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Investigation of a Very High Frequency (VHF) Directional Power Detector for the Remote Maintenance Monitoring System (RMMS)

John L. Wiley

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16. Abstract

This report describes a series of tests performed on newly-developed very high frequency directional power detector (DPD). It was concluded that this DPD met the specified requirements and is acceptable as a sensor for the Remote Maintenance Monitoring System (RMMS).

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PREFACE

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EXECUTIVE SUMMARY

Under the Remote Maintenance Monitoring System (RMMS) program at the Federal Aviation Administration Technical Center, one task was to develop modules and sensors for monitoring radio frequency (RF) transmitters. To measure the power in an RF transmission line, a directional power detector (DPD) is used. Because of problems with existing DPD's, a very high frequency (VHF) DPD was developed by a vendor, based on requirements given to him by the FAA Technical Center.

This report describes the tests performed on this DPD to validate its performance and determine its suitability for use as an RF sensor in the Remote Maintenance Monitoring System (RMMS). It is concluded that this DPD met the specified requirements and is acceptable as a sensor for RMMS.

INTRODUCTION

PURPOSE.

The purpose of this task was to investigate the performance of very high frequency (VHF) directional power detectors (DPD) for possible use as sensors in test functional module (TFM) applications.

BACKGROUND.

As part of Task 9 of 9550-AAF-501-78-002, the Federal Aviation Administration (FAA) Technical Center was tasked to develop TFM's for the Remote Maintenance Monitoring System (RMMS). Under the TFM development effort, one requirement is the need to monitor radio frequency (RF) signals for communications equipment. An investigation of the DPD's that are presently being used in FAA transmitters disclosed that several problems existed with these sensors. The first of these problems is that the transfer function of the DPD voltage output, with respect to the transmission line power, is a nonlinear equation. This makes interfacing the DPD to a microcomputer system more difficult due to the calculations required. The second problem with this DPD is that the output signal voltage from the reflected power port is very small (reference 1) making it susceptible to interference and noise. The third problem is that the low directivity of the DPD limits the accuracy of voltage standing wave ratio (VSWR) calculations (reference 2). Because of these problems, a VHF directional power detector was developed and built by Coaxial Dynamics Incorporated (CDI), Cleveland, Ohio, based on requirements given to them by the FAA Technical Center.

DISCUSSION

GENERAL.

DESCRIPTION OF THE DIRECTIONAL POWER DETECTOR. The VHF directional power detector, model 3182, from CDI has the following specifications:

1. Maximum forward and reflected transmission line powers are 60 watts and 15 watts, respectively.

2. Reflected power port directivity is greater than 40 decibels (dB).

3. Output voltage squared is linear with respect to the transmission line power with less than two percent linearity error.

The CDI detector has built-in amplifiers to increase the output voltage and provide a low impedance output, thus, it requires ± 18 volts direct current (d.c.) to operate. The physical dimensions of the detector are 3.0 inches long by 1.75 inches wide by 1.0 inches high. The detector has a female TNC connector on the input from the transmitter and a female N connector on the output to the antenna. The forward and reflected ports have female SMA connectors. (These connectors were specified by the FAA Technical Center to make this DPD physically compatible with existing FAA DPD's.)

TESTS CONDUCTED.

A series of seven tests were conducted on the CDI detector. These tests were run to investigate linearity, accuracy, insertion losses, and modulation problems. The seven tests are described in subsequent paragraphs.

The following test equipment were used in these tests:

Alford Slotted Line assembly consisting of:

Alford Slotted Line, Type 1026C-6
Alford Taper Reducers, Types 1122C and 1122D
Alford Tuned Probe, Type 2162X

Bird Terminator 50 ohmns, Model 81B

CDI RF Tap-off, Model 7992

Hewlett-Packard (HP) Attenuator with power sensor, Model 8481B
HP Audio Generator, Model 200AB
HP Modulation Analyzer, Model 8901A
HP Power Meters, Models 436A, 435B
HP Power Sensors, Models 8481A, 8481H
HP Signal Generator, Model 8640B
HP SWR Meter, Model 415E

International Telephone and Telegraph VHF Radio Transmitter, Model T1108/GRT21

Narda Directional Coupler, Model 3020A

RF Communications, RF Amplifier, Model RF-815

Systron Donner Digital Voltmeter, Model 7005A

To produce a range of different VSWR values for these tests, a set of mismatched loads were used. The mismatched loads were made by connecting different length coaxial cable stubs in parallel with the 50 ohm line termination using a tee connector, as shown in the related test configuration drawings.

TESTS 1 AND 2. The pupose of tests 1 and 2 was to determine the relationship of the detector DC voltage output to the transmission line power. In test 1 the CDI detector was located closest to the transmitter, followed by the Narda coupler, then the stub and a 50 ohm load (see figure 1). For test 2 the CDI detector and the Narda coupler were reversed (see figure 2). The reason for the switching of the position of the CDI and the Narda was to allow the insertion losses of the two devices to be seen in the test data.

The tests were conducted at three frequencies in the VHF band: 118.00, 127.00, and 133.125 megahertz (MHz); the low end, middle, and upper end of the band, respectively. The VSWR was also varied for these tests by the use of stubs in front of the 50 ohm load. The range of VSWR's were from approximately 1.02:1 to 1.75:1 with one additional VSWR of greater than 4.00:1 at 133.125 MHz. This range of VSWR's was used because it is the typical VSWR range for communication transmitters used by the FAA. The one VSWR greater than 4.0:1 was run to check the operation of the detector outside the expected VSWR range.

The last variable that was changed in these two tests was the transmitter output power. This power was varied from 5 to 15 watts in 1 watt increments, as seen by the Narda coupler. For each set of tests the d.c. offset voltage of the detector was recorded from both the forward and reflected ports when there was no power in the transmission line (transmitter unkeyed). The reason for recording these data was to later assess its effects on the VSWR and power calculations.

Included in test 1 data was a run of data with and without 5,000 ohm loading resistors across the detector outputs. This test was run to determine if loading resistors were needed and what effects they would have on the detector's output voltage. The data taken in this test is shown in table 1.

TESTS 3 AND 4. Tests 3 and 4 were designed to compare the actual VSWR of the transmission line against the VSWR calculated from the CDI detector's data and the Narda coupler's data. The actual VSWR of the transmission line was measured with a slotted line and SWR meter.

In test 3 the Narda coupler was used in the system (see figure 3). In this test the Narda was located closest to the transmitter, followed by the slotted line, then the stub and the 50 ohm load. Test 4 used the CDI detector instead of the Narda coupler (see figure 4).

These two tests were conducted under the same conditions as tests 1 and 2 with the exception that only three transmitter power levels were used: 5, 10, and 15 watts. The power was adjusted to the required level as seen by the Narda coupler in test 3 and CDI detector in test 4. The power levels for the CDI detector were derived from test 1 data.

TEST 5. The purpose of test 5 was to determine the effect of the Narda coupler and the CDI detector on the VSWR in the transmission line. The results of this test were needed to validate the assignment of the CDI detector voltages to the power levels found in tests 1 and 2.

This test was conducted in three parts. Part A was the measurement of the VSWR of the transmission line without the coupler or detector. The test configuration included the slotted line, a connector, a tee with stubs, and a 50 ohm load (see figure 5). The extra connector was inserted into the

system to account for any VSWR change caused by the adapter on the CDE detector and the Narda coupler. For part B the CDI detector was added where the connector had been (see figure 5). In part C the CDI detector was replaced by the Narda coupler (see figure 5). All three parts of test 5 were conducted at approximately 10 watts forward power and with the same set of stubs. The data values for the VSWR from part A were used as the reference values for parts B and C. In part B, with the CDI detector added, the VSWR readings from the slotted line were taken with the detector's ±18 volt supply on and off. This was done to see if the VSWR changed due to the CDI detector's supply voltage. See figure 5 for data from test 5.

TEST 6. The purpose of test 6 was to measure the effect of transmitter frequency change on the output voltage of the CDI detector. The test configuration consisted of the ITT VHF radio transmitter, the CDI detector, a 30 dB attenuator, and the HP power meter with power sensor (see figure 6). The reason for the 30 dB attenuator is to allow the power meter to directly measure the RF power in the transmission line without affecting the impedance of the transmission line.

The first part of test 6 compared the forward port voltage of the CDI detector against the power in the transmission line. These data are shown in table 2. The second part of test 6 compared the reflected port voltage of the CDI detector against the power in the transmission line. For this second part, the CDI detector was reversed in the transmission line. The data from this part of test 6 is shown in table 2.

TEST 7. The purpose of this test was to determine if there is an appreciable d.c. voltage level shift out of the CDI detector's ports when the transmitter is modulated with various percentages of sine wave modulation. The reason for this test is that an earlier test of directional power detectors (reference 1) found that some detectors have an appreciable d.c. level shift when sine wave modulation of 50 percent was applied to the transmitter. The configuration for test 7 was a signal generator, an RF amplifier, an RF tap-off, a modulation analyzer, the CDI detector, and a 50 ohm load (see figure 7). The test was run at 118.00 MHz with the output power from the RF amplifier set to 2 watts. The signal generator was varied from 0 to 100 percent modulation. The data are shown in table 3.

TEST RESULTS.

TESTS 1 AND 2. The data from tests 1 and 2 are used to relate CDI detector voltage to transmission line power. When the CDI detector's output voltages are squared and compared to the power levels, the relationship between them is found to be approximately linear. The plots of forward CDI detector voltage squared versus forward Narda coupler power and reflected CDI detector voltage squared versus relected Narda coupler power are shown in figures 8 through 19. Each plot shown has a straight line superimposed over the line that traces the data points. This straight line was calculated from the data points by the use of linear regression techniques; the equation of the straight line is given at the top of each graph. The linearity of the detector was relatively constant throughout the power and VSWR range (see figures 20 through 23) but did change in offset and slope

with a change in frequency (see "Discussion of Results"). From the data taken at 133.125 MHz with greater than 4.0:1 VSWR, it was found that the detector was still linear (see figures 24 through 27). It should be noted, for RMMS use, that a VSWR of 4.0:1 is far above the normal operating range of VHF communications equipment.

As part of these tests, the effect of the detector's offset voltage (the output voltage of the detector when the transmitter is not keyed) on the linearity was investigated. It was found that the linearity of the CDI data was slightly improved when the offset voltage was not subtracted (see figures 28 and 29).

The last part of test 1 was to examine the effects of loading resistors on the output ports of the CDI detector. It was found that the loading resistors had no effect on the output voltage (see table 1).

TESTS 3 AND 4. Tests 3 and 4 data were used to calculate the VSWR from the CDI detector and the Narda coupler. These VSWR values were then compared to the slotted line VSWR. The VSWR values with the percent deviation from the slotted line are shown in tables 4 through 12. These data show that the Narda coupler has a small, but constant, deviation from the slotted line. This deviation is approximately two percent over the normal operating range of the transmitter, 1.4:1 to 2.0:1 VSWR.

The CDI detector VSWR was compared to the slotted line's VSWR in two ways. The first comparison used the detector's VSWR without the offset correction taken into account. It was found that this VSWR was very close to the slotted line VSWR values, with a deviation of approximately one percent in the normal operating range. The second comparison used the detector's VSWR with the offset correction taken into account. These data show a larger deviation from the slotted line (approximately an added two and one-half percent error).

TEST 5. The data from test 5 (see figure 5) show that there is no significant change in VSWR caused by the insertion of the Narda coupler or the CDI detector in the transmission line. The change in the VSWR for either device was less than one-half of one percent. The test also showed that the VSWR in the transmission line did not change if the d.c. power to the detector was on or off. It should be noted that this small a change in VSWR is very hard to detect and probably includes some reading errors from the slotted line.

TEST 6. Test 6 was conducted to determine the effect of transmitter frequency on the CDI detector output voltage. The plots of the data from this test are shown in figures 30 through 33. The first two plots are of the CDI detector output voltages squared, forward, and reflected versus the power in the transmission line with the offset voltage subtracted from the CDI output voltages. In the second two plots the offset voltage is not subtracted from the CDI output voltages. All four plots show that the CDI detector's output voltage squared versus the power in the transmission line is very insensitive to frequency change within the VHF frequency range. The plots without the offset voltage subtracted (figures 32 and 33) show less effect from frequency change than the plots with the offset voltage subtracted (figures 30 and 31).

TEST 7. The data from test 7 (see figure 7 and table 3) show a very small decrease in d.c. voltage out of the detector as the sine wave modulation increases from 0 to 100 percent. The reason for this decrease in the d.c. voltage is that the signal generator does not output a perfectly symmetrical sine wave and the CDI detector averages the sine wave peaks. The data show the percent modulation of both the positive and negative peaks as seen by the modulation analyzer.

Test 7 also indicates that the modulation voltage out of the CDI detector is linear to the percentage of modulation in the transmission line. A plot of CDI peak-to-peak voltage versus percent modulation in the transmission line is shown in figure 34.

DISCUSSION OF RESULTS.

The results from test 1 and test 2 show that the output voltage squared of the CDI detector is linear with respect to the power in the transmission line. This linearity makes the calculation of the forward power, reflected power, and the VSWR in the transmission line easier than with nonlinear detectors. As noted earlier, the detectors that had been previously tested required a higher order equation to translate output voltage to transmission line power.

There are many ways to do this translation when using a microcomputer but the two most used techniques are table lookup and breaking of the curve. Table lookup means that a table of values is stored in memory and these values correspond to known input values. In the case of the old detector, the values stored in the table are the power in the transmission line and the table's address is found from the detector's output voltage. The problem with using lookup tables is that as the resolution of the output goes up, or, if there is a wide range to be covered, the size of the table becomes large. For RMMS work with the old detector, the lookup table would become very large and, therefore, take up a large amount of system memory.

The technique of breaking the curve means that the high order curve is split into small pieces and a low order equation (usually linear) is used to approximate each small piece. The problem with this approach is that error can be large if the curve is not broken into small enough pieces. But on the other side, the smaller the pieces the more equations to be run by the microcomputer, therefore, more software is required.

The new CDI detector, with the linear output, only required the microcomputer to square the voltage and then use a linear equation to get the power. There is one problem that arises with the new detector. The microcomputer must be able to multiply numbers to get the forward power. This could be done in hardware with a math-processor chip or in software. However, the VSWR calculation is simplified with a linear detector, as the VSWR can be caculated with a linear equation (see appendix A).

The plots from test 1 or test 2, when compared with each other over the frequency range of the tests, show that there was a change in the equations of the lines. This change shows in both the offset and slope values of the

equations. Because of this potential problem, test 6 was conducted. Test 6 showed that the CDI detector had little output voltage change as the frequency changed. Test 6 was also run using the Narda coupler (test data are not shown in this report) and it was found that the Narda was injecting the output shift with frequency. Because of this problem it should be noted that the data from tests 1 and 2 can only be used to check the linearity of the CDI and not to set up a data base to be used to compare power in the transmission line to the voltage output of the CDI detector.

Test 1 also shows that the loading resistors had no effect on the output voltage of the detector. This result was expected due to the use of operational amplifiers (op-amps) in the detector. Op-amps characteristically have a low output impedance and the presence of the loading resistors is insignificant. The reason the op-amps are used in the detector is for amplifying the output voltages. This built-in amplification helps to eliminate the noise problems found in the earlier detectors.

Test 4 results show that under the typical operating range of VSWR for FAA VHF transmitters (1.4:1 to 1.6:1), the CDI detector's calculated VSWR was very close to the VSWR of the transmission line. It was found that the error between the detector and the slotted line was less if the detector's d.c. offset voltage was not subtracted from the output voltage.

There is one important note about the VSWR in a transmission line that must be considered. Due to attenuation in the transmission line, the VSWR as seen by the transmitter will not be the same as seen at the antenna. Appendix B discusses this phenomenon. The uses of the detector for RMMS is not only to measure the transmitter's forward power, but also to determine if any problems exist in the transmission line or the antenna. Because the VSWR seen at the transmitter is not the VSWR of the antenna, it would be better to physically locate a detector as close as possible to the antenna. This was not feasible with older detectors due to the noise problems, but is feasible with the new detector with the built-in amplifiers.

The last test results to be discussed are from test 7. The data (see table 3) show that there was no appreciable CDI voltage level shift out of the detector as the modulation increases. But this test also showed that the modulation out of the detector was linear to the modulation in the transmission line. The output of the detector did not distort or cause phase shift to the input sine wave modulation.

CONCLUSIONS

Based on these tests, it is concluded that:

1. The directional power detector (DPD) tested is acceptable as a sensor for Remote Maintenance Monitoring System (RMMS).

2. The DPD performed satisfactorily over the required power and frequency range.

3. The Coaxial Dynamics Incorporated (CDI) detector voltage squared output is linear with respect to transmission line power.

4. The voltage standing wave ratio (VSWR) calculated from the output of the CDI detector without the offset correction is within ± 3 percent when compared to the slotted line value over the tested VSWR range. With the offset correction included, the deviation is within ± 6 percent.

5. The CDI detector can be used to determine percent modulation in the transmission line.

6. The directivity of the CDI detector is acceptable for RMMS work.

RECOMMENDATIONS

It is recommended that:

1. A selection of the directional power detectors be obtained from a production run and that similiar testing be conducted on them to verify that their characteristics are consistent.

2. An ultra high frequency (UHF) directional power detector (Model 3183) made by Coaxial Dynamics Incorporated (CDI), with specifications similiar to the very high frequency (VHF) detector, should be tested to verify its characteristics.

3. Have CDI add lightning protect circuitry to the detector and then test the detector to verify its characteristics.

4. An investigation and tests be conducted to determine the feasibility of placing the CDI detector at the antenna in addition to the transmitter.

REFERENCES

1. Talotta, Nicholas J. and Rehmann, Albert J., Development of an Automated Remote Communications Air-Ground (RCAG) Monitoring System, FAA-RD-79-125, April 1980.

2. Talotta, Nicholas J. and Rehmann, Albert J., Recommendations for an RCAG Monitoring System, Subprogram 066-222, FAA LetterReport NA-78-4-LR, February 1978. (Limited Distribution)

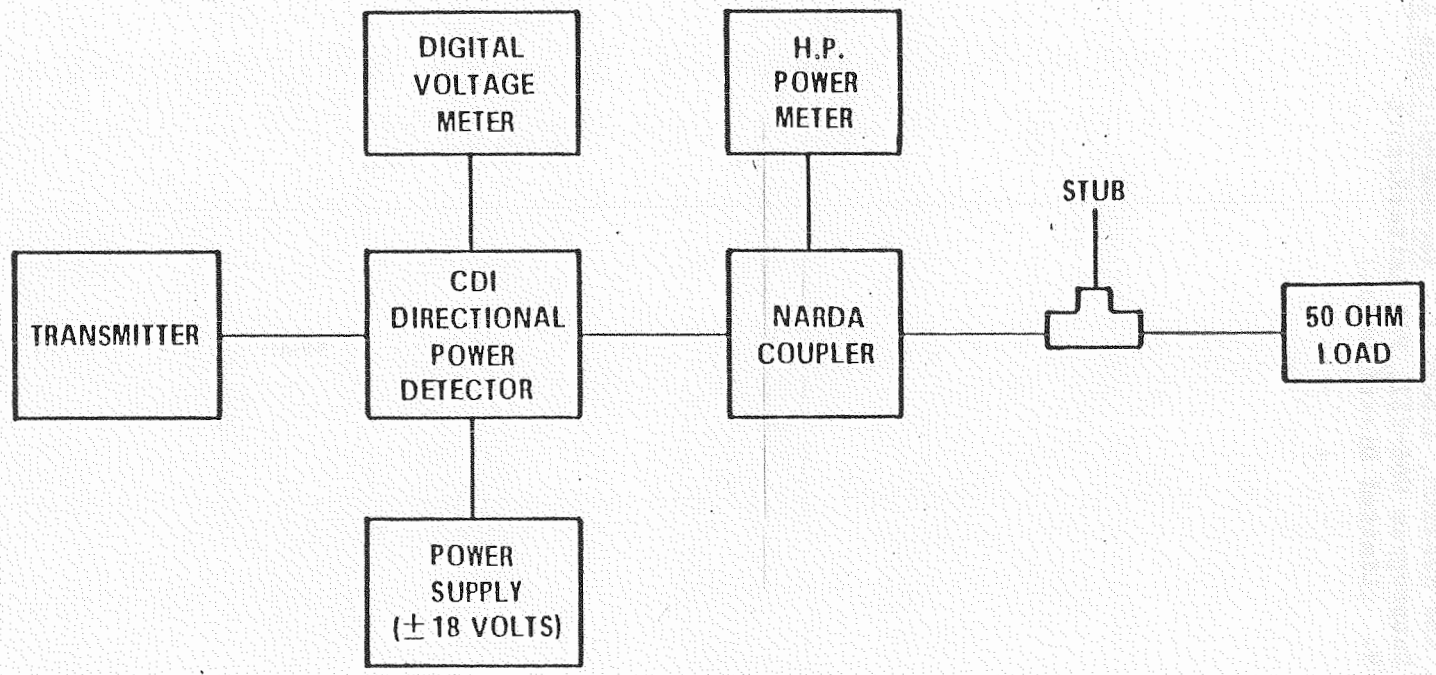


FIGURE 1. TEST 1 CONFIGURATION

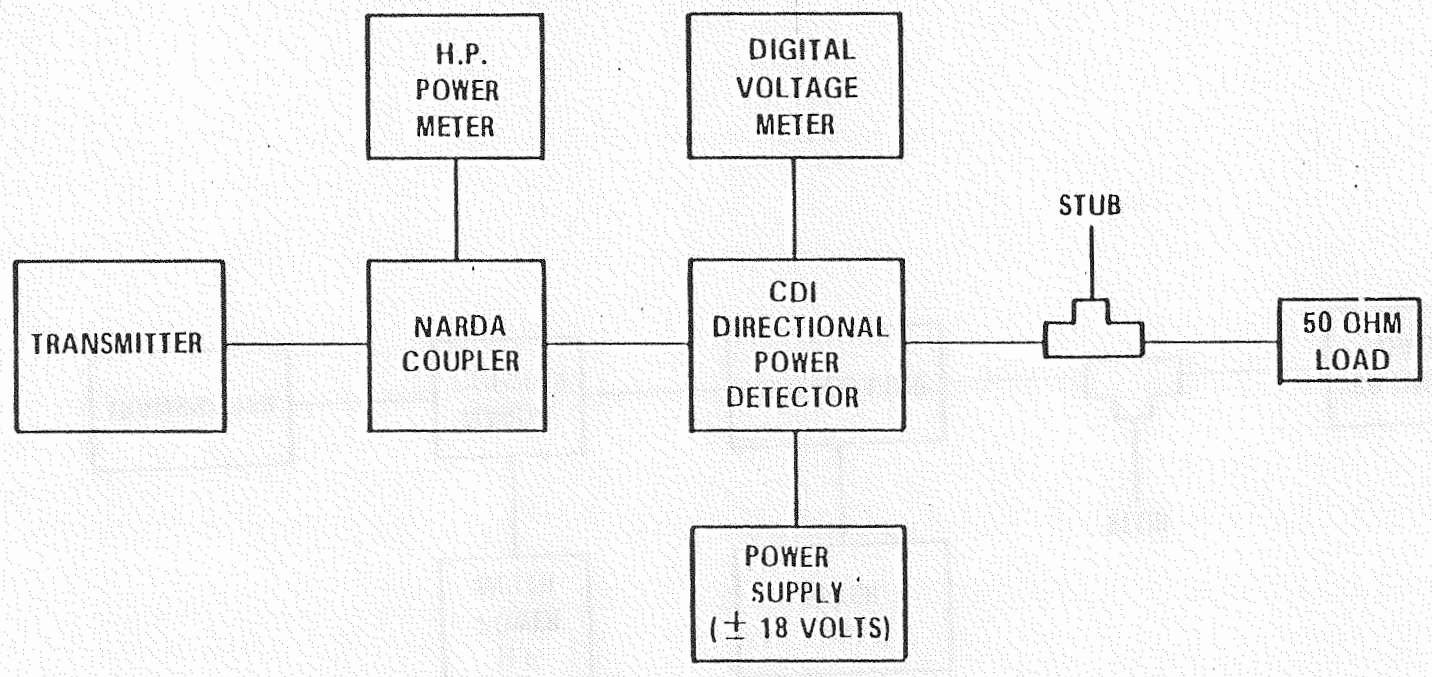


FIGURE 2. TEST 2 CONFIGURATION

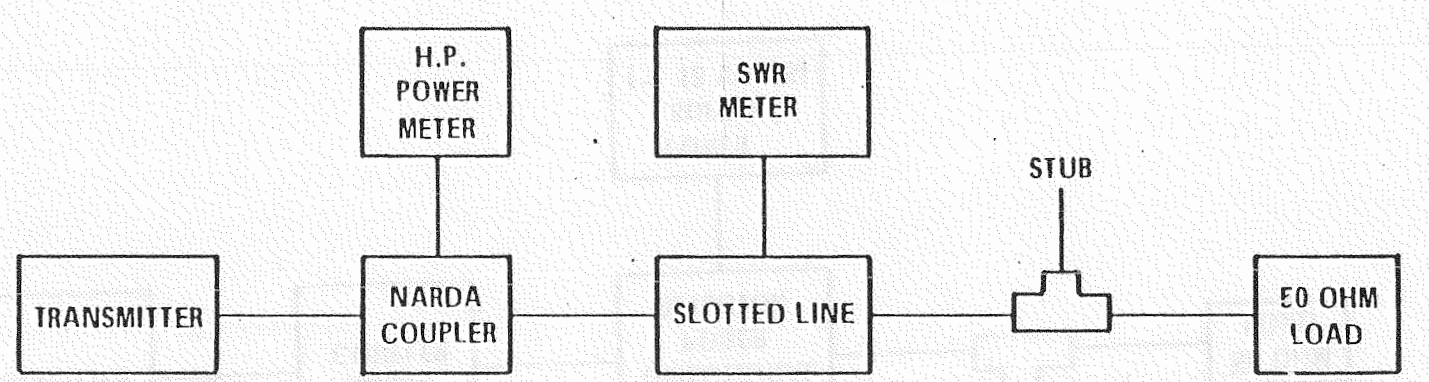


FIGURE 3. TEST 3 CONFIGURATION

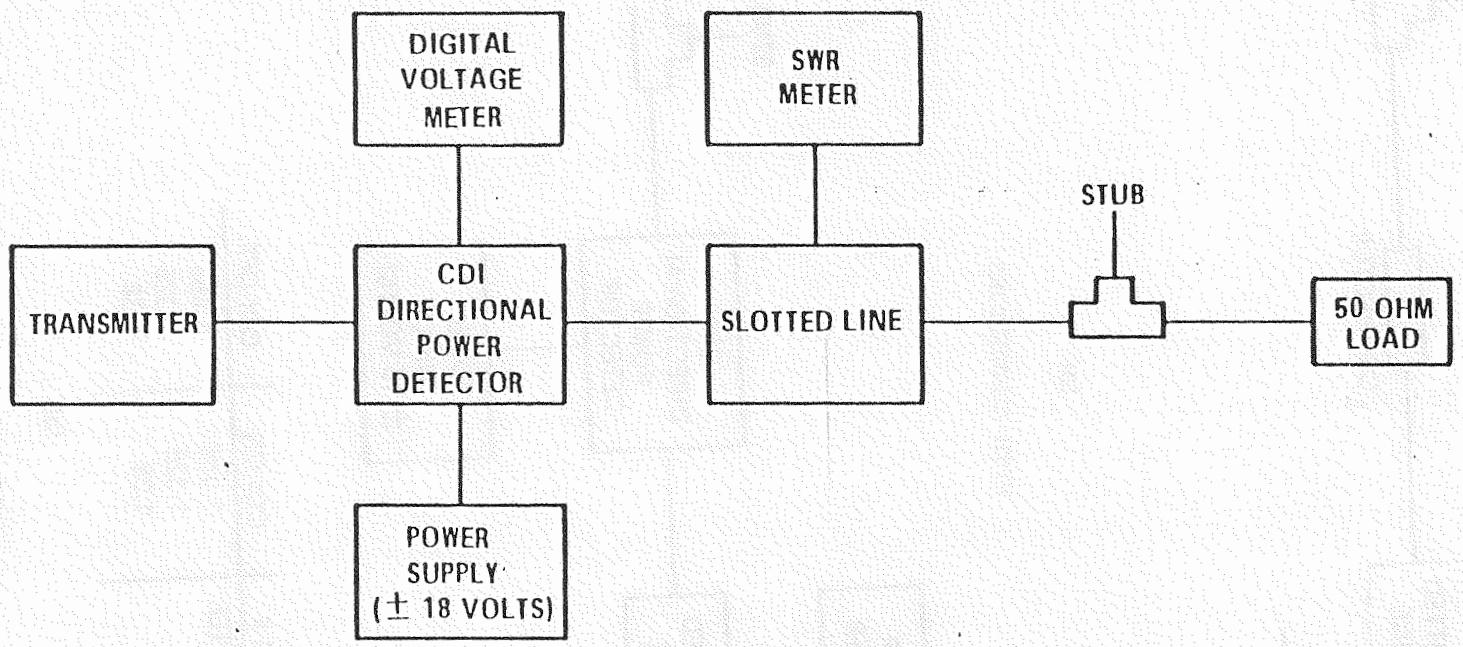
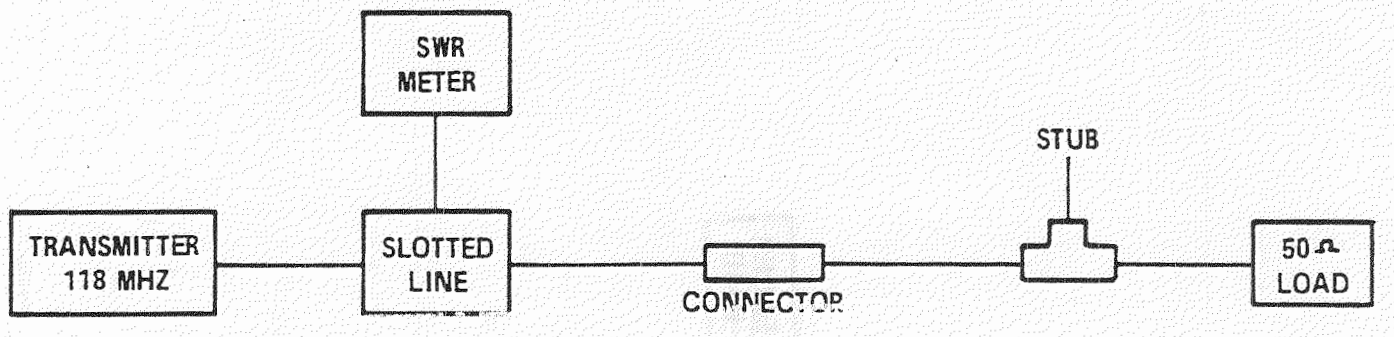


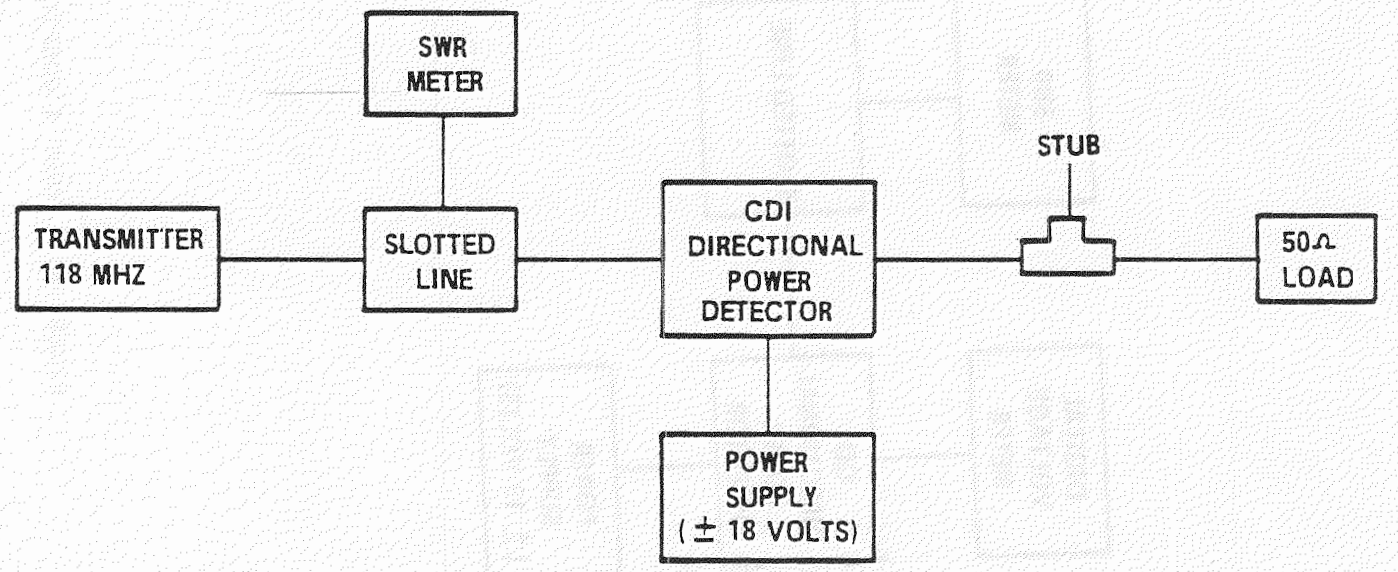
FIGURE 4. TEST 4 CONFIGURATION



STUB #	VSWR
WITH TEE	1.065
# 1	1.321
# 2	1.375

(a)

WITH CONNECTORS

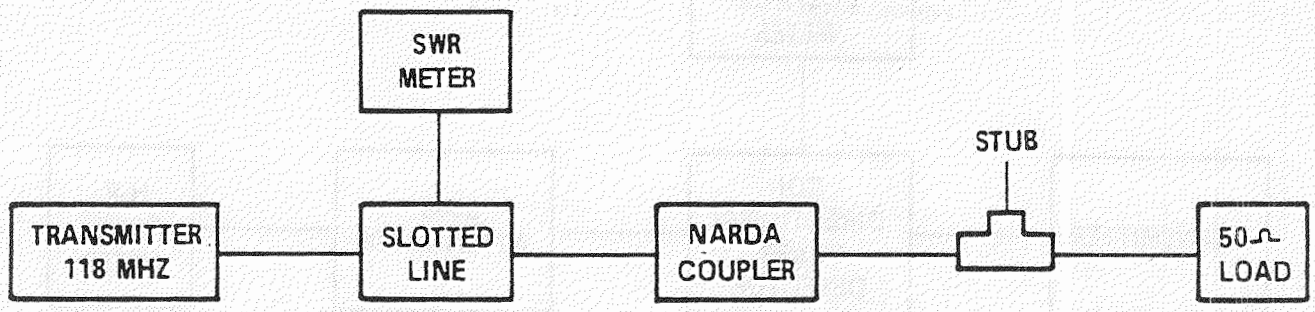


STUB #	CDI ON	CDI OFF
WITH TEE	1.065	1.065
# 1	1.325	1.325
# 2	1.38	1.38

(b)

WITH CDI DETECTOR

FIGURE 5. TEST 5 CONFIGURATION (SHEET 1 OF 2)



STUB #	VSWR
WITH TEE	1.065
# 1	1.330
# 2	1.375

(c)

WITH NARDA COUPLER

FIGURE 5. TEST 5 CONFIGURATION (SHEET 2 OF 2)

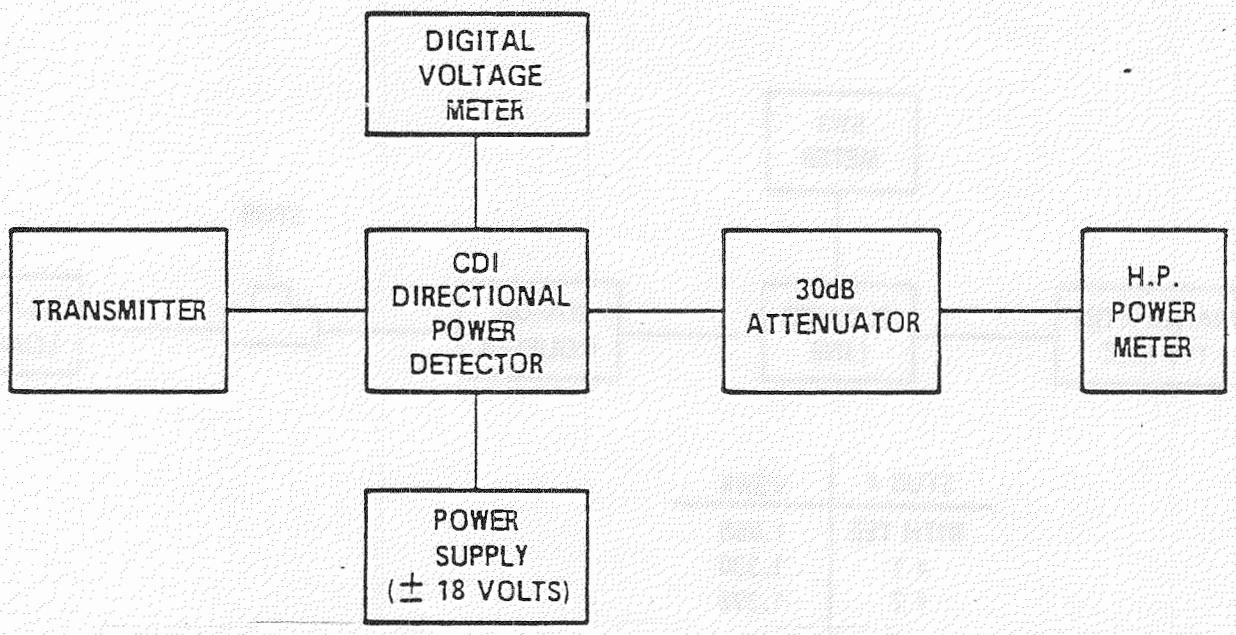


FIGURE 6. TEST 6 CONFIGURATION

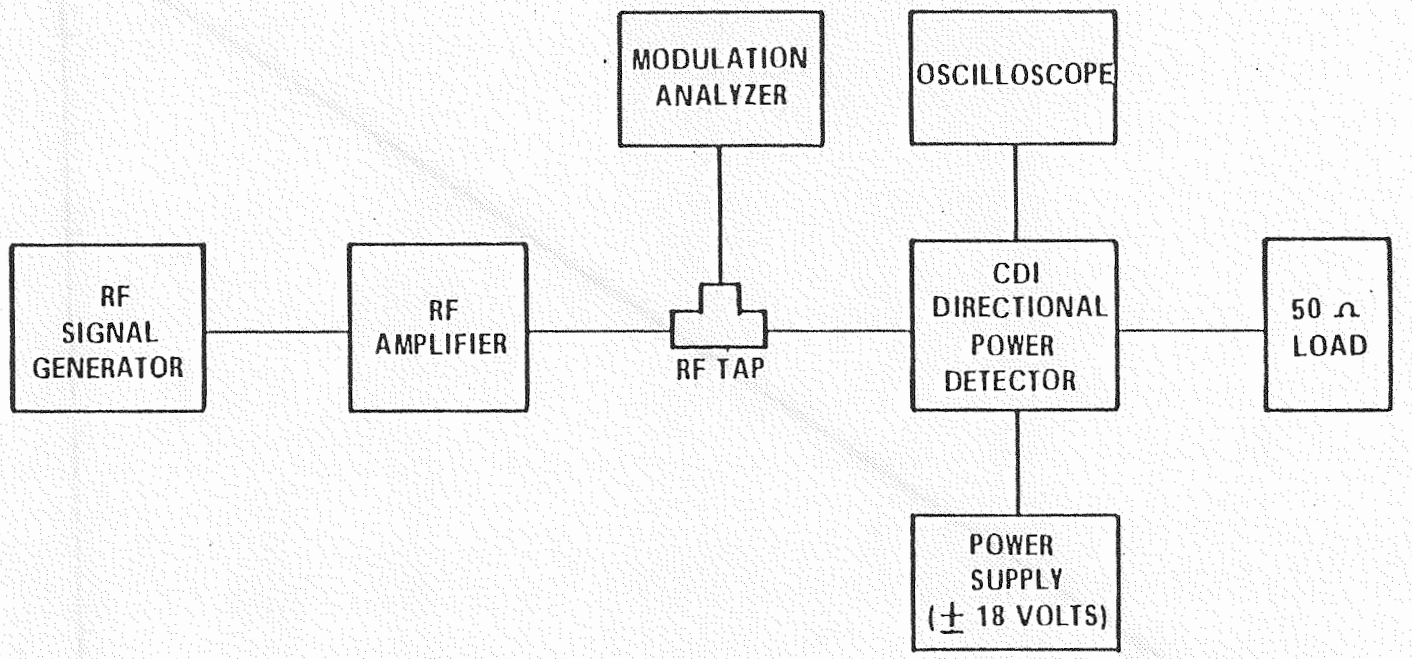


FIGURE 7. TEST 7 CONFIGURATION

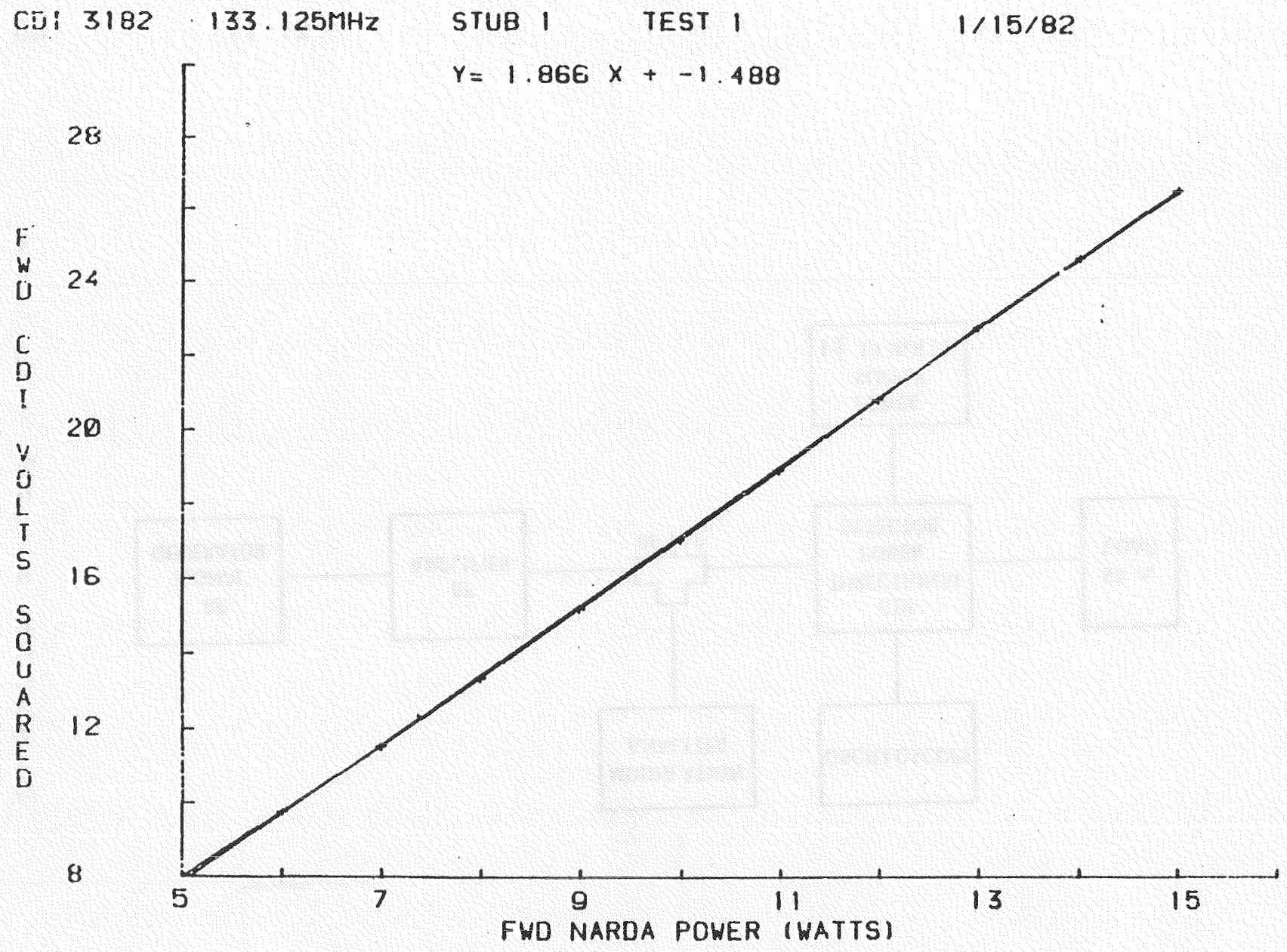


FIGURE 8. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH STRAIGHT LINE SUPERIMPOSED

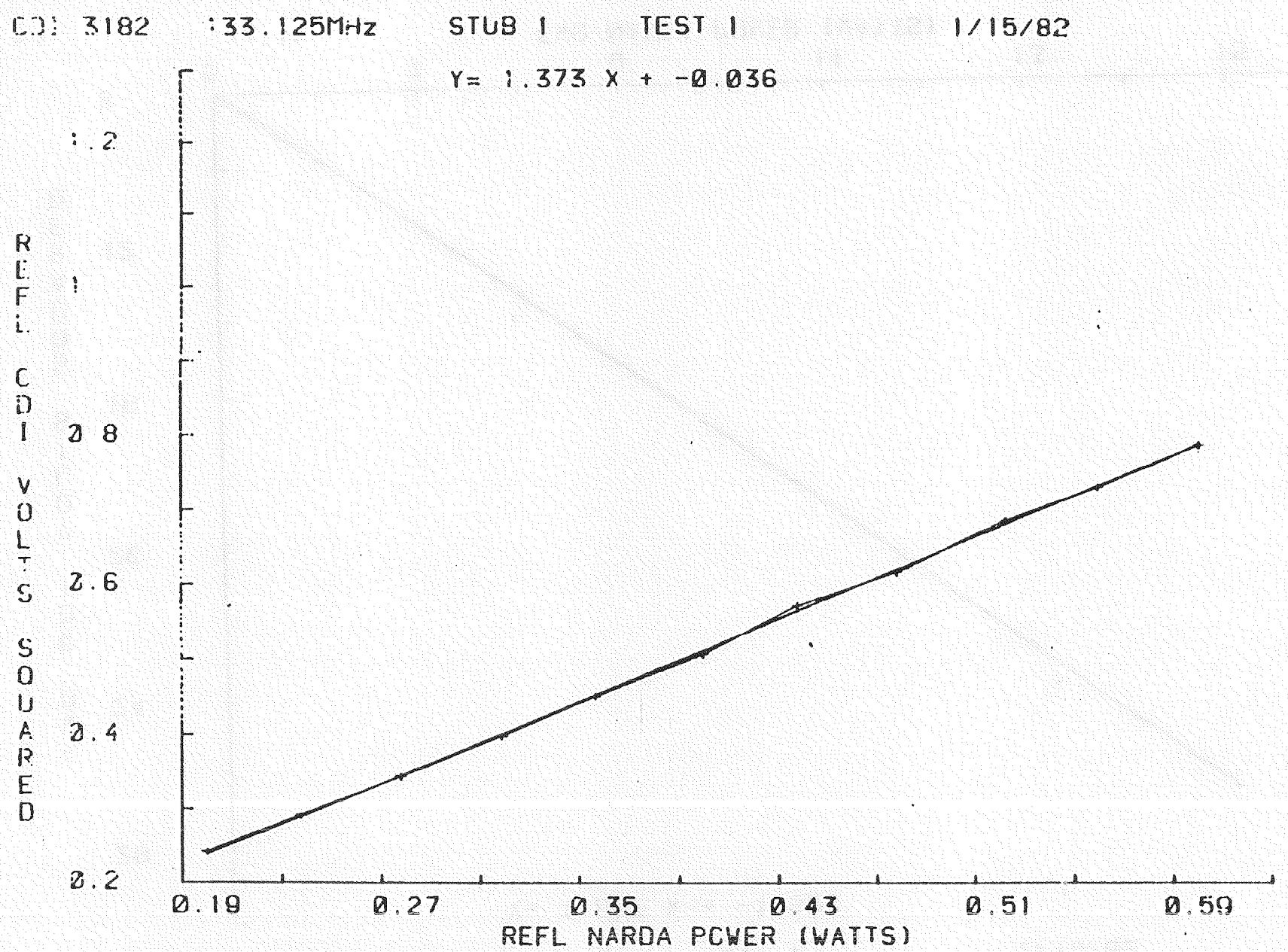


FIGURE 9. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH STRAIGHT LINE SUPERIMPOSED

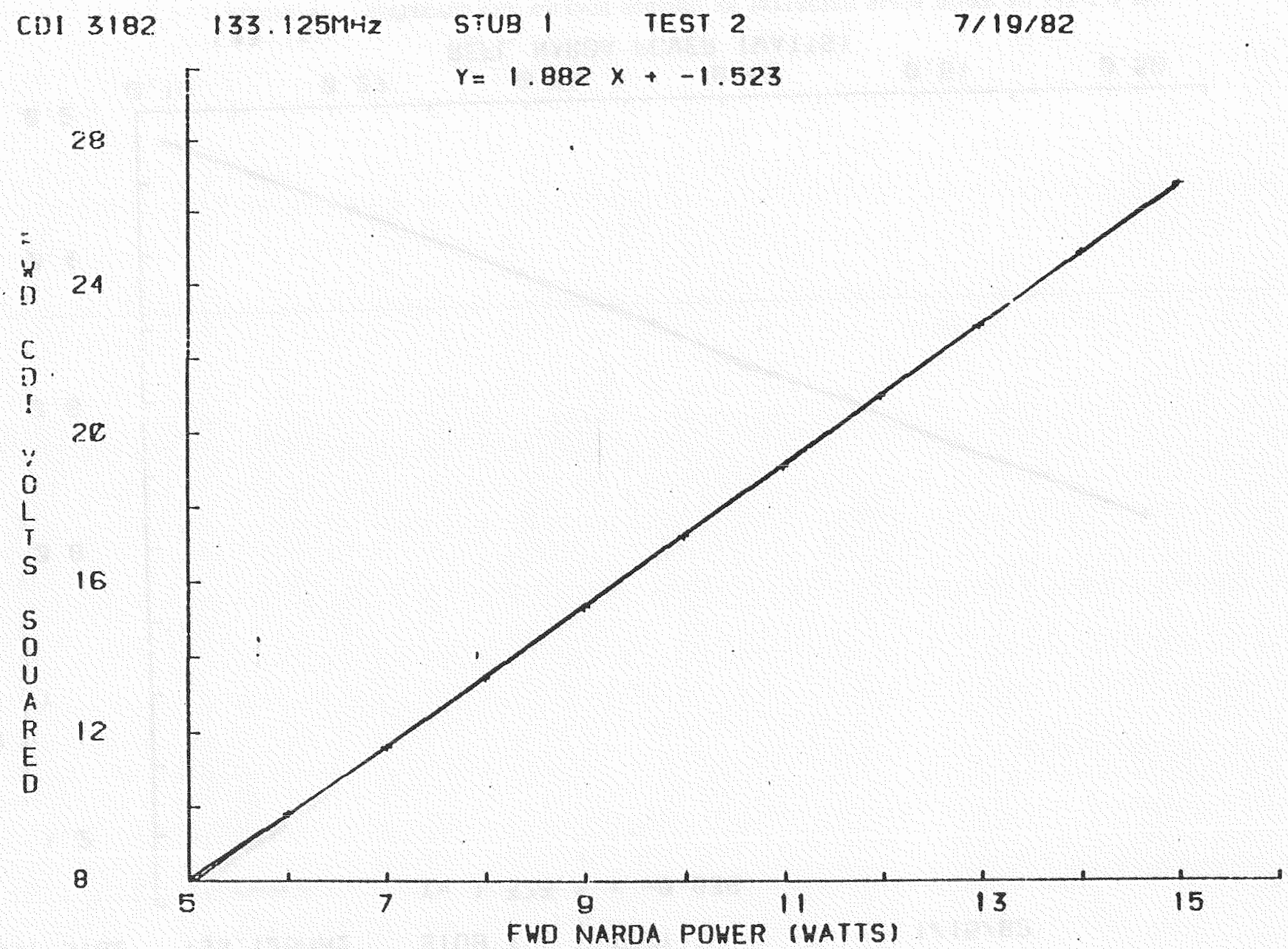


FIGURE 10. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

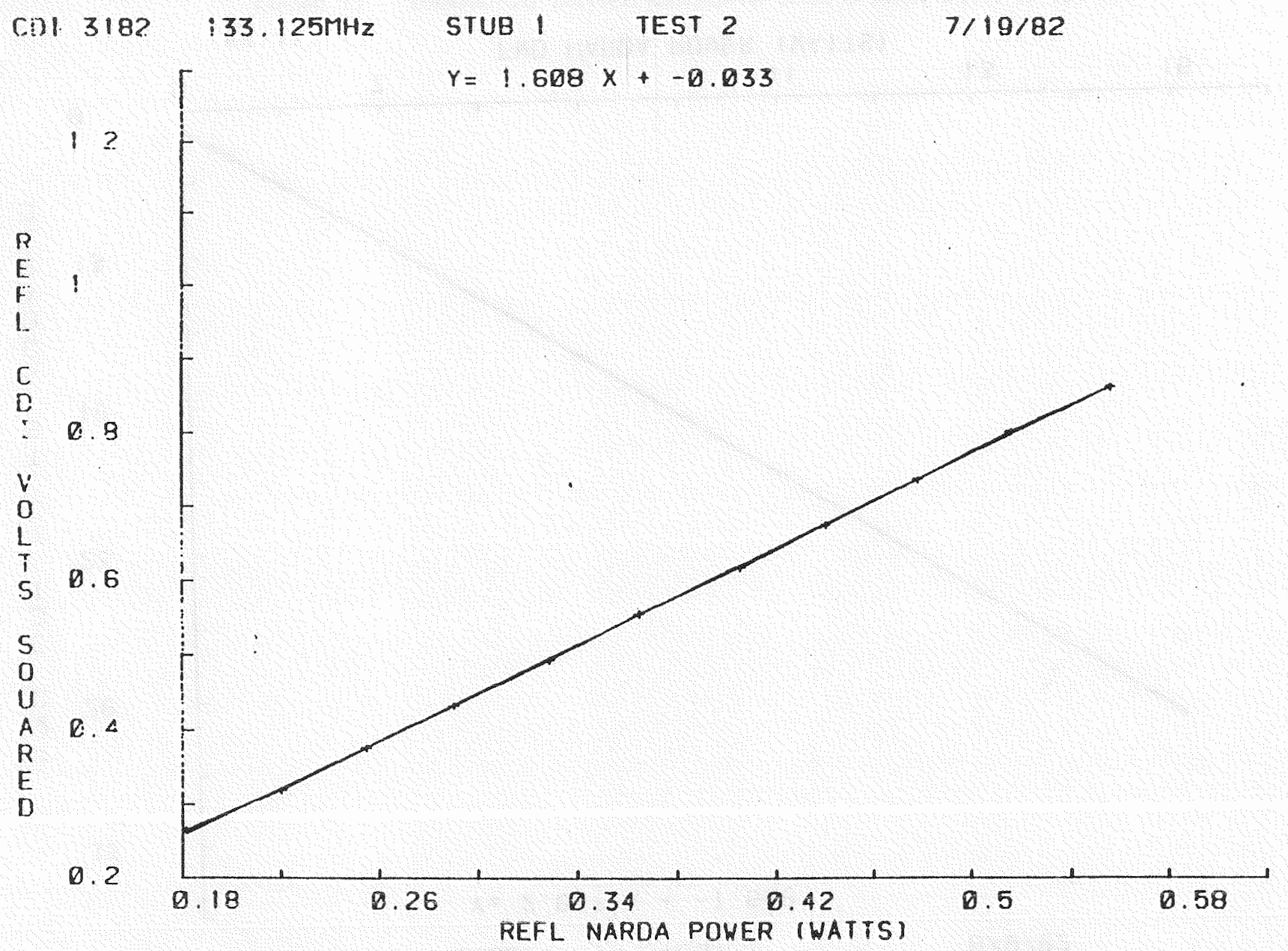


FIGURE 11. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

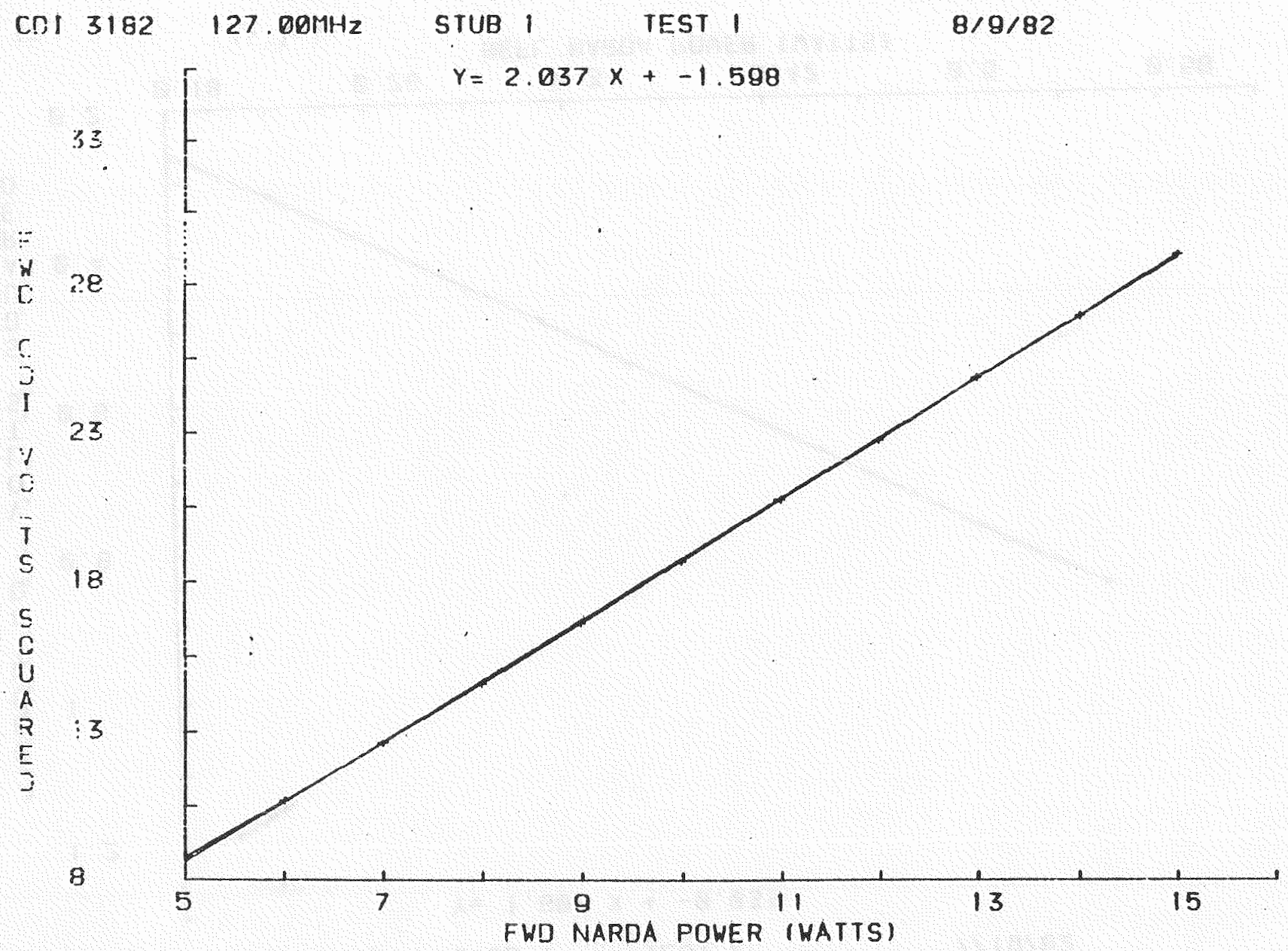


FIGURE 12. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 127 MHz (FROM TEST 1) WITH STRAIGHT LINE SUPERIMPOSED

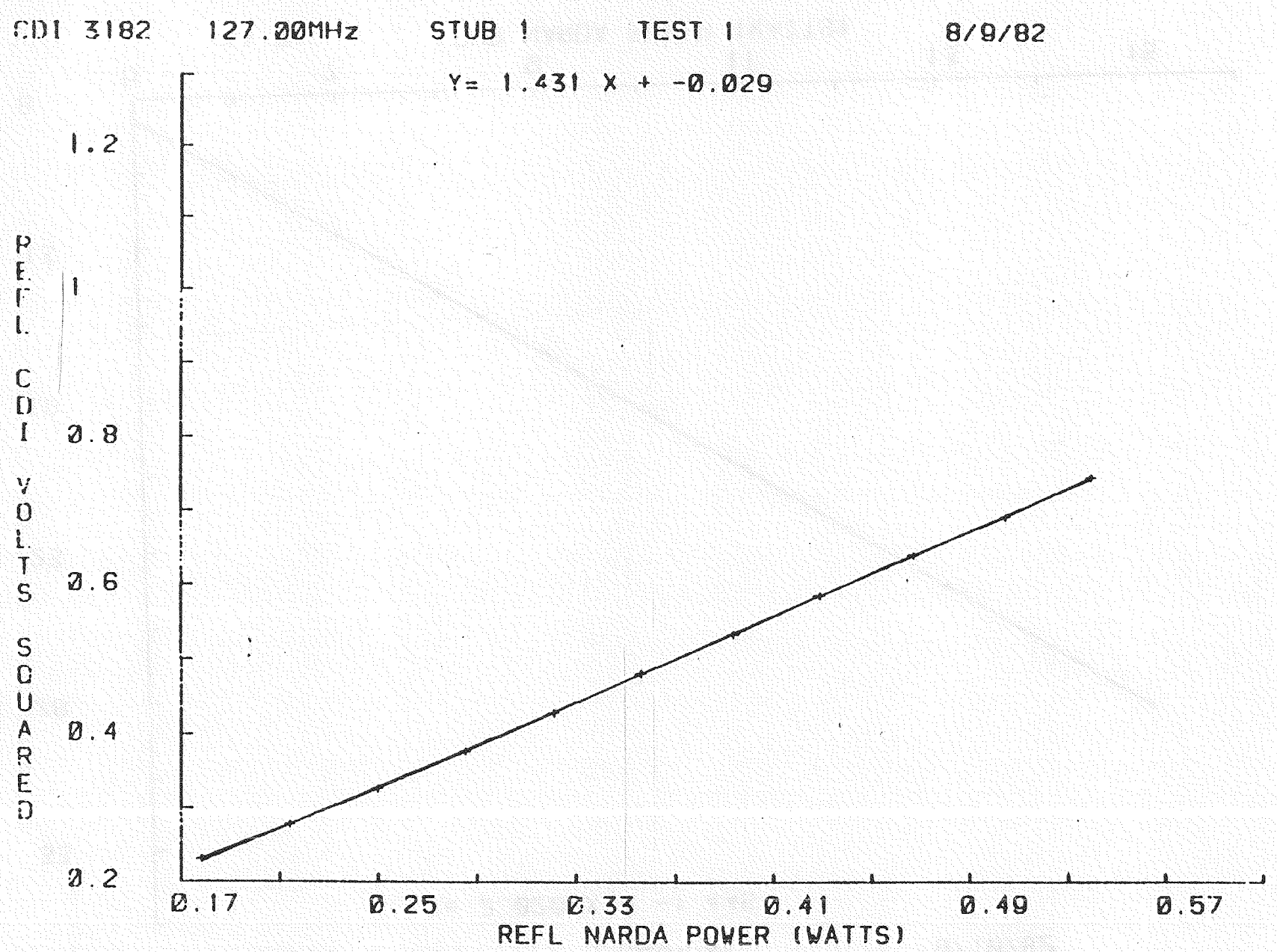


FIGURE 13. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 127 MHz (FROM TEST 1) WITH STRAIGNT LINE SUPERIMPOSED

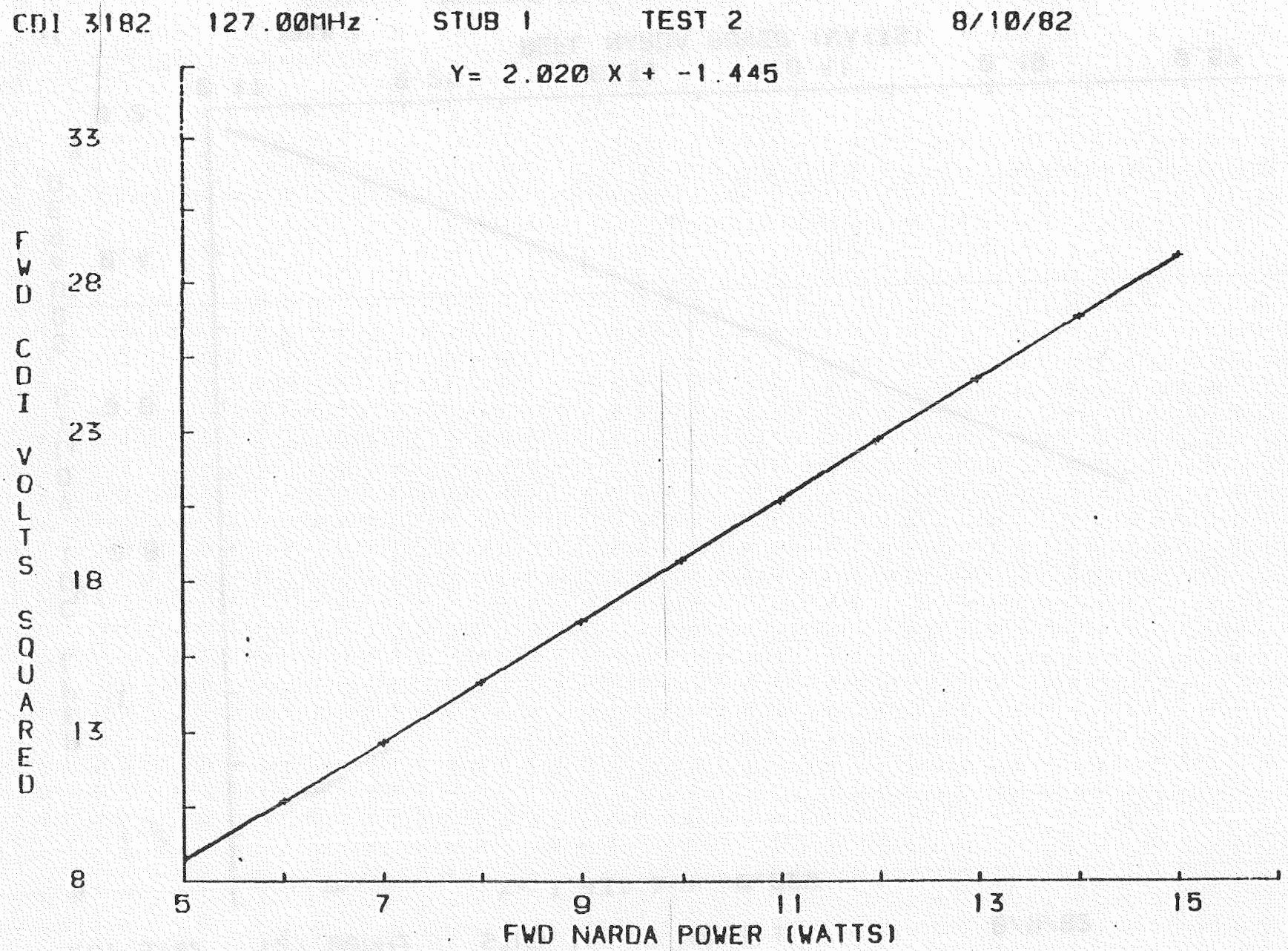


FIGURE 14. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 127 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

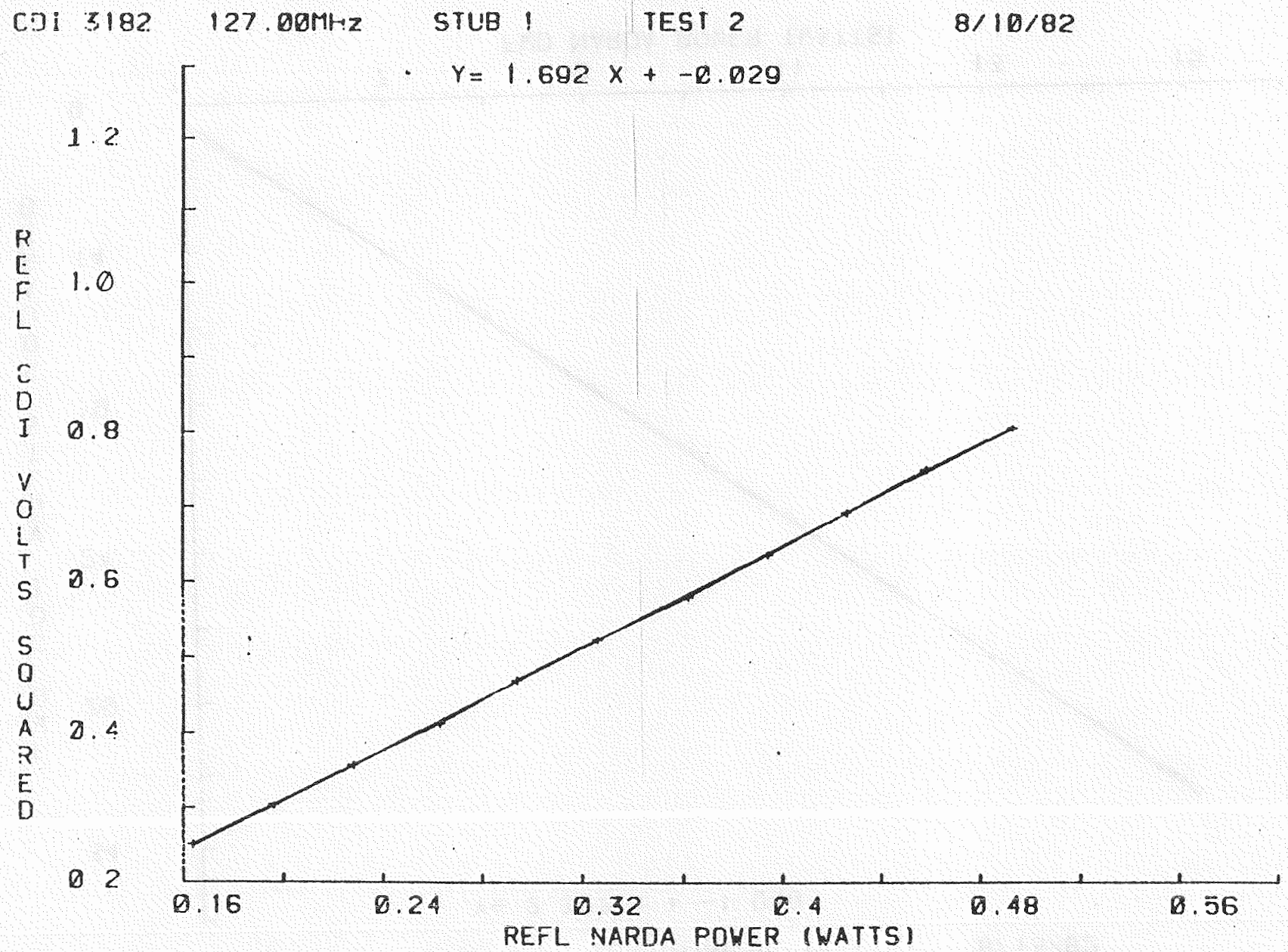


FIGURE 15. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED VS REFLECTED NARDA POWER AT 127 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

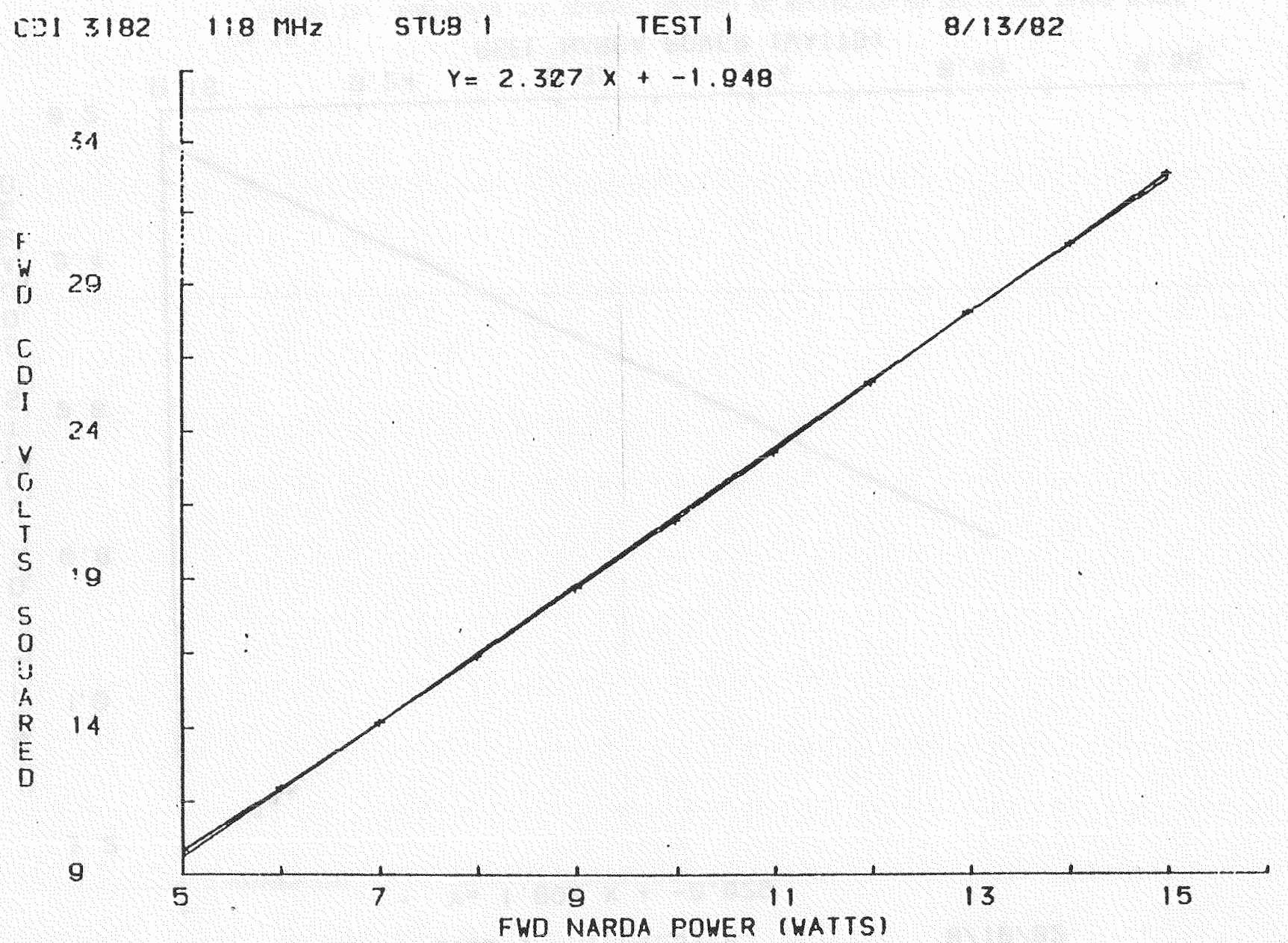


FIGURE 16. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 118 MHz (FROM TEST 1) WITH STRAIGHT LINE SUPERIMPOSED

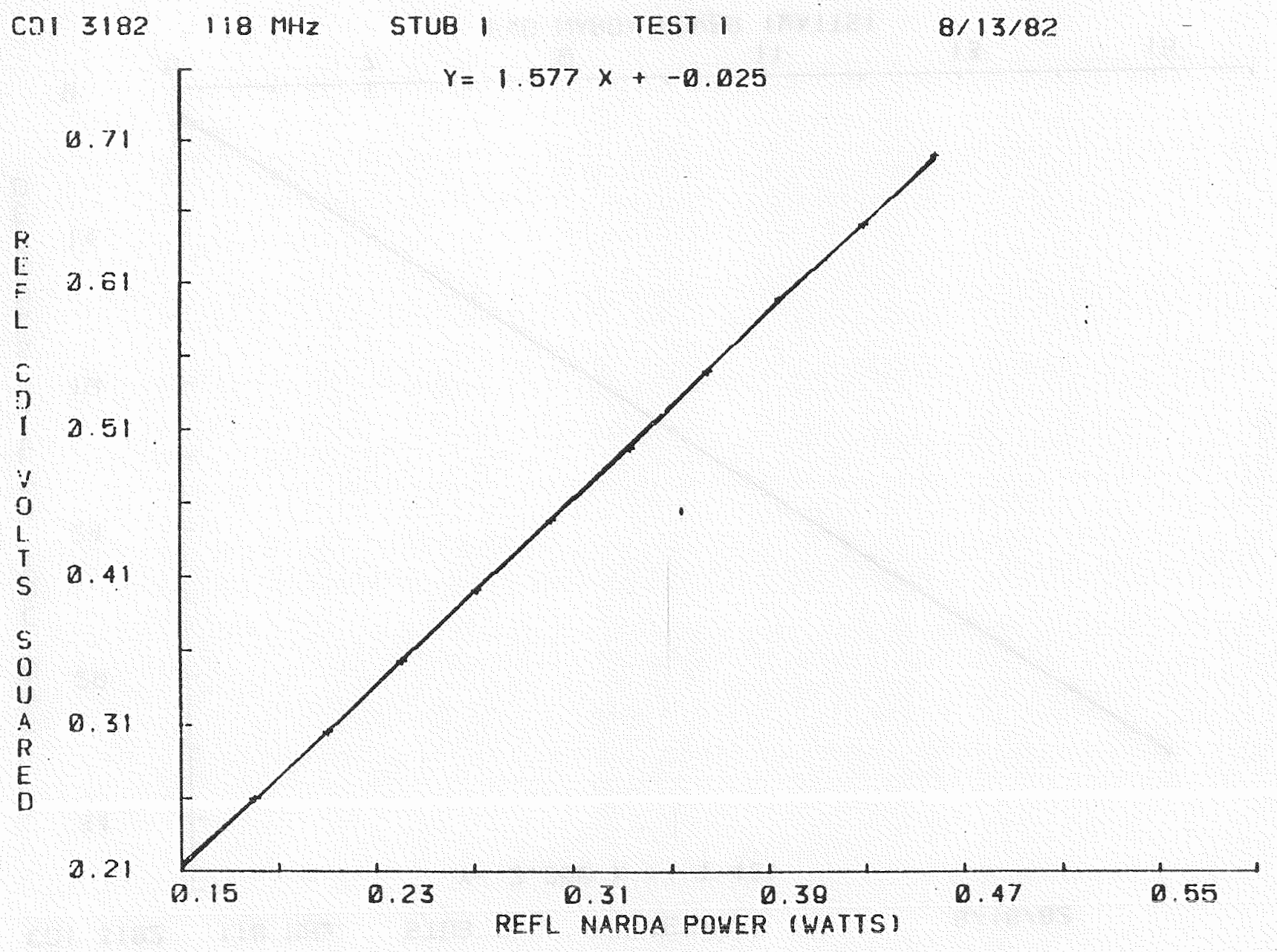


FIGURE 17. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 118 MHz (FROM TEST 1) WITH STRAIGHT LINE SUPERIMPOSED

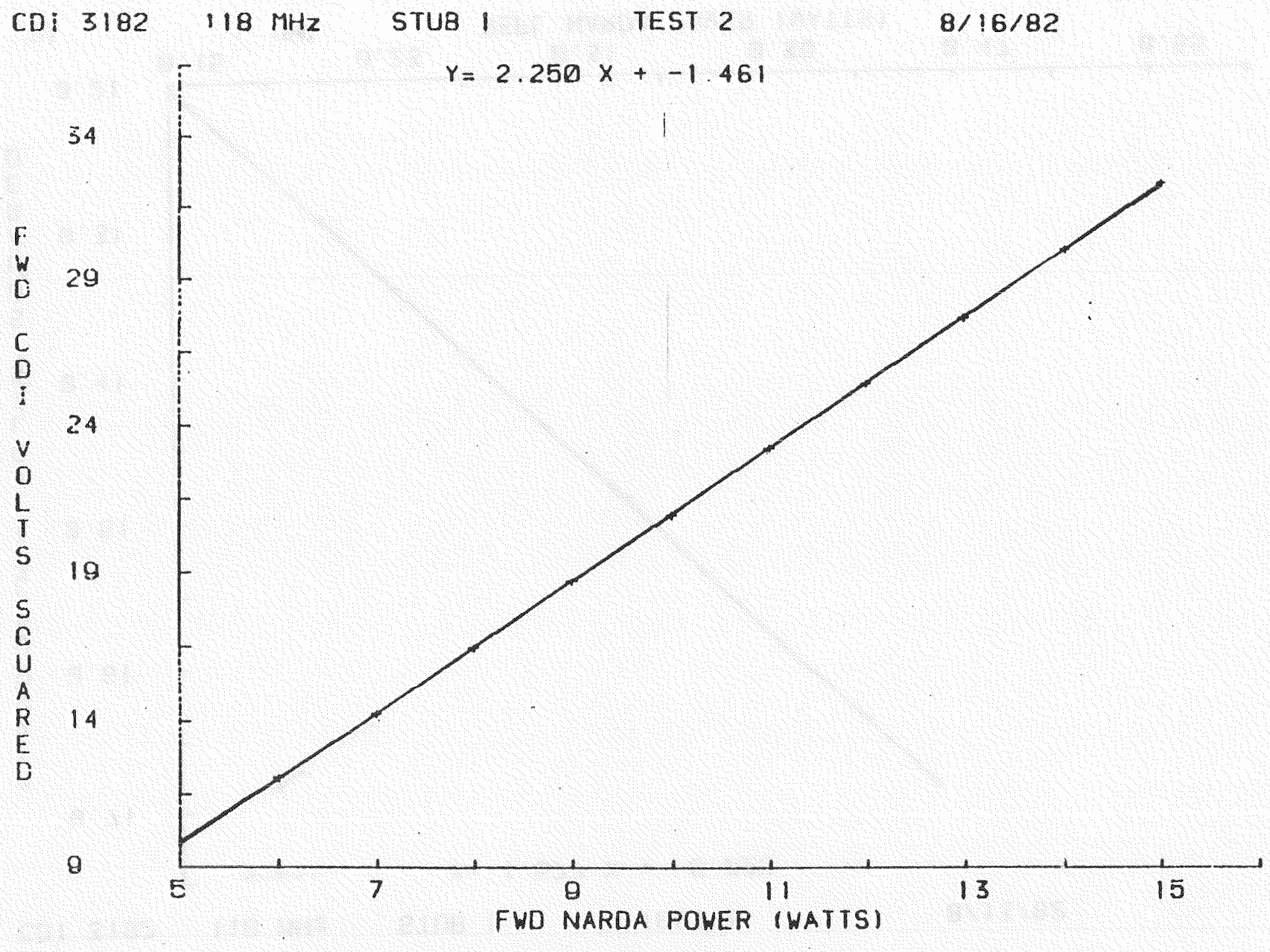


FIGURE 18. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 118 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

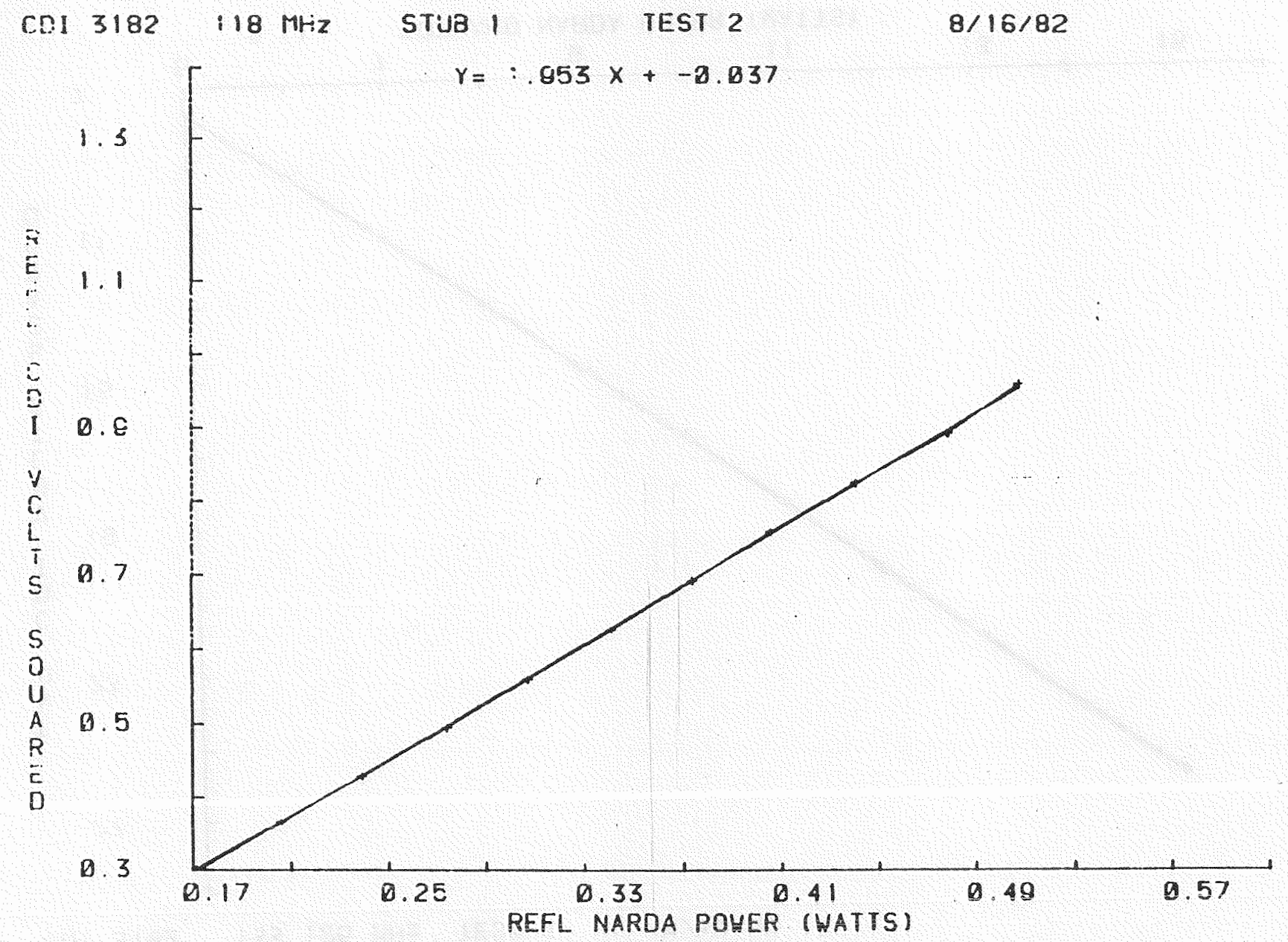


FIGURE 19. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 118 MHz (FROM TEST 2) WITH STRAIGHT LINE SUPERIMPOSED

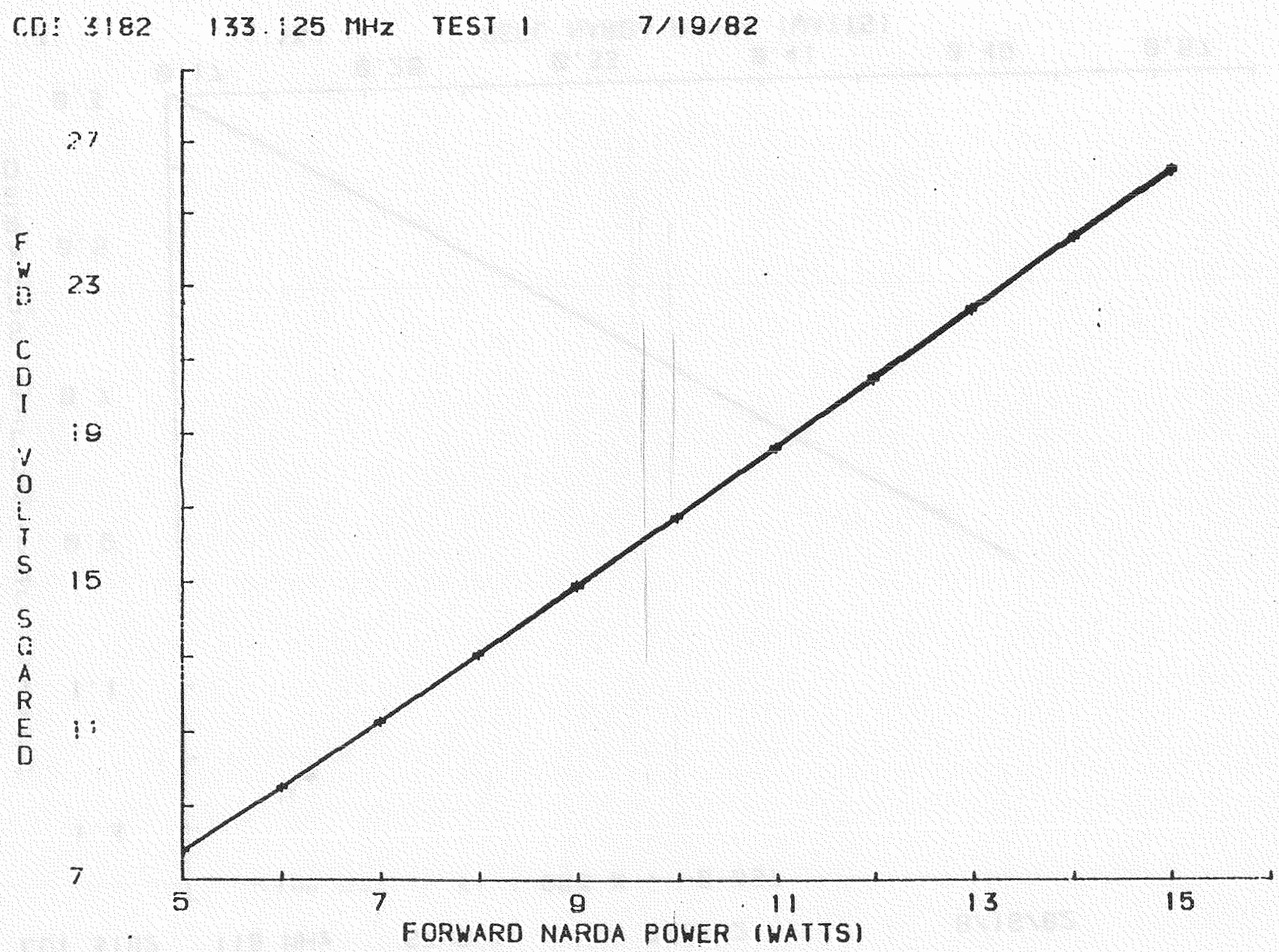


FIGURE 20. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH DATA FROM ALL 7 STUBS SUPERIMPOSED

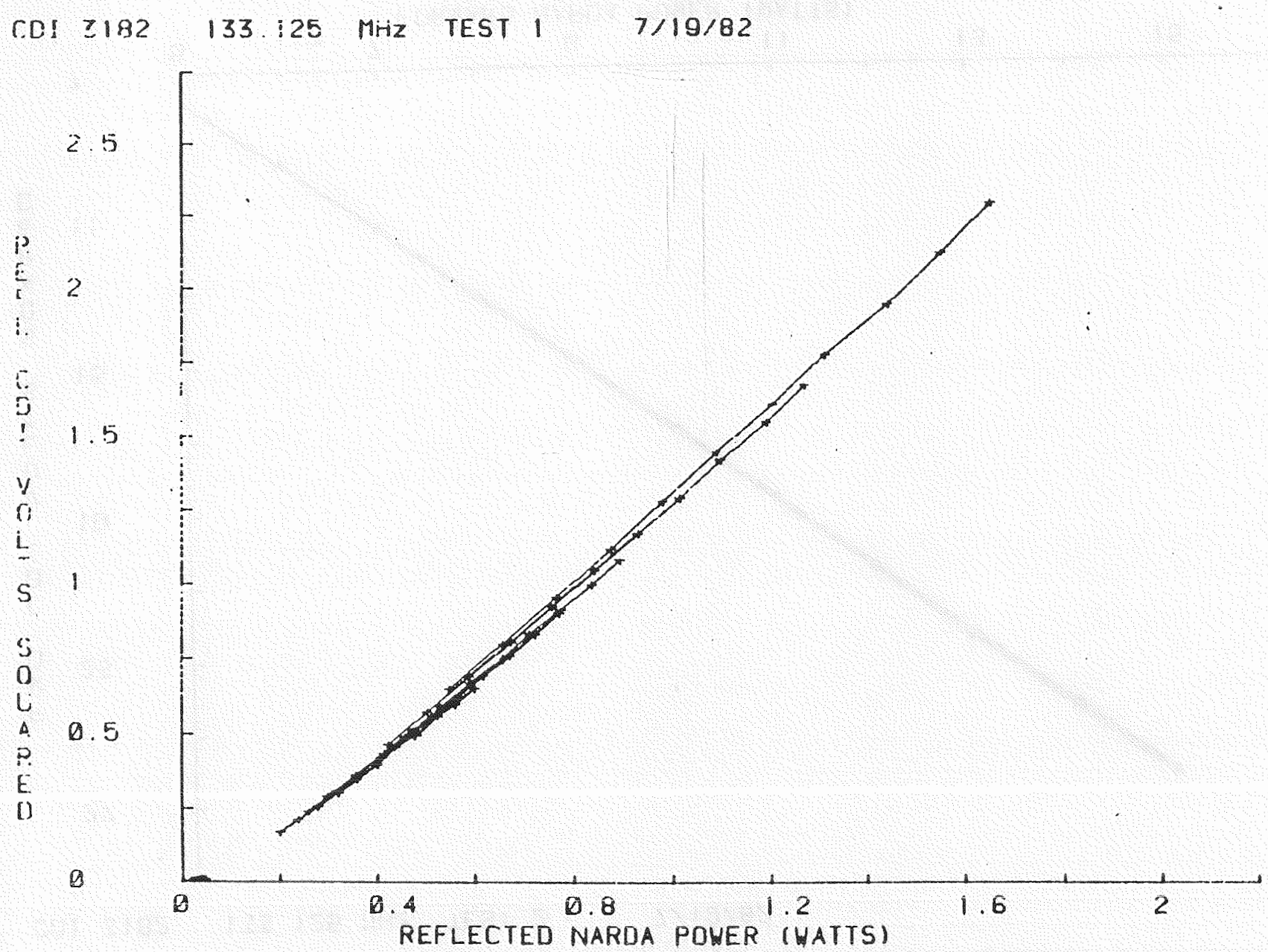


FIGURE 21. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH DATA FROM ALL 7 STUBS SUPERIMPOSED

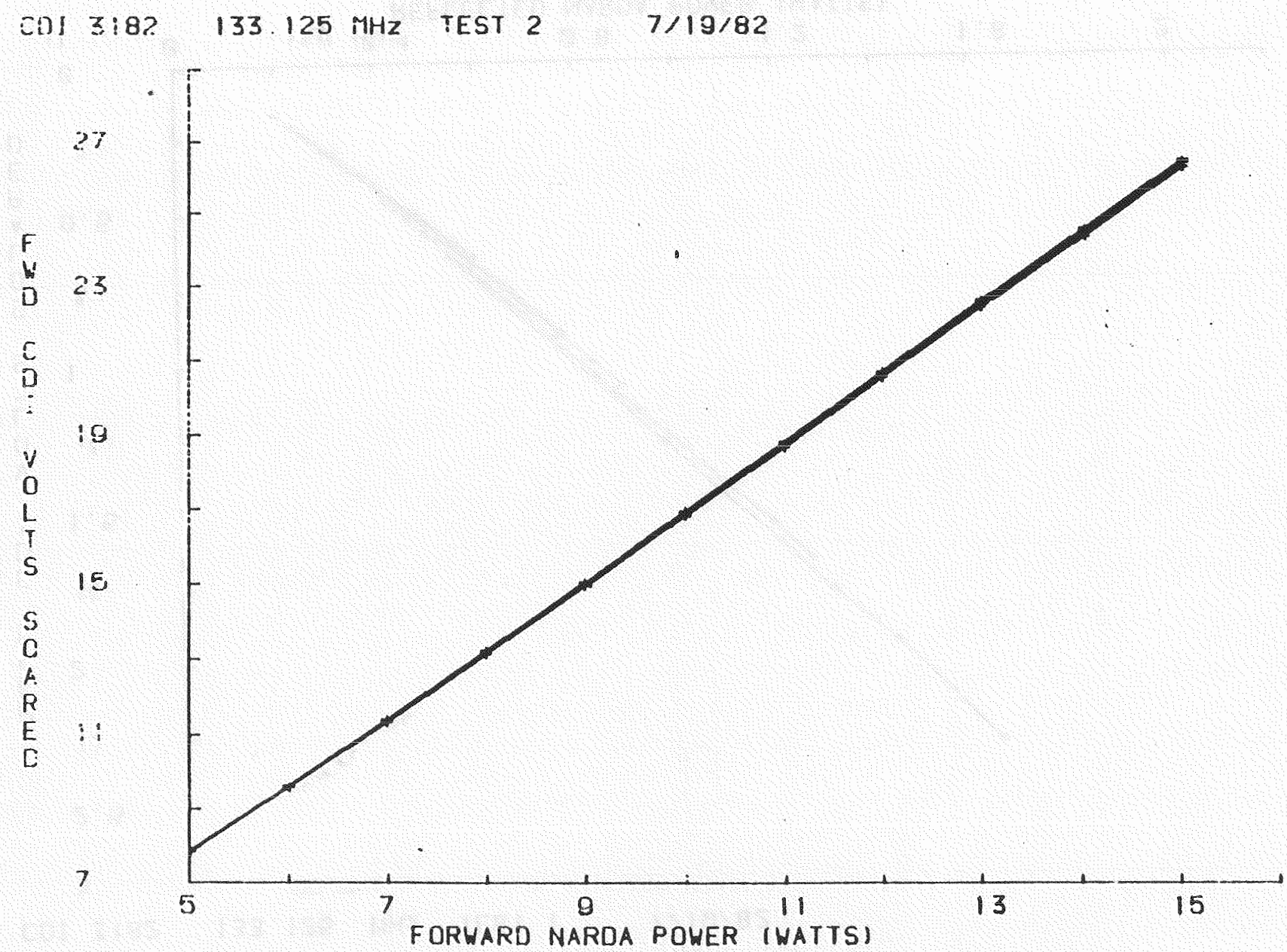


FIGURE 22. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH DATA FROM ALL 7 STUBS SUPERIMPOSED

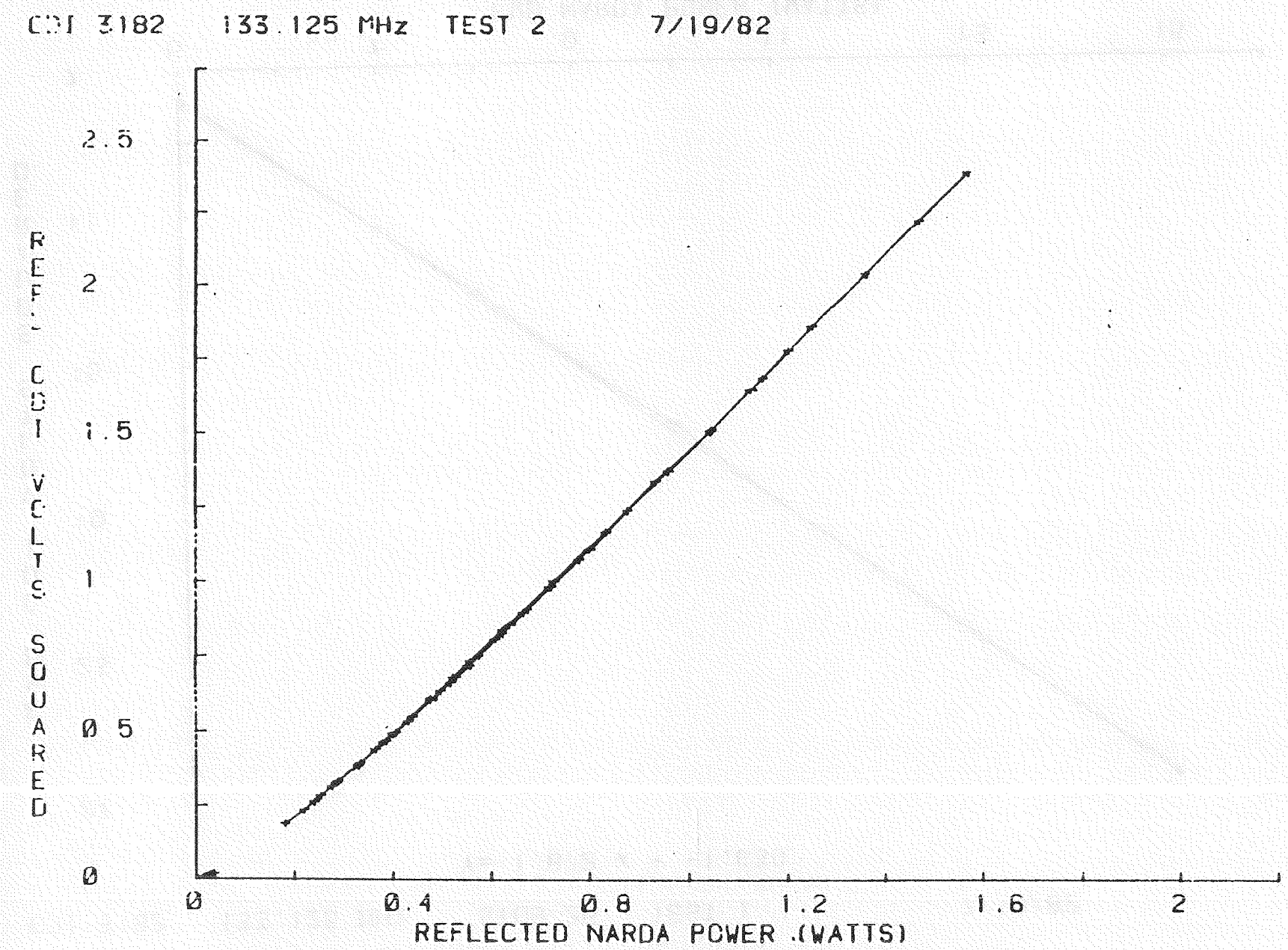


FIGURE 23. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH DATA FROM ALL 7 STUBS SUPERIMPOSED

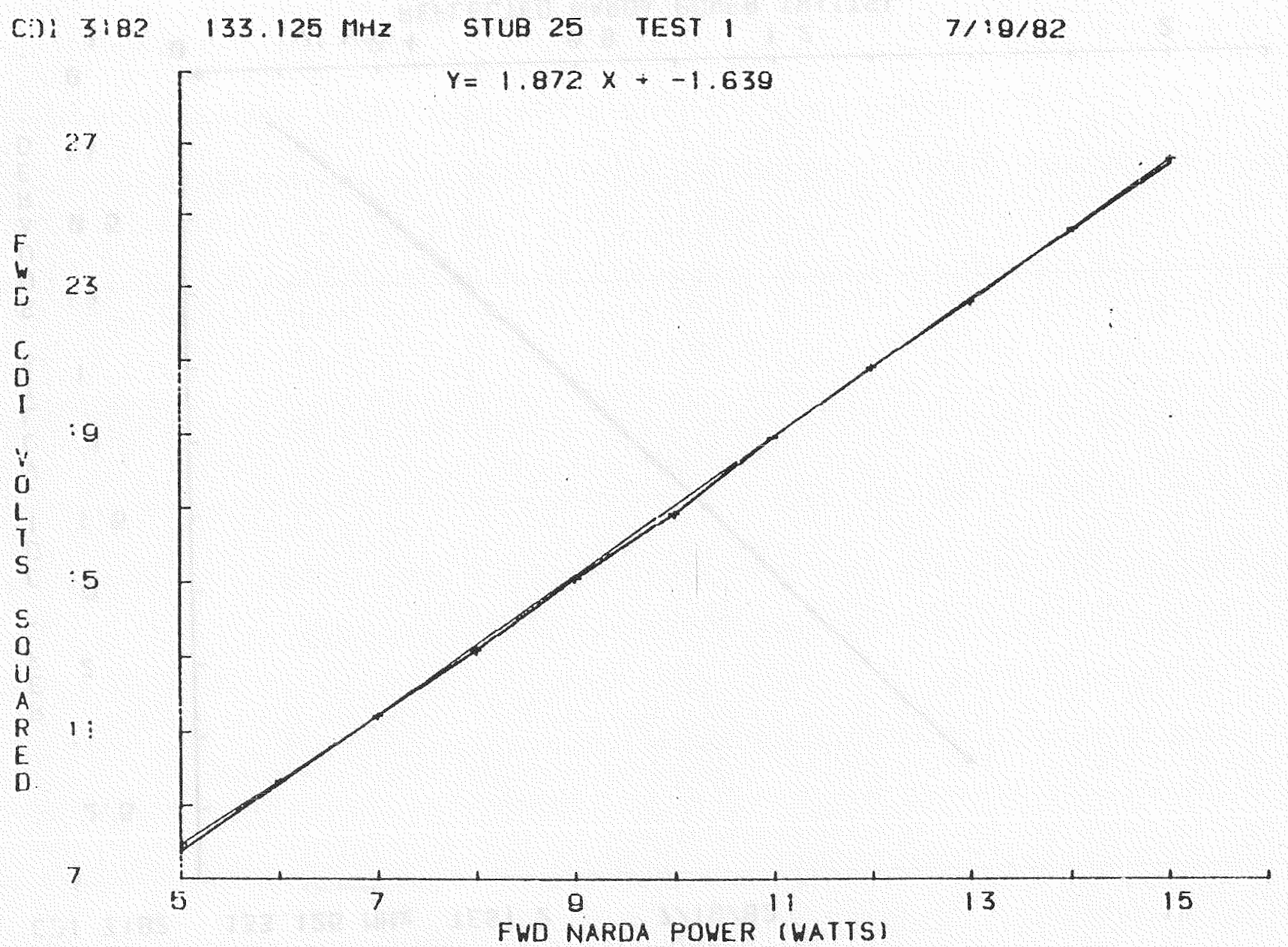


FIGURE 24. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH A VSWR GREATER THAN 4:1

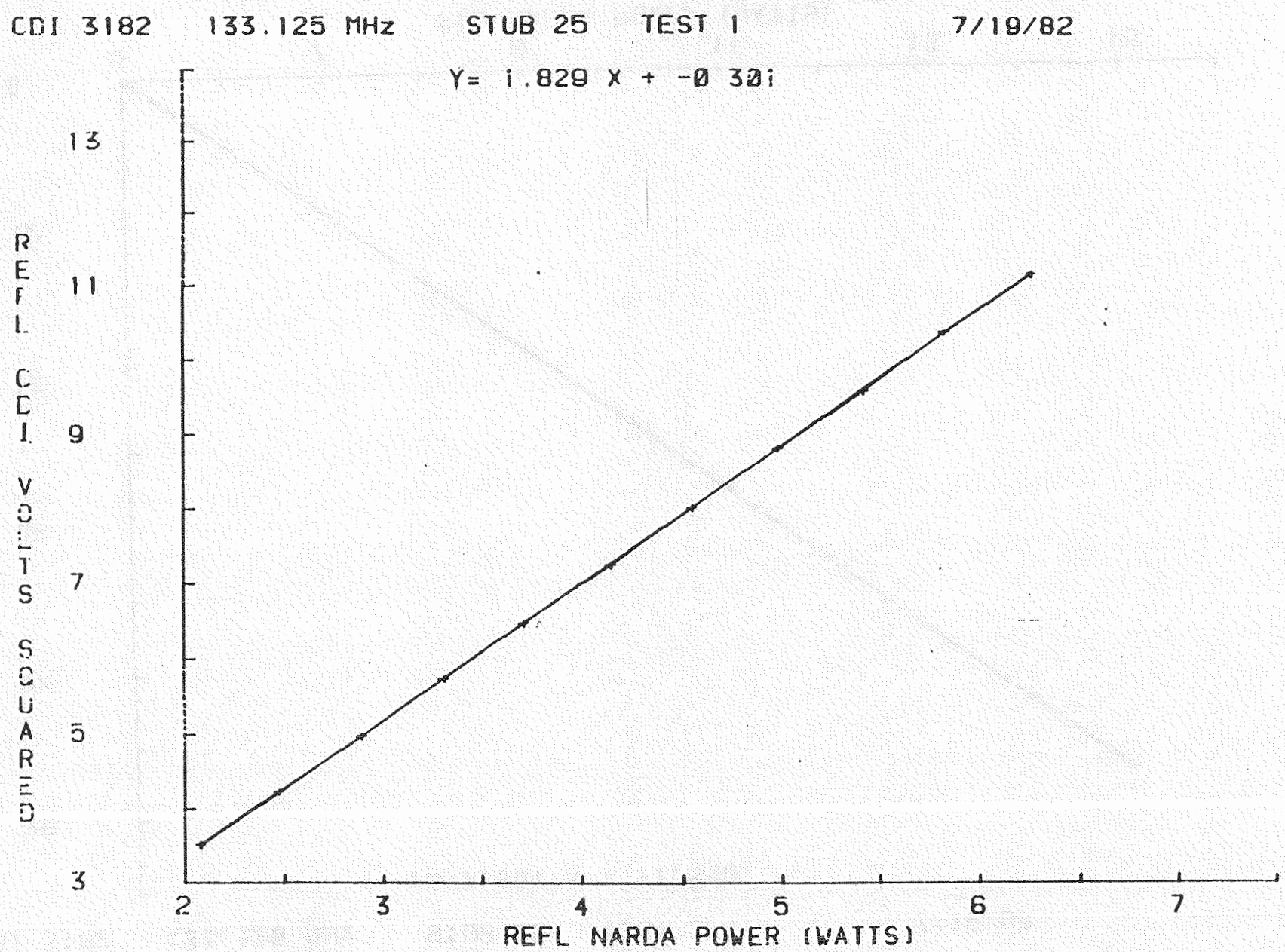


FIGURE 25. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 1) WITH A VSWR GREATER THAN 4:1

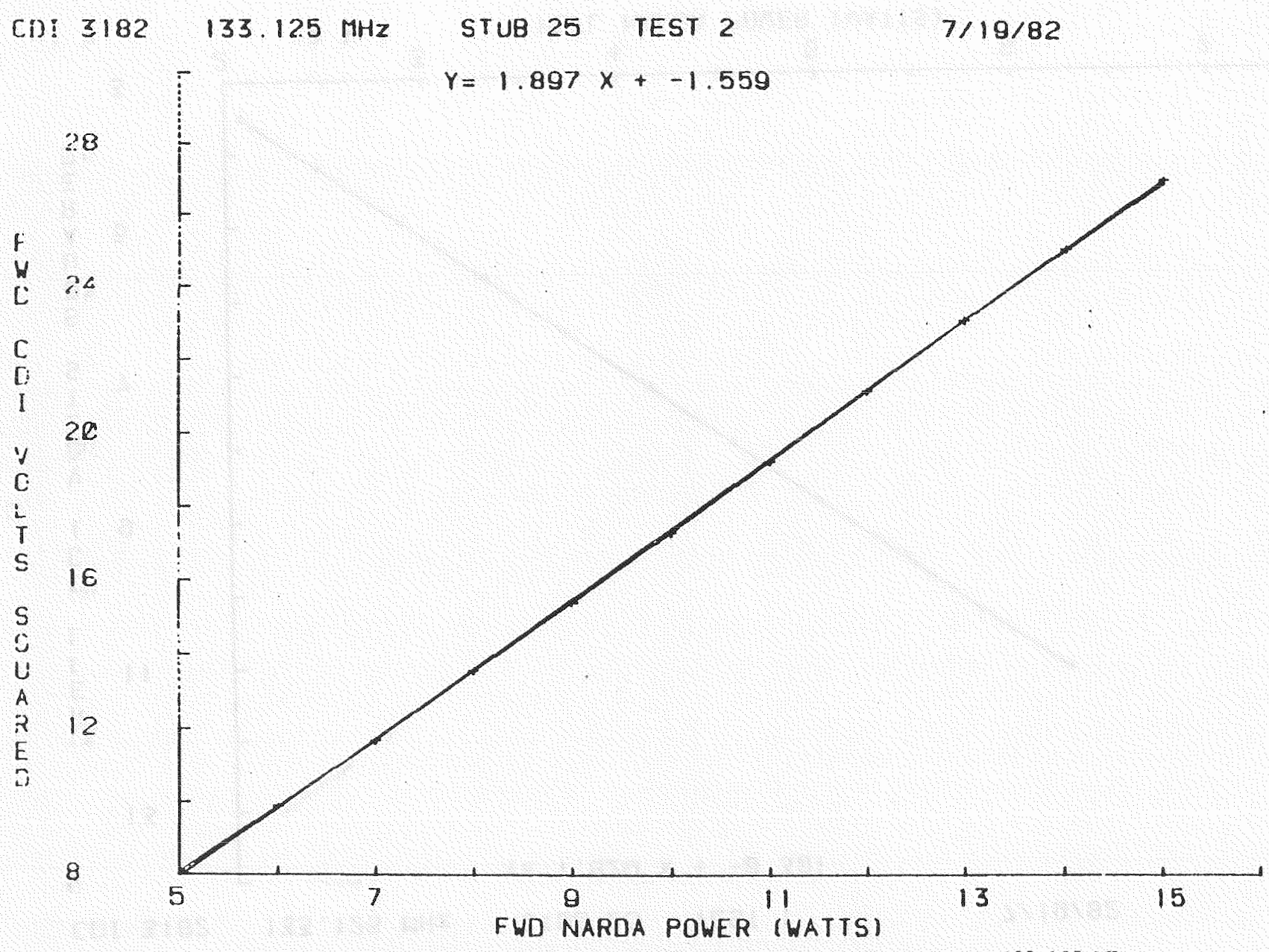


FIGURE 26. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH A VSWR GREATER THAN 4:1

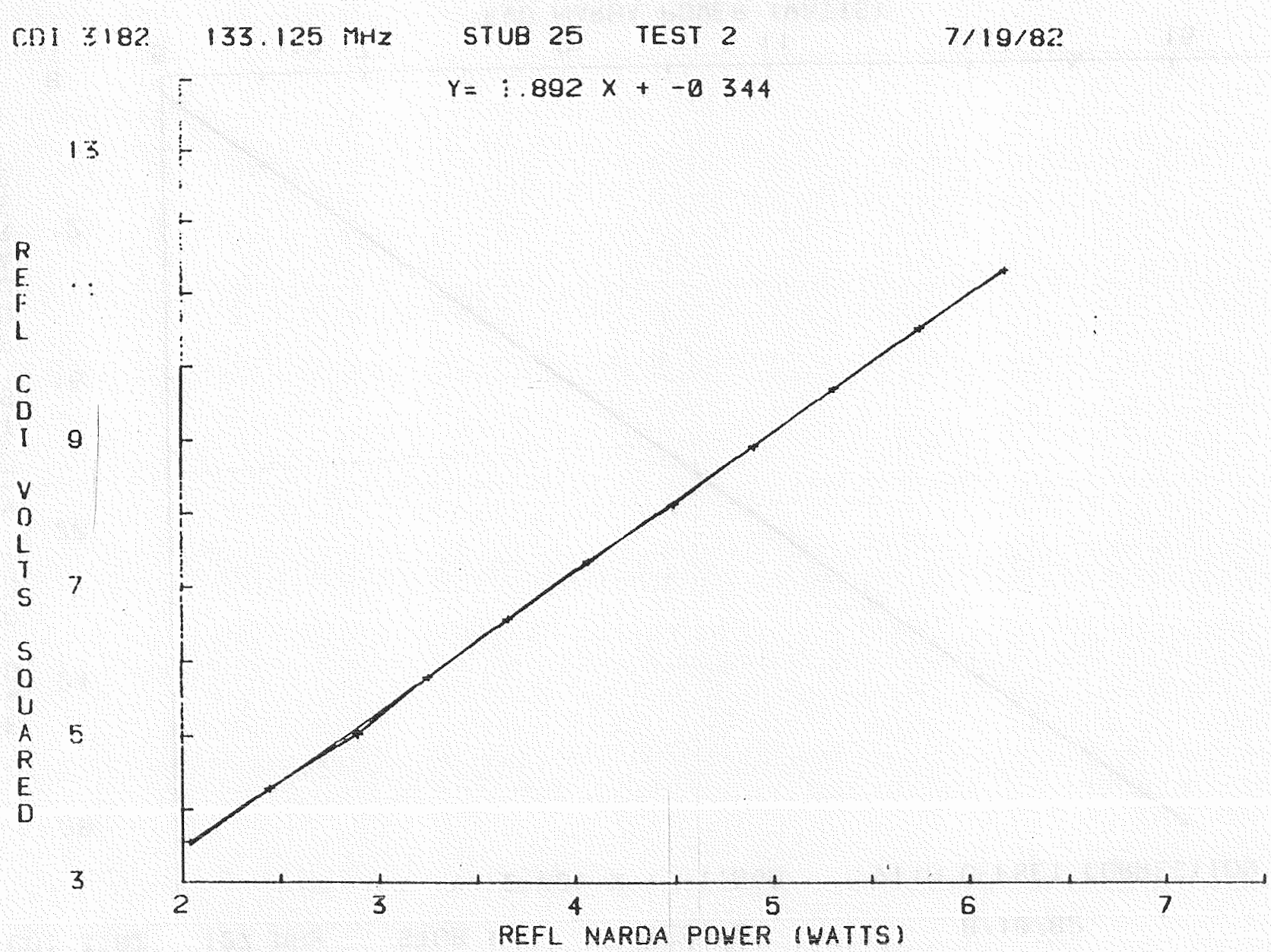


FIGURE 27. REFLECTED CDI VOLTAGE SQUARED VS REFLECTED NARDA POWER AT 133.125 MHz (FROM TEST 2) WITH A VSWR GREATER THAN 4:1

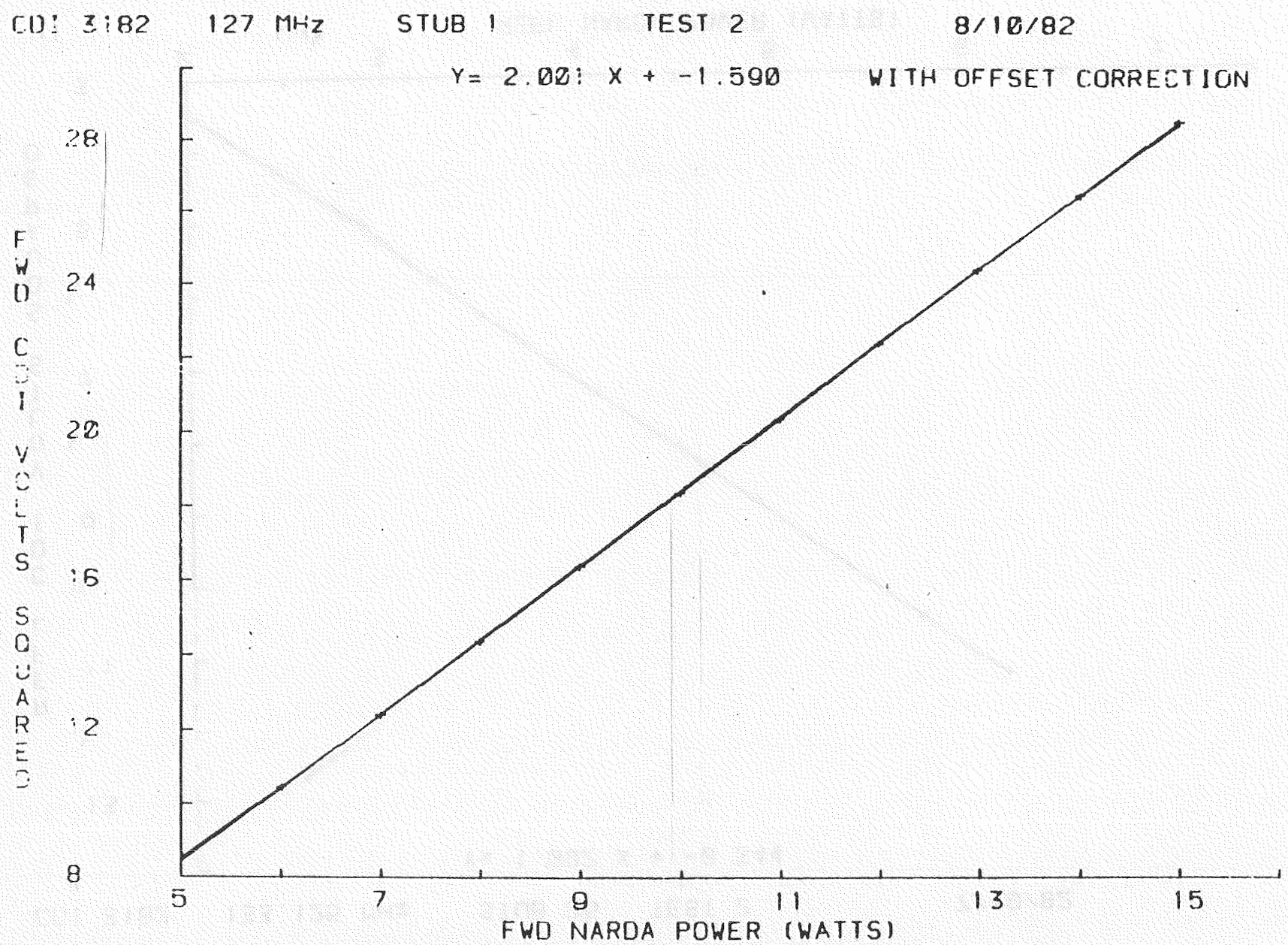


FIGURE 28. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 127 MHz (FROM TEST 2) WITH OFFSET CORRECTION WITH STRAIGHT LINE SUPERIMPOSED

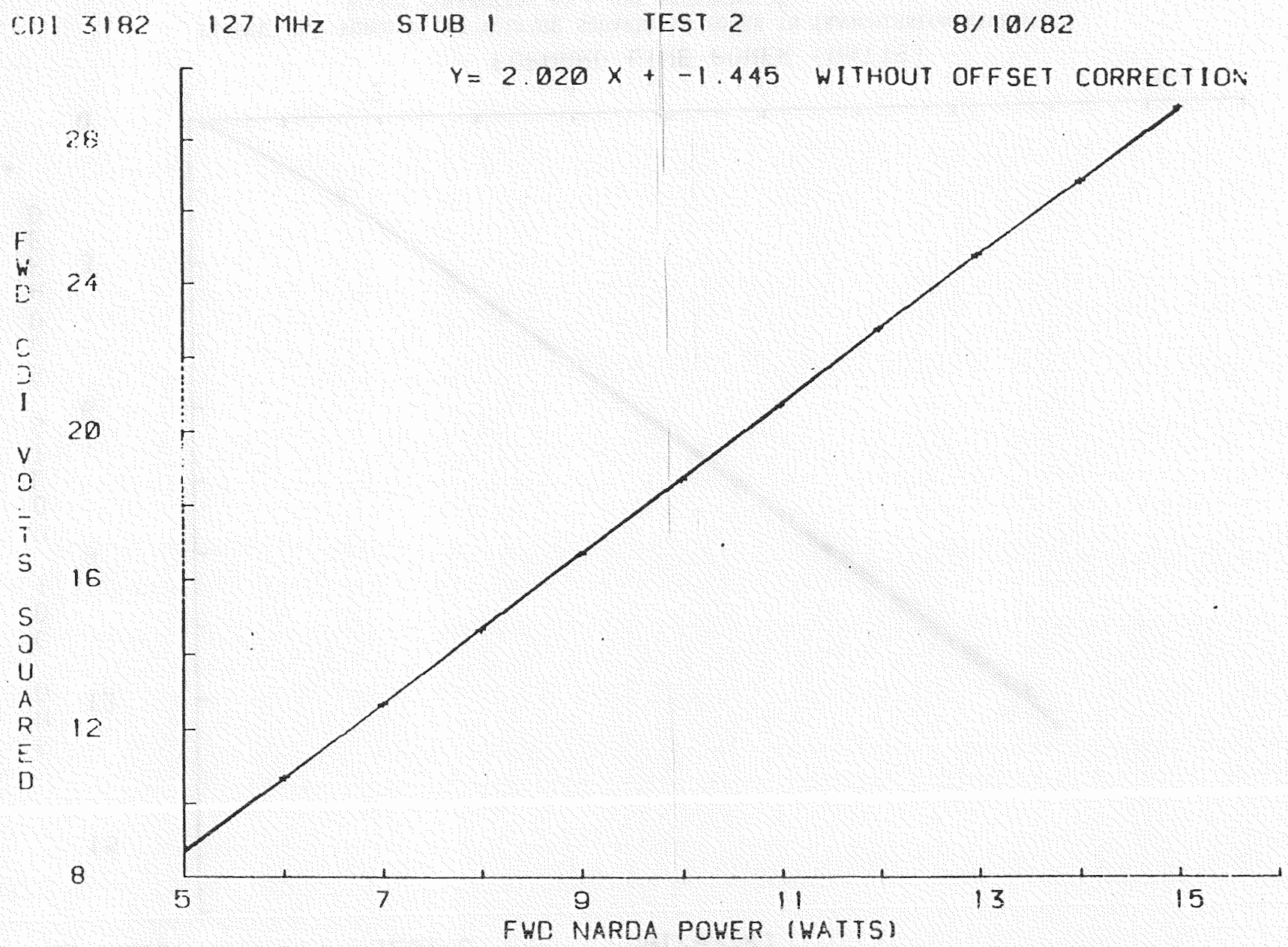


FIGURE 29. FORWARD CDI VOLTAGE SQUARED VS FORWARD NARDA POWER AT 127 MHz (FROM TEST 2) WITHOUT OFFSET CORRECTION WITH STRAIGHT LINE SUPERIMPOSED

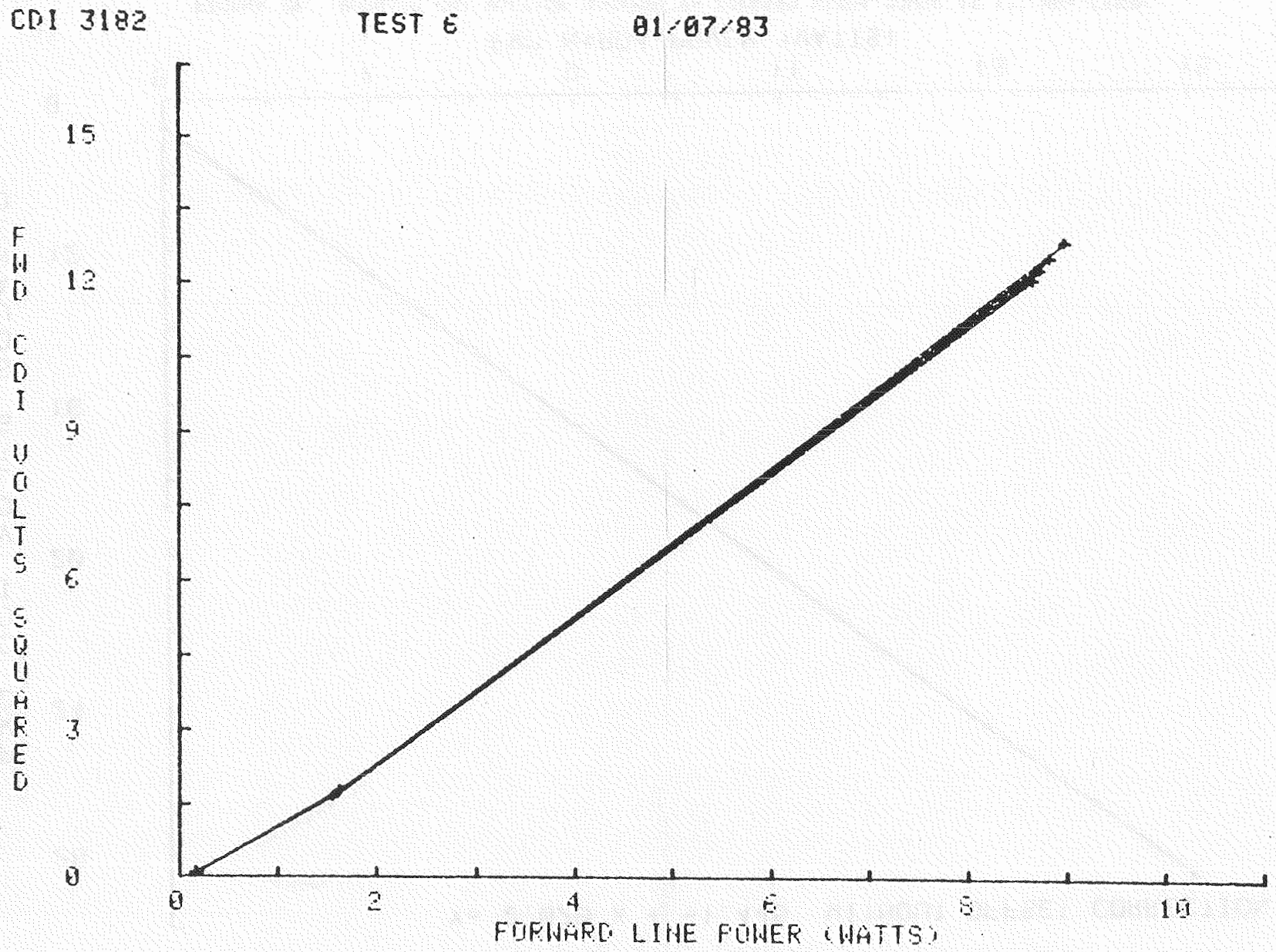


FIGURE 30. FORWARD CDI VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE WITH OFFSET CORRECTION AT 4 VHF FREQUENCIES

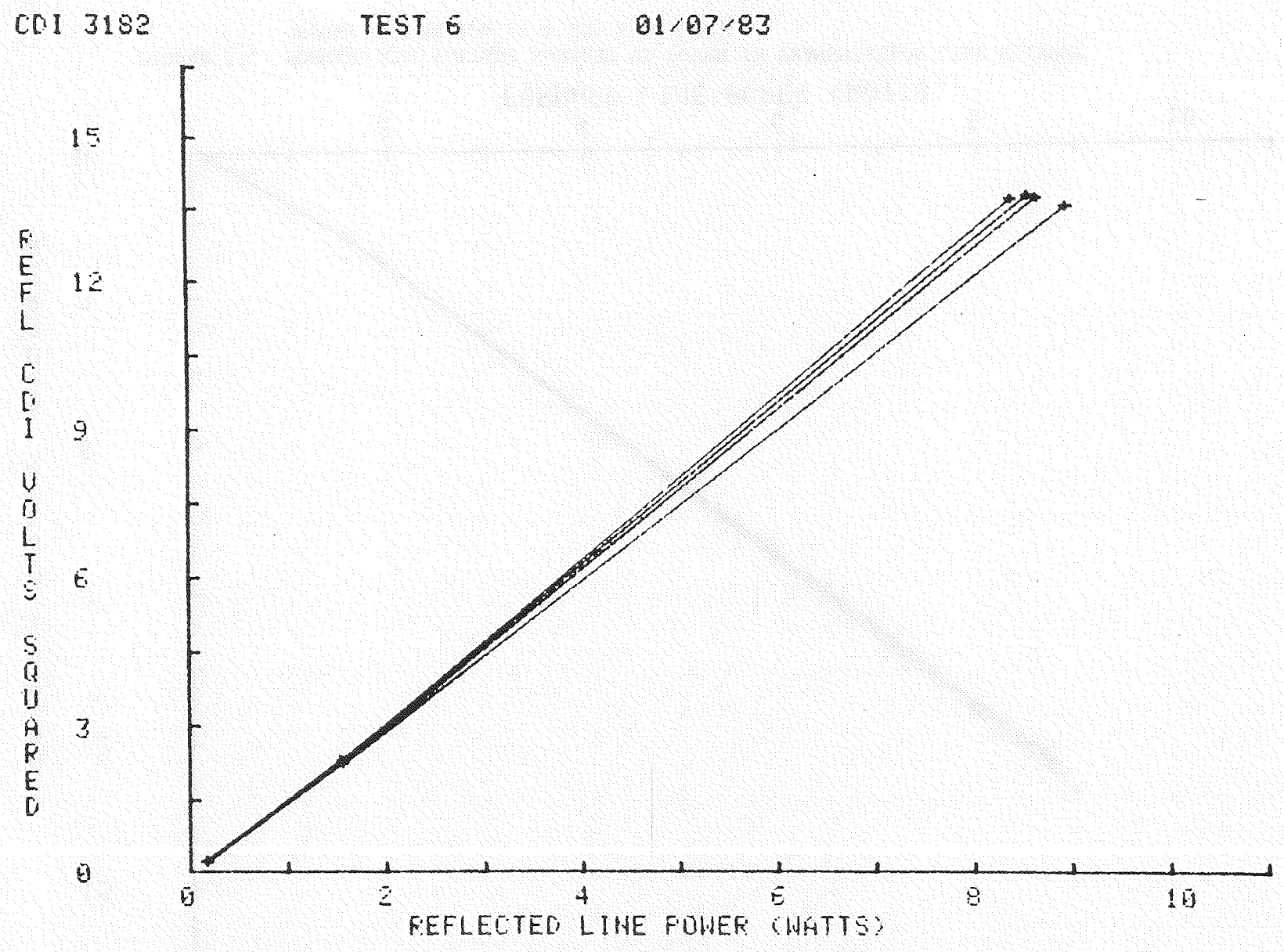


FIGURE 31. REFLECTED CDI VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE WITH OFFSET CORRECTION AT 4 VHF FREQUENCIES

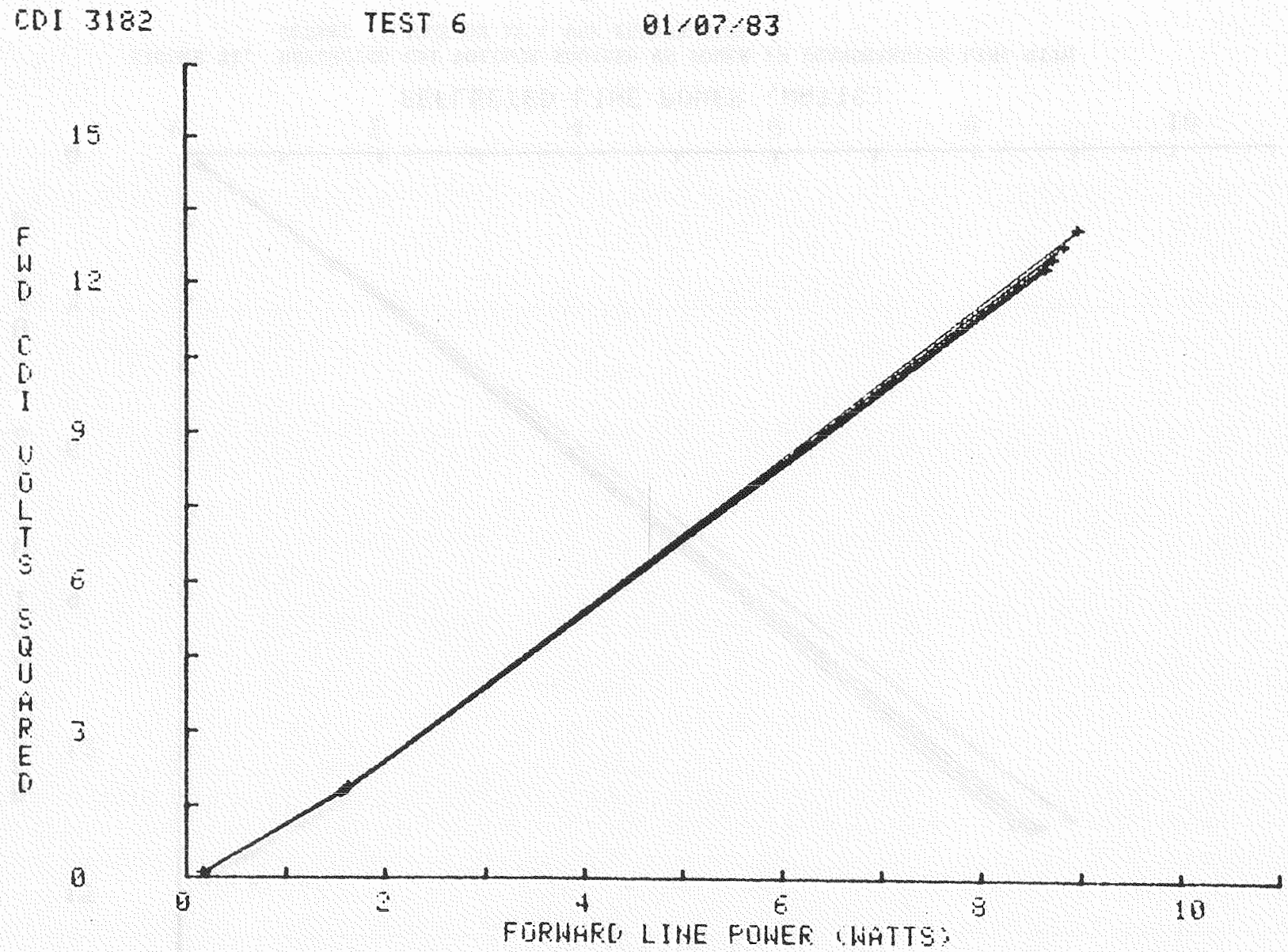


FIGURE 32. FORWARD CDI VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE WITHOUT OFFSET CORRECTION AT 4 VHF FREQUENCIES

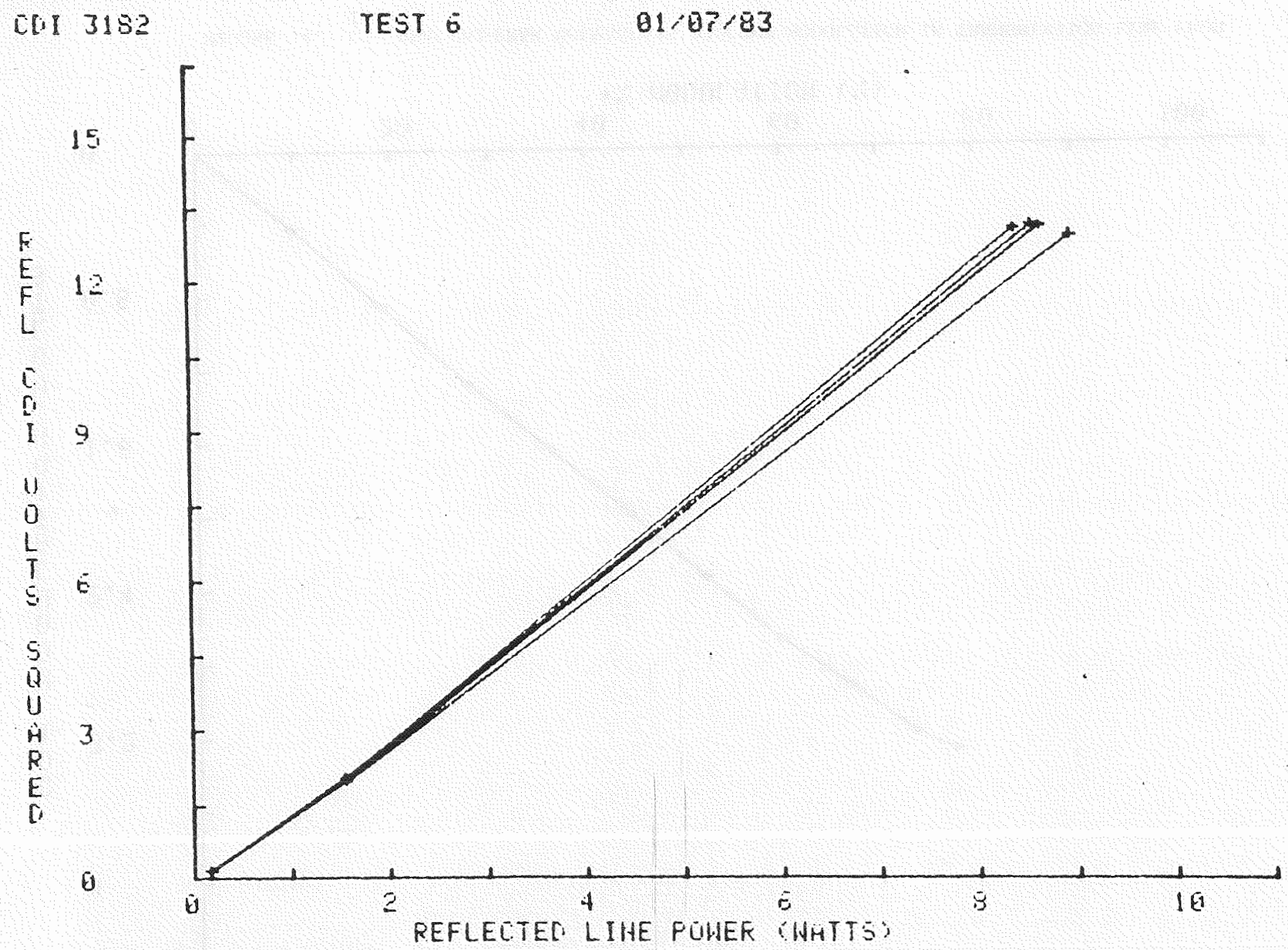


FIGURE 33. REFLECTED CDI VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE WITHOUT OFFSET CORRECTION AT 4 VHF FREQUENCIES

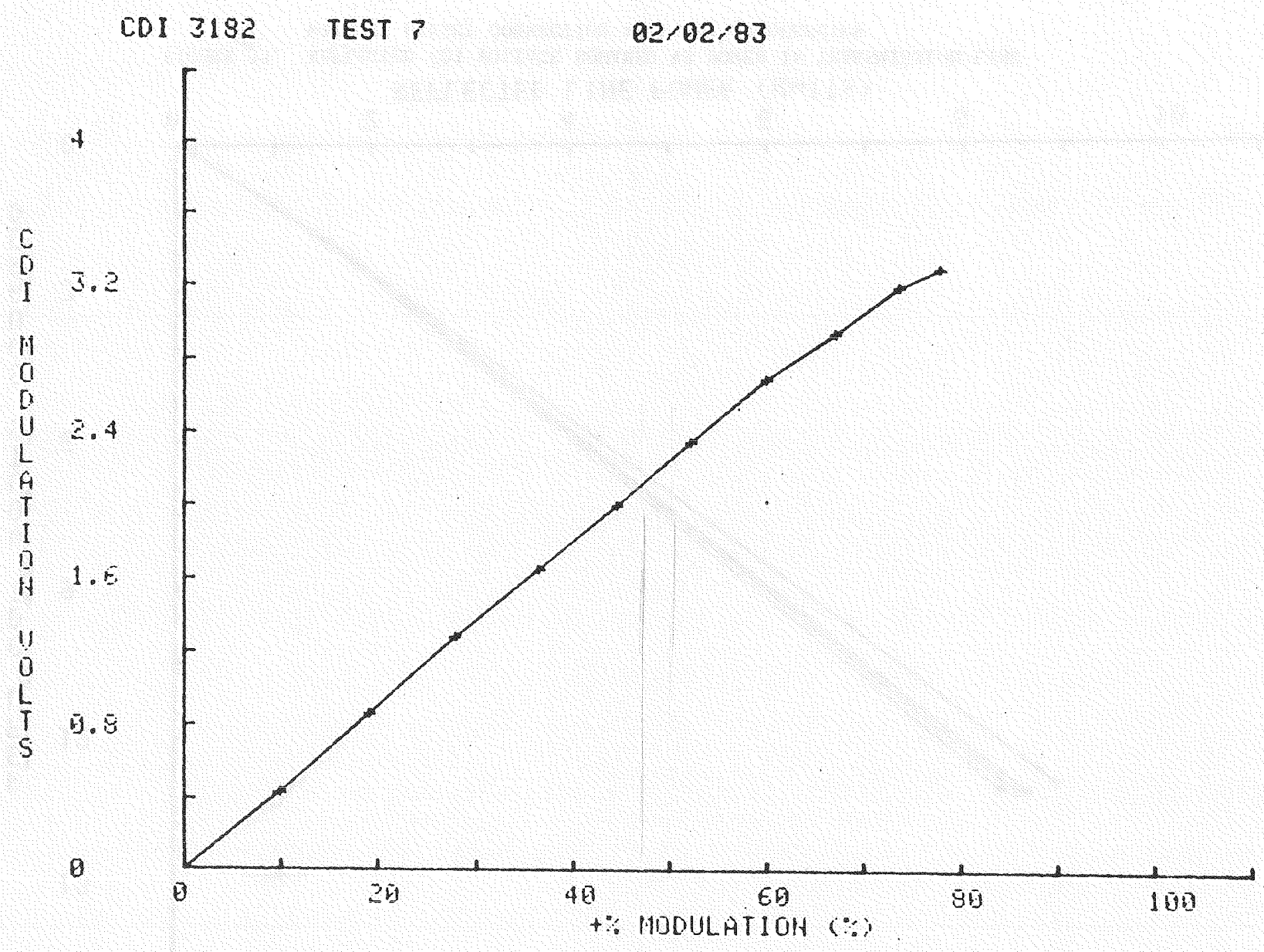


FIGURE 34. CDI PEAK-TO-PEAK VOLTAGE VS PERCENT MODULATION IN TRANSMISSION LINE FROM TEST 7

TABLE 1. CDI DATA WITH AND WITHOUT LOADING RESISTORS (DATA TAKEN AT 133.125 MHz FROM TEST 1 at 2:1 VSWR)

NARDA POWER		CDI WITH RESISTOR		CDI WITHOUT RESISTOR	
FORWARD (mw)	REFLECTED (mw)	FORWARD (volts)	REFLECTED (volts)	FORWARD (volts)	REFLECTED (volts)
54.2	5.30	4.895	1.532	4.893	1.530
50.6	4.94	4.742	1.490	4.737	1.489
46.9	4.58	4.566	1.469	4.560	1.466
43.3	4.22	4.384	1.420	4.387	1.419
39.7	3.88	4.200	1.373	4.198	1.373
36.1	3.53	4.009	1.323	4.010	1.323
32.5	3.17	3.802	1.284	3.798	1.285
28.9	2.82	3.590	1.239	3 607	1.239
25.3	2.47	3.364	1.195	3.359	1.195
21.7	2.14	3.150	1.146	3.148	1.142
18.1	1.77	3.094	1.090	3.090	1.093

TABLE 2. CDI DETECTOR VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE (SHEET 1 of 2)

FORWARD

TRANSMITTER FREQUENCY (MHz.)	TRANSMITTER POWER (WATTS)	CDI VOLTAGE SQUARED $(VOLTS)^2$
136.00	8.99	13.117
136.00	1.63	1.885
136.00	.173	0.1086
130.00	8.84	12.777
130.00	1.59	1.810
130.00	.166	0.1014
125.00	8.74	12.521
125.00	1.56	1.756
125.00	.168	0.1017
121.00	8.66	12.330
121.00	1.55	1.733
121.00	.161	0.0958

TABLE 2. CDI DETECTOR VOLTAGE SQUARED VS POWER IN TRANSMISSION LINE (SHEET 2 of 2)

REFLECTED

TRANSMITTER FREQUENCY (MHz.)	TRANSMITTER POWER (WATTS)	CDI VOLTAGE SQUARED $(VOLTS)^2$
136.00	8.40	13.716
136.00	1.54	2.311
136.00	.163	0.2120
130.00	8.58	13.793
130.00	1.55	2.299
130.00	.166	0.2144
125.00	8.67	13.749
125.00	1.55	2.263
125.00	.169	0.2143
121.00	8.67	13.572
121.00	1.55	2.238
121.00	.168	0.2096

TABLE 3. MODULATION DATA FROM TEST 7 AT 118.0 MHz.

TRANSMITTER MODULATION PERCENTAGE (+%)	TRANSMITTER MODULATION PERCENTAGE (-%)	CDI VOLTAGE PEAK TO PEAK (VOLTS)	CDI DC OFF-SET VOLTAGE (VOLTS)
0.0	0.0	0.00	1.90
9.8	10.0	0.42	1.90
19.1	20.0	0.86	1.85
27.9	30.0	1.28	1.80
36.5	40.0	1.65	1.80
44.5	50.0	2.00	1.75
52.3	60.0	2.35	1.75
60.0	70.0	2.70	1.70
67.1	80.0	2.95	1.65
73.7	90.0	3.20	1.65
77.9	100.0	3.30	1.65

TABLE 4. VSWR PERCENT DEVIATION, NARDA VS SLOTTED LINE AT 133.125 (FROM TEST 3)

CDI 3182 133.125 MHZ TEST 3 07/20/82

VSWR NARDA	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
1.01097	1.030	-1.88245
1.01021	1.029	-1.85964
1.00991	1.028	-1.79151
TEE, NO STUB		
1.09943	1.085	1.31251
1.09812	1.084	1.28594
1.09702	1.084	1.18691
STUB #1		
1.47400	1.460	0.94966
1.47504	1.460	1.01966
1.47238	1.460	0.84073
STUB #2		
1.56046	1.550	0.67026
1.56007	1.550	0.64526
1.55777	1.550	0.49909
STUB #4		
1.61600	1.610	0.37109
1.61356	1.610	0.22547
1.61413	1.610	0.25606
STUB #7		
1.79133	1.790	0.07432
1.78918	1.790	-0.04564
1.78766	1.790	-0.13073
STUB #9		
1.95811	1.950	0.41404
1.95092	1.960	-0.46520
1.95289	1.960	-0.36384
STUB #25		
4.50899	4.540	-0.68783
4.47901	4.550	-1.58487
4.48637	4.570	-1.86410

TABLE 5. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 133.125 MHz (FROM TEST 4) WITHOUT OFFSET CORRECTION

CDI 3182 133.125 MHZ CDI 4 07/22/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0000	OFFSET REF(V)=0.0000	
1.03410	1.030	0.39666
1.04212	1.029	1.25861
1.05987	1.028	3.00692
TEE, NO STUB		
1.08331	1.085	-0.15602
1.08635	1.084	0.21644
1.09812	1.084	1.28608
STUB #1		
1.44431	1.460	-1.08649
1.44487	1.460	-1.04705
1.45136	1.460	-0.59517
STUB #2		
1.53213	1.550	-1.16648
1.53332	1.550	-1.08776
1.54112	1.550	-0.57624
STUB #4		
1.58768	1.610	-1.40573
1.58983	1.610	-1.26847
1.59864	1.610	-0.71048
STUB #7		
1.76726	1.790	-1.28645
1.77113	1.790	-1.06563
1.78401	1.790	-0.33570
STUB #9		
1.93890	1.950	-0.57268
1.94000	1.960	-1.03067
1.95954	1.960	-0.02344
STUB #25		
4.76842	4.540	4.79033
4.87124	4.550	6.59468
4.51433	4.570	-1.23324

TABLE 6. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 133.125 MHz (FROM TEST 4) WITHOUT OFFSET CORRECTION

CDI 3182 133.125 MHZ CDI 4 07/22/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0302		OFFSET REF(V)=0.0802
1.00250	1.030	-2.74359
1.00249	1.029	-2.64468
1.00164	1.028	-2.63175
TEE, NO STUB		
OFFSET FWD(V)=0.0298		OFFSET REF(V)=0.0795
1.05074	1.085	-3.26021
1.04568	1.084	-3.66462
1.03854	1.084	-4.37731
STUB #1		
OFFSET FWD(V)=0.0311		OFFSET REF(V)=0.0797
1.40199	1.460	-4.13754
1.39212	1.460	-4.87599
1.37458	1.460	-6.21453
STUB #2		
OFFSET FWD(V)=0.0333		OFFSET REF(V)=0.0800
1.48736	1.550	-4.21169
1.47746	1.550	-4.90943
1.45979	1.550	-6.17971
STUB #4		
OFFSET FWD(V)=0.0315		OFFSET REF(V)=0.0791
1.54162	1.610	-4.43578
1.53238	1.610	-5.06509
1.51482	1.610	-6.28348
STUB #7		
OFFSET FWD(V)=0.0315		OFFSET REF(V)=0.0791
1.71576	1.790	-4.32698
1.70689	1.790	-4.86883
1.69008	1.790	-5.91219
STUB #9		
OFFSET FWD(V)=0.0315		OFFSET REF(V)=0.0791
1.88193	1.950	-3.61730
1.86903	1.960	-4.86706
1.85569	1.960	-5.62124
STUB #25		
OFFSET FWD(V)=0.0315		OFFSET REF(V)=0.0791
4.58484	4.540	0.97796
4.63585	4.550	1.85190
4.21214	4.570	-8.49582

TABLE 7. VSWR PERCENT DEVIATION, NARDA VS SLOTTED LINE AT 127 MHz (FROM TEST 3)

CDI 3182 127 MHZ TEST 3 08/11/82

VSWR NARDA	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
1.03822	1.020	1.75490
1.03818	1.020	1.75153
1.03864	1.020	1.79474
TEE, NO STUB		
1.05652	1.075	-1.74889
1.05736	1.075	-1.66811
1.05706	1.075	-1.69714
STUB #1		
1.38521	1.400	-1.06800
1.38542	1.420	-2.49613
1.38478	1.420	-2.54315
STUB #2		
1.45846	1.490	-2.16271
1.45872	1.500	-2.83003
1.45888	1.500	-2.81887
STUB #4		
1.50746	1.550	-2.82192
1.50700	1.550	-2.85312
1.50657	1.560	-3.54613
STUB #7		
1.65358	1.680	-1.59792
1.65329	1.700	-2.82550
1.65250	1.730	-4.68969
STUB #9		
1.78868	1.850	-3.42847
1.78918	1.850	-3.39912
1.78766	1.850	-3.48706

TABLE 8. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 127 MHz (FROM TEST 4) WITHOUT OFFSET CORRECTION

CDI 3182 127 MHZ CDI 4 08/11/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0000	OFFSET REF(V)=0.0000	
1.03627	1.020	1.56981
1.04455	1.017	2.63708
1.06316	1.020	4.05927
TEE, NO STUB		
1.07862	1.070	0.79947
1.08207	1.067	1.39235
1.09496	1.065	2.73574
STUB #1		
1.41245	1.400	0.88154
1.41440	1.420	-0.39584
1.42055	1.420	0.03840
STUB #2		
1.49324	1.490	0.21698
1.49494	1.500	-0.33854
1.50171	1.500	0.11380
STUB #4		
1.54476	1.550	-0.33920
1.54686	1.550	-0.20295
1.55555	1.560	-0.28602
STUB #7		
1.70559	1.680	1.50054
1.70903	1.700	0.52809
1.72143	1.730	-0.49773
STUB #9		
1.85419	1.850	0.22620
1.85929	1.850	0.49966
1.87423	1.850	1.29286

TABLE 9. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 127 MHz (FROM TEST 4) WITHOUT OFFSET CORRECTION

CDI 3182 127 MHZ CDI 4 08/11/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0401	OFFSET REF(V)=0.0878	
1.00307	1.020	-1.68780
1.00291	1.017	-1.40539
1.00205	1.020	-1.79106
TEE, NO STUB		
OFFSET FWD(V)=0.0395	OFFSET REF(V)=0.0871	
1.04464	1.070	-2.42717
1.03956	1.067	-2.63911
1.03277	1.065	-3.12030
STUB #1		
OFFSET FWD(V)=0.0410	OFFSET REF(V)=0.0874	
1.36953	1.400	-2.22502
1.36078	1.420	-4.35213
1.34268	1.420	-5.75839
STUB #2		
OFFSET FWD(V)=0.0411	OFFSET REF(V)=0.0869	
1.44833	1.490	-2.87731
1.43886	1.500	-4.24899
1.42025	1.500	-5.61514
STUB #4		
OFFSET FWD(V)=0.0419	OFFSET REF(V)=0.0870	
1.49844	1.550	-3.44112
1.48899	1.550	-4.09751
1.47137	1.560	-6.02368
STUB #7		
OFFSET FWD(V)=0.0422	OFFSET REF(V)=0.0871	
1.65451	1.680	-1.54073
1.64525	1.700	-3.32807
1.62854	1.730	-6.23042
STUB #9		
OFFSET FWD(V)=0.0418	OFFSET REF(V)=0.0873	
1.79838	1.850	-2.87043
1.78959	1.850	-3.37571
1.77265	1.850	-4.36354

TABLE 10. VSWR PERCENT DEVIATION, NARDA VS SLOTTED LINE AT 118 MHz (FROM TEST 3)

CDI 3182 118 MHZ TEST 3 08/16/82

VSWR NARDA	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
1.01360	1.025	-1.12505
1.01376	1.020	-0.61538
1.01353	1.022	-0.83610
TEE, NO STUB		
1.01969	1.070	-4.93375
1.01949	1.075	-5.44521
1.01918	1.080	-5.96731
STUB #1		
1.35922	1.400	-3.00033
1.35915	1.400	-3.00560
1.35138	1.400	-3.59780
STUB #2		
1.42664	1.455	-1.98754
1.42599	1.460	-2.38479
1.41724	1.460	-3.01729
STUB #4		
1.46781	1.500	-2.19316
1.46574	1.500	-2.33714
1.45888	1.500	-2.81887
STUB #7		
1.59625	1.630	-2.11436
1.59448	1.630	-2.22783
1.58532	1.630	-2.81853
STUB #9		
1.71367	1.750	-2.11982
1.69852	1.750	-3.03099
1.69844	1.750	-3.03591

TABLE 11. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 118 MHz (FROM TEST 4) WITHOUT OFFSET CORRECTION

CDI 3182 118 MHZ CDI 4 08/16/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0000	OFFSET REF(V)=0.0000	
1.03728	1.025	1.18403
1.04449	1.025	1.86562
1.06276	1.025	3.55271
TEE, NO STUB		
1.06750	1.077	-0.88958
1.07160	1.077	-0.50395
1.08513	1.077	0.74965
STUB #1		
1.36061	1.400	-2.89516
1.36209	1.400	-2.78313
1.36944	1.400	-2.23191
STUB #2		
1.42978	1.460	-2.11395
1.43160	1.460	-1.98370
1.43811	1.460	-1.52182
STUB #4		
1.47328	1.500	-1.81386
1.47519	1.500	-1.68190
1.48355	1.500	-1.10874
STUB #7		
1.60933	1.630	-1.28425
1.61122	1.630	-1.16546
1.62069	1.630	-0.57447
STUB #9		
1.73505	1.750	-0.86159
1.73955	1.750	-0.60096
1.75253	1.750	0.14422

TABLE 12. VSWR PERCENT DEVIATION, CDI VS SLOTTED LINE AT 118 MHz (FROM TEST 4) WITH OFFSET CORRECTION

CDI 3182 118 MHZ CDI 4 08/16/82

VSWR CDI	VSWR SLOTTED LINE	% DEVIATION
NO TEE		
OFFSET FWD(V)=0.0370	OFFSET REF(V)=0.0850	
1.00687	1.025	-1.80073
1.00649	1.025	-1.83910
1.00679	1.025	-1.80843
TEE, NO STUB		
OFFSET FWD(V)=0.0423	OFFSET REF(V)=0.0902	
1.03452	1.077	-4.10614
1.03050	1.077	-4.51263
1.02475	1.077	-5.09910
STUB #1		
OFFSET FWD(V)=0.0435	OFFSET REF(V)=0.0901	
1.32024	1.400	-6.04138
1.31194	1.400	-6.71219
1.29612	1.400	-8.01444
STUB #2		
OFFSET FWD(V)=0.0429	OFFSET REF(V)=0.0900	
1.38759	1.460	-5.21869
1.37915	1.460	-5.86254
1.36155	1.460	-7.23090
STUB #4		
OFFSET FWD(V)=0.0423	OFFSET REF(V)=0.0902	
1.42970	1.500	-4.91715
1.42110	1.500	-5.55222
1.40437	1.500	-6.80931
STUB #7		
OFFSET FWD(V)=0.0412	OFFSET REF(V)=0.0899	
1.56195	1.630	-4.35692
1.55235	1.630	-5.00210
1.53466	1.630	-6.21279
STUB #9		
OFFSET FWD(V)=0.0407	OFFSET REF(V)=0.0900	
1.68383	1.750	-3.92964
1.67583	1.750	-4.42582
1.65912	1.750	-5.47740

APPENDIX A

EQUATION FOR POWER AND VSWR

VSWR for transmission line is calculated using the expression:

$$S = \frac{1 + \sqrt{Pr/Pf}}{1 - \sqrt{Pr/Pf}} \qquad \text{(A-1)}$$

where

S = VSWR
Pf = Forward Power
Pr = Reflected Power

To calculate VSWR from the Narda coupler, the Forward and Reflected power outputs of the Narda must first be rescaled. The Narda output ports are -24.42 dB (forward port) and -24.62 dB (reflected port) with respect to the power in the transmission line. Therefore,

Pf = PFN/3.6141E-3
Pr = PRN/3.4514E-3

where

PFN = Forward Power at Narda Port
PRN = Reflected Power at Narda Port
Pf = Forward Power in Transmission Line
Pr = Reflected Power in Transmission Line

To calculate the VSWR from the CDI detector, equation A-1 must first be rewritten using the following expression for power:

$$P = \frac{V^2}{Z}$$

where

P = Power
V = Voltage
Z = Impedance

therefore,

$$S = \frac{1 + \sqrt{(Vr^2/Zr)/(Vf^2/Zf)}}{1 - \sqrt{(Vr^2/Zr)/(Vf^2/Zf)}} \qquad \text{(A-3)}$$

where

Vf = Forward CDI Voltage
Vr = Reflected CDI Voltage
Zf = Impedance seen by Forward CDI Probe
Zr = Impedance seen by Reflected CDI Probe

Since the probes of the CDI detector are spaced very close together, it can be assumed that the line impedance at each CDI's probe is essentially the same. This allows equation A-3 to become:

$$S = \frac{1 + \sqrt{(Vr^2/Vt^2)}}{1 - \sqrt{(Vr^2/Vf^2)}} \qquad \text{(A-4)}$$

Equation A-4 can be rewritten as:

$$S = \frac{1 + (Vr/Vf)}{1 - (Vr/Vf)} \qquad \text{(A-5)}$$

Thus, the equation for S is a linear equation.

APPENDIX B

TRANSMISSION LINE EFFECTS

The transmission line will add attenuation to the system. This attenuation can cause the VSWR measurement taken at the output of the transmitter to be different then the VSWR at the antenna. The change in the VSWR may make the SWR, as seen at the transmitter be within the tolerance allowed, but at the antenna it may be outside the allowed tolerance. The table below gives the VSWR at both the antenna and the transmitter through a 3 dB loss transmission line.

Forward Power		Reflected Power		VSWR	
at Transmitter	at Antenna	at Transmitter	at Antenna	Transmitter	Antenna
10 watts	5 watts	0.0694 watts	0.139 watts	1.18	1.4
10	5	0.1	0.2	1.22	1.5
10	5	0.133	0.266	1.26	1.6
10	5	0.204	0.408	1.33	1.8
10	5	0.278	0.556	1.4	2.0
10	5	0.625	1.25	1.67	3.0
10	5	2.5	5.0	3.0	0

The equations to calculate the VSWR are given in appendix A. A sample of how the values were calculated is done below for a 2.0:1 VSWR at the antenna with 10 watts out of the transmitter. Since the transmission line has 3 dB of attenuation, the power received by the antenna is 5 watts (a ratio of 2 to 1). Equation A-1 can be rewritten as follows:

$$Pr = Pf \left[\frac{SWR - 1}{SWR + 1}\right]^2 \qquad \text{(B-1)}$$

where

Pf = Forward Power at the Antenna
Pr = Reflected Power at the Antenna
VSWR = Antenna's VSWR

Putting in the values, Equation B-1 becomes:

$$Pr = 5 \left[\frac{2-1}{2+1}\right]^2 = 0.556 \text{ watts}$$

after this reflected power goes back through the transmission line, it becomes 0.278 watts at the transmitter (3 dB down). If this reflected value is then used in equation A-1, the actual VSWR is found to be:

$$S = \frac{1 + \sqrt{0.556/10}}{1 - \sqrt{0.556/10}} = 1.4:1 \text{ VSWR}$$

Therefore, the VSWR at the transmitter is 1.4:1 but the VSWR at the antenna is 2.0:1.