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Worth Research Associates

TM 129
(DRAFT)

SUMMARY REPORT

Contract N00014-83-C-2004

1982

Introduction

Under this contract, Worth Research continued work which was initiated under Contract N00014-82-2079 to operate and maintain the SEA ECHO high frequency radio facility at San Clemente Island, California, in support of the Naval Research Laboratory CHANNEL PROBER project.(1) This project is concerned with an experimental determination of wide-band propagation parameters in the HF spectrum. Propagation characteristics of both sky-wave and ocean-surface surface-wave modes were the subject of the investigations. To provide near-full-scale measurement ranges, ocean propagation paths from San Clemente Island to Pt. Mugu, California, (site of the Navy Pacific Missile Test Center) and to Pt. Arguello (Vandenberg Air Force Base) were used.

Generally, field operations were conducted over periods of two to three weeks at times which allowed varied samples of seasonal ionspheric conditions. Test campaigns were conducted from October 18 through November 1, 1982; January 10 through January 17; and May 1 to May 14, 1983. In addition, a short series of tests was run with the SEA ECHO facility alone in the period from March 7 to March 10, 1983. A summary of each of these operations is given in the following section, together with the results of measurements made at the SEA ECHO facility. (These measurements provide values for transmitted radio frequency power as a function of frequency, a necessary input to the overall CHANNEL PROBER determination of propagation loss.)

In the course of the investigations conducted under this contract, experience gained from earlier tests revealed need for more detailed understanding of the quantitative parameters of the SEA ECHO facility - in particular, the antenna and the way its characteristics varied with frequency. In earlier test missions, values for radiated power were based on measurements of final amplifier output power - derived from the SEA ECHO power monitor system discussed in detail elsewhere(2) - and the assumption that the SEA ECHO antenna and its individual elements varied smoothly over the frequency band being utilized. Furthermore, it had been assumed - in effect - that substantially all of the power being input to the antenna elements was being radiated and in the forward direction. (It should be noted that the half-rhombic elements used are "long-wire" elements and that the assumption noted above was based on the prior assumption that all substantial energy would be dissipated by radiation at the front end of the rhombic, leaving no appreciable energy to be reflected.)

In view of these assumptions, measurements of SEA ECHO power output levels were restricted to a relatively few points across the spectrum, and power output was interpolated as a smooth function.

Later analyses of data acquired at the CHANNEL PROBER receiving site showed strong - and reproduceably periodic - fluctuations across the band, however, that indicated the foregoing assumptions were not valid. Accordingly, several steps were taken to provide a more quantitatively accurate understanding of those antenna characteristics which are germaine to true values for radiated power.

The first of these was to conduct a limited series of power output measurements (the March tests) in which, for a limited spectral span, measurements were taken at closely-spaced frequency intervals. These tests and their results are discussed below, but generally showed that - as determined by the SEA ECHO power monitor system - there is indeed a periodic fluctuation in frequency which had earlier gone undetected. (It should be noted that the CHANNEL PROBER automatic data acquisition and waveform generation systems sample with very closely-spaced frequency increments, hence readily detected the fluctuation.)

Within the frequency interval measured in the March tests (4.5 to 6.5 Mhz), the peak-to-peak fluctuation in final amplifier power output level appeared to be about 4 db. The variation noted at the receiving site, however, was more nearly 10 db or so, which provided some insight that the measured variation of power input to the antenna elements was actually only partially indicative of a frequency-dependent antenna characteristic which as a more substantial influence on effective radiated power.

As a consequence of these considerations, a task was added to the contract to conduct limited test measurements on the antenna itself. These measurements in effect comprised a set of frequency dependent antenna gain measurements made with the aid of field-strength equipment carried on a charter boat. The siting of this equipment was carefully determined to be at a relatively short range (5+ nmi), yet in the antenna far field and to be accurately within the antenna main beam. These tests are described in a later section of the report.

Test Mission Synopses

A review of the test missions of October 1982 and January, March and May 1983 is given in the following, together with measurement results made at the SEA ECHO facility for each.

During the October 1982 test mission, conducted for a test path from San Clemente Island to Pt. Mugu, the following items were accomplished in addition to routine operation of the system.*

In response to revised parameters of the current test program, tests were run throughout most of this campaign with only five elements of the antenna array actively excited. Since each of the antenna elements is individually driven with its own final amplifier, this arrangement was readily accomplished by turning off prime power to the rest of the final amplifiers. Elements 11, 12, 13, 14 and 15 in the center of the 25-element array were selected for use. (Later, for a short period, Element 13 alone was used.)

Calculations by NRL of the SEA ECHO array pattern showed that for extreme azimuthal steering angles - as required to illuminate the Pt. Mugu receiving

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*In the work conducted under this contract, Worth Research provided all technical labor required to operate both the SEA ECHO and the NRL-provided equipment at San Clemente Island.

site - high-angle elevation side-lobes are significantly reduced over those experienced at azimuthal bore-site. At the short range to Pt. Mugu, suitable sky-wave launch angles are quite high. Accordingly, the reduction in array elements was selected to augment the effect of normal high-angle side-lobes expected from the SEA ECHO rhombic elements.

In order to optimize the transmitted power levels, a selection was made among the available 25 transmitters, and five of the most robust final amplifiers were moved into the active positions in the array. Subsequently one of this group was inadvertently overdriven and failed and was replaced with a sixth unit.

Power Calibrations

Transmitted power calibrations were made as described in Worth Research Report TM 123.(3)

Briefly, this consists of making careful signal level measurements of the CHANNEL PROBER waveforms for a selection of frequencies, and then determining the final RF power output levels for all final amplifiers (with the SEA ECHO power-monitoring system) using a relatively long pulse from a SEA ECHO test equipment source whose input amplitude is matched to that determined for the CHANNEL PROBER SOUNDER and PROBER waveforms for each frequency. A previously-determined downward adjustment of, respectively, 2 db and 8 db is applied to the long pulse measurements to arrive at the values for true power output for the CHANNEL PROBER excitation.

As in earlier tests, the PROBER drive levels were increased relative to those for the SOUNDER mode in recognition of the fact that the amplitude response of the SEA ECHO amplifiers is attenuated with very short pulse modulation.

Because of the reduced number of active elements, it was desirable to keep the system output as high as possible. Considerable care was exercised in setting the drive levels in response to two considerations.

With low drive levels the scope-displayed power-analog signals can become too low to read with accuracy. Conversely, consideration must be given to high drive levels since in the final, substituted long pulse operation, the final amplifiers are being driven to levels which are considerably higher than those experienced during the normal runs since the RF amplifiers are more responsive to the long pulses.

Two improvements were introduced in the overall system and were used during all data runs. In the first of these, a simple RC weighting filter was introduced in the SEA ECHO input circuits to compensate for a tendency of the final amplifiers to roll off to reduced output at frequencies above about 15 MHz. Since this is a lossy filter, extra gain was provided via a commercial wide band amplifier and suitable extra attenuation to keep input levels reasonably low. This arrangement is shown in Figure 1. Also shown in this figure is the second modification, namely the use of a matched power splitter and pad in the scope sampling circuit used to determine and match drive levels between the CHANNEL PROBER excitation and the SEA ECHO long-pulse test signal. This change was introduced for the purpose of avoiding standing-wave resonances in the jumper cables connecting to the scope high-impedance input, a factor which can distort true levels between different connections.

Table I and Figures 2 and 3 give the calibrated values for the CHANNEL PROBER RF power output using the five elements noted and operating with the MID-String.

Power Calibration Improvements

As noted in the foregoing section (and earlier reports) power output calibration was complicated by certain SEA ECHO system characteristics (intended for much longer pulse lengths). These include (a) a peculiarity of the RF transistors which appear to undergo a "warm-up" period of a microsecond or less and (b) the filter time-constants of the power monitoring and commutating systems. During this test period, Worth Research undertook a design improvement investigation on a spare unit in the laboratory which showed promise of resolving the problems noted. Briefly, this amounted to inserting a second, peak-reading detector in the power monitor circuit which in effect produces a well-filtered DC output rather than a "video" reproduction of the RF pulse envelope. A series of measurements were made in the lab using a tapped resistive dummy load where the "normal" power monitor output was calibrated against the dummy load output using the new "DC" circuit and a SEA ECHO long-pulse drive. The calibration was unchanged from that made before the circuit change. Then both "PROBER" and "SOUNDER" signals were used for drive and again the comparison with the dummy load remained unchanged. Finally the modified lab unit was installed in the antenna array (position #5, powered only for this test) and produced a normal (in fact, cleaner) display on the commutated scope. In later tests this modification was installed on all final amplifiers used.

Telephone Data Line

During this period, various discussions were held with the Navy Public Works Center and Pacific Telephone representatives about the requested telephone data line and its mode of operation. Also, a new multi-pair armored cable was installed between the air terminal at San Clemente Island and the SEA ECHO site. This provided two pair for the data line circuit (Circuit #5GD 5274) and puts the San Clemente Island extension (4459) and toll station (Wilson Cove 10) in a new cable which avoids potential problems with an old cable run under the airfield runway.

In the January 1983 test mission, as in that of October 1982, Worth Research provided all tasks of experiment development, maintenance and operation of the SEA ECHO high frequency radio facility at San Clemente Island. Actual test operations were run during the period January 11 through 16 with a few days of prior support provided at San Clemente Island for telephone data-line installation and other equipment preparation.

The SEA ECHO transmitting equipment operated to full specification during the tests, as did the equipment provided by the Naval Research Laboratory. Fixes required for both facilities were minor in nature. The parameters and circuit arrangements as used in the October 1982 exercise were exactly duplicated with the one exception that the SEA ECHO input drive attenuator was set to 18 db of attenuation rather than 20 db as previously. (The following discussion notes that the resulting RF final output is increased by more than the 2 db difference.)

The NRL data line, ordered by NRL from the two southern California telephone companied involved, was brought on line before the start of tests and greatly facilitated the use - by the NRL controlling station at Pt. Mugu - of digital control programs and, in particular, verbal communications between the two test sites.

As in the October tests, RF emission was restricted to five transmitter/antenna elements (positions 11, 12, 13, 14 and 15). For a limited test, one element, No. 13, was used. As discussed in the following section, an improved circuit was installed in the transmitter power-monitor systems which facilitated the acquisition of RF power data and probably also improved the accuracy of these data.

RF Power Calibration

Radio frequency power output calibrations were made - as in previous campaigns - using the SEA ECHO power monitoring system. In the January tests, a circuit modification was installed in the five transmitter/amplifiers used. This modification introduced a second, clamping, detector and filter after the RF peak detector used in the monitoring circuits. Tests conducted in the laboratory compared the output of this modified circuit with measurements made with a well-calibrated dummy load. These tests showed that the output of the modified power monitor circuits provided a close match between "long-pulse" SEA ECHO modulation (used in previous exercises in a substitution method) and both PROBER and SOUNDER modulation. This is illustrated in Figure 4 which plots power-monitor output for a representative group of amplifiers (six) operating with long (approximately 0.5 millisecond) SEA ECHO pulses, as well as both PROBER and SOUNDER modulation (one transmitter).

The modification, in effect, produces a peak-reading DC output monitor signal rather than a pulse envelope. For this reason, earlier time-constant-dependent effects are avoided, both in the power monitor circuits and in the solid-state switching scanner which is used to display the output of all operating transmitters in one oscilloscope sweep. (While the individual power monitor outputs are essentially at DC, the dynamic sampling of the scanner produces a step pulse for each transmitter in the output display.)

The consequences of this modification are two-fold. First, the power output levels for the various CHANNEL-PROBER frequencies and pulse-widths can be determined directly, i.e., without recourse to the substitution method used previously. Secondly, because of the differing response of the SEA ECHO transmitters to long SEA ECHO pulses and short CHANNEL-PROBER pulses, the drive levels for the latter had to be depressed somewhat to avoid over-drive when calibrations were run. In the new mode, the output levels for the CHANNEL-PROBER tests could be increased somewhat. The consequences of this can be seen by comparison of the power output curves for these tests and those previously performed in October 1982.

Tables II and III list, respectively, the results of these power calibrations for operation with five transmitters (and associated antenna elements) and one transmitter. Figures 5, 6, 7 and 8 plot the same data. (The "MID" set of antenna strings was used for all tests and calibrations.)

Comparison of the five-element results for these calibrations and those of the October 1982 tests show close agreement in their frequency-dependent response. Drive level for the January tests was 2 db higher than for October; the somewhat higher ratio between final output is to be expected in view of the SEA ECHO amplifiers' somewhat non-linear amplitude response.

In another observation, comparison of the ratio of forward to reverse power at the transmitters' output has shown that impedance match to the antennas is such that at frequencies above 8.5 MHz, inclusion of reverse power in the calibration has an influence of the order of only 0.1 db; below that frequency, the influence is of the order of 1 db. Reverse power has been included in the data presented here for the lower band.

Telephone Data Line

After previous attempts to provide digital data communication between the Pt. Mugu and San Clemente Island sites with, first, nominal telephone lines and, second a single-pair dedicated line, a full two-pair data/voice-alternate line was installed with appropriate terminating equipment and line adjustment by telephone experts. This system worked impeccably during the January tests, providing both noise-free data communication and voice. Since this line is essentially a permanent connection between the two stations - albeit via land-line and microwave links as well as two telephone company facilities - it provided instant and reliable communication between the sites and greatly facilitated the exercise. (For reference, the designation of this circuit has been #5GD 5274, ordered through the General Telephone Company.)

As noted in the Introduction, a special series of tests were run in March by NRL request. These tests consisted of measurements of the SEA ECHO power output, made for the purpose of investigating fine-grained fluctuations - as a function of frequency - in the SEA ECHO output power.

Because of temporary (and later resolved) difficulties with the NRL equipment, tests were made using the SEA ECHO test drive with a pulse repetition interval of 2.4 msec and pulse width of 0.27 msec. The power measurements included the output of transmitters 11, 13, 14 and 15. (No. 12 was feeling poorly and hence was not included.)

The antenna MID string was used and the drive level into the SEA ECHO 805 amplifier was at +7 dbm. The signal source was a 606A generator whose output was monitored with a Data Precision 5845 frequency meter. Frequency was held to within one kiloHertz of each 100 KHz step.

Two sets of measurements were taken under identical conditions, on on March 8 and one on March 9.

Data for the four elements - taken collectively - are listed for the two days in Tables IV and V and are plotted in Figure 9.

To investigate the consequences of radiation from reflections in the SEA ECHO unterminated rhombic antenna, these same data were used to determine - for one element (#14) - forward and reflected power as measured by the transmitter power monitor system and, finally, the ratio of these values. These values are listed in Tables VI and VII and plotted in Figure 10.

It seems clear from this information that the antenna elements as used (and perhaps the combination of antenna and transmitter) produce some degree of frequency-dependent periodic variation in effective radiated power. The periodicity of the effect - revealed when measurements are sufficiently closely-spaced - suggests a series of resonances which either (or both) influences the coupling between transmitter and antenna, or the effective radiation resistance of the antenna.

Based on these results and comparison with related amplitude variations with frequency observed with the receiving equipment at Pt. Mugu, it was decided to conduct in situ measurements of the SEA ECHO antenna as part of the next full scaled test mission which was subsequently conducted in May.

For the test mission conducted in May 1983, the NRL receiving equipment was moved to Pt. Arguello, a location at Vandenberg Air Force Base on the California coast, which increased the propagation path from San Clemente Island to roughly twice the distance to Pt. Mugu. (The surface projection of the straight line path to the Pt. Arguello site grazes the western tip of Santa Cruz Island whose elevations reach to 2000 feet MSL. Received signal levels reported at the Pt. Arguello site were diminished below that expected by the increase in range, suggesting that scattering or obscuration was taking place.)

In preparation for the antenna gain tests (described in the next section), special resistors had been ordered by Worth Research to provide matched terminations for all strings of the five central elements, i.e. the active elements, of the antenna array. These resistors, obtained on special order from Power Film Systems of Yellville, Arkansas, are a thin-film tubular type which are non-reactive over the frequency band used. The characteristics are 150 ohms and 100 watts dissipation. In some of the regular CHANNEL-PROBER runs, the terminating resistors were connected to the antenna elements and, in some cases, were disconnected. Generally, SEA ECHO elements No. 11, 12, 13, 14 and 15 were used for all testing, although late in the test period it was noted that element No. 11 was showing equal levels of forward and reflected power, suggesting an effective disconnect from its antenna element.

The testing program proceeded routinely with no more than the nominal number of equipment problems expected of experimental equipment in the field. These included some difficulties with both commercial test equipment and project equipment at both transmitting and receiving sites. In particular, both the General Radio and PTS synthesizers in the NRL driver equipment at the SEA ECHO site showed a tendency for occasional intermittency. The PTS unit was later found to have been incompletely wired. However, part of the difficulty seemed clearly associated with the corrosive effects of the near-sea-side environment. The SEA ECHO site is equipped with a special long-life 3 kw diesel generator (currently in need of service). It would be highly desirable for future operations to put this unit into service and use it to power air-drying and conditioning equipment in the operating trailers. In operating condition, this generator is capable of unattended operation for two to three years.

The SEA ECHO equipment worked satisfactorily, including the antenna phasing system which was steered to the new azimuth of 313^0. Phasing relays and the control logic for this azimuth as well as the 339^0 azimuth used for the antenna gain measurements were checked and found to be operable. Also, as a one-time check of the delay cable connections, a phasing comparison measurement was made using a dual beam Tektronics oscilloscope. By using the fastest sweep speed available on this instrument, the phase shift between the inputs to Element 11 and successive adjoining elements could be checked for magnitude and sense, both with steers to the right and to the left of boresite (339^0 and 313^0 true). The system checked satisfactorily. One final amplifier, heavily overdriven in initial testing, failed. (The consequences of overdrive are that the transmit-receive switching circuits are overpowered and as much as a kilowatt of RF energy applied across low-power transistors. In this case, an entire circuit board was destroyed. The unit was replaced with one from an unused position in the array, and all units appeared to be working properly thereafter. However, late in the test program, a preliminary examination of the power monitor records showed that the unit in Position #11, while generating a healthy signal, was showing nearly-equal amplitudes on both forward and reverse power monitor circuits, thereby probably indicating an open circuit between the amplifier output and the antenna.

Accordingly, all test results should be based on assumed operation with elements (array positions) No. 12, 13, 14 and 15.

Measurements of SEA ECHO power input to the (four element) antenna array were made on May 11 and May 14.* The May 11 data are listed in Tables VIII and IX for, respectively, SOUNDER and PROBER modulations, and the same data are plotted in Figures 11 and 12. On May 14, an additional set of power measurements were made, using a SEA ECHO long-pulse wave form. For these measurements the NRL PTS synthesizer was used to establish an accurate radio frequency input to the SEA ECHO pulse modulator. The latter was adjusted to produce 0.5 millisecond pulses at 588 pps. (Since this long-pulse modulation tends to produce higher level outputs from the SEA ECHO final amplifiers, the interface attenuator was set to 21 db, i.e. somewhat higher than for routine tests. The comparable frequency-dependent output for this measurement matched with that for the results shown in Figures 11 or 12 is more or less coincidental; the shape of the curves was of primary interest.

The results of these latter measurements are listed in Table X and plotted in Figure 13.

SEA ECHO Antenna Measurements

Analysis of data from earlier phases of the CHANNEL PROBER field tests had showed excursions from theoretically-derived values of expected surface-

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* The May 11 measurement sequence was interrupted near the end by an equipment failure. The sequence was completed on May 13 without apparent damage to overall consistency.

wave propagation loss as a function of frequency and range.(4) While no attempt was made in this work to establish absolute values of propagation loss, nonetheless it was expected that a reasonable fit would be found between predicted and measured loss functions when the latter was suitably normalized. The excursions of the experimental from the theoretical curves appeared to be generally of two kinds, one of which was a periodic fluctuation of the experimental values as a function of frequency - where the peak-to-peak fluctuation exceeded 10 db in some cases. The second discrepancy was a general deviation at the high frequency end of the spectrum.

With respect to the first of these anomalies, it should be noted that rhombic antenna elements, such as those used in the SEA ECHO system, are usually front-terminated with a lumped resistance equal to the element characteristic impedance. This is done primarily to inhibit backward radiation of the antenna and, to some degree, to provide a constant input impedance at the driving end of the element. In both instances, otherwise undesired effects are produced by signal - albeit attenuated by radiation in the forward or desired direction - which is reflected backward along the long-wire rhombic element. Terminating resistors were originally provided in the SEA ECHO system, but because of mechanical design deficiencies, and corrosion from the sea air, they had failed electrically and had been removed some time ago. In consideration of CHANNEL PROBER test results which provided quantitative measurements at closely-spaced frequency intervals, it seemed highly probable that previously un-noted characteristics of the SEA ECHO antenna were producing a strong effect. Accordingly, two special tests were conducted where the San Clemente antenna was the principal focus of attention. The first of these was the test conducted in March in which, over a limited spectrum, the input to the antenna was measured with frequency increments of 100 Khz which was significantly more fine grained than had been previously assayed. The results of these tests indicated clearly that to the degree that antenna characteristics influence final amplifier output, there is indeed a periodic fluctuation with frequency which generally matches that seen by the CHANNEL PROBER receiving equipment. The fact that the peak-to-peak fluctuation amplitude at the final amplifiers is significantly less than that which is apparently radiated suggests that the antenna is doing something which is only partly indicated by the amplifier power-output monitors.

Following this limited investigation, preparations were made for a direct measurement of the SEA ECHO antenna by the direct approach of simultaneously measuring power into the antenna and field strength (in the main beam) at a down-range distance which was small enough so excess propagation loss could be ignored, yet large enough to be in the antenna far field. The platform for the field strength measurements was provided by charter boat. In these measurements, the objectives were to determine (a) the influence of antenna terminating resistors, (b) the quantitative influence of the sea as an imperfect ground plane on antenna gain in the vertical plane, and (c) generally, if possible, the absolute gain of the antenna as a function of frequency at horizontal elevation.

The test arrangements for the measurements of the SEA ECHO antenna were as follows:

Using (effectively) four active antenna elements, the system was operated with the CHANNEL PROBER wave form generator running in the SOUNDER mode. Input attenuation at the SEA ECHO input interface was 17 db (the value used throughout the May and earlier tests). SEA ECHO output power was measured as usual with the power monitor system whose components had earlier been modified to permit direct read-out of the wide-band CHANNEL PROBER wave form. Antenna steer was set to 339 degrees true, the azimuth to Pt. Mugu (where the majority of previous tests had been run).

The receiving facility was a Stoddard Model NM 25T field strength meter situated on a charter boat, the FISHERETTE, out of San Diego, commanded by Mr. Dean Carlson of Marine Experimental Services. Since positioning of the measuring platform is critical in this form of measurement and also difficult at sea without support from costly instrumentation radar, considerable care was taken to assure satisfaction of the quantitative goals of the test. Range from the radar was determined with the FISHERETTE marine radar using a 20-inch corner reflector located on top of SEA ECHO tower #11 as a target. This target was reported from the boat as clear and unambiguous. Bearing angle was was determined at the boat by visual alignment of two high-intensity range lights installed at the SEA ECHO site. These lights, 500 watt quartz halogen type, were located, respectively, on Tower #13 at approximately the 40-foot level (roughly 90 feet MSL) and at roughly the same altitude on the hillside behind the site. (Separation between the lights was about 1000 feet.) The lights were carefully triangulated to align with the 339 degree steer angle of the antenna, and sufficient power cable was laid to allow re-alignment to 313 degrees (although this was not done). At the operating range of 5.3 nmi, the lights were reported by the boat crew as clearly visible in bright daylight. (Periodic scans from shore with binoculars, looking along the range-light axis, showed that Captain Carlson did an exemplary job of staying in position.)

Communications for the test were maintained using the FISHERETTE VHF marine-band transceiver and a similar leased unit at the SEA ECHO site.

With the boat-deployed field strength equipment in the 339° beam at 5.3 nmi, measurements were taken with 150 ohm terminating resistors in place and with the resistors removed. The measurements were made in two groups, namely one in which frequency was incremented in 100 Khz steps between 4.5 and 6.5 Mhz, and one in which the steps were 1.0 Mhz between 2.5 and 28.5 Mhz. The measured total power output from the SEA ECHO transmitters is listed in Tables XI, XII, XIII and XIV, and plotted in Figures 14 and 15. Data from the field strength measurements and resulting values for antenna gain, and, ultimately, propagation loss were being reduced at NRL at the time of this report.

July 11, 1983

References

(1) Summary Report, Contract N00014-82-C-2079, Worth Research Associates Report TM 125, August 1982.

(2) Second Progress Report, Contract N00014-83-C-2004, Worth Research Associates Report TM 127, January 1983

(3) First Progress Report, Contract N00014-82-C-2079, Worth Research Associates Report TM 123, February 1982.

(4) Private communication, J.A. Goldstein, NRL.

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TABLE I

RF POWER OUTPUT

(MID STRING)

FREQUENCY	SOUNDER MODE	PROBER MODE
2.5 MHz	23.0 dbw	23.5 dbw
3.5	27.4	27.5
4.5	25.5	26.0
5.5	27.8	27.4
6.5	27.3	27.0
8.5	24.7	27.7
10.5	25.4	26.9
12.5	27.7	27.4
15.5	30.6	27.5
18.5	29.6	28.5
20.5	27.5	28.1
23.5	26.9	26.0
28.5	26.3	24.6

TABLE II

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RF POWER OUTPUT

(MID-STRING)
Five Elements

FREQUENCY	SOUNDER MODE	PROBER MODE
2.5 MHz	20.8 dBw	27.6 dBw
3.5	-	32.2
4.5	27.0	30.9
5.5	32.3	33.8
6.5	31.7	33.7
8.5	29.8	33.1
10.5	32.2	32.6
12.5	33.4	33.7
15.5	34.4	33.9
18.5	34.9	34.4
20.5	34.1	33.2
23.5	30.5	30.0
28.5	29.5	30.1

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TABLE III

RF POWER OUTPUT

(MID-STRING)
One Element

FREQUENCY	SOUNDER MODE	PROBER MODE
2.5 MHz	16.2 dBw	24.1 dBw
3.5	-	28.6
4.5	24.0	27.9
5.5	28.9	30.4
6.5	27.9	29.6
8.5	25.7	29.2
10.5	27.9	28.6
12.5	30.4	29.9
15.5	30.7	29.6
18.5	30.4	30.2
20.5	29.6	29.2
23.5	24.1	23.5
28.5	25.2	27.1

TABLE IV

RF POWER OUTPUT - UNITS 11, 13, 14, 15

MARCH ~~MAY~~ 8, 1983 DATA

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
4.5 MHz	1916 W	145 W	32.48 dBw
4.6	1680	110	31.96
4.7	2152	110	33.10
4.8	2142	47	32.21
4.9	2500	67	33.86
5.1	3721	398	35.22
5.2	4336	592	35.73
5.3	4145	481	35.64
5.4	4009	481	35.48
5.5	3403	370	34.82
5.6	2371	173	33.42
5.7	2146	132	33.04
5.8	1777	27	32.43
5.9	2624	75	34.06
6.0	4360	607	35.74
6.1	4178	596	35.54
6.2	3835	404	35.35
6.3	3102	249	34.55
6.4	2996	215	34.44
6.5	2422	145	33.57

TABLE V

RF POWER OUTPUT - UNITS 11, 13, 14, 15

MARCH ~~MAY~~ 9, 1983 DATA

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
4.5 MHz	1536 W	107 W	31.6 dBw
4.6	1424	102	31.2
4.7	1832	102	32.4
4.8	1758	47	32.3
4.9	2217	67	33.3
5.1	3500	308	35.0
5.2	3685	434	35.1
5.3	3490	364	34.9
5.4	3438	283	35.0
5.5	2849	250 (est)	34.1
5.6	2118	132	33.0
5.7	1744	86	32.2
5.8	1479	12	31.7
5.9	2246	43	33.4
6.0	3839	445	35.3
6.1	3866	472	35.3
6.2	3356	350	34.8
6.3	3064	268	34.5
6.4	2720	167	34.1
6.5	2491	107	33.8

2491 − 107 = 2384

10 log 2384 = 33.8

TABLE VI

RF POWER RATIO - UNIT 14

MARCH ~~MAY~~ 8, 1983 DATA

FREQUENCY	FORWARD POWER	REVERSE POWER	FORWARD POWER / REVERSE POWER
4.5 MHz	290 W	73 W	4.0
4.6	290	73	4.0
4.7	453	73	6.2
4.8	534	30	17.8
4.9	428	13	32.9
5.1	652	179	3.6
5.2	783	213	3.7
5.3	783	148	5.3
5.4	783	148	5.3
5.5	592	120	4.9
5.6	403	63	6.4
5.7	480	37	13.0
5.8	403	18	22.4
5.9	592	37	16.0
6.0	853	250	3.4
6.1	783	250	3.1
6.2	716	163	4.4
6.3	480	95	5.1
6.4	428	120	3.6
6.5	428	83	5.2

TABLE VII

RF POWER RATIO - UNIT 14

MARCH ~~MAY 9~~, 1983 DATA

FREQUENCY	FORWARD POWER	REVERSE POWER	FORWARD POWER/REVERSE POWER
4.5 MHz	213 W	53 W	4.0
4.6	250	73	3.4
4.7	427	73	5.9
4.8	427	24	17.8
4.9	333	53	6.3
5.1	534	95	5.6
5.2	480	95	5.1
5.3	428	63	6.8
5.4	428	73	5.9
5.5	379	- missing data	-
5.6	290	24	12.1
5.7	270	13	20.8
5.8	250	6	41.7
5.9	379	13	29.2
6.0	653	179	3.6
6.1	592	179	3.3
6.2	534	148	3.6
6.3	480	120	4.0
6.4	453	83	5.5
6.5	428	53	8.1

TABLE VIII

RF POWER OUTPUT

MAY 11, 1983 DATA - SOUNDER MODE

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
2.5 MHz	249 W	50 W	23.0 dBw
2.8	1274	271	30.0
3.2	4897	2270	34.2
3.5	1722	433	31.1
3.8	841	83	28.8
4.2	2046	854	30.8
4.6	1022	202	29.1
5.2	3243	1157	33.2
5.6	1764	509	31.0
6.0	3421	928	34.0
6.5	2955	1044	32.8
7.0	2280	590	32.3
7.8	1685	385	31.1
8.6	1386	212	30.6
9.5	1801	361	31.6
10.5	1250	218	30.1
11.5	2542	531	33.0
12.5	2088	413	32.2
13.5	2903	532	33.7
14.5	2068	393	32.2
15.5	2356	448	32.8
16.5	2530	299	33.5
17.5	2871	606	33.6
18.5	3537	710	34.5
19.5	3543	983	34.1
20.5	3150	319	34.5
21.5	3570	534	34.8
22.5	2506	300	33.4
23.5	1678	294	31,4
24.5	1150	232	29.6
25.5	1163	465	28.4
26.5	842	253	27.7
27.5	1336	197	30.6
28.5	603	109	26.9

average = 31.4°

TABLE IX

RF POWER OUTPUT
MAY 11, 1983 DATA - PROBER MODE

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
2.5 MHz	1408 W	551 W	29.3 dBw
2.8	2025	931	30.4
3.2	3561	1494	33.2
3.5	3232	921	33.6
3.8	1671	505	30.7
4.2	1736	495	30.9
4.6	2134	722	31.5
5.2	2727	1334	31.4
5.6	2506	736	32.5
6.0	2746	790	32.9
6.5	3202	1114	33.2
7.0	3400	824	34.1
7.8	2803	583	33.6
8.6	2055	371	32.3
9.5	2382	1265	30.5
10.5	3201	306	34.6
11.5	3866	420	35.4
12.5	3195	429	34.4
13.5	3650	486	35.0
14.5	3050	634	33.8
15.5	3261	506	34.4
16.5	4752	494	36.3
17.5	3862	459	35.3
18.5	3734	212	35.5
19.5	3400	425	34.7
20.5	2652	87	34.1
21.5	2698	300	33.8
22.5	2267	101	33.4
23.5	2252	182	33.2
24.5	2038	97	32.9
25.5	1662	90	32.0
26.5	1551	15	31.9
27.5	2008	49	32.9
28.5	1299	37	31.0

TABLE X

RF POWER OUTPUT - SEA ECHO MODULATION
MAY 14, 1983 DATA - ELEMENTS 12, 13, 14, 15

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
2.5 MHz	259 W	36 W	23.5 dBw
2.8	2202	295	32.8
3.2	5806	2848	34.7
3.5	2727	687	33.1
3.8	1382	104	31.1
4.2	2935	1311	32.1
4.6	1369	203	30.7
5.2	4087	1473	34.2
5.7	1815	337	31.7
6.3	2659	657	33.0
6.8	2606	2	34.2
7.2	2833	229	34.2
7.6	3063	203	34.6
8.5	3629	68	35.5
9.2	4444	402	36.1
10.5	3605	93	35.5
11.5	4640	505	36.2
12.5	3490	278	35.1
14.0	3810	345	35.4
16.0	4090	200	35.9
18.0	4533	448	36.3
21.0	3705	646	34.9
24.0	1624	86	31.9
27.0	2667	16	34.2
29.0	670	2	28.2

TABLE XI

RF POWER OUTPUT

MAY 7, 1983 DATA - WITH TERMINATING RESISTORS

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
6.5 MHz	2023 W	1268 W	28.8 dBw
6.4	2175	1367	29.1
6.3	2046	1288	28.8
6.2	1659	942	28.6
6.1	1577	841	28.7
6.0	1604	841	28.8
5.9	1494	765	28.6
5.8	1204	477	28.6
5.7	1085	373	28.5
5.6	1234	411	29.2
5.5	989	348	28.1
5.4	915	243	28.3
5.3	868	263	27.8
5.2	981	369	27.9
5.1	1051	340	28.5
4.9	956	326	28.0
4.8	842	370	26.7
4.7	881	282	27.8
4.6	724	225	27.0
4.5	666	248	26.2

TABLE XII

RF POWER OUTPUT
MAY 7, 1983 DATA - NO TERMINATING RESISTORS

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
6.5 MHz	1663 W	879 W	28.9 dBw
6.4	1668	914	28.8
6.3	1614	936	28.3
6.2	1584	1058	27.2
6.1	1778	781	30.0
6.0	2035	961	30.4
5.9	1311	710	27.8
5.8	897	286	27.9
5.7	731	251	26.3
5.6	979	408	27.6
5.5	1130	570	27.5
5.4	1278	570	28.5
5.3	1580	705	29.4
5.2	1980	781	30.8
5.1	1875	746	30.5
4.9	1128	343	28.9
4.8	1029	368	28.2
4.7	741	270	26.7
4.6	627	250	25.8
4.5	705	330	25.7

TABLE XIII

RF POWER OUTPUT
MAY 7, 1983 DATA - WITH TERMINATING RESISTORS

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
28.5 MHz	308W	102 W	23.1 dBw
27.5	425	131	24.7
26.5	314	190	20.9
25.5	516	315	23.0
24.5	988	509	26.8
23.5	1609	836	28.9
22.5	1456	724	28.6
21.5	1665	886	28.9
20.5	2547	1278	31.0
19.5	2489	1613	29.4
18.5	2530	1598	29.7
17.5	2329	1334	30.0
16.5	1680	1114	27.5
15.5	1727	1091	28.0
14.5	1401	975	26.3
13.5	1696	1107	27.7
12.5	1071	823	23.9
11.5	1123	751	25.7
10.5	652	378	25.8
9.5	739	448	24.6
8.5	703	427	24.4
7.5	752	470	24.5
6.5	1911	1164	28.7
5.5	1248	481	28.8
4.5	858	298	27.5
3.5	1356	273	30.3
2.5	586	90	27.0

TABLE XIV

RF POWER OUTPUT

MAY 7, 1983 DATA - NO TERMINATING RESISTORS

FREQUENCY	FORWARD POWER	REVERSE POWER	NET
28.5 MHz	428W	75W	25.5 dBw
27.5	559	139	26.2
26.5	408	200	23.2
25.5	558	308	24.0
24.5	missing		
23.5	1641	925	28.6
22.5	2572	876	32.3
21.5	1696	954	28.7
20.5	2626	1405	30.9
19.5	2350	1611	28.7
18.5	2528	1965	27.5
17.5	2493	1548	29.8
16.5	1866	1336	28.0
15.5	1631	1225	26.1
14.5	1455	1004	26.5
13.5	1383	882	27.0
12.5	949	756	22.9
11.5	1037	683	25.5
10.5	626	291	25.3
9.5	783	404	25.8
8.5	672	392	24.5
7.5	655	277	25.8
6.5	1534	833	28.5
5.5	1014	544	26.7
4.5	685	159	27.2
3.5	995	302	28.4
2.5	317	96	23.4

([illegible] = 26.8

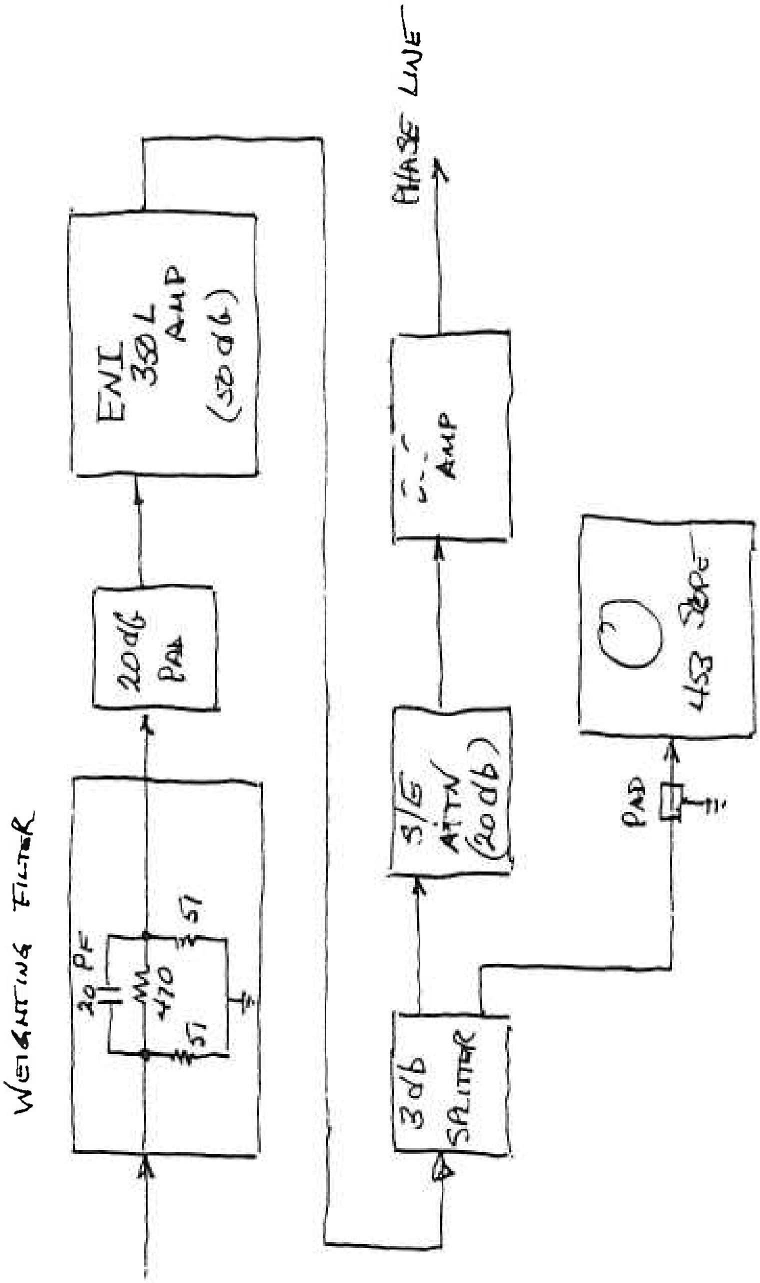

WEIGHTING FILTER
20 PF
470
51
51
20db PAD
ENI 350L AMP (50db)
3db SPLITTER
3/G ATTN (20db)
AMP
PHASE LINE
PAD
453 SCOPE

Figure 1

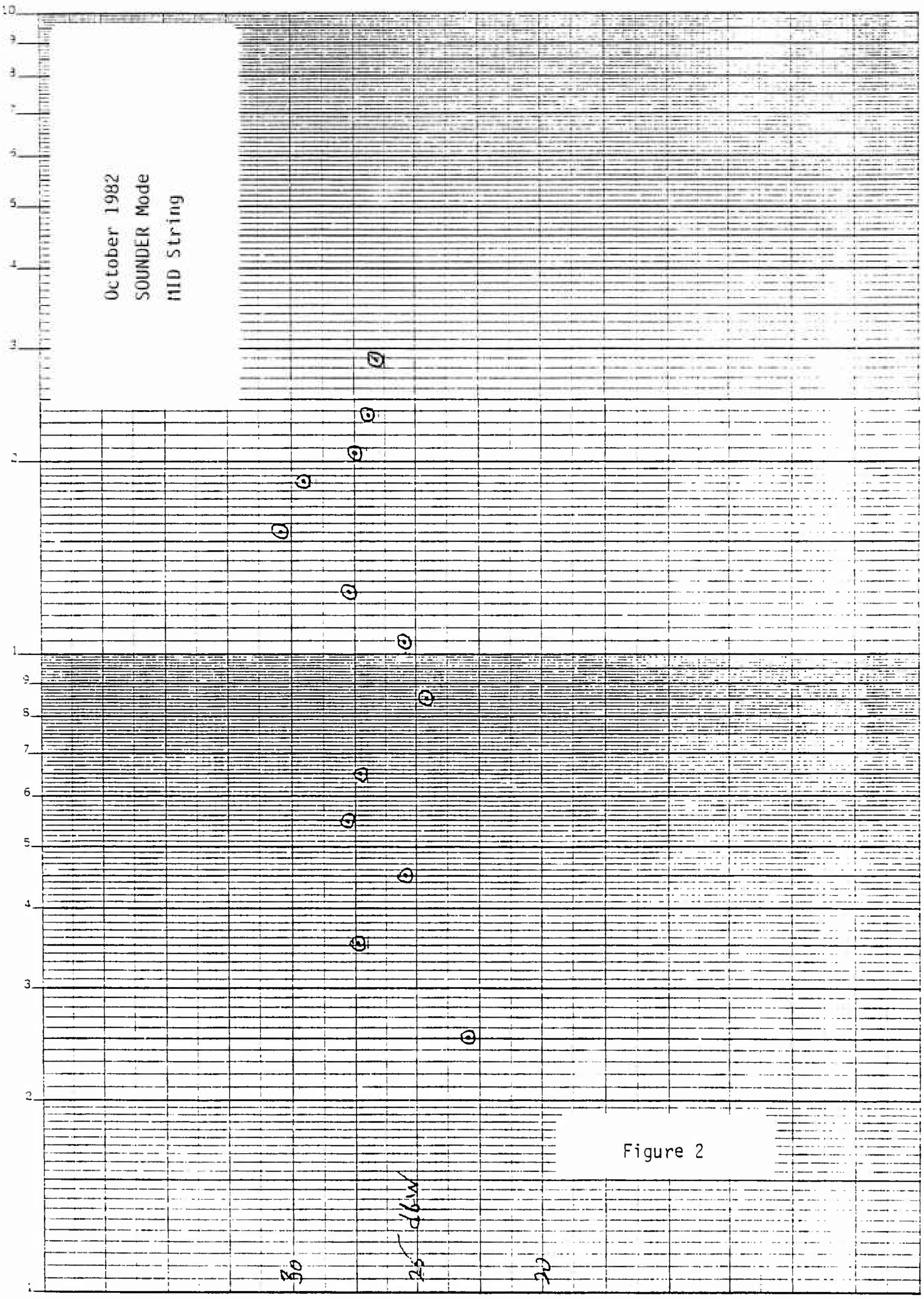

October 1982
SOUNDER Mode
MID String
10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
30
25
20
dBW

Figure 2

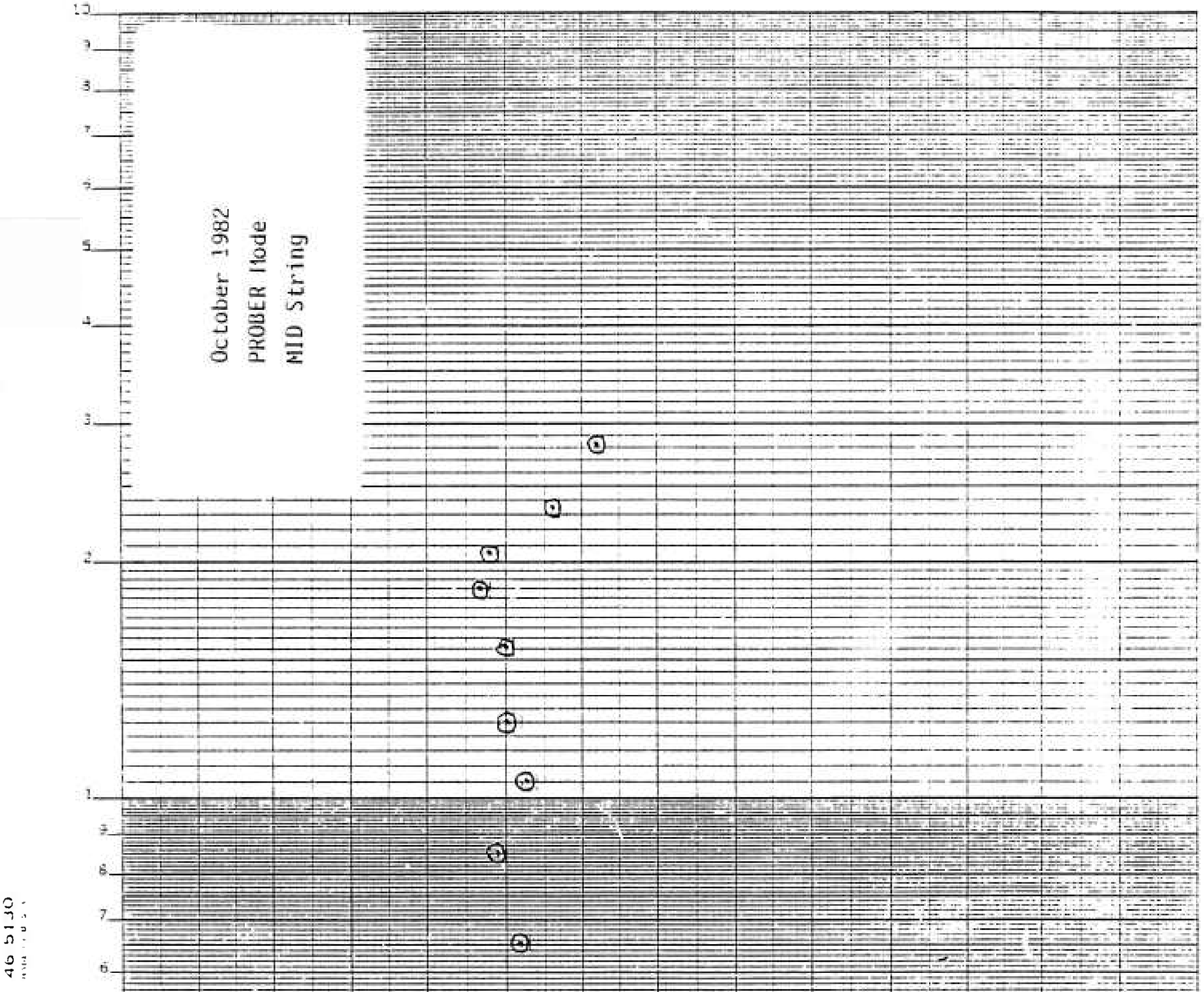


Figure 3

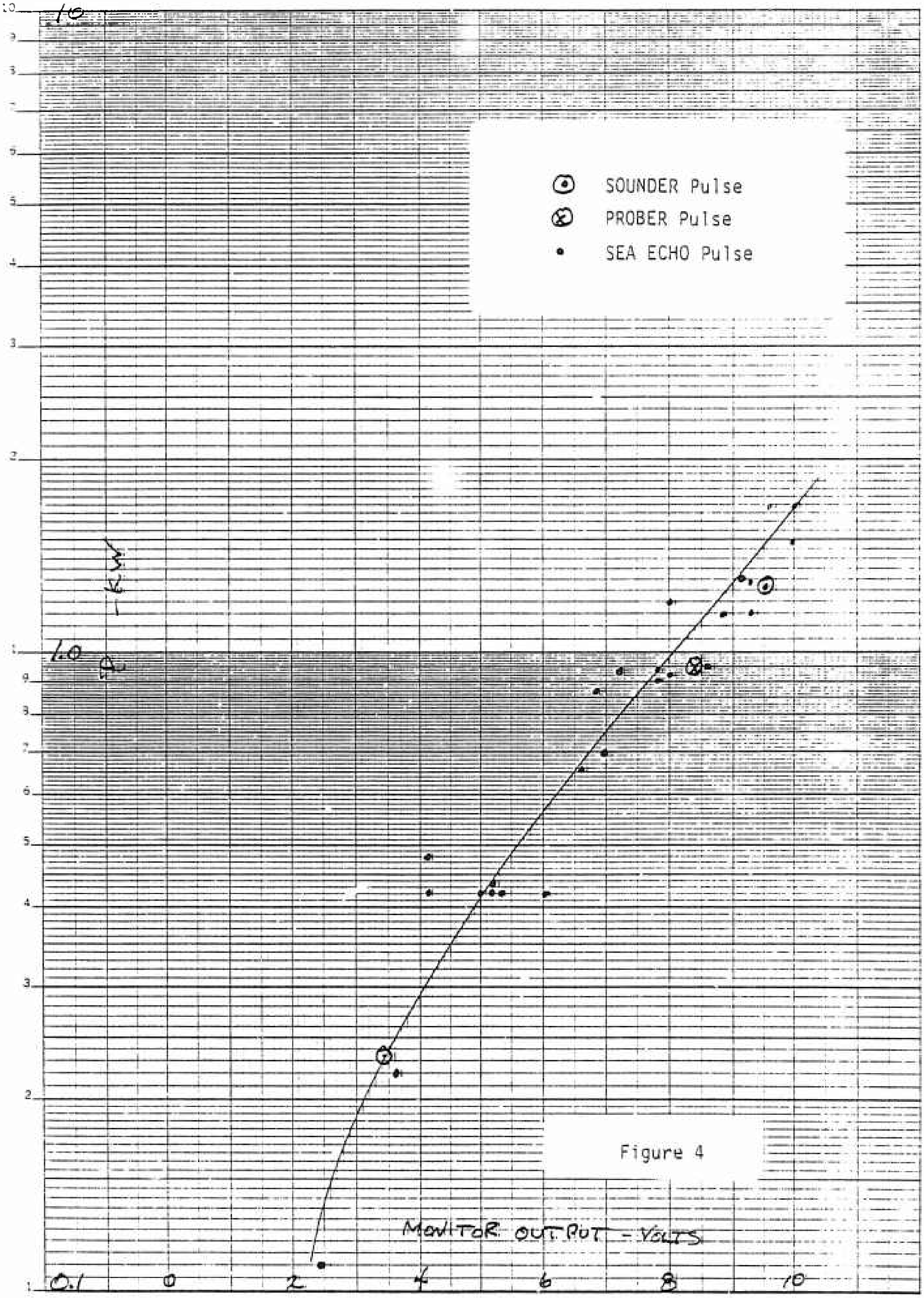

10
10
9
8
7
6
5
4
3
2
1.0
P - KW
9
8
7
6
5
4
3
2
1
SOUNDER Pulse
PROBER Pulse
SEA ECHO Pulse
MONITOR OUTPUT - VOLTS
0.1
0
2
4
6
8
10

Figure 4

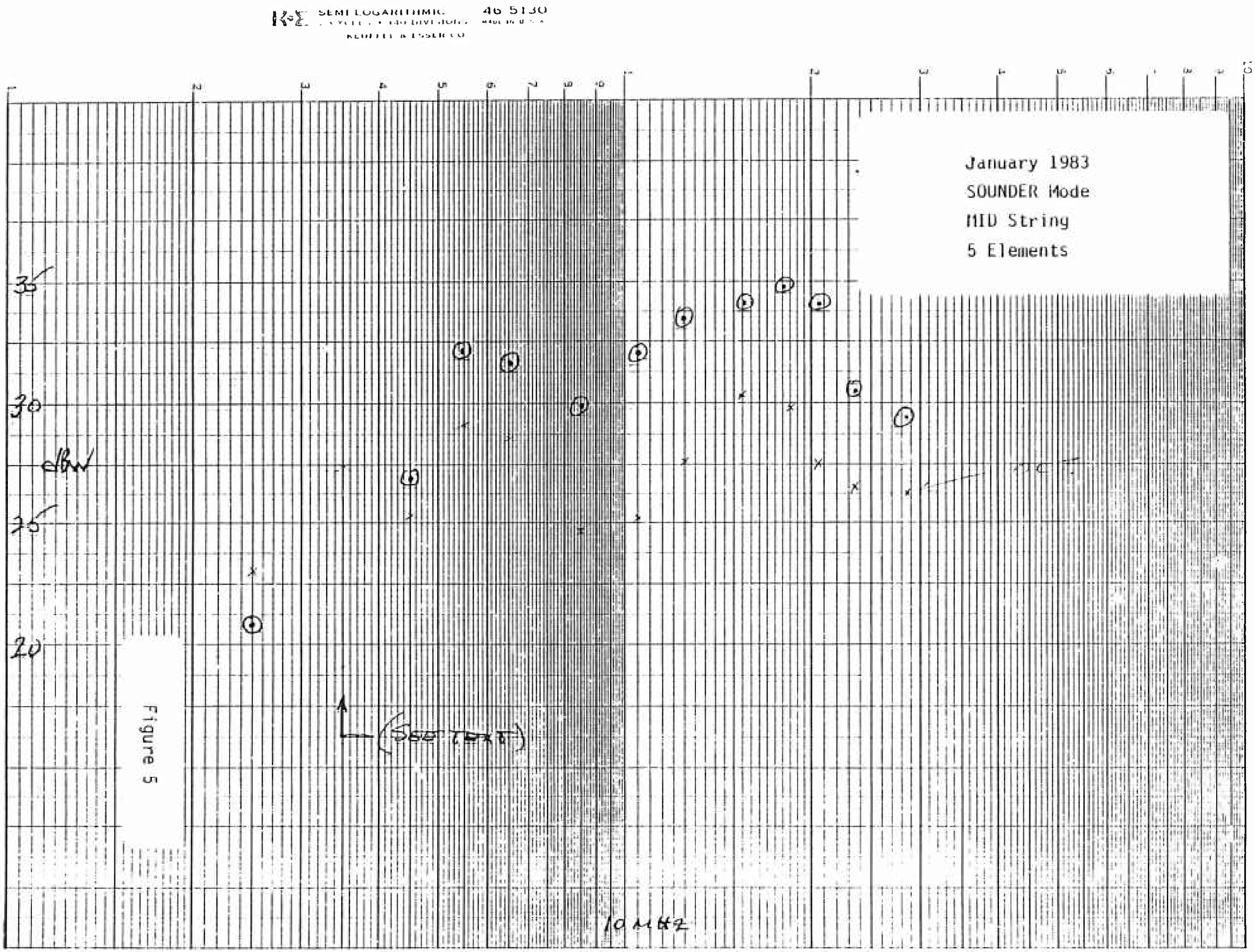
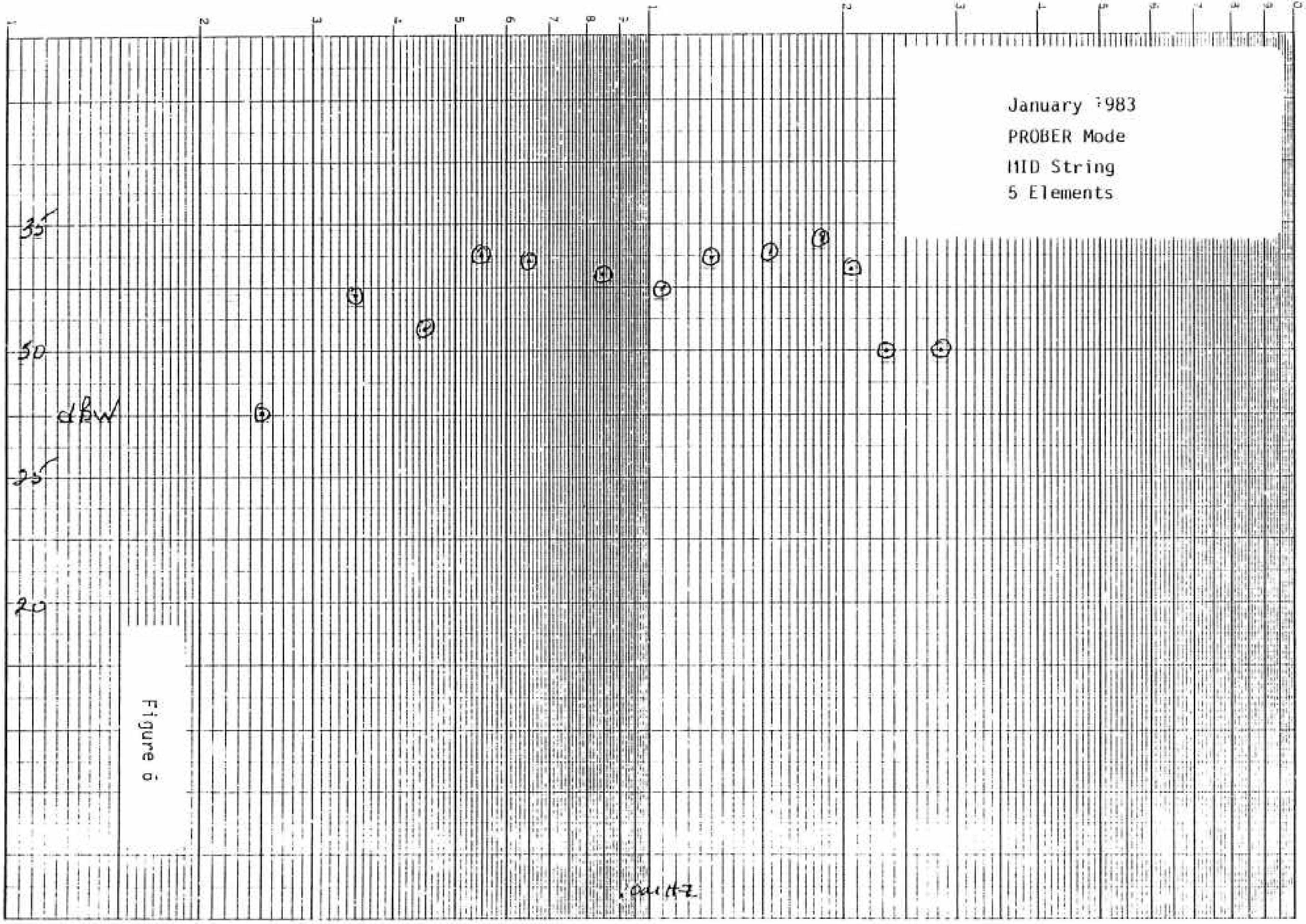

K&E SEMI-LOGARITHMIC 46 5130
KEUFFEL & ESSER CO.
January 1983
SOUNDER Mode
MID String
5 Elements
35
30
dBW
25
20
(See text)
10 MHz
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10

Figure 5



January 1983
PROBER Mode
MID String
5 Elements

Figure 6

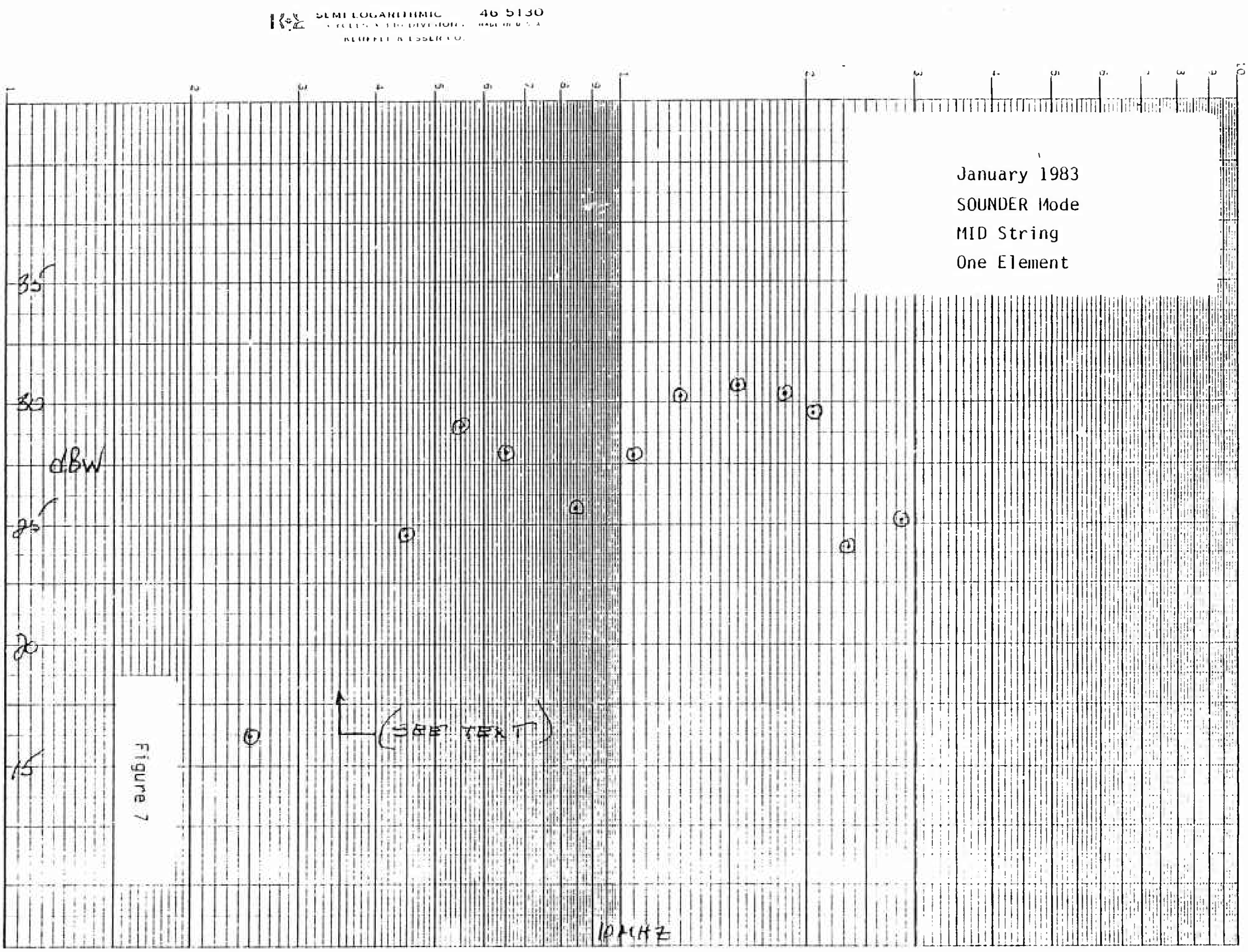

K&E SEMI-LOGARITHMIC 46 5130
KEUFFEL & ESSER CO.
35
30
dBW
25
20
15
10 MHz
(SEE TEXT)
January 1983
SOUNDER Mode
MID String
One Element

Figure 7

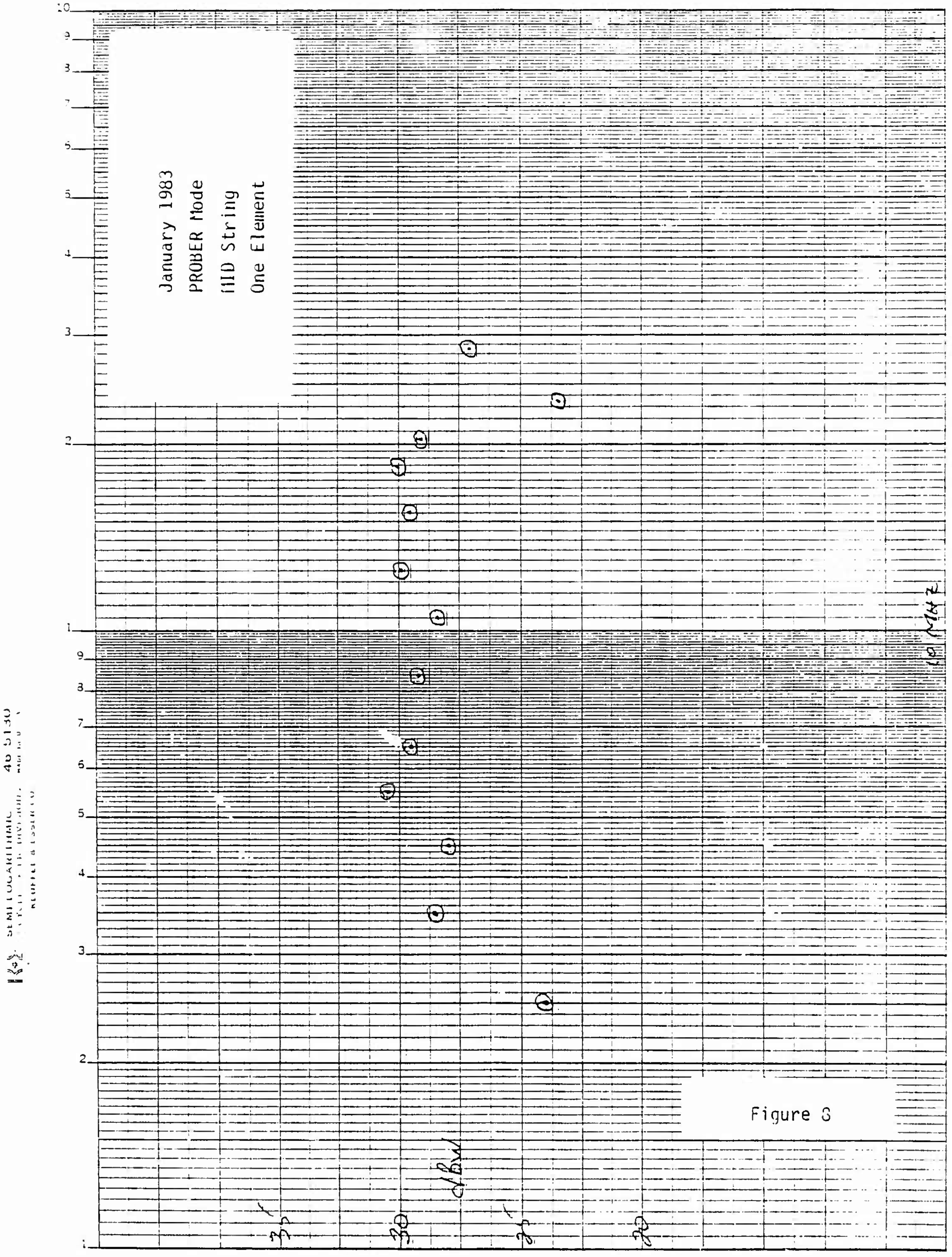

January 1983
PROBER Mode
MID String
One Element
10 MHz
dBW
35
30
25
20
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10

Figure 8

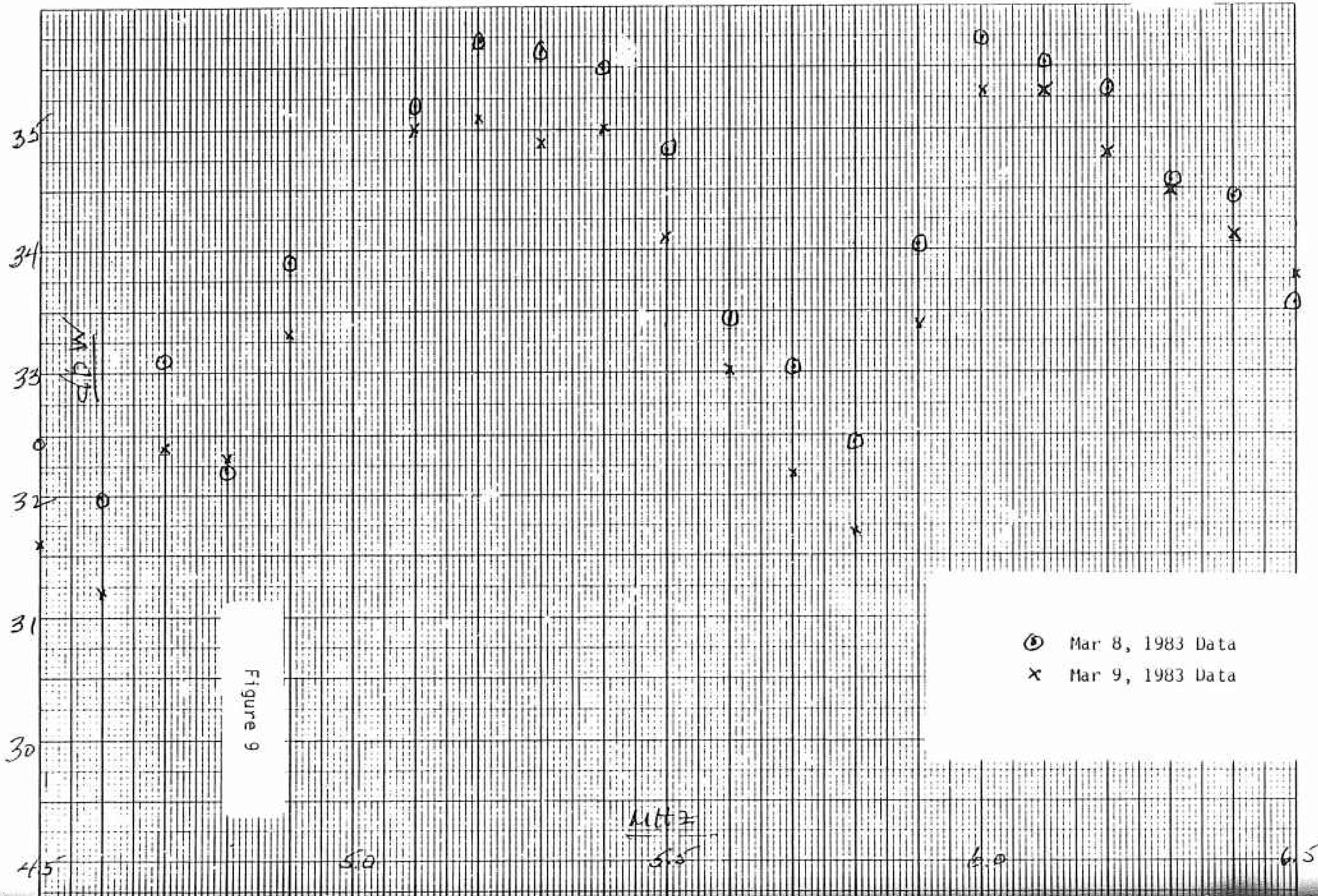

35
34
33
32
31
30
dB
4.5
5.0
5.5
6.0
6.5
MHz
⦿ Mar 8, 1983 Data
× Mar 9, 1983 Data

Figure 9

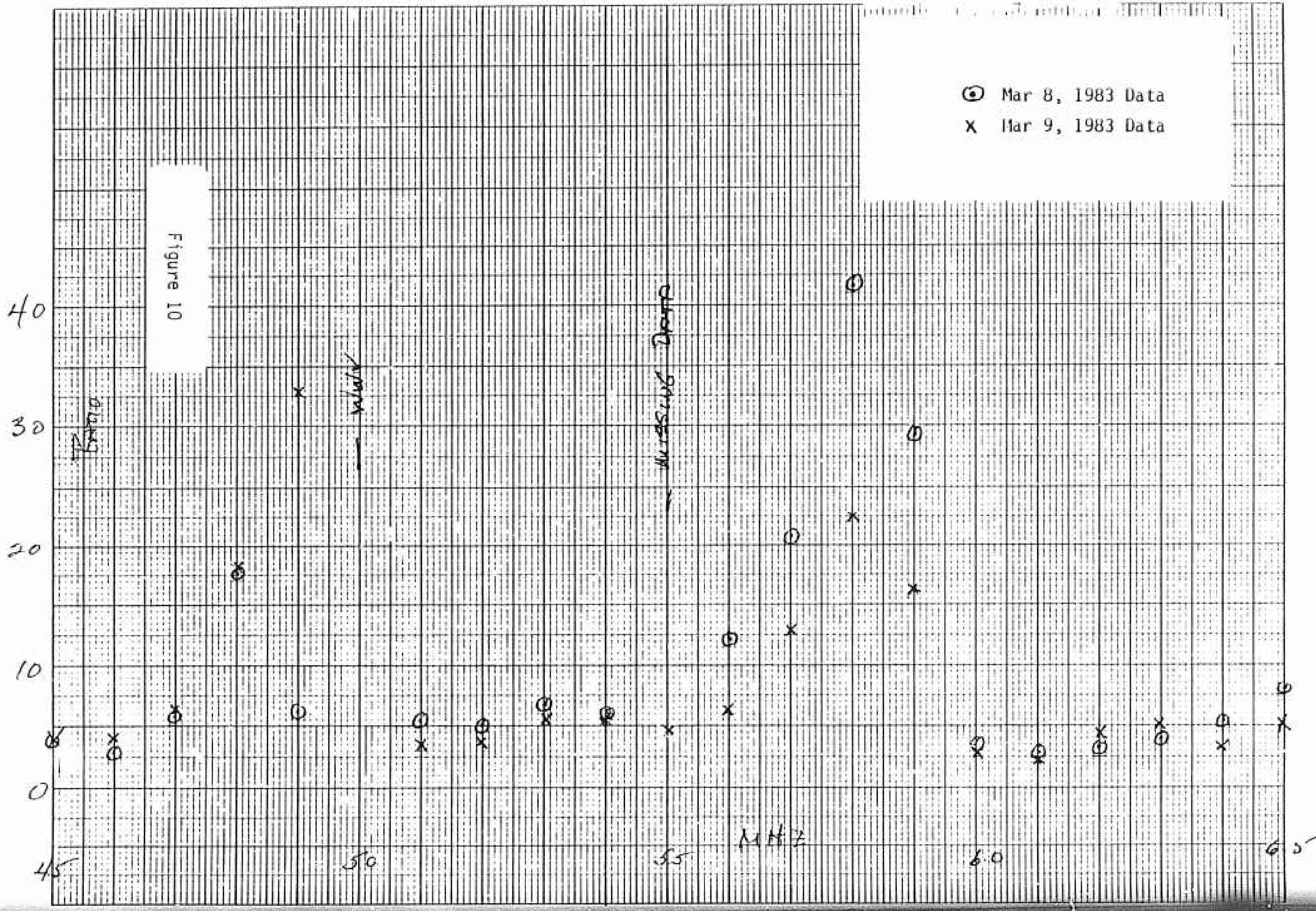
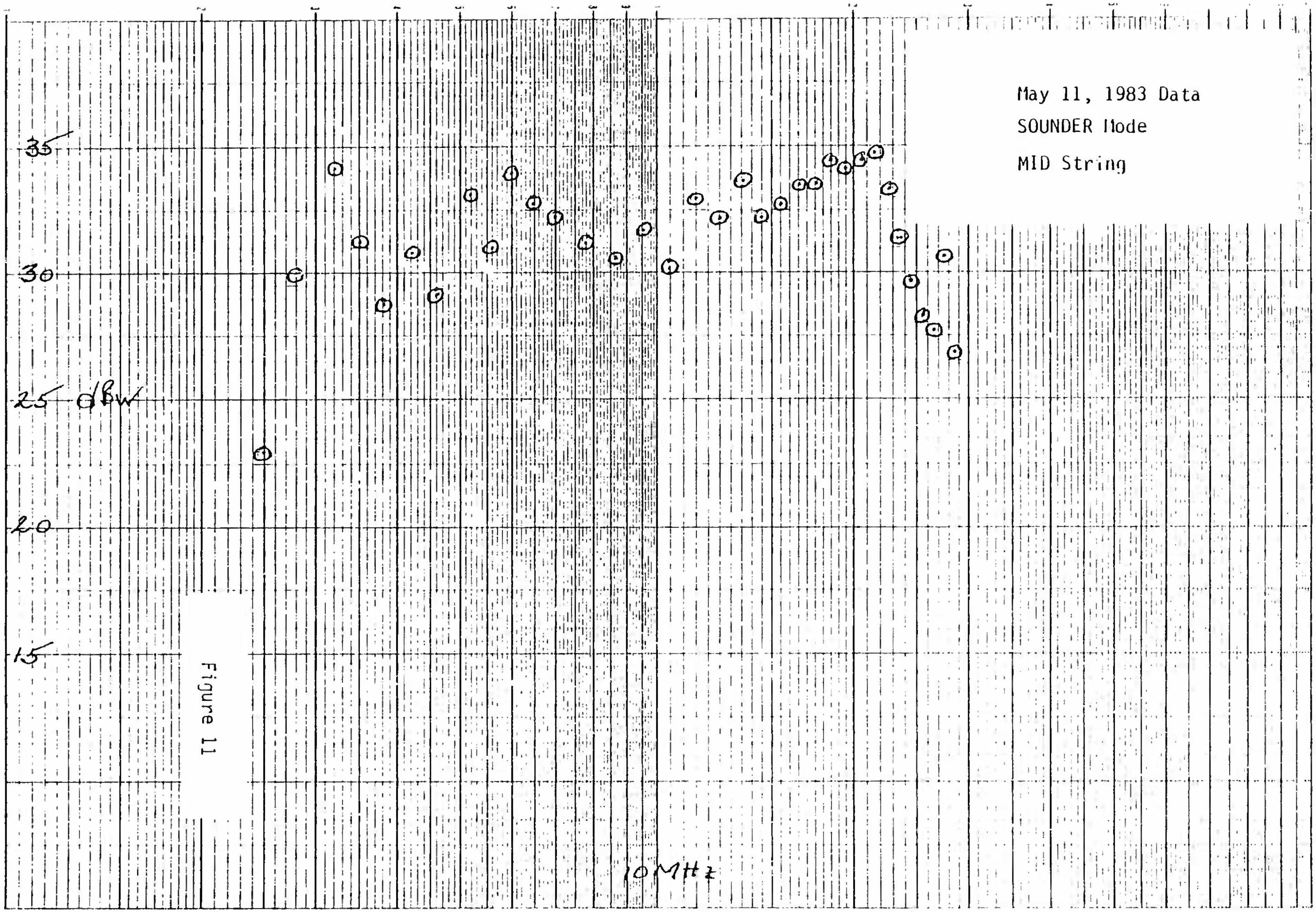
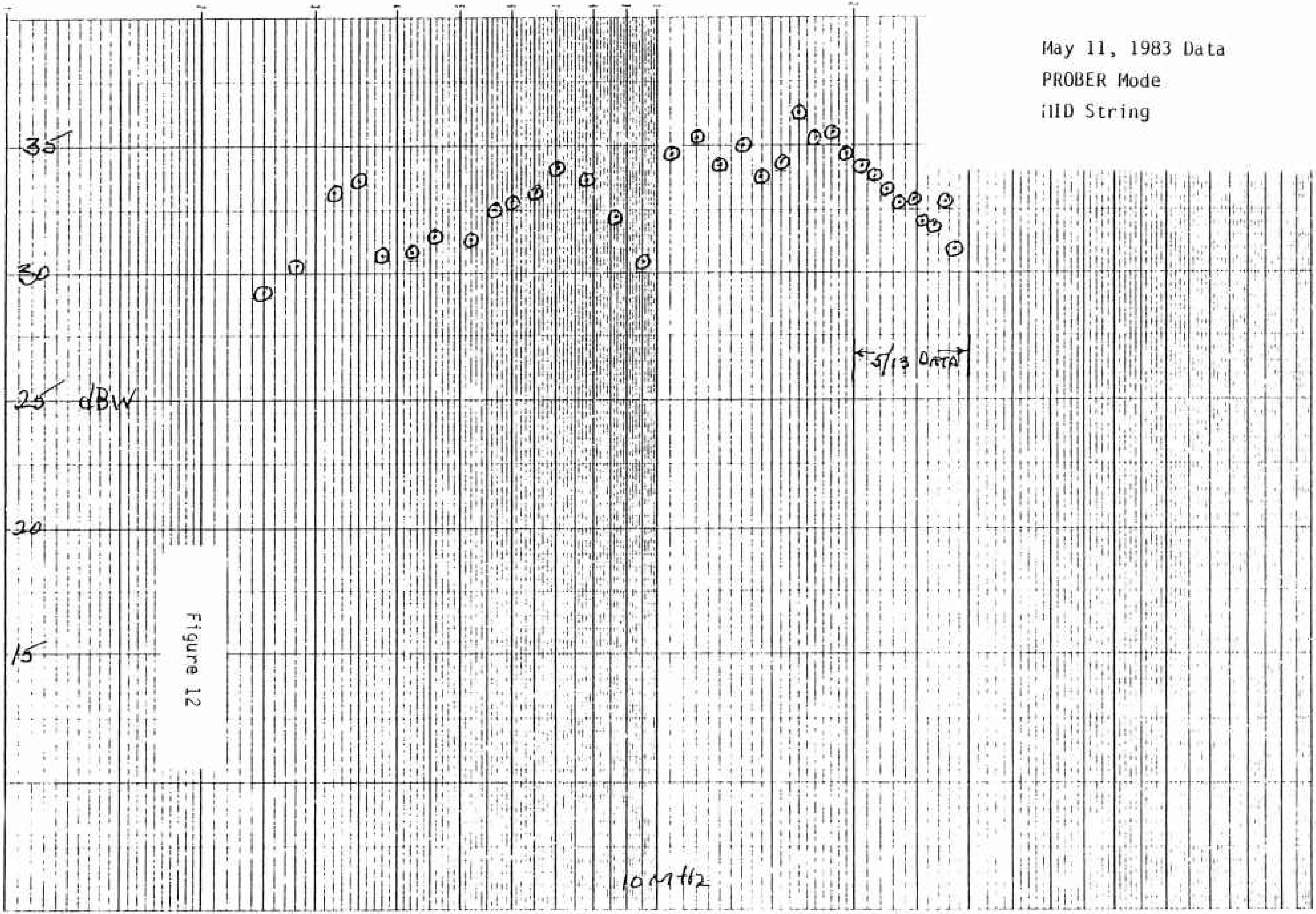

Mar 8, 1983 Data
Mar 9, 1983 Data
40
30
20
10
0
45
50
55
60
65
MHz
Wide
Missing Data

Figure 10



May 11, 1983 Data
SOUNDER Mode
MID String

Figure 11



May 11, 1983 Data
PROBER Mode
HID String

Figure 12

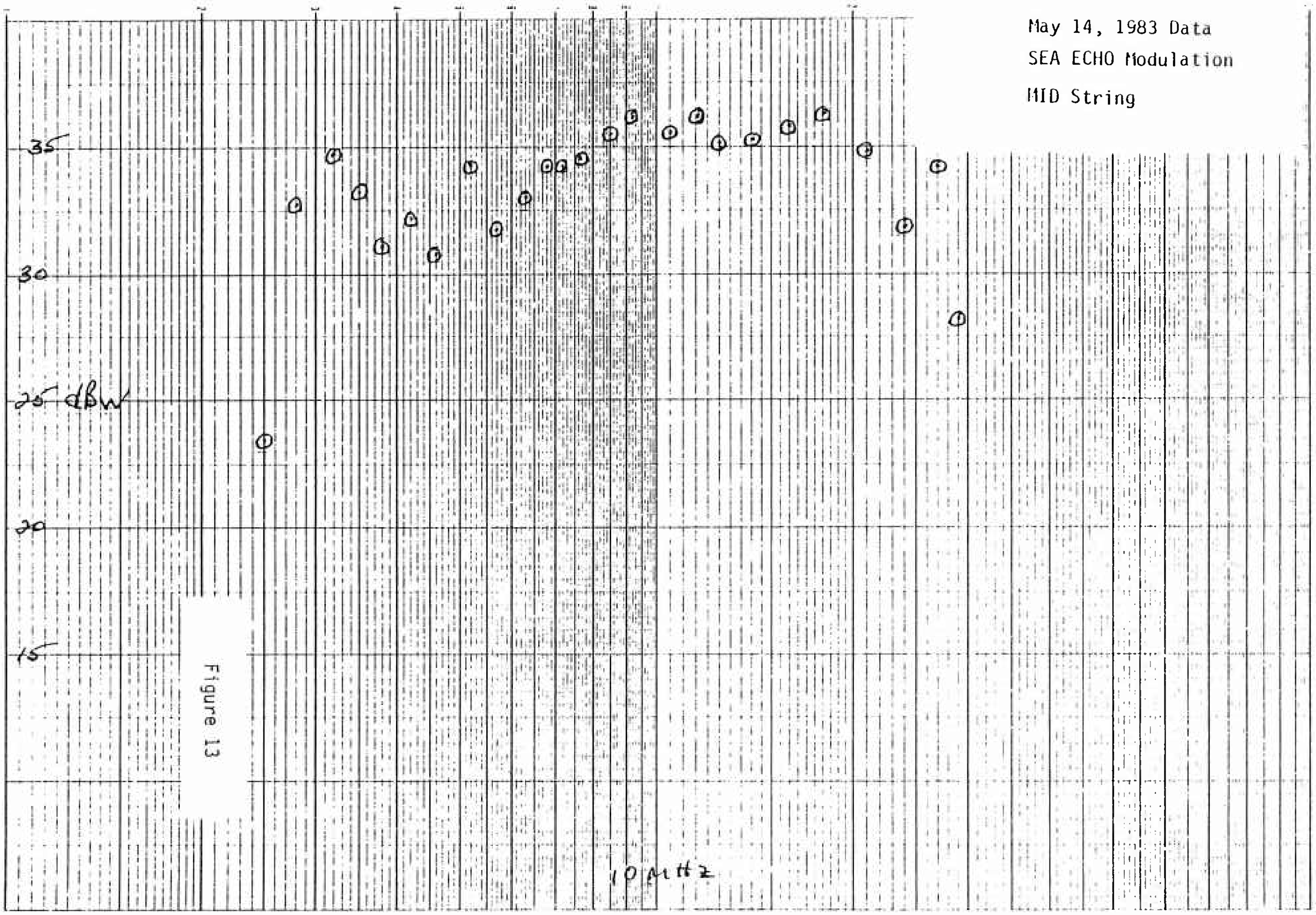

May 14, 1983 Data
SEA ECHO Modulation
MID String

Figure 13

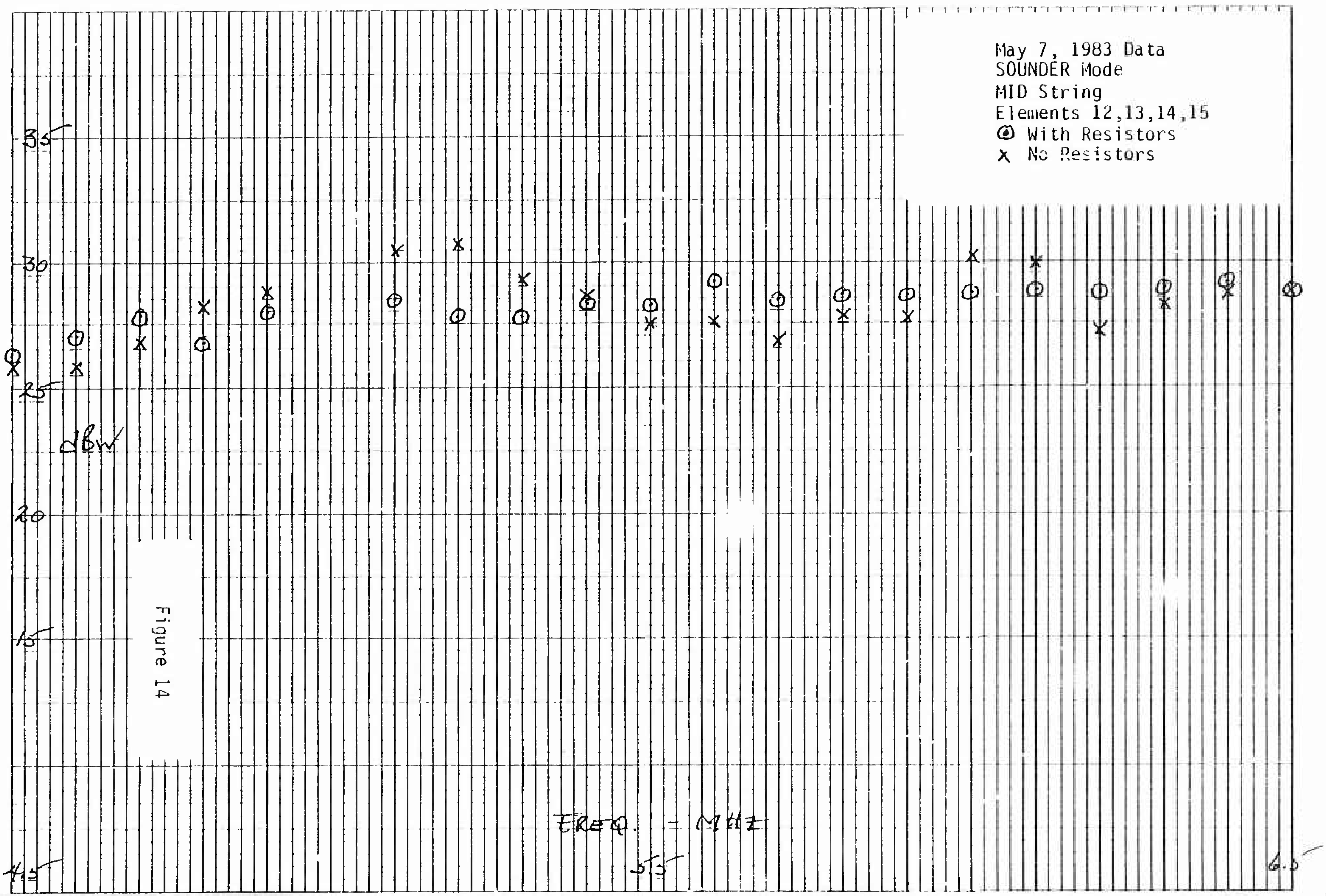

May 7, 1983 Data
SOUNDER Mode
MID String
Elements 12,13,14,15
⊙ With Resistors
x No Resistors
35
30
25
20
15
dBW
4.5
5.5
6.5
FREQ. - MHz

Figure 14

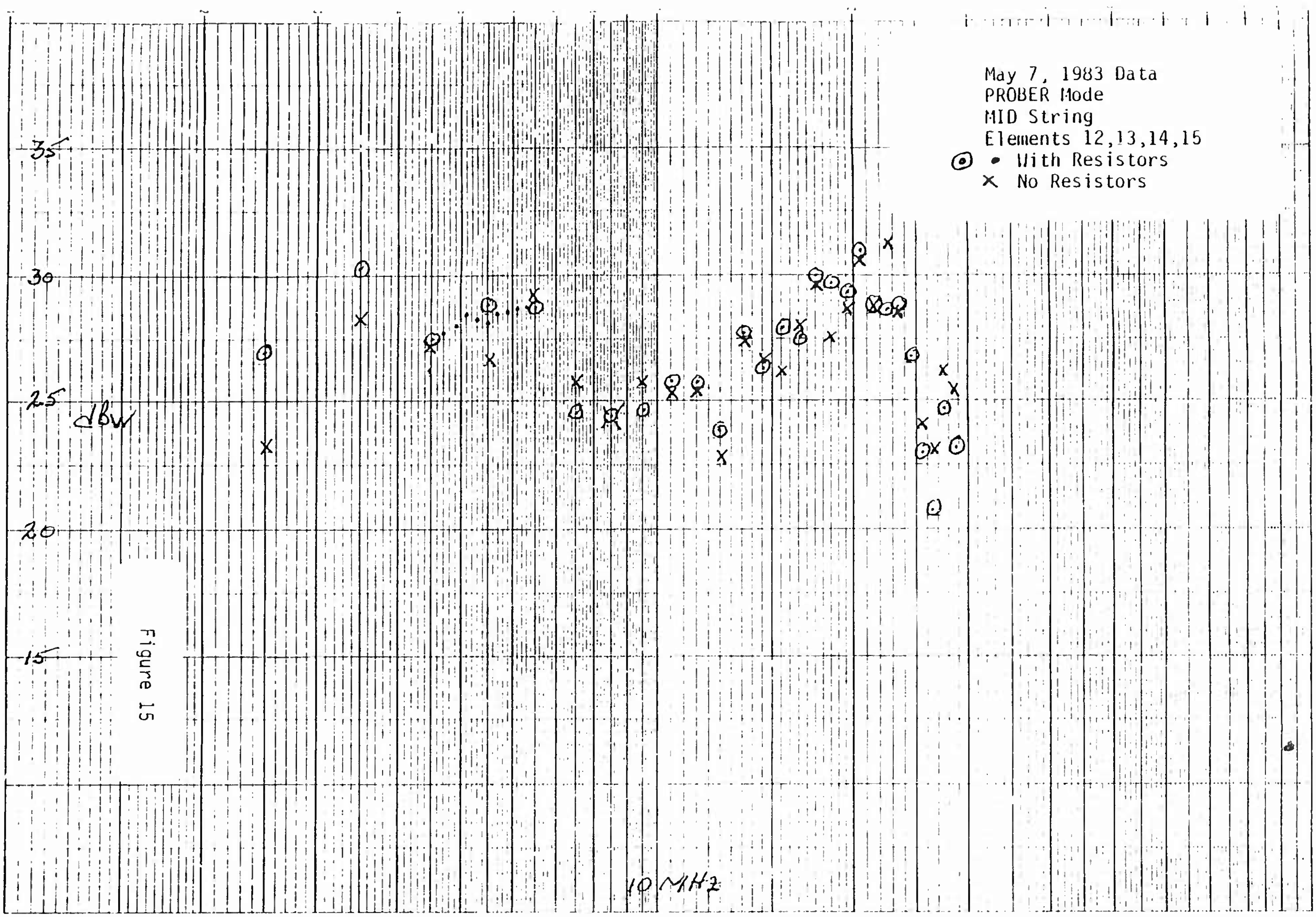

May 7, 1983 Data
PROBER Mode
MID String
Elements 12,13,14,15
⊙ • With Resistors
X No Resistors
35
30
25
20
15
dbW
10 MHz

Figure 15