difference between 30 and 60 Hz; however, the 120 Hz rate proved 4 dB worse at 10^{-4} BER. A bit rate of 60 Hz was therefore selected as the highest desirable from an error standpoint.

The 60 Hz selection is also a great advantage on the basis of bit synchronization. At low S/N (12 to 14 dB) the toughest problem by far is the recovery of bit synchronization not obtaining low BER from a synchronized detector. Therefore, if we use a 60 Hz bit rate we can use the 60 Hz powerline frequency as a system clock and thus have perfect bit synchronization and be able to integrate out output data over a full cycle of 60 Hz coherent interference. Also, we then make our bit decisions at the zero crossings of the 60 Hz where interference in our detector is a minimum.

6.5 DETECTION SCHEME

On the basis of the arguments contained in paragraph 6.4, it would seem that an integrate and dump detector should be superior to a sampling device in the face of the impulsive noise on the powerlines. The results of comparative testing showed an 8 dB improvement in favor of the integrate and dump detector at 10^{-4} BER.

CHAPTER VII. APPLICATION OF RESULTS TO BAS COMMUNICATIONS SYSTEM DESIGN

7.1 TRANSMITTER POWER

Using typical high-noise interfering sources operating on the powerline, we are able to operate with 40 dB attenuation of a +23 dBm transmitter and obtain 10^{-4} BER. The worst case line attenuation has been measured at 28.5 dB using a phase to phase coupling device; therefore, we have an 11.5 dB worst case margin under extremely high intentional interference.

In order to reduce the probability of units in adjacent buildings or apartments from interfering, it was decided to reduce this margin by 6 dB and specify the minimum transmitter power output as +17 dBm (50 mw).

7.2 OPERATING FREQUENCY

As noted earlier a nominal operating frequency of 170 kHz has been chosen on the basis of estimated interfering sources. A nominal tolerance of ±1 percent will be reasonable to maintain in production and stay well within the passband of realizable receiver preselector filters. Therefore, the transmitter frequency is specified as 170 kHz ± 2 kHz.

7.3 MODULATION

As noted earlier FSK modulation has been chosen as optimum in view of the erratic phase characteristics of the propagation medium. In order to obtain a high modulation index and improved S/N in the receiver, 10 kHz peak to peak deviation is selected based once again on the characteristics of realizable preselector filters and the ability to obtain a reasonably large output signal from a Phase Locked Loop demodulator.

7.4 BIT RATE

A bit transmission rate of 60 Hz is optimum based upon the use of the powerline frequency as a solid system clock for bit synchronization generation and recovery.

7.5 MODULATION FORMAT

Split phase modulation is chosen for application to BAS in that DC restoration is not required and in the absence of the powerline clock frequency bit synchronization may easily be recovered from the incoming data on a bit by bit basis.

7.6 RECEIVER SENSITIVITY

In that receiver noise itself will never be a limit upon data reception, the noise figure will not be of concern. Rather, we must insure that high levels of interference will not block reception. The worst case can of course be a transmitter and receiver adjacent for a maximum input of +20 dBm. In that an 80 dB dynamic range is quite easy for a receiver of this nature, -60 dBm has been selected as the rated sensitivity of the receiver itself for a 10^{-6} BER.

7.7 RECEIVER DEMODULATOR

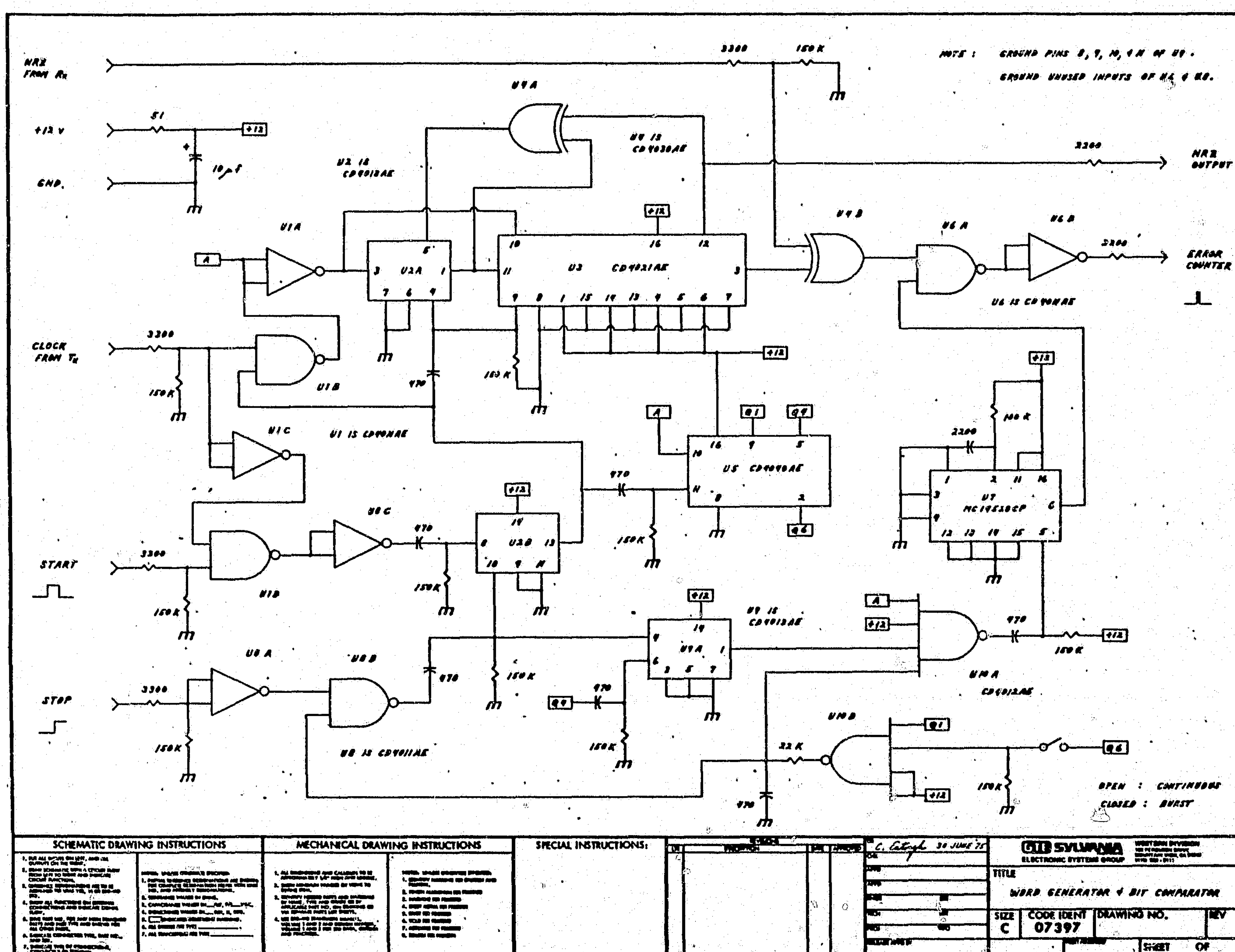
Phase lock demodulation has been selected early in the program based upon the availability of existing IC chips and the ease of obtaining squelch information while requiring no inductors.

7.8 FINAL SPECIFICATIONS

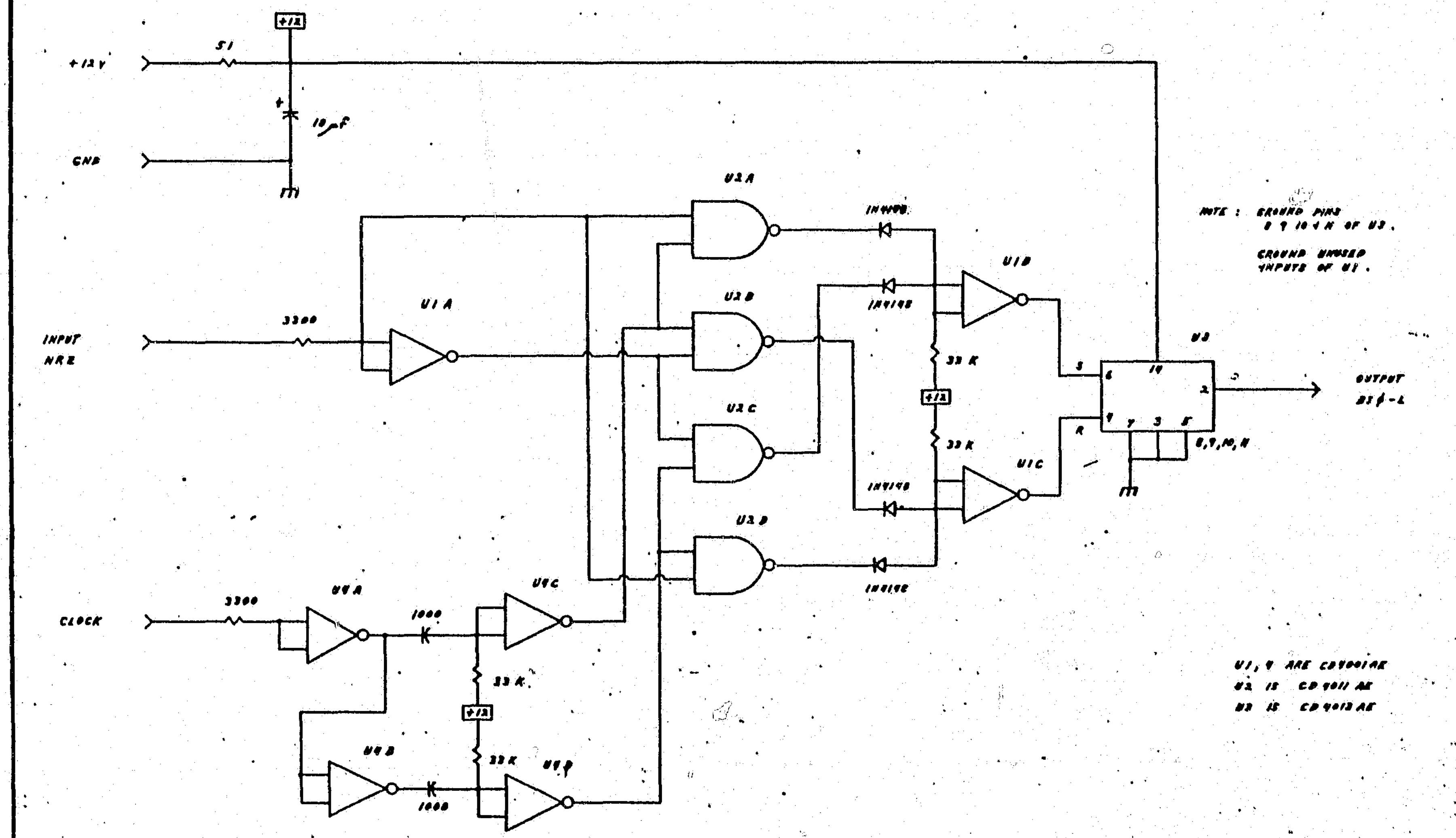
Transmitter Power	50 mw into 20 ohm load
Transmitter Frequency	170 ±2 kHz
Modulation	Binary FSK, Split Phase Code
Deviation	10 kHz peak to peak
Bit Rate	60 bps, synchronization with powerline
Receiver Frequency	170 ±2 kHz
Sensitivity	+20 to - 60 dBm
Preselection	Doubled tuned
Demodulation	PLL
Squelch	Automatic; obtained from PLL
Outputs	NRZ-L data at 60 bps plus separate clock

APPENDIX A

SCHEMATICS FOR BAS TEST EQUIPMENT


NRZ FROM Rx
+12 V
GND.
CLOCK FROM Tx
START
STOP
NOTE : GROUND PINS 8, 9, 10, 4 11 OF U9.
GROUND UNUSED INPUTS OF U4 & U8.
U4 A
U4 IS CD4030AE
U2 IS CD4013AE
U1 A
U2A
U3 CD4031AE
U4 B
U6 A
U6 B
U6 IS CD4049AE
U1 B
U1 C
U1 IS CD4049AE
U1 D
U8 C
U2B
U5 CD4040AE
U7 MC14520CP
U9 IS CD4013AE
U9A
U8 A
U8 B
U8 IS CD4011AE
U10 A CD4012AE
U10 B
NRZ OUTPUT
ERROR COUNTER
OPEN : CONTINUOUS
CLOSED : BURST
SCHEMATIC DRAWING INSTRUCTIONS
MECHANICAL DRAWING INSTRUCTIONS
SPECIAL INSTRUCTIONS:
SYLVANIA
ELECTRONIC SYSTEMS GROUP
TITLE
WORD GENERATOR & BIT COMPARATOR
SIZE C
CODE IDENT 07397
DRAWING NO.
REV
SHEET OF

A-3



SCHEMATIC DRAWING INSTRUCTIONS

MECHANICAL DRAWING INSTRUCTIONS

SPECIAL INSTRUCTIONS:

C. Catazzi 13 June '75

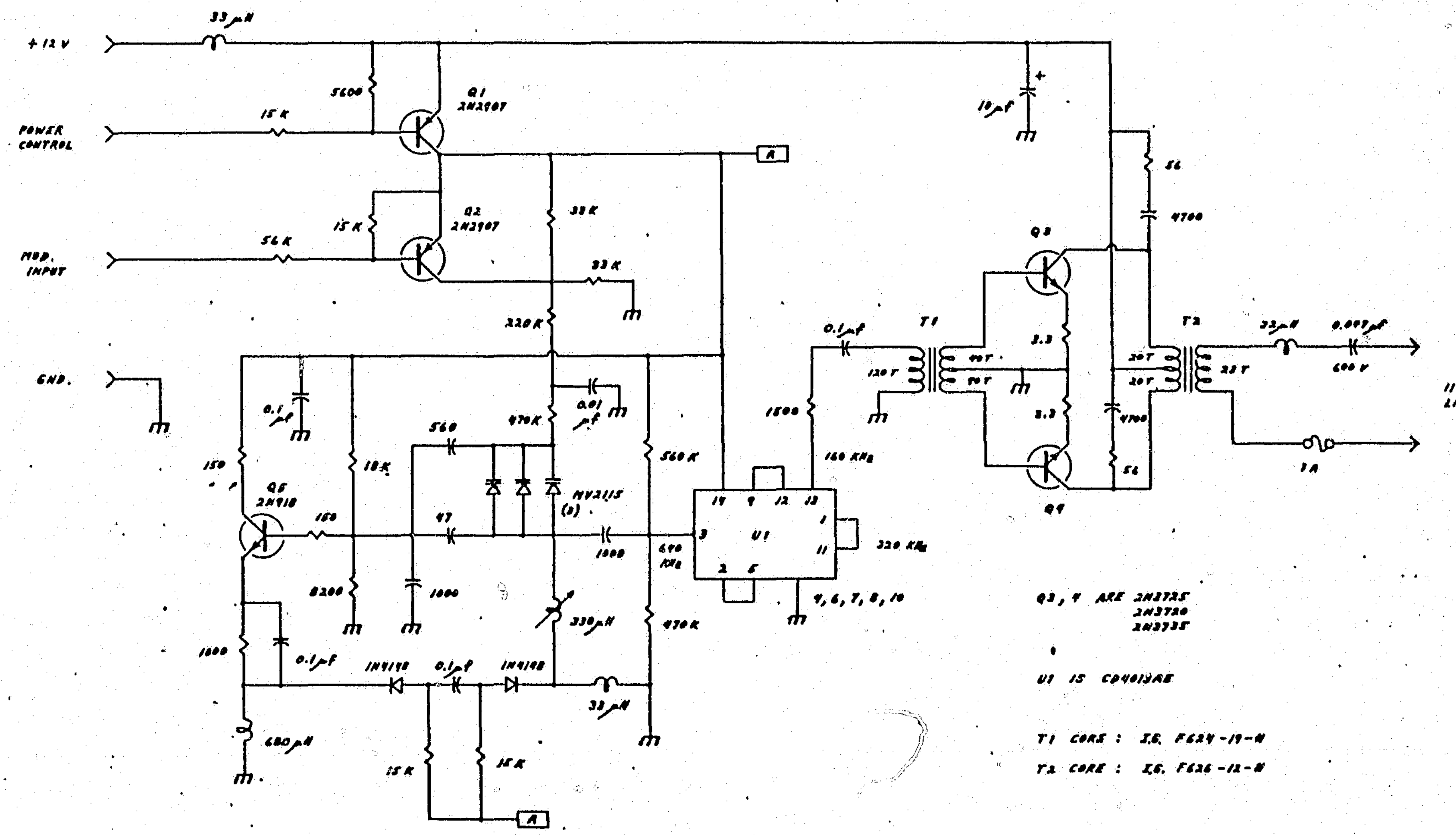
GTE SYLVANIA
ELECTRONIC SYSTEMS GROUP

TITLE
NRZ TO BIφ-L CONVERTER, BAS Tx

SIZE	CODE IDENT	DRAWING NO.	REV
C	07397		

SHEET OF

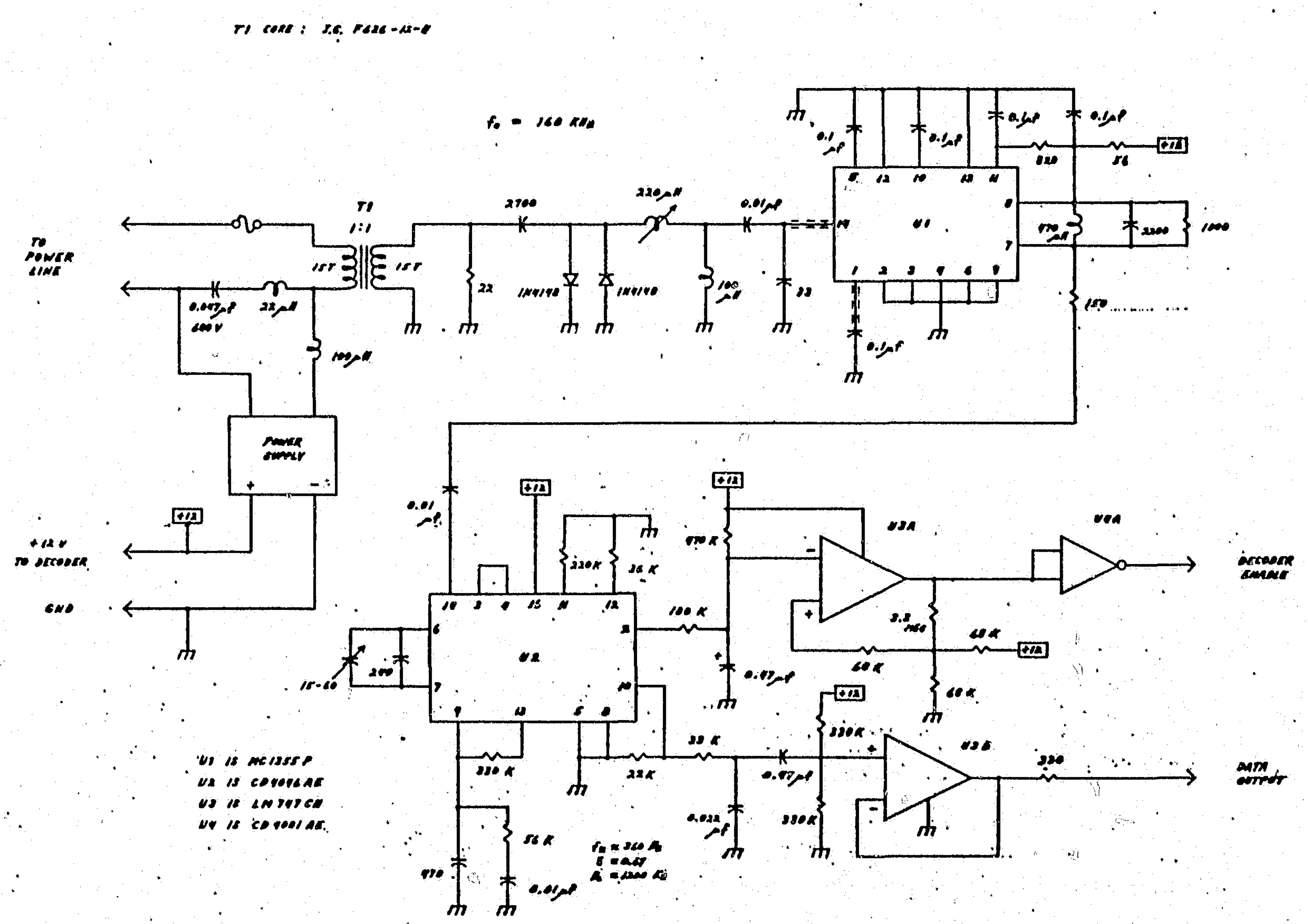
ESG-WD-3226 (2-72)



SCHEMATIC DRAWING INSTRUCTIONS	MECHANICAL DRAWING INSTRUCTIONS	SPECIAL INSTRUCTIONS:	REVISIONS	GTE SYLVANIA ELECTRONIC SYSTEMS GROUP — WESTERN DIVISION
				TITLE: BAS TEST Tx
				SIZE: C · CODE IDENT: 07397 · DRAWING NO.: · REV:
				SHEET OF

ESG-WD-3226 (2-72)

A-5



SCHEMATIC DRAWING INSTRUCTIONS	MECHANICAL DRAWING INSTRUCTIONS	SPECIAL INSTRUCTIONS:

SYLVANIA ELECTRONIC SYSTEMS GROUP

TITLE BAS RECEIVER

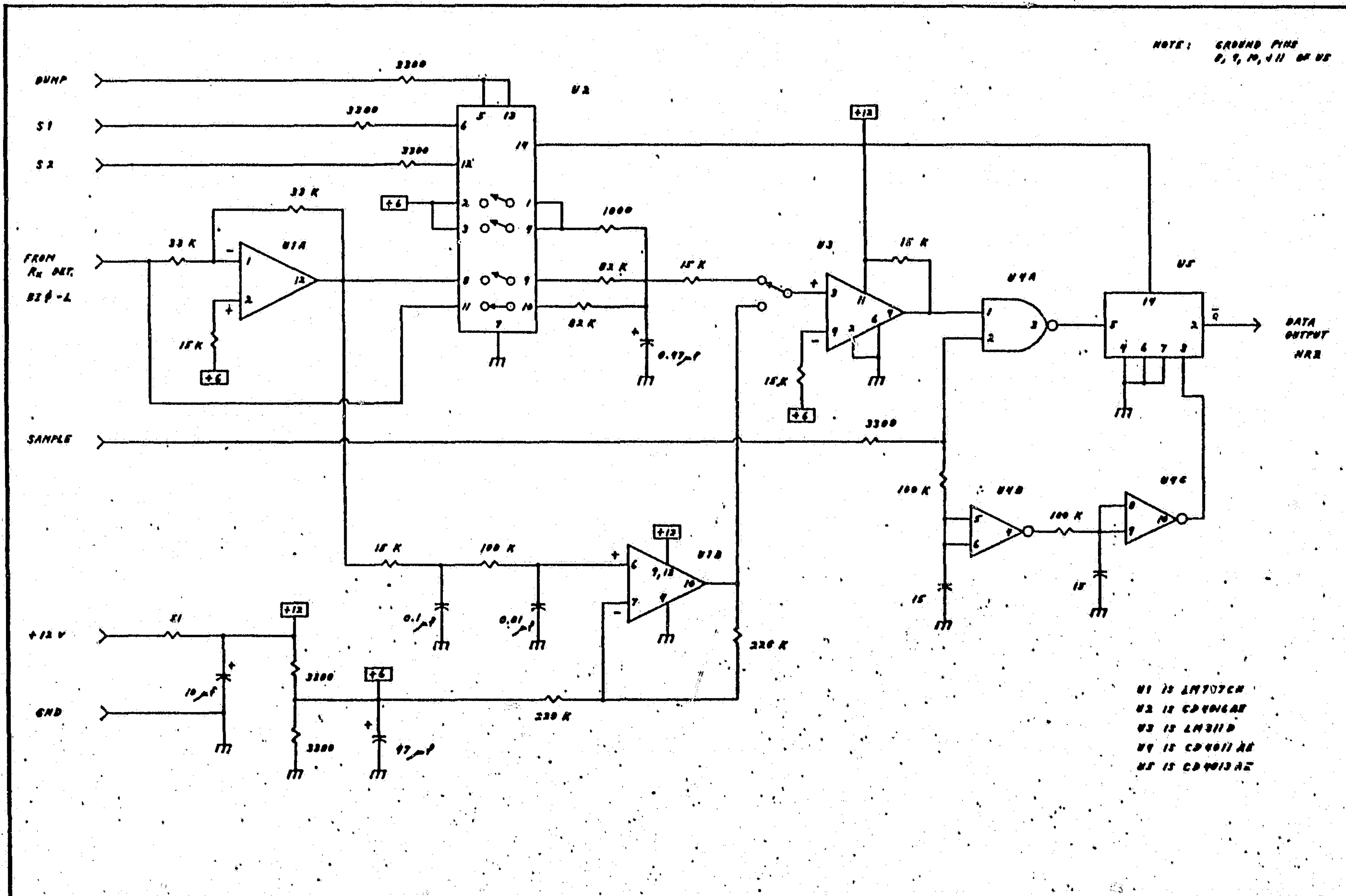
SIZE C | CODE IDENT 07397 | DRAWING NO. | REV

SHEET OF

ESG-WE-3236 (3-72)

1

A-6



SCHEMATIC DRAWING INSTRUCTIONS

MECHANICAL DRAWING INSTRUCTIONS

SPECIAL INSTRUCTIONS:

SYLVANIA ELECTRONIC SYSTEMS GROUP

TITLE

BIT DETECTOR , BAB Rx

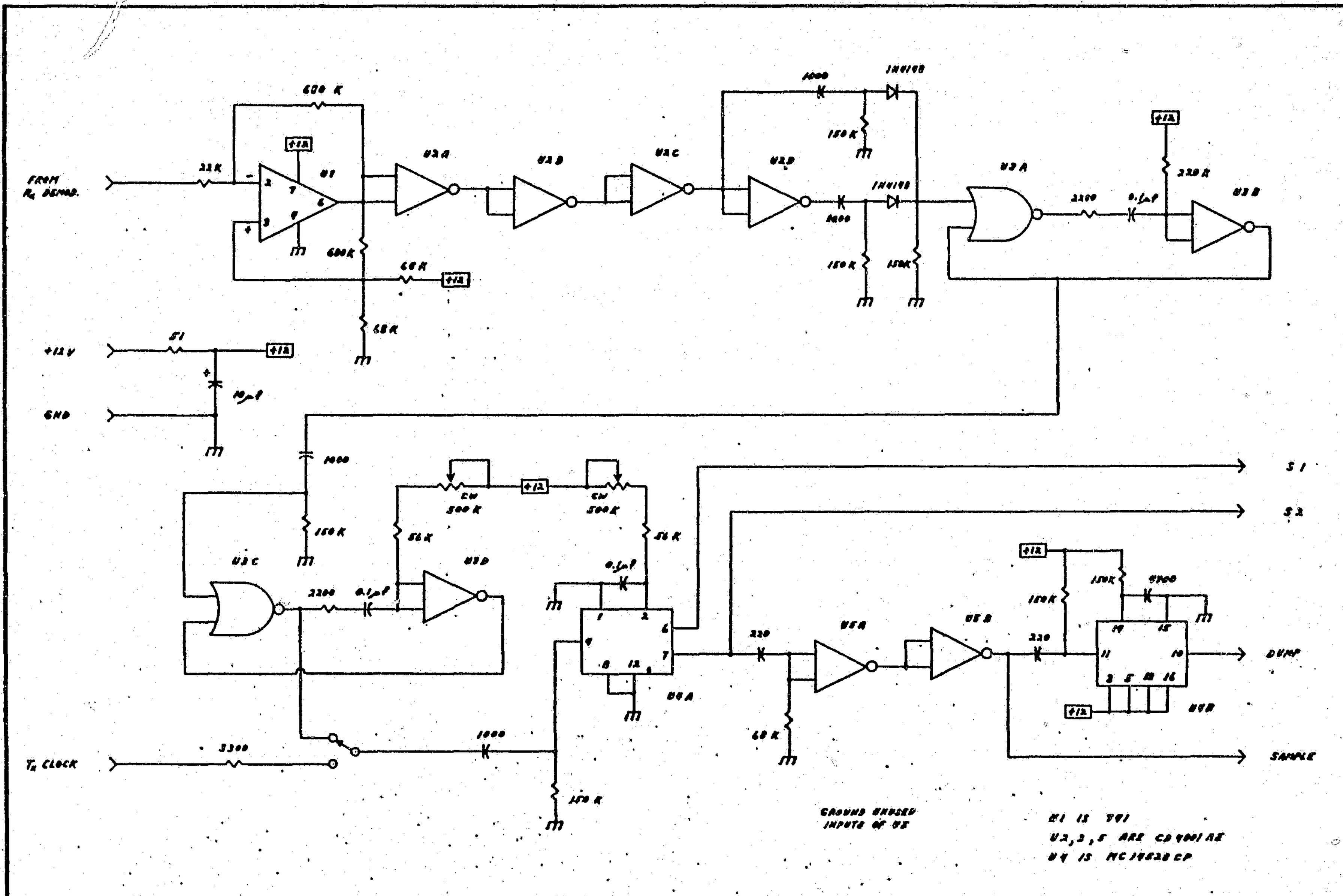
SIZE	CODE IDENT	DRAWING NO.	REV
C	07397		

SHEET OF

ESD-WD-3236 (2-72)

CONTINUED

1 OF 2



SCHEMATIC DRAWING INSTRUCTIONS | MECHANICAL DRAWING INSTRUCTIONS | SPECIAL INSTRUCTIONS:

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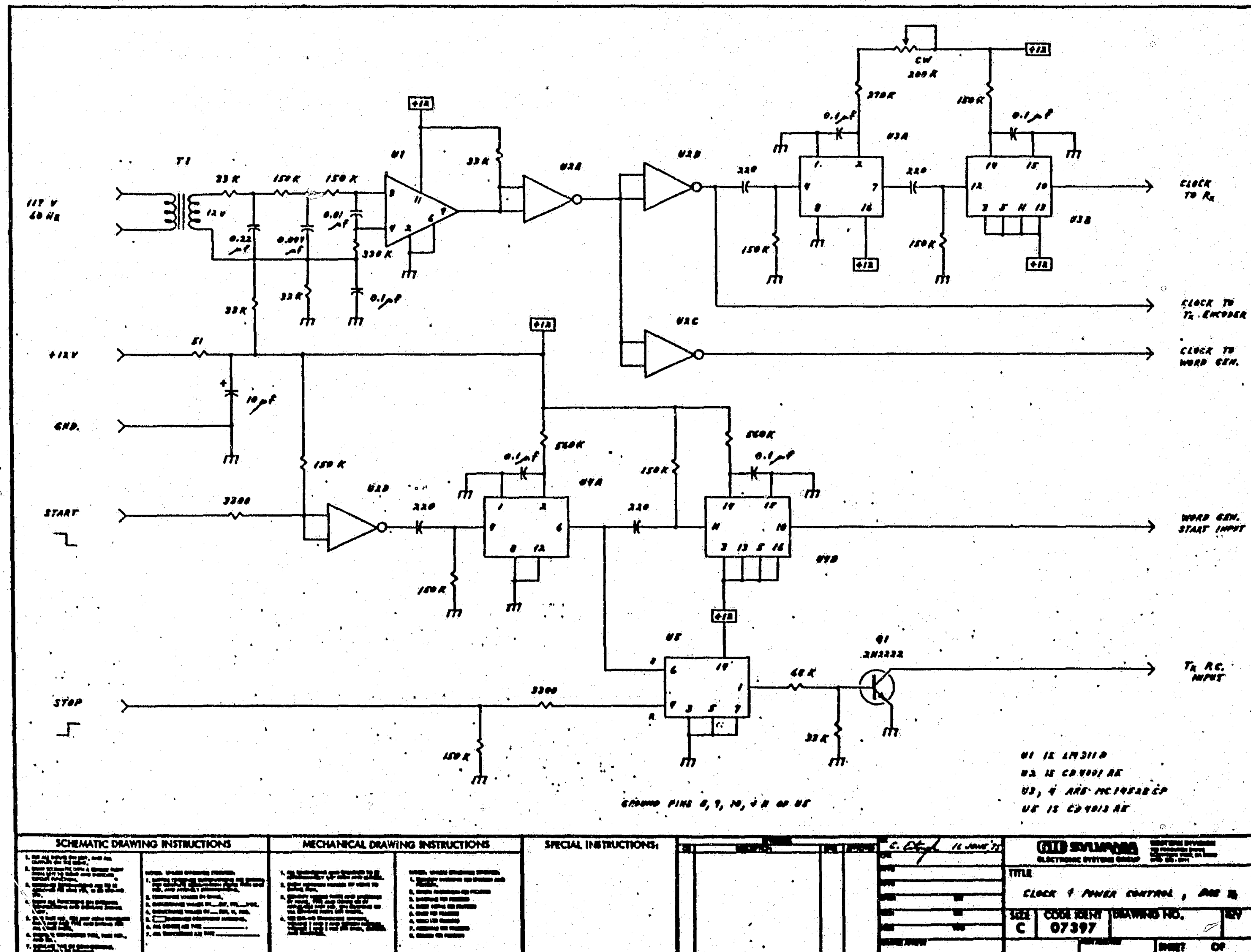
TITLE: CLOCK. RECOVERY ; BRS Rx

SIZE: C | CODE IDENT: 07397 | DRAWING NO. | REV

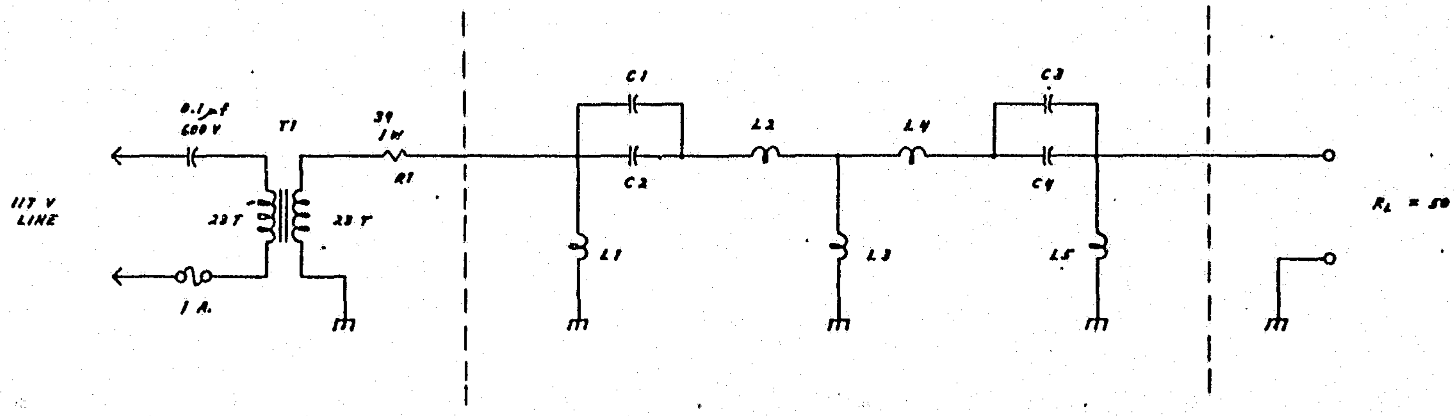
SHEET OF

ESG-WD-3226 (2-72)



ESG-WD-3136 (3-72)

T1 CORE : IG F626-12-N



FREQUENCY	BW	L1	C1	C2	L2	L3	L4	C3	C4	L5
170 KHz	3 KHz	10 μH Q ≥ 50	220 pf MICA	3900 pf MICA	200 μH Q ≥ 180	3.5 μH Q ≥ 50	200 μH Q ≥ 180	220 pf MICA	3900 pf MICA	10 μH Q ≥ 50
320 KHz	6 KHz	5.1 μH Q ≥ 50	120 pf MICA	2200 pf MICA	100 μH Q ≥ 180	1.8 μH Q ≥ 50	100 μH Q ≥ 180	120 pf MICA	2200 pf MICA	5.1 μH Q ≥ 50
450 KHz	8 KHz	3.9 μH Q ≥ 50	82 pf MICA	1500 pf MICA	75 μH Q ≥ 180	1.3 μH Q ≥ 50	75 μH Q ≥ 180	82 pf. MICA	1500 pf MICA	3.9 μH Q ≥ 50

SCHEMATIC DRAWING INSTRUCTIONS

MECHANICAL DRAWING INSTRUCTIONS

SPECIAL INSTRUCTIONS:

SYLVANIA ELECTRONIC SYSTEMS GROUP

TITLE BAND PASS TEST FILTERS, BAS

SIZE C | CODE IDENT 07397 | DRAWING NO. | REV

SHEET OF

ESG-WD-3236 (2-72)

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