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Report

To The

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SEMIANNUAL STATUS REPORT #5

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SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE/ HIGH RESOLUTION MICROWAVE SURVEY TEAM MEMBER

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Report Period: March 1, 1993 through August 31, 1993

Submitted by

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I. INTRODUCTION AND SUMMARY

This semiannual status report describes activities conducted by the Principal Investigator during the first half of this third year of the NASA High Resolution Microwave Survey (HRMS) Investigator Working Group (IWG). As a (HRMS) Team Member with primary interest in the Sky Survey activity, this investigator attended IWG meetings at NASA/Ames and U.C. - Santa Cruz in April and August 1992, and has traveled independently to NRAO/Kitt Peak, Arizona (April 1993) and Woodbury, Georgia (July 1993). During the July 1993 visit to the Georgia Tech Research Corporation/Woodbury Research Facility, an experiment was conducted to study the effects of interference from C-band (3.7 - 4.2 GHz) geostationary spacecraft on the Sky Survey operation in that band. At the first IWG meeting in April of this year, results of a SETI observation conducted at the 203 GHz positronium hyperfine resonance using the NRAO facility at Kitt Peak, AZ, were presented, as well as updates on the development of the spaceborne RFI data bases developed for the project. (See Appendix II and Section II.) At the second meeting, results of the study of interference from C-band geostationary spacecraft were presented (see Appendix III). Likewise, a presentation was made at the accompanying 1993 Bioastronomy Symposium describing the SETI observation at the positronium hyperfine resonance (Steffes and DeBoer, 1993a--see Appendix I). This work has also been submitted to Icarus (see Appendix II, Steffes and DeBoer, 1993b) after being approved by the IWG Publications Coordinator.

In the remainder of this grant year (through February 28, 1994), we expect to continue the development of the spaceborne RFI data base. Specifically, we intend to release a new revision including an expanded section containing the most up-to-date information on low earth orbiting satellites. Likewise, we will assist in planning the Summer 1994 Sky Survey deployment at the Owens Valley Radio Observatory, so as to assure that portions of the L-Band spectrum which will soon be occupied by the mobile satellite service will be surveyed before they are occupied by spaceborne transmitters.

II. DEVELOPMENT OF DATA BASE OF SPACEBORNE TRANSMITTERS

We have formed a data base of all non-classified satellites, giving transmission frequencies and orbital parameters on each. The original data was derived from six sources:

1) World Satellite Annual and the quarterly World Satellite Transponder Loading Reports (published by Mark Long Enterprises, Inc.). This includes all commercial satellites.
2) The Satellite Situation Report (published by Project Operations Branch, NASA/GSFC). This document includes all earth orbiting spacecraft, but has only limited information on transmitting frequencies.
3) The Space Frequency Coordination Group (SFCG) Data Base. This includes both earth orbiting and deep-space spacecraft. (Owned by governments)
4) The Communications Center (Clarksburg, MD) data base. Includes all governmental and non-governmental geostationary spacecraft.
5) The International Satellite Directory (Design Publishers). This overlaps (1), and because of its high cost, will not be used in future updates.

6) <u>QuikTrak 4.0</u> (Low Earth Orbiter Tracking Software - AMSAT Corp.) Provides position, right ascension, declination, etc. for low earth or biting spacecraft. Orbital elements are obtained electronically from a database maintained by AFIT (Air Force Institute of Technology).

In the past six months, additional data has been derived from the Space 2000 Database, which was purchased from Space Analysis and Research, Inc., Colorado Springs, CO; and from a database maintained by Dr. Wesley Sizemore at NRAO/Green Bank, WV. We have found the Space 2000 Database to be extremely useful in that it contains transmitter frequencies for many low-earth orbiting satellites (LEO's) not listed elsewhere.

As described in previous reports, our database management and search software (HRS) has now been distributed to 25 users both within and external to the HRMS Project. We expect to release an updated version of the database itself in September 1993.

III. OBSERVATIONAL STUDIES

At the beginning of this year, we completed development of a 64,000 channel spectrum analyzer which simulated behavior of the Sky Survey system over a 1 MHz bandwidth. This spectrum analyzer was used in two different observation studies:

1) A SETI search of 40 solar-type stars at the 203 GHz positronium hyperfine resonance was conducted from the NRAO-Kitt Peak, AZ facility. (A complete description of this observation is included in Appendix II.)

2) An observational experiment was conducted using a 30-meter antenna at the Georgia Tech Research Corporation/Woodbury Research Facility in order to characterize the nature of interference from geostationary satellites transmitting in the 3.7 - 4.2 GHz frequency band to the Sky Survey element operating in that band. A complete description of, and results from this experiment are given in Appendix III of this report.

IV. CONCLUSION

In the remainder of this grant year we expect to complete our latest updating to the HRS (HRMS RFI Search) data base and distribute it electronically to all users. Likewise, we will use information about the upcoming launches of L-Band satellites in the mobile satellite service (MSS) in order to help determine those frequencies most at risk, and which should be observed in the 1994 OVRO deployment of the Sky Survey prototype system.

V. REFERENCES

Steffes, P.G. and D.R. DeBoer, 1993a. A SETI Search of Nearby Solar-Type Stars at the 203 GHz Positronium Hyperfine Resonance. Presented at the 1993 Bioastronomy Symposium: Progress in the Search for Extraterrestrial Life, p. 30.

Steffes, P.G. and D.R. DeBoer, 1993b. A SETI Search of Nearby Solar-Type Stars at the 203 GHz Positronium Hyperfine Resonance. Submitted to Icarus.

APPENDIX A:

A SETI Search of Nearby Solar-Type Stars at the 203 GHz Positronium Hyperfine Resonance

PAUL G. STEFFES and DAVID R. DeBOER

The development of advanced millimeter-wave technology has made it possible to construct low noise receivers and high power transmitters comparable to those available at much lower frequencies. This technology, plus certain physical characteristics of the millimeter-wave spectrum suggest possible advantages for use of this wavelength range for interstellar communications. As a result, a SETI type search has been conducted for narrow bandwidth signals at frequencies near the positronium hyperfine spectral line (203.385 GHz), a potential natural reference frequency. A total of 40 solar type stars within 18 parsecs were observed, in addition to 3 locations near the galactic center using the NRAO 12-meter millimeter-wave radio telescope at Kitt Peak, Arizona. No detections were made at the detection threshold of 8×10^{-20} w/m^2 in each of two linear polarizations. Future observations will be made with a higher resolution fast Fourier transform spectrum analyzer (FFTSA) which should improve sensitivity by an order of magnitude, and reduce required observing time.

APPENDIX B:

A SETI Search of Nearby Solar-Type Stars at the 203 GHz Positronium Hyperfine Resonance

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ABSTRACT

The development of advanced millimeter-wave technology has made it possible to construct low noise receivers and high power transmitters comparable to those available at much lower frequencies. This technology, plus certain physical characteristics of the millimeter-wave spectrum suggest possible advantages for use of this wavelength range for interstellar communications. As a result, A SETI (Search for Extraterrestrial Intelligence) type search has been conducted for narrow bandwidth signals at frequencies near the positronium hyperfine spectral line (203.385 GHz) a potential natural reference frequency. A total of 40 solar type stars within 23 parsecs were observed, in addition to 3 locations near the galactic center. No detections were made at the detection threshold of 10^{-19} w/m,^{2} in each of two linear polarizations. Future observations will be made with a higher resolution Fast Fourier Transform Spectrum Analyzer (FFTSA) which should improve sensitivity by an order of magnitude, and reduce required observing time.

I. INTRODUCTION

The development of advanced millimeter-wave technology has made it possible to construct low noise receivers and high power transmitters comparable to those available at much lower frequencies. This makes a SETI (Search for Extraterrestrial Intelligence) type search at millimeter wavelengths desirable for a number of reasons:

1. The higher gains obtainable for a given antenna size at millimeter wavelengths result in larger transmitted EIRP (Effective Isotropic Radiated Power), and thus increase the detectable range. (See, for example, Steffes, 1993.)
2. The effect of the "quantum limit" or "photon noise" on receiver sensitivity is still minimal (less than 15 K) for frequencies below 300 GHz.
3. A spectral marker exists at 203.385 GHz (the hyperfine ground state spectral line of the lightest artificial atom, positronium). (Ref: Kardashev, 1979).
4. Interstellar scintillation is far less pronounced at millimeter-wavelengths than at centimeter wavelengths. (ref: Cordes and Lazio, 1991).
5. Radio Frequency interference (RFI) from earth-orbiting transmitters is far less severe than at centimeter wavelengths.

Since no previous millimeter-wavelength SETI searches have been reported, we conducted this initial search at the 203.385 GHz positronium hyperfine resonance using the NRAO/Tucson 12-meter radio telescope. This is similar to the first centimeter-wavelength SETI search conducted some 33 years previously at NRAO/Green Bank, at frequencies near the hydrogen hyperfine resonance (Drake, 1961). The increased gain at higher frequencies makes millimeter-wave SETI very attractive and the existence of a spectral marker at 1.48 mm (203 GHz) is fortuitous. Further, since there is a low abundance of positronium and a small transition probability, the natural line does not contribute significantly to the sky temperature and mask any potential signal. Other reasons for the selection of the positronium hyperfine resonance as the preferred search frequency are detailed by Kardashev (1979).

In this paper, we give the description and results of our observations of 40 solar-type stars and of three regions near the galactic enter, at frequencies surrounding the 203.385 GHz positronium hyperfine resonance. While no artificial signals were detected, an upper limit on potential signal flux density has been derived, and approaches for quicker, more sensitive searches are presented.

II. OBSERVATIONS

Observations of 40 solar type stars and three regions near the galactic center were conducted on April 9 and 10, 1993 at frequencies surrounding the positronium hyperfine resonance, measured as 203.8459 $\pm$ 0.0012 GHz by Egan et al. (1977). The observations were conducted with the 12-meter-diameter NRAO millimeter-wave radio telescope located at Kitt Peak, Arizona. (The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.) The purpose of the search was to detect spectrally compact, coherent signals such as targeted beacons or other nearly monochromatic emissions directed toward our solar system. Unlike SETI searches conducted at longer wavelengths (see, for example, Backus, 1993 or Klein et al., 1993) where detection of unintentional "leakage" signals may be remotely possible, the highly directive nature of millimeter-wavelength antennas and the large, time-variable doppler shifts introduced by planetary motion makes detection of unintentional signals highly unlikely. Thus, the search was conducted assuming a transmission targeted toward our solar system with high spectral stability.

A. Observational Approach

Since we assume that the potential transmissions are targeted, any doppler shifts due to planetary motion at the transmitting locations are assumed to be corrected, relative to a stable reference frame by the transmitting civilization. (Obviously, our knowledge of the motions of planets within distant solar systems is currently non-existent.) However, there is still the question as to which stable reference frame the transmissions would be referenced. The obvious choices would be the frame of the transmitting star system, the local standard of rest (LSR), or our sun (heliocentric). We chose the third (heliocentric), based on the assumption that a civilization capable of targeting a transmission toward our solar system would be able to estimate the radial velocity of our star and would correct for it. While referencing to LSR was our second choice, the variability of its definitions by other civilizations would likely add to the overall uncertainty. Even if the transmitting civilization were to reference to our solar system, there is an inherent uncertainty in estimates of radial velocity, which would be reflected in the transmitted frequency. As a result, we observed a 5 MHz-wide spectral window centered at the 203.3849 GHz positronium hyperfine resonance, adjusted to a heliocentric rest frame (i.e., heliocentric $\pm$ 3.7 km/sec).

B. Equipment Configuration

All observations were conducted with the NRAO 12-meter Cassegrain antenna. Dual, linearly polarized SIS receivers were used, exhibiting system noise temperatures of 600 K and 1000 K, respectively. Recent realignment of the reflector surface panels resulted in an overall aperture efficiency of over 32%, providing an effective aperture of 37 m^2 at the operating wavelength of 1.5 mm. Since the antenna beamwidth is extremely narrow (approximately 30 arcseconds), and because none of the target stars are strong emitters at this wavelength, normal tracking techniques involving signal peaking were not used. However, open-loop tracking accuracies of 10 arcseconds can be achieved with this telescope, and a collinear optical telescope is connected to a video display in the control room which verifies the pointing to the majority of the targets, which are visible with a moderate optical telescope.

A block diagram of the observing system is shown in Figure 1. In order to be sensitive to signals transmitted over interstellar distance, extremely narrow channel bandwidths are necessary. Two types of multichannel spectrum analyzers were developed. The first was a 32,000 channel Fast Fourier Transform Spectrum Analyzer (FFTSA) which used an 8-bit analog-to-digital converter in conjunction with a 64 k-point complex FFT computer and displayed using MATLAB software on a 386-based personal computer. By using a Hamming window and a 2 MHz sampling rate, individual channel resolution bandwidths of approximately 32 Hz were obtained. The total instantaneous bandwidth was 1 MHz, and the total time to sample, compute, and display each spectrum was approximately 45 seconds. Because of the narrow channel bandwidths involved, all local oscillators were locked to a maser reference signal obtained from the neighboring VLBA facility so as to maintain frequency stabilities of 10^{-12} or better. The second spectrum analyzer used was a Tektronix 2710 digital storage spectrum analyzer, which analyzed the same 1 kHz - 1.001 MHz range as the FFTSA. Nine spectra were averaged, each with a resolution bandwidth of 3 kHz, and a video bandwidth of 30 Hz. The resulting averaged 1 MHz-wide spectrum hand an equivalent noise bandwidth of 100 Hz in each spectral bin, and took approximately 100 seconds to measure, average, and display. Since both systems analyzed only a 1 MHz-wide spectrum, the receiver local oscillator was stepped so as to allow taking of 5 individual 1 MHz-wide spectra, giving a total bandwidth of 5 MHz. The entire process was repeated for the orthologonal polarization, as well. The local oscillator system also provided doppler corrections for earth motion relative to the heliocentric reference frame.

Unfortunately, the FFTSA (which was the more sensitive and more rapid of the two systems) was irreparably damaged by the carrier responsible for transporting it to NRAO/Tuscon. As a result, all measurements were conducted with the slower, less sensitive conventional spectrum analyzer. The detection threshold for this system was calculated from the relation

$$F_{min} = kTB\,(C/N)_{min}/A_{eff} \tag{1}$$

where F_{min} is the minimum detectable flux density (w/m^2), k is Boltzman's constant (1.38×10^{-23} J/K), T is the system noise temperature, B is equivalent noise bandwidth (Hz), $(C/N)_{min}$ is the minimum carrier-to-noise ratio required so as not to produce an excessive false alarm rate (we chose 5dB for our observation), and A_{eff} is the effective area of the receiving antenna. For our observations, the resulting minimum detectable flux density was 10^{-19} w/m^2.

C. Targets

A total of forty stars were observed, in addition to three locations near the galactic center. The forty stars were selected from a list of solar-type stars (F6 through K7 dwarfs, luminosity class 5) within 23 pc of the earth, which was provided by D. Latham and G. Torres (private communication). These stars are listed in Table I, together with information on position, distance, radial velocity, spectral type, and the elevation above the horizon when the observation of that star commenced. (A typical observation lasted approximately 25 minutes.)

In addition to observations of the target stars, observations of 3 sites at and near the galactic center from where 5113PkeV emission had been detected were made (See for example, Leahy, 1991; or Ligenfelter and Ramaty, 1989). Note that 511keV corresponds to the electron-positron annihilation energy.) Because of the short lifetime of positronium (approximately 10 nsec), the broadening of any natural positronium hyperfine emission would be substantial (at least 100 MHz).

As a result, observations of the galactic enter region were conducted using a 256 channel, wide band (2MHz per channel) filter bank. Detection of emission at the positronium hyperfine resonance is highly unlikely, however, due to the vastly stronger annihilation process.

III. RESULTS, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

No detections of coherent emission at the level of 10^{-19} w/m^2 or higher were made in our search of 40 target stars in the frequency range from 203.3834 to 203.3884 GHz (referenced to a heliocentric rest frame). Likewise, as expected, no incoherent emissions due to the positronium hyperfine resonance were detected from observations at the galactic center. We note that had our Fast Fourier Transform Spectrum Analyzer (FFTSA) not been destroyed in shipment, a factor of 3 sensitivity improvement would have been achieved. Additionally, the FFTSA could have been "clocked down" to run in a high resolution mode, providing an additional factor-of-ten sensitivity improvement in selected bands (3 x 10^{-21} w/m^2).

While no signals were detected, the conduct of such millimeter wavelength SETI searches should not be abandoned. As with the initial microwave searches conducted by Drake (1961), this observation has set an initial reference point from where more complete and more sensitive searched can be conducted. The substantive improvement and relatively low cost of FFTSA systems will make it possible to conduct more complete searches, in shorter periods of time. Likewise, the improvements in receiver sensitivity and antenna performance at millimeter wavelengths will make searches at dramatically improved sensitivity levels possible. Finally, the measurements conducted showed a very low "false-alarm" level. This was, of course, due to the absence of radio frequency interference (RFI) at these short wavelengths, and a minimum of scintillation. As a result, we expect that this spectral range will hold potential in the Search for Extraterrestrial Intelligence for many years to come.

ACKNOWLEDGEMENTS

The authors are deeply grateful to Dr. W. Whitfield Smith, Mr. David Lashley, and Mr. Richard Tatem of Georgia Institute of Technology for their assistance in the preparation and conduct of this observation. We are also extremely grateful to the staff and operators at NRAO/Tuscon-Kitt Peak, Arizona for their tireless help, especially Drs. Robert Freund and Philip Jewell whose efforts in bringing some level of functionality back to our damaged equipment were truly heroic. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation. Support for this work was received from the High Resolution Microwave Survey (HRMS) Project of the National Aeronautics and space Administration under Grant NAG2-700 from NASA Ames Research Center.

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Table I: Observation list of solar-type stars from millimeter-wave search.

Name	RA (1950) Dec	Distance (pc)	Radial Velocity (km/sec)	Spectral Type	Elevation At Start of Observation
GL 34 A	00h 46m 03s +57° 33.1′	5.94	+ 8.2	G3 V	50.4° r
GL 34 B	00h 46m 03s +57° 33.1′	5.94	+ 10.5	K7 V	50.4° r
GL 71	01h 41m 45s -16° 12.0′	3.50	- 17.0	G8 Vp	40.6° r
GL 124	03h 05m 27s +49° 25.4′	10.82	+ 49.5	G0 V	67.3° r
GL 135	03h 16m 30s -03° 01.4′	15.58	+ 22.5	G1.5 V	54.5° r
GL 160	04h 02m 22s +21° 52.5′	17.39	+ 23.9	G5 V	70.7° r
GL 177	04h 45m 21s -17° 01.5′	12.67	+ 21.7	G1 V	39.3° s
GL 178	04h 47m 07s +06° 52.5′	7.51	+ 24.4	F6 V	64.9° s
GL 188	05h 04m 30s +18° 34.8′	17.01	+ 20.6	G4 V	76.2° r
GL 197	05h 15m 37s +40° 03.4′	14.39	+ 66.5	G2 IV-V	69.5° s
GL 198	05h 16m 37s -18° 10.9′	15.70	+ 40.3	G0 V	28.3° s
GL 202	05h 21m 30s +17° 20.3′	15.34	+ 38.1	F8 Ve	53.7° s
GL 245	06h 43m 08s +43° 37.8′	15.10	- 23.9	G0 V	62.7° s
GL 262	07h 00m 20s +29° 25.4′	17.06	+ 25.4	G4 V	53.8° s
GL 302	08h 16m 01s -12° 27.7′	12.61	+ 30.5	G7.5 V	45.8° s
GL 368	09h 45m 22s +46° 15.3′	13.28	+ 5.0	G0.5 Va	42.3° s
GL 387 A	10h 14m 30s +23° 21.5′	16.45	+ 37.5	F8 Vbw	42.8° s
GL 392 A	10h 24m 59s +49° 03.2′	19.27	- 6.8	F9 V	39.1° s
GL 434	11h 38m 25s +34° 29.0′	8.62	- 5.9	G8 Ve	63.3° s
GL 451 A	11h 50m 06s +38° 04.7′	8.62	- 99.1	G8 VI	76.2° r
GL 475	12h 31m 22s +41° 37.7′	8.72	+ 6.6	G0 V	61.5° s
GL 484	12h 42m 38s +39° 33.0′	15.75	+ 80.7	G0 V	52.3° s
GL 502	13h 09m 32s +28° 07.9′	8.35	+ 5.1	G0 V	56.0° s
GL 504	13h 14m 18s +09° 41.1′	13.48	- 27.4	G0 V	48.4° s
GL 547	14h 20m 42s +01° 28.5′	17.27	- 18.9	G1 V	44.1° s
GL 549 A	14h 23m 30s +52° 04.9′	14.28	- 11.4	F7 V	55.7° r
GL 564	14h 48m 02s +24° 07.0′	14.35	- 2.7	G2 V	50.2° r
GL 566 A	14h 49m 05s +19° 18.4′	6.71	+ 2.2	G8 Ve	60.5° r
GL 566 B	14h 49m 05s +19° 18.4′	6.71	+ 3.1	K4 Ve	60.5° r
GL 598	15h 44m 01s +07° 30.5′	11.92	- 68.5	G0 V	54.0° r
GL 602	15h 50m 57s +42° 35.4′	17.39	- 56.4	F9 V	73.9° r
GL 611 A	16h 03m 13s +39° 17.4′	12.48	- 60.0	G8 V	43.9° s
GL 616	16h 12m 54s -08° 14.3′	15.36	+ 12.0	G1 V	37.7° r
GL 632	16h 34m 28s +79° 53.7′	22.32	- 16.9	dG3	40.9° r
GL 641	16h 50m 27s +00° 04.5′	16.53	+ 45.4	G8 V	37.6° s
GL 651	17h 01m 12s +47° 08.4′	16.18	- 47.3	G8 V	44.9° s
GL 672	17h 18m 47s +32° 31.9′	13.57	- 79.1	G2 V	71.3° r
GL 779	20h 01m 51s +16° 56.0′	16.61	+ 4.8	G1 V	37.1° s
GL 788	20h 17m 02s +66° 41.6′	13.72	- 4.6	G5 V	48.7° s
GL 882	22h 55m 00s +20° 30.0′	17.12	- 33.7	G4 V	78.5° r

Under elevation: "r" refers to a rising object while "s" refers to a setting object.

FIGURE CAPTION

Figure 1: **Block diagram of system used for 203 GHz search for narrowband signals.**

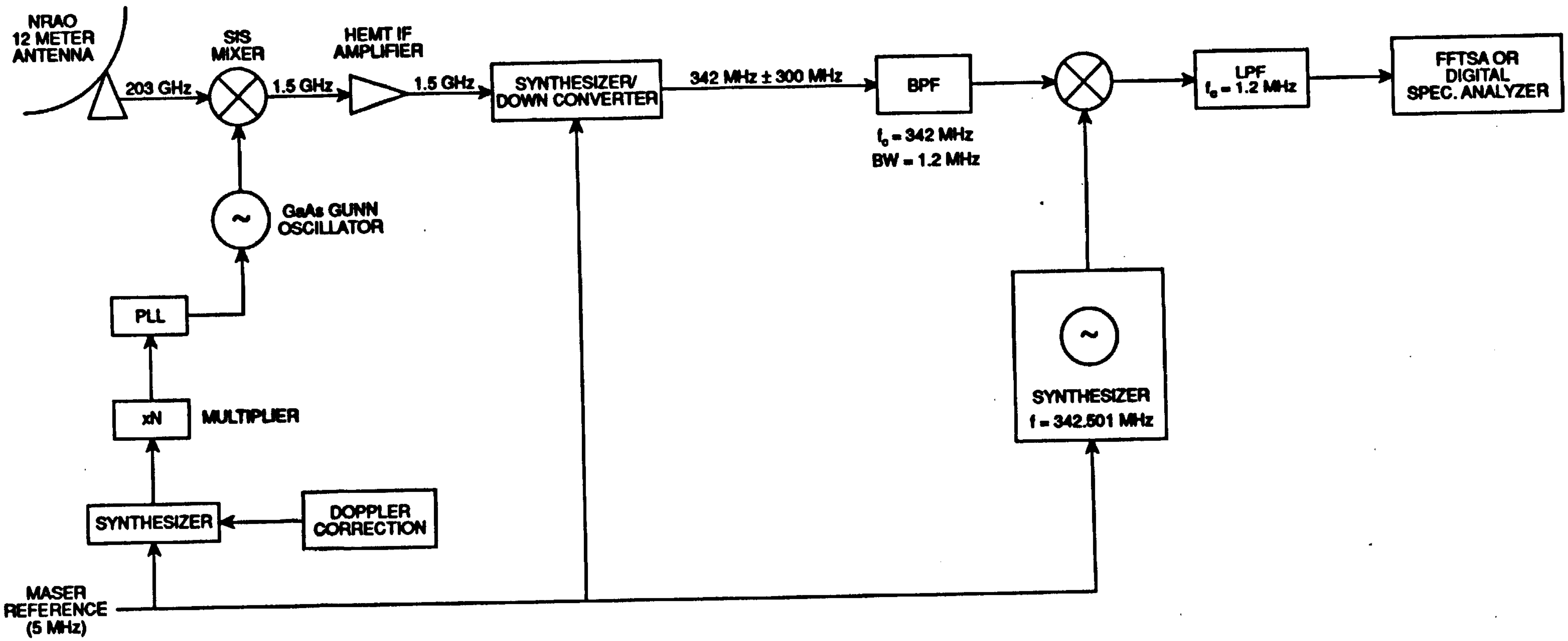

Figure 1 (Steffes and DeBoer)

APPENDIX C:

Impact of Satellite Radio Frequency Interference (RFI) on the High Resolution Microwave Survey (HRMS) Sky Survey at C-band Frequencies

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Impact of Satellite Radio Frequency Interference (RFI) on the High Resolution Microwave Survey (HRMS) Sky Survey at C-band Frequencies

ABSTRACT:

This paper describes an experiment to determine the level of interference from domestic geostationary satellites transmitting at C-band (3.7 - 4.2 GHz) frequencies. Specifically, we discuss the use of a High Resolution Fast Fourier Transform Spectrum Analyzer (HRSA) to obtain exceptional sensitivity in conjunction with an antenna aperture of 30 meters in order to study the impact of sidelobe interference on an HRMS search. The results of this experiment, and implications for future searches in the C-band range are also presented.

I. INTRODUCTION

The growth in satellite communication technology has fueled the entry of new satellite service companies, adding congestion to what is already an overcrowded C-band downlink spectrum (3.7 - 4.2 GHz). With recent adjustments to the orbital spacing of geostationary satellites, the concern about effects of RFI upon the HRMS Sky Survey observation at C-band is significant. As of April 2, 1993, the number of active geostationary satellites transmitting at C-band was believed to be about 150. As a result, any attempt to conduct a high resolution survey for a narrow band signal source originating beyond the geostationary arc would be most challenging. To this end, this paper will describe just such an experiment to observe the interference of a typical C-band commercial satellite, Telstar-302. The goal was to observe the signal level of a carrier as a function of antenna elevation. The authors found that even with the antenna pointed approximately 23.3° above the geostationary arc, the received carrier level was approximately 15 dB above the noise floor at a spectral resolution of 32 Hz in a total instantaneous bandwidth of 1 MHz.

II. OBSERVATION

The observation of Telstar-302 as the RFI source was conducted on July 17, 1993 at the Georgia Tech Woodbury Research Facility located in Woodbury, Georgia. The observation facility consists of two 30 meter diameter Cassegrain antennas equipped with C-band feeds and an accompanying 14,000 square foot building. Originally built by Aeronutronic Ford Corporation for AT&T in 1976, the antennas are currently being refurbished under the direction of Dr. W. Whitfield Smith of Georgia Tech's School of Electrical and Computer Engineering.

The purpose of the experiment was to observe the spectral energy level of a typical C-band satellite as the ground station receiving antenna was moved in elevation off the main beam of the satellite while holding the azimuth fixed. With the use of a high resolution spectrum analyzer, comparable to that used in the HRMS sky survey element, the received signal strength of a specific satellite carrier could be observed hundreds of beamwidths away from direct pointing toward the source.

A. EQUIPMENT CONFIGURATION

The observation of Telstar-302 was conducted at the Georgia Tech Woodbury Research Facility using the southernmost 30 meter Cassegrain antenna. Dual, orthogonal linearly polarized receive signals are separated by an Orthomode Transducer (OMT) which directs each polarization to orthogonal ports with an inherent isolation of 40 dB between ports. The horizontal polarization feed was attached to a 45°K noise temperature low noise amplifier (LNA) providing 55 dB of gain. Based on original technical specifications of the AT&T 30 meter antenna, an elevation half power beam width of 0.145° at 4.1995 GHz is given for the Woodbury, GA site. This implies an aperture illumination efficiency of 91.8%. The elevation antenna pattern for the Woodbury antenna is attached in Appendix D of this report.

A block diagram of the observation system is shown in Fig 1. In order to be sensitive to signals transmitted over interstellar distances, extremely narrow channel bandwidths are necessary. To satisfy this criterion, a high resolution spectrum analyzer (HRSA) was developed. It is a 32,000 channel Fast Fourier Transform Spectrum Analyzer which uses an 8-bit analog to digital (A/D) converter in conjunction with a 64K point complex FFT computed and displayed using MATLAB software on a 486-DX 66 MHz personal computer. By using a Hamming window and a 2 MHz sampling rate, individual channel resolution bandwidths of approximately 32 Hz were observed. The total instantaneous bandwidth was 1 MHz, and the total time to sample, compute, and display each spectrum was approximately 30 seconds.

To process the received C-band signals, a Harris 6522 receiver was used to allow selection of a desired transponder, and to downconvert the RF input to a 70 MHz IF output signal. A second downconverter was built to downconvert this 70 MHz signal to baseband for input to the 8-bit A/D card. The instantaneous bandwidth of the downconverter is 1 MHz wide and by adjusting the local oscillator (LO), a desired transponder signal could be shifted to fall within the passband response of the HRSA. Note that both downconverters used synthesizer-based local oscillators to maintain the necessary stability.

B. OBSERVATIONAL APPROACH

The observational approach consisted of two parts: (i) Acquisition of Telstar-302 at the computed look angles of 51.7° elevation, 180.85° azimuth referenced from Woodbury, GA, and then peaking the received signal level by slight adjustments in azimuth and elevation while monitoring an HP 8558-B spectrum analyzer, (ii) establishing a reference mark for the peak signal with respect to the elevation and monitoring signal levels from a specific transponder on Telstar-302 as a function of antenna offset in elevation above the reference mark.

To acquire Telstar-302, the look angles were first computed and then the antenna was positioned accordingly. To ensure that the correct satellite was found, the latest publication of the "World Satellite Transponder Report" was consulted in conjunction with a color television to visually confirm correct antenna positioning. Given the large antenna aperture and construction design, the computed beam width was found to be 0.15° at 4.0 GHz. Hence it required several iterations in adjusting both azimuth and elevation until the main lobe was acquired.

To begin observation, an active transponder (channel) was selected using the Harris 6522

C-band receiver, which provided a single sharp carrier using the full transponder power. Just such a channel was found on Transponder 18 which remained active throughout our observation period. Spectra of the main lobe signal were taken using the HRSA. Subsequently the 1st, 2nd, and 3rd side lobes were observed on the HRSA. The observations sequence then consisted of moving the antenna's main lobe away from the satellite to selected positions (offsets above the elevation reference mark), until finally the stow position of 75° was reached. The construction of the 30 meter dish does not allow for an elevation above 85°. For Telstar-302, an elevation of 75° corresponds to an offset of 23.3° above the geostationary arc, approximately 155 beam widths away. At this position, the HRSA observed a signal strength approximately 15 dB above the receiver noise floor at a spectral resolution of 32 Hz in a total instantaneous bandwidth of 1 MHz. It should be mentioned that this signal level may not have been the peak signal strength of the corresponding sidelobe since no effort was made to move the antenna beyond the stow position to observe the corresponding local maximum. Once the series of observations were made, the antenna was repositioned back on the main satellite lobe to verify that the signal was still being transmitted at the same power level and modulation rate.

III. RESULTS

The observation of Telstar-302 plainly shows the substantial likelihood of RFI to be encountered at C-band frequencies (3.7 - 4.2 GHz) for an HRMS sky survey. Included with this report are the spectral plots made during the observation (see Appendix A). A series of 13 plots illustrating the peak spectral intensity levels over the 1 MHz window is provided as a function of antenna elevation offset. The "lollypop" plots consist of plotting the maximum frequency value per bin, where a bin size of 128 points was chosen thus providing 256 maximum signal points (bins) per plot. Due to the enormous gain and low noise of our receiving system, it was calculated that a carrier to noise ratio (C/N) of 88.0 dB would be achieved at the input to the C-band receiver/downconverter. Hence the Harris 6522 receiver was highly saturated when the main receive lobe was pointed directly at the satellite. In fact the manufacturer's specification for maximum RF input power is -60.0 dBW for the Harris receiver. However when the antenna was pointed directly at Telstar-302, a received power of -44.0 dBW was achieved. For the first sidelobe, a received signal strength of -66.0 dBW was achieved which despite being approximately 20 dB down still nearly manages to saturate the C-band receiver.

In addition to the maximum intensity plots, several full band spectral plots were made to illustrate the signal spectra that was used to characterize this experiment. Specifically, full spectra plots occurring at the main lobe, 1st side lobe, 2nd side lobe, and antenna stow position (23.3° away) are provided in Appendix B. Finally, a summary bar graph illustrating received signal level vs. elevation offset is included in Appendix C illustrating the relative signal strengths at offsets ranging from several beam widths out to approximately 155 beam widths away.

During the observation of Telstar-302, as the antenna offset reached approximately 7.0° above the geostationary arc, a second in-band signal was detected which was believed to be from an adjacent geostationary satellite. The signal strength of this new signal was observed to rise and fall as the antenna swept through the peaks and nulls of this signal. Hence the possibility of RFI from other geostationary satellites is highly likely since the distance to Telstar-302 or it's neighbors at this antenna offset is about the same.

During the observation of Telstar-302, as the antenna feed system was increased in inclination, an out of band oscillation was generated by our LNA due to an unterminated sma connector on the feed waveguide used to couple in a noise source. This oscillation was occurring at approximately 30 MHz away from the center frequency of 4060 MHz corresponding to channel 18 of the Harris receiver. The net result was that this artificially lowered the noise floor on several of our observation points until the problem was rectified. There was no effect on the characteristics of the in-band signal we were monitoring, hence this did not effect the integrity of the experiment.

Upon completion of the observation, a measurement of antenna noise temperature was made by observing the change in the system noise floor as a mechanical waveguide switch was used to toggle the antenna feed between a known 300°K noise source and the antenna. Taking into account the insertion loss of the waveguide switch as well as other salient losses and component noise temperatures, an antenna noise temperature of 37.9°K was obtained. This corresponds to a system noise temperature of approximately 85.0°K for the horizontal polarization feed used for this observation.

IV. CONCLUSION

By using a high resolution spectrum analyzer in conjunction with the Georgia Tech Woodbury Research Facility, we have shown that substantial RFI would be received by the HRMS Sky Survey System at C-band frequencies, almost regardless of antenna pointing. This suggests that resources would be better devoted to efforts not involving a search at C-band (3.7 - 4.2 GHz) until less contaminated spectrum regions have first been explored.

Future activities may include several similar observation scenarios involving other domestic C-band satellites over a wider range of elevation offsets. With the successful development of the HRSA running on a 486-based PC, the observations of several geostationary satellites could be made in one or two days with instantaneous feedback of results. It is believed that by the end of 1993, full motion tracking capability will exist at the Woodbury site enabling full radio astronomy capability.

REFERENCES

1. M. Long, "World Satellite Transponder Report", Mark Long Enterprises, Inc. Vol. 4 No. 2, pp. 56-57, May, 1993.

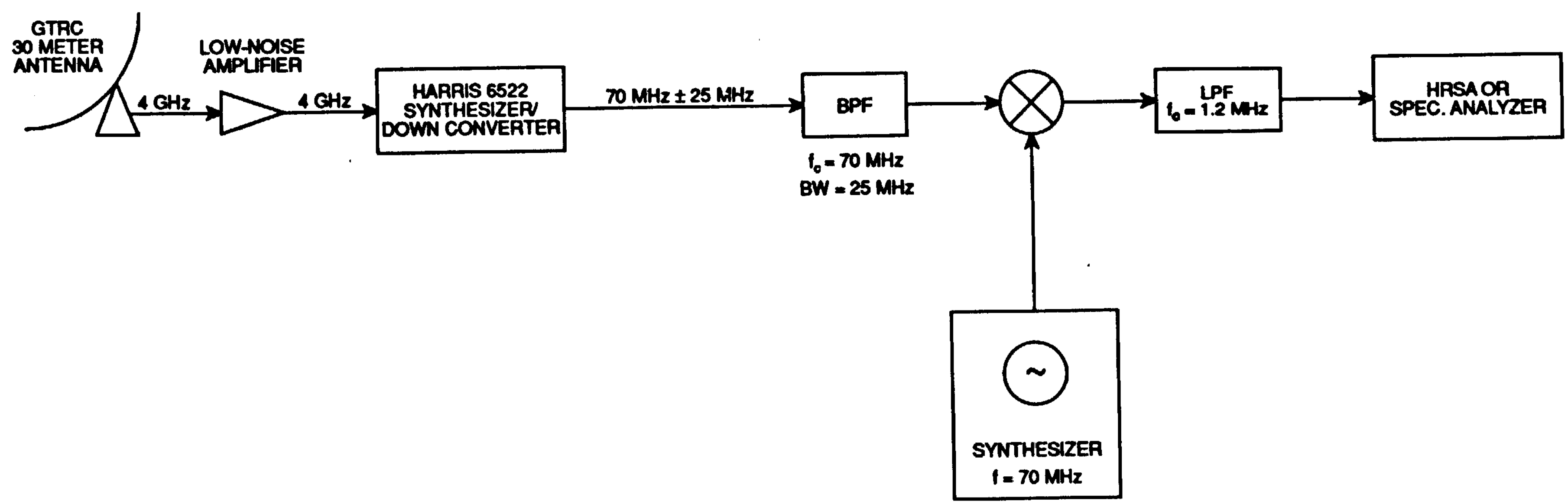
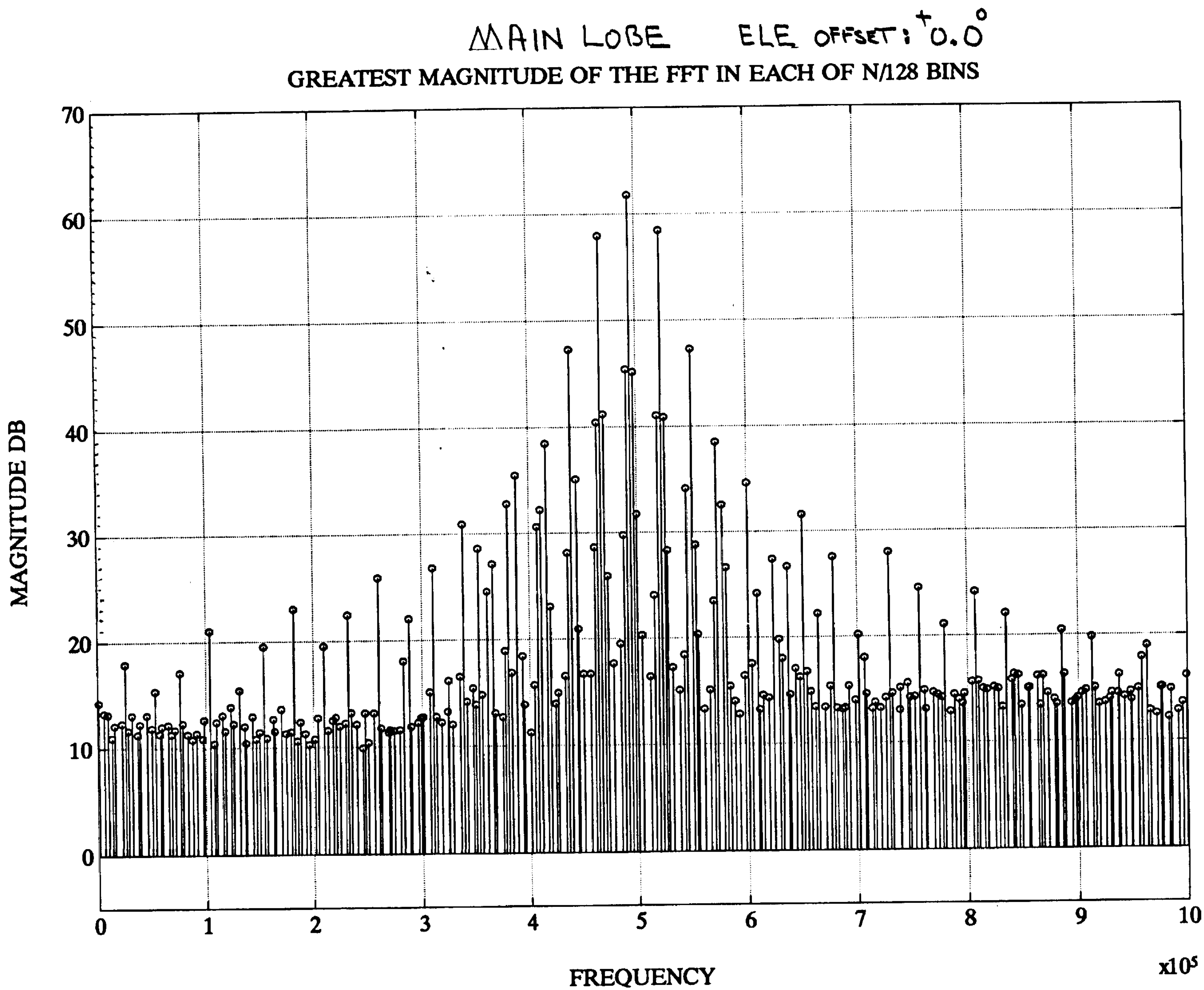

GTRC
30 METER
ANTENNA
4 GHz
LOW-NOISE
AMPLIFIER
4 GHz
HARRIS 6522
SYNTHESIZER/
DOWN CONVERTER
70 MHz ± 25 MHz
BPF
f_c = 70 MHz
BW = 25 MHz
SYNTHESIZER
f = 70 MHz
LPF
f_c = 1.2 MHz
HRSA OR
SPEC. ANALYZER

Fig. 1

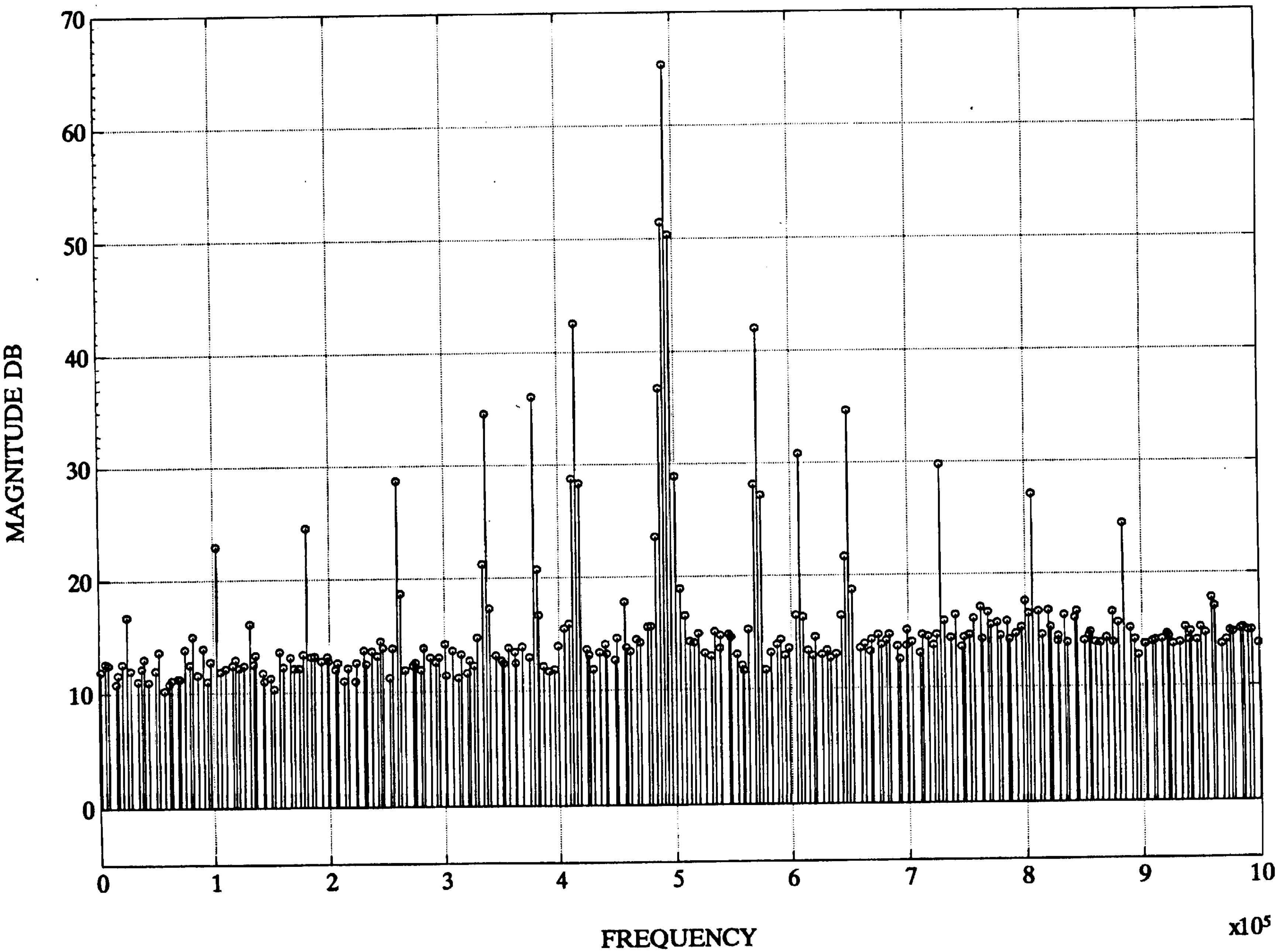
APPENDIX A

Peak Intensity Spectral Plots
vs.
Antenna Elevation Offset


MAIN LOBE ELE OFFSET: ±0.0°
GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS
MAGNITUDE DB
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY
x10^5

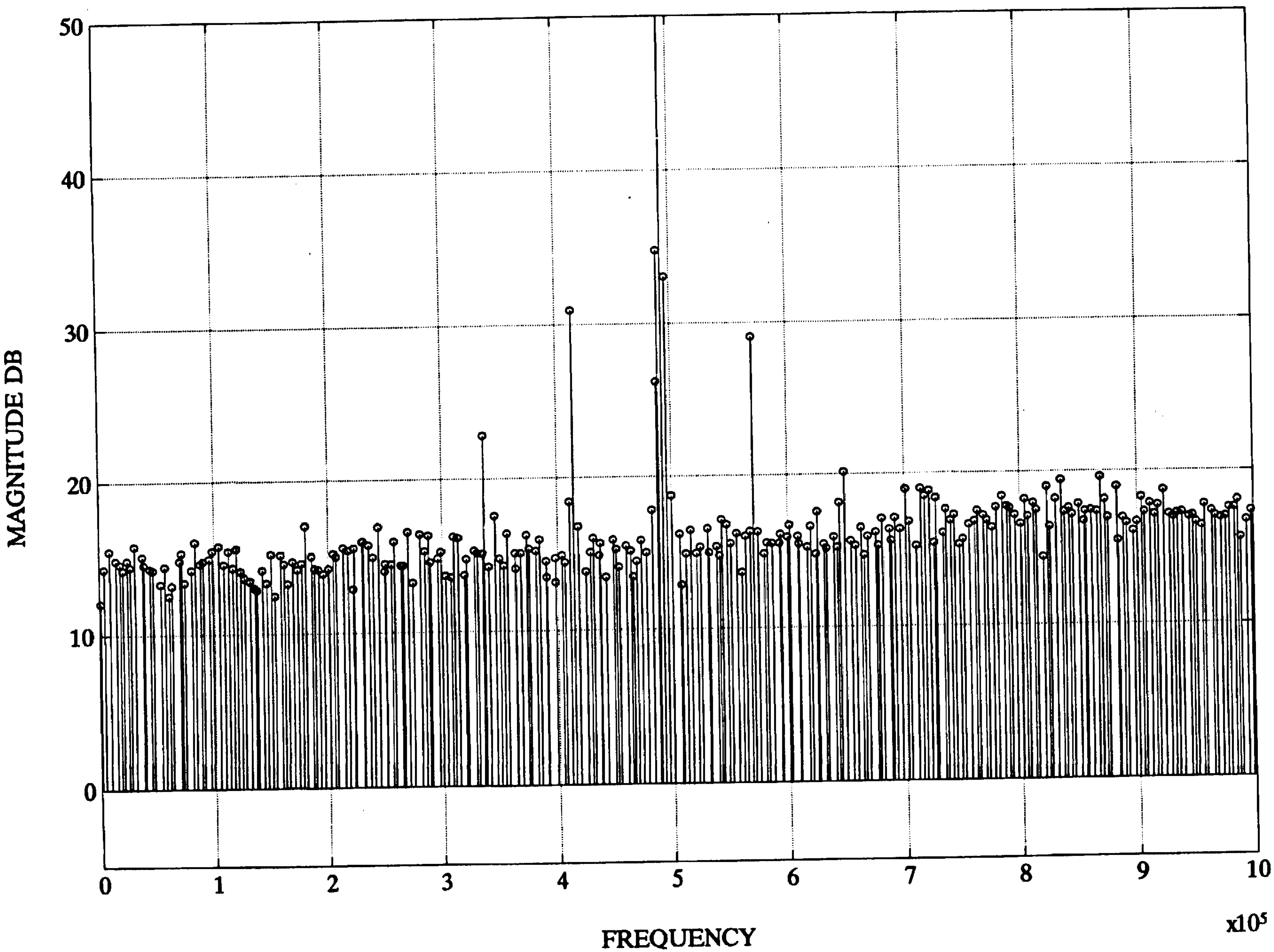
FIRST SIDE LOBE ELE OFFSET: $\pm 0.2^{\circ}$

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



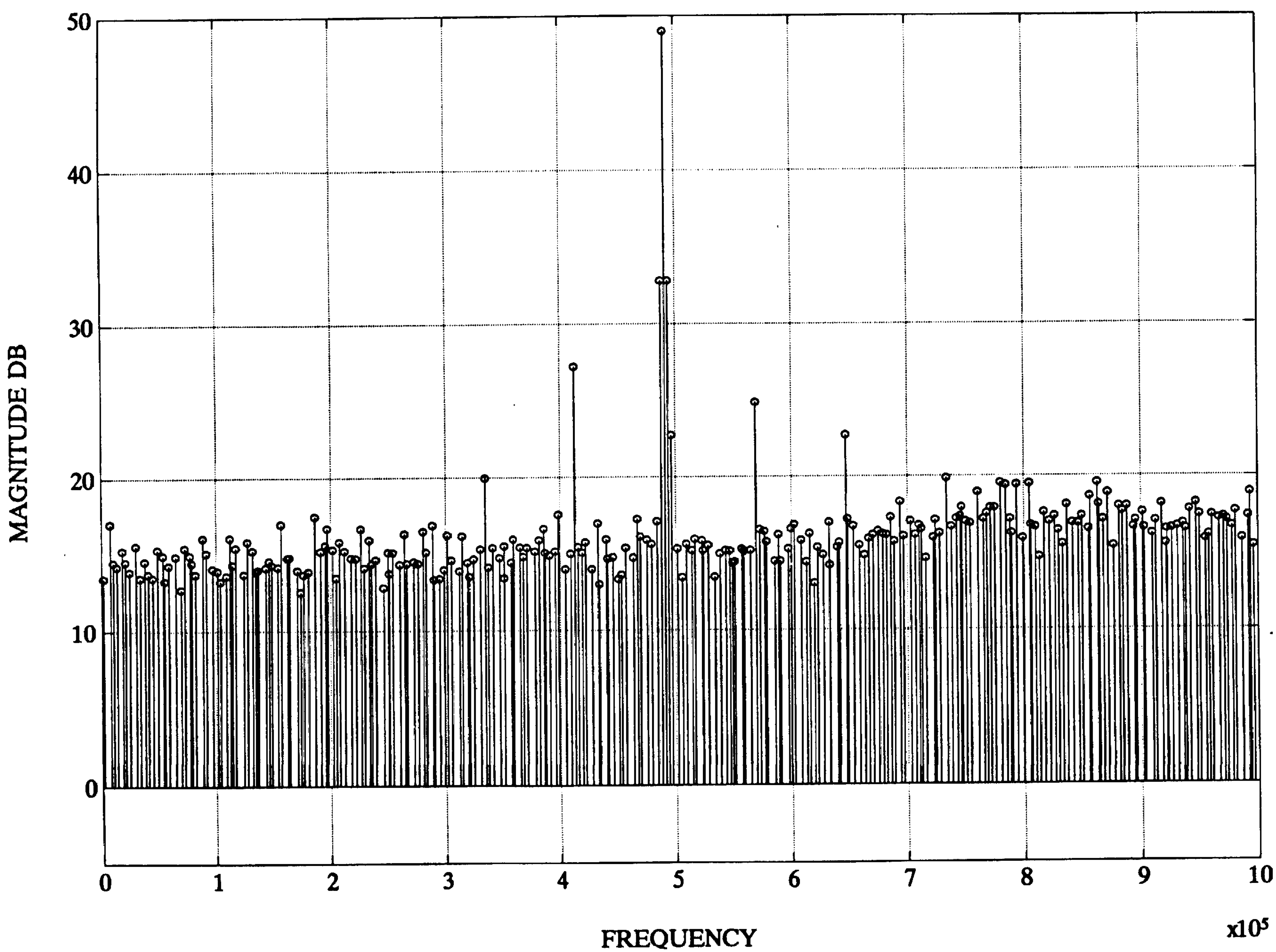
2nd Side LOBE   ELE offset: $\pm$ 0.34°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS

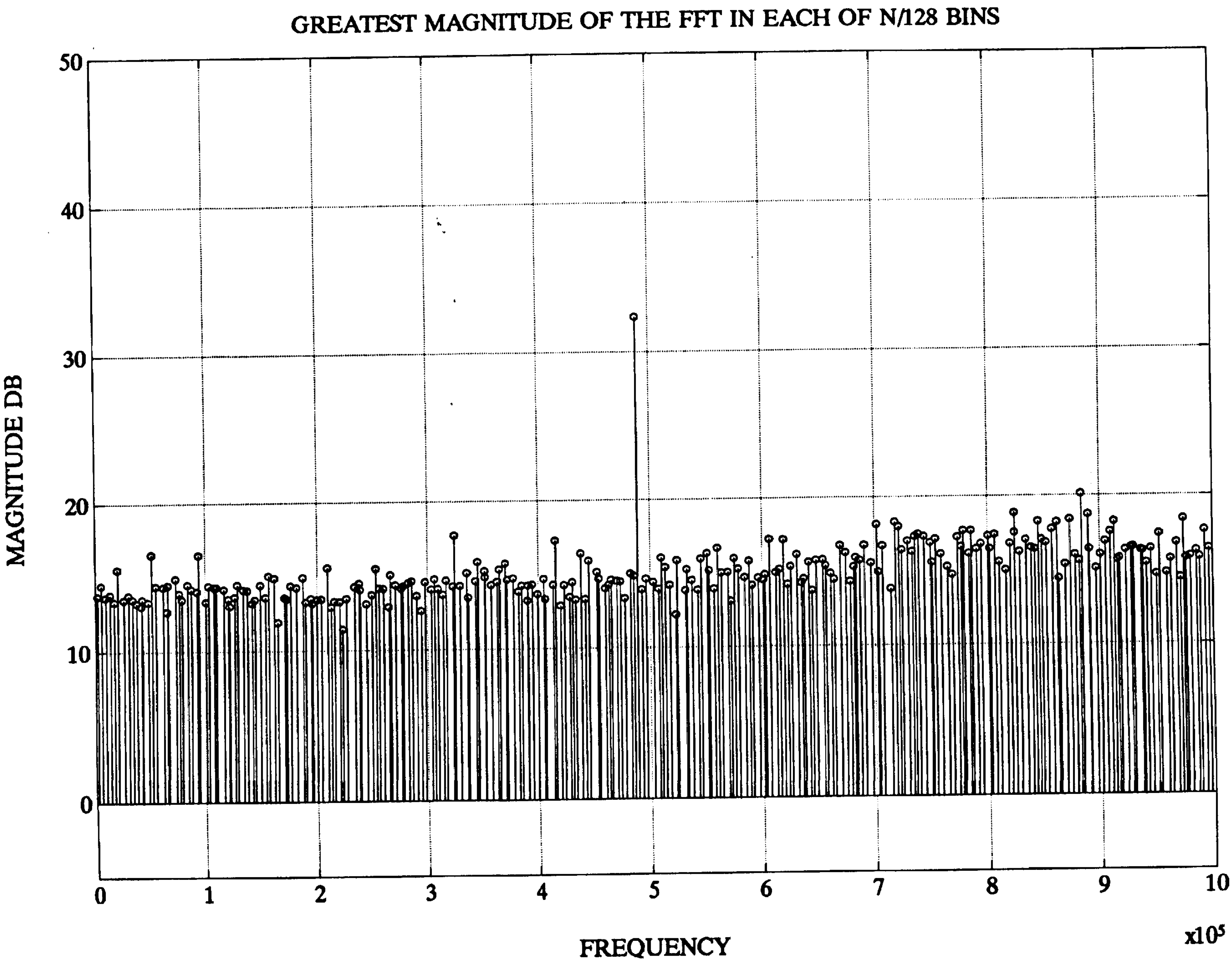


ELE OFFSET: ≈ +0.40°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS

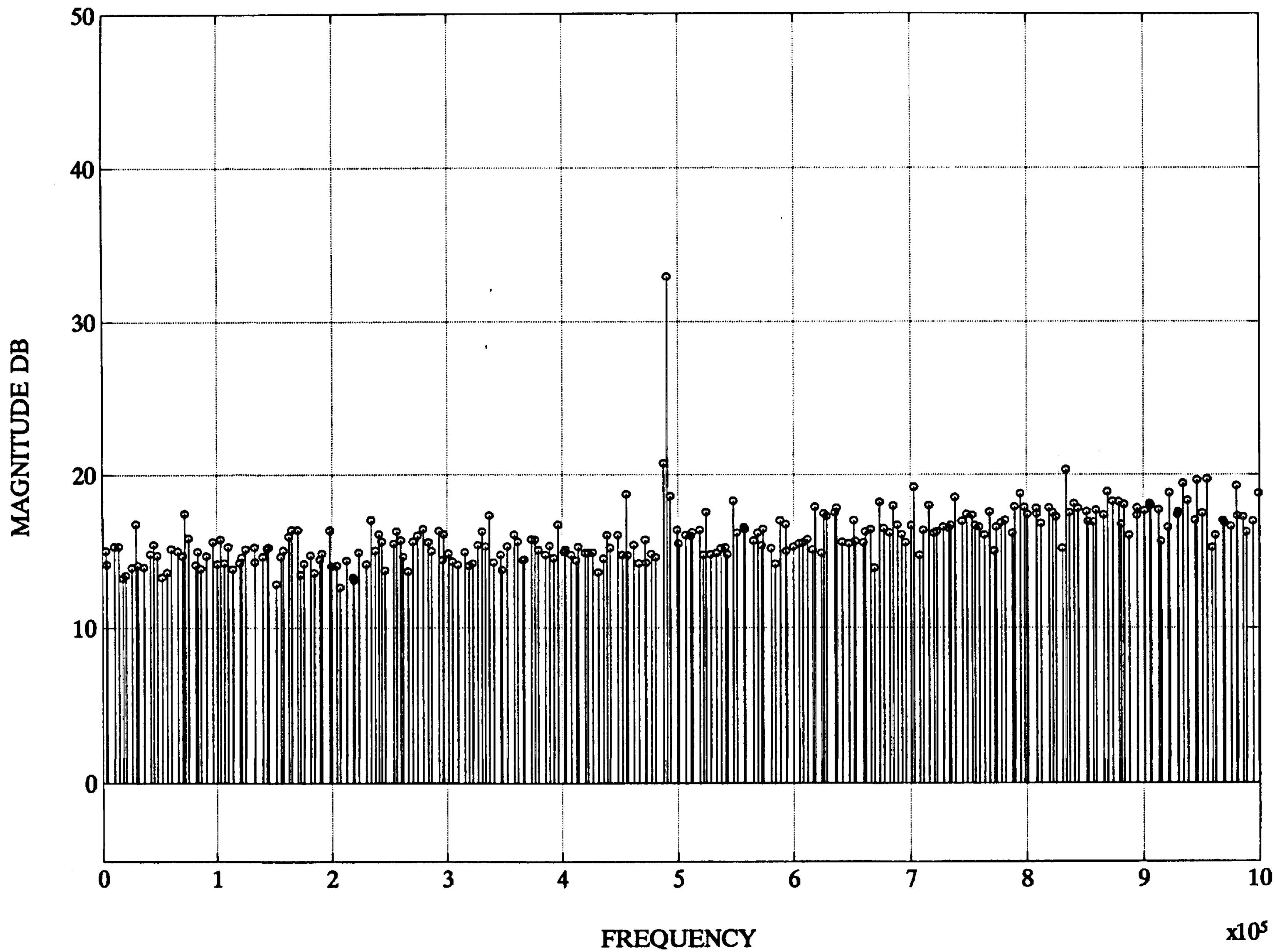


ELE OFFSET: $\approx^{+}$ 1.39°



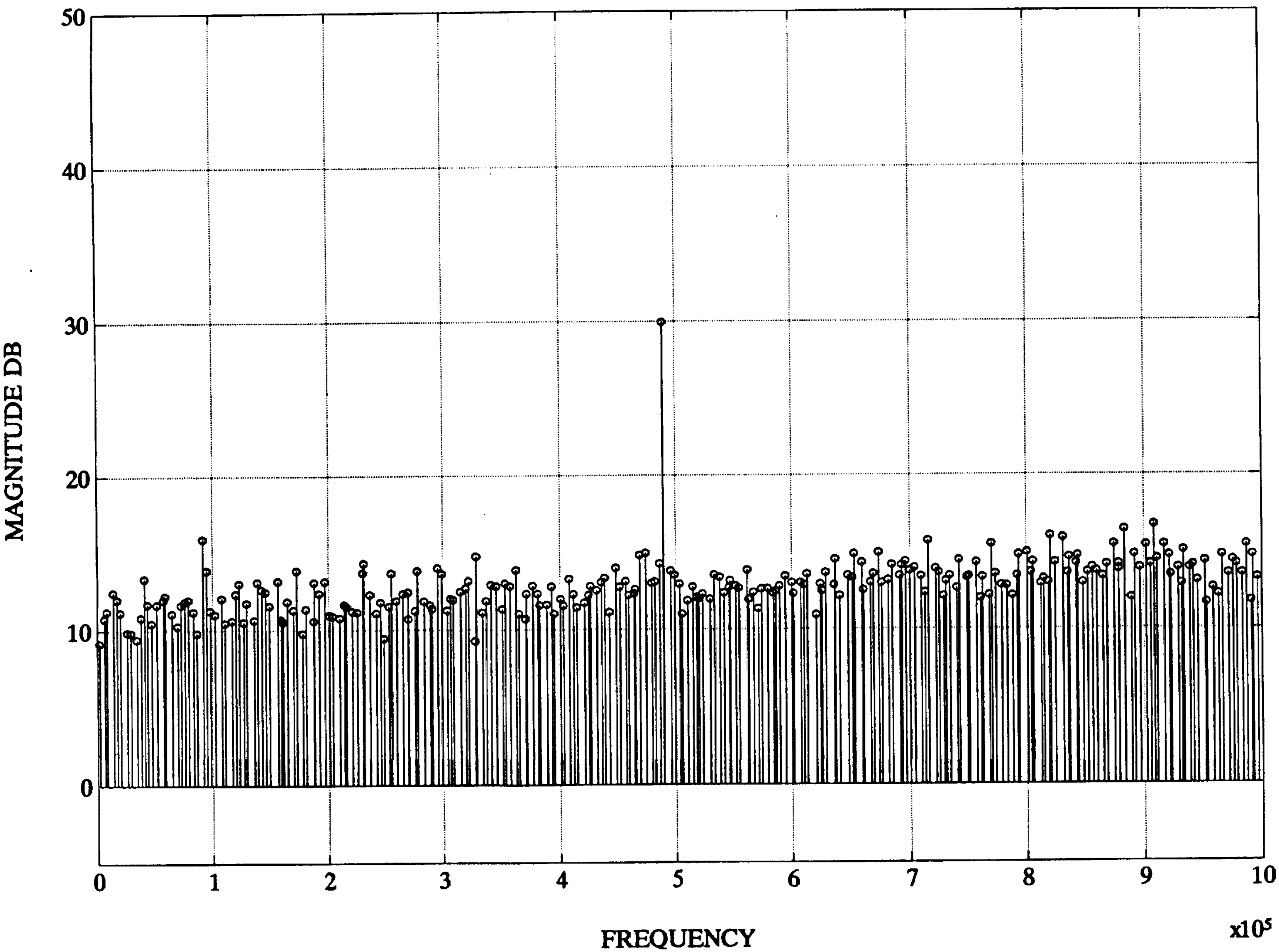
ELE OFFSET: +≈ 2.8°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



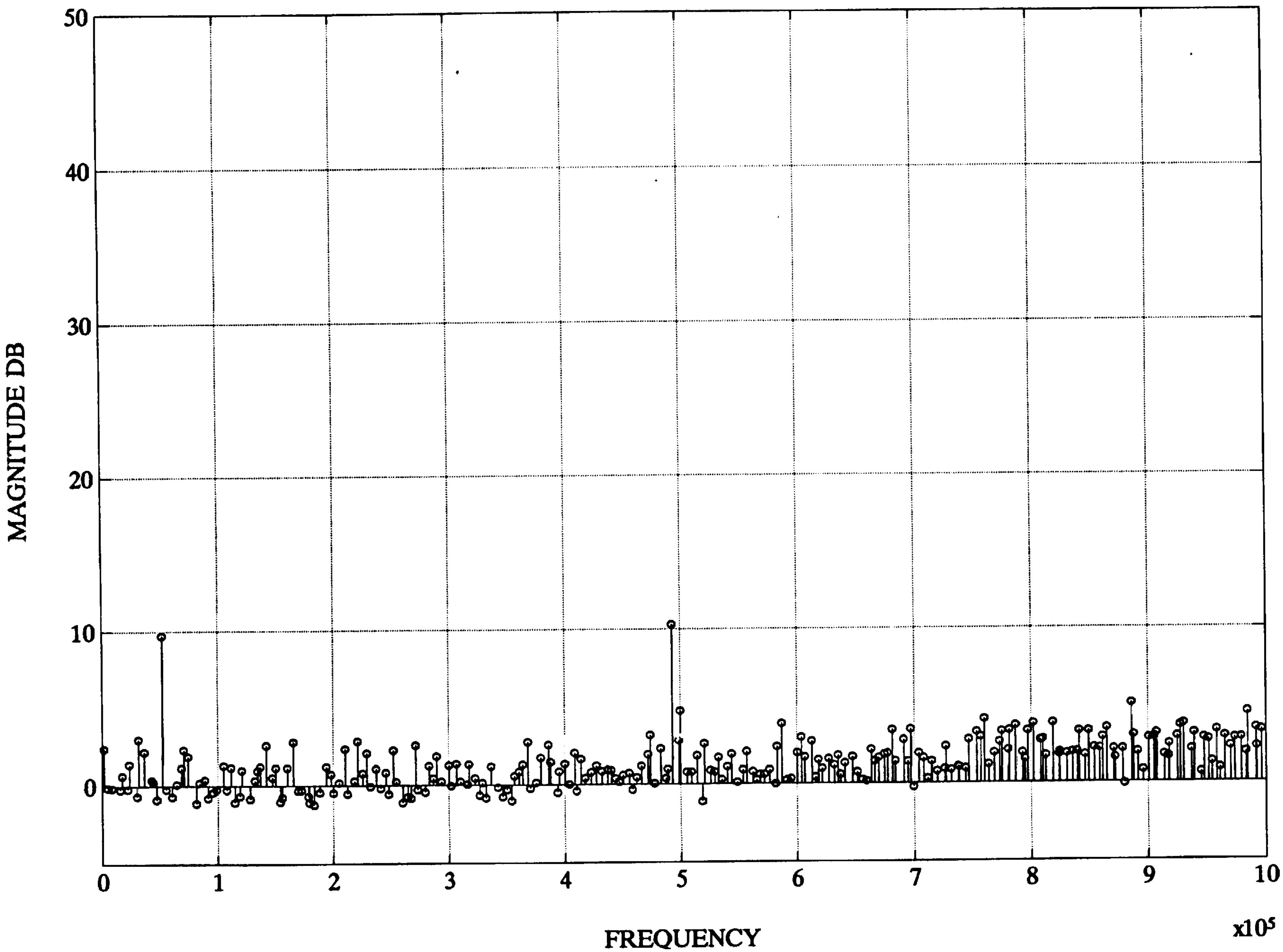
ELE OFFSET: ≈ +4.3°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



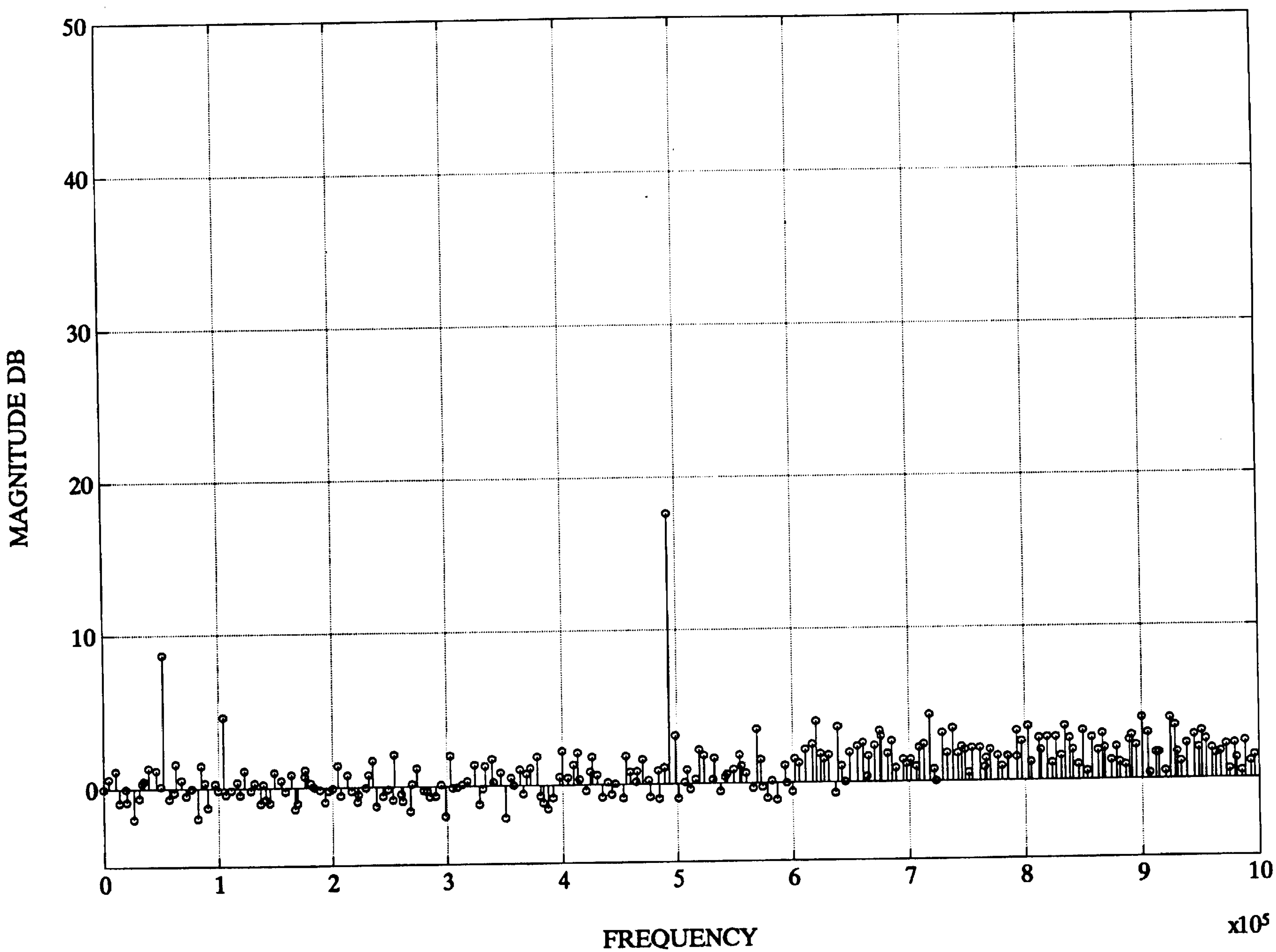
ELE OFFSET: $\approx 6.3^\circ$ +

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



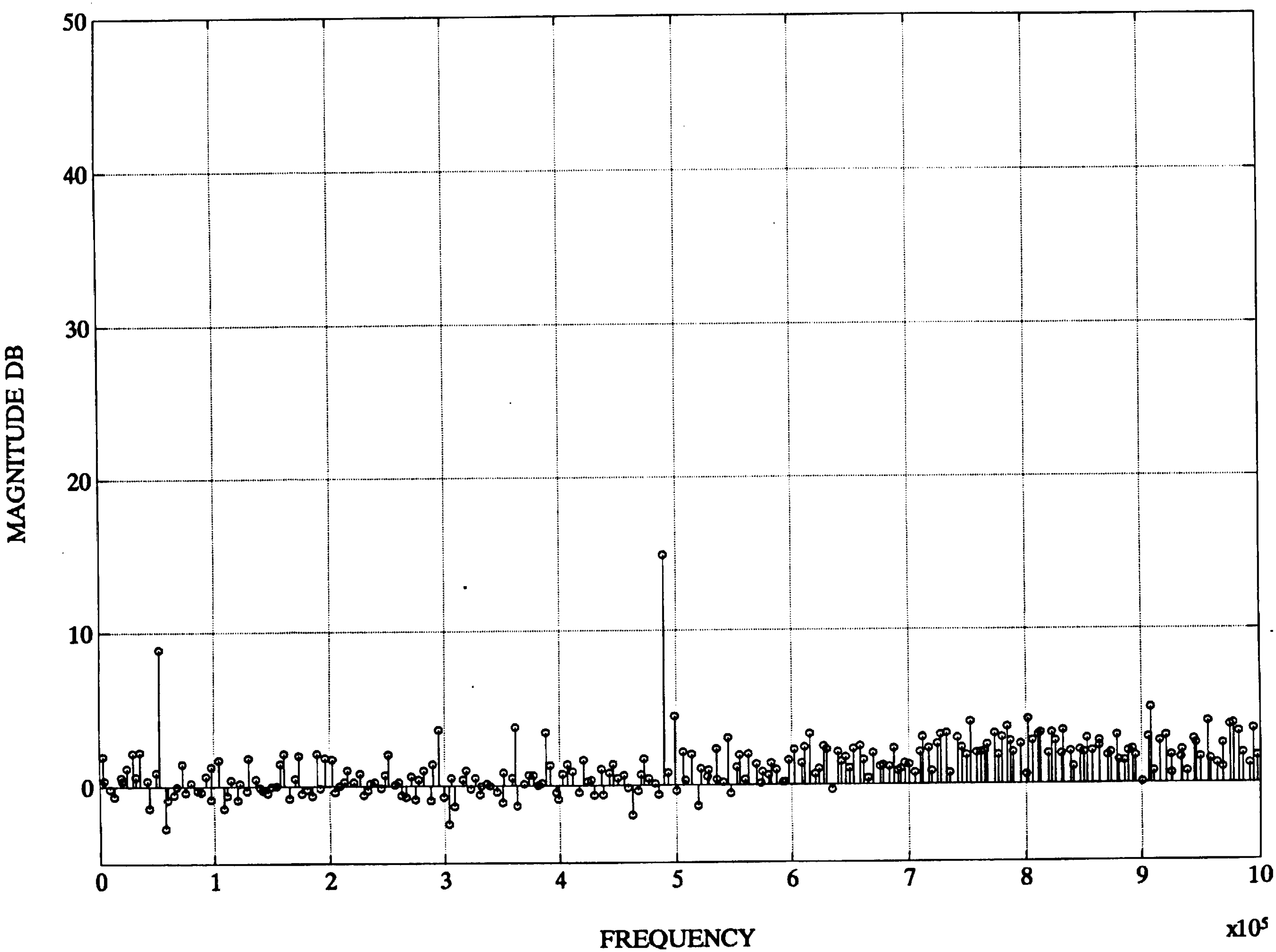
ELE OFFSET: ≈ 9.05^{+0}

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



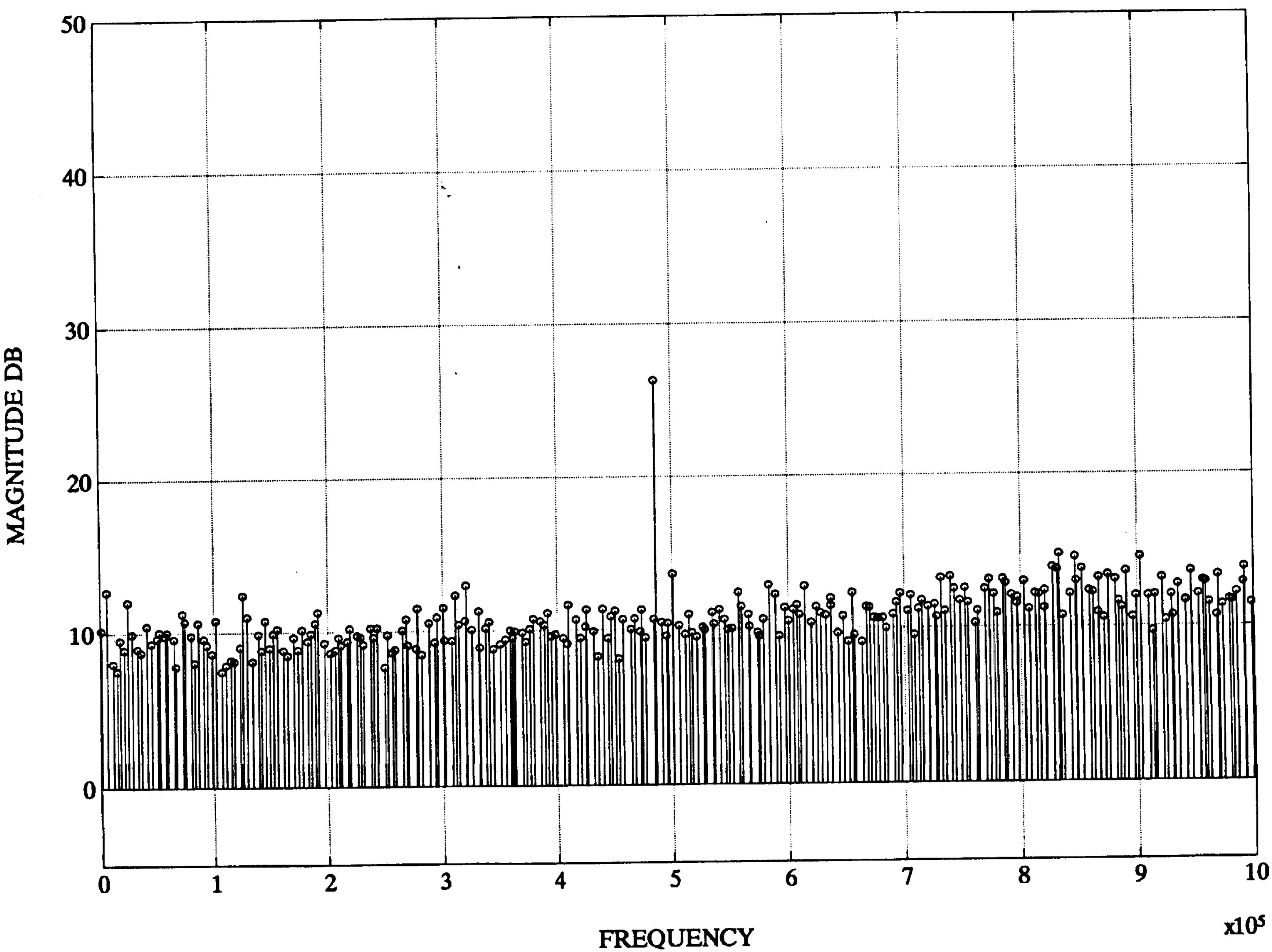
ELE OFFSET: ≈ 10.3°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS

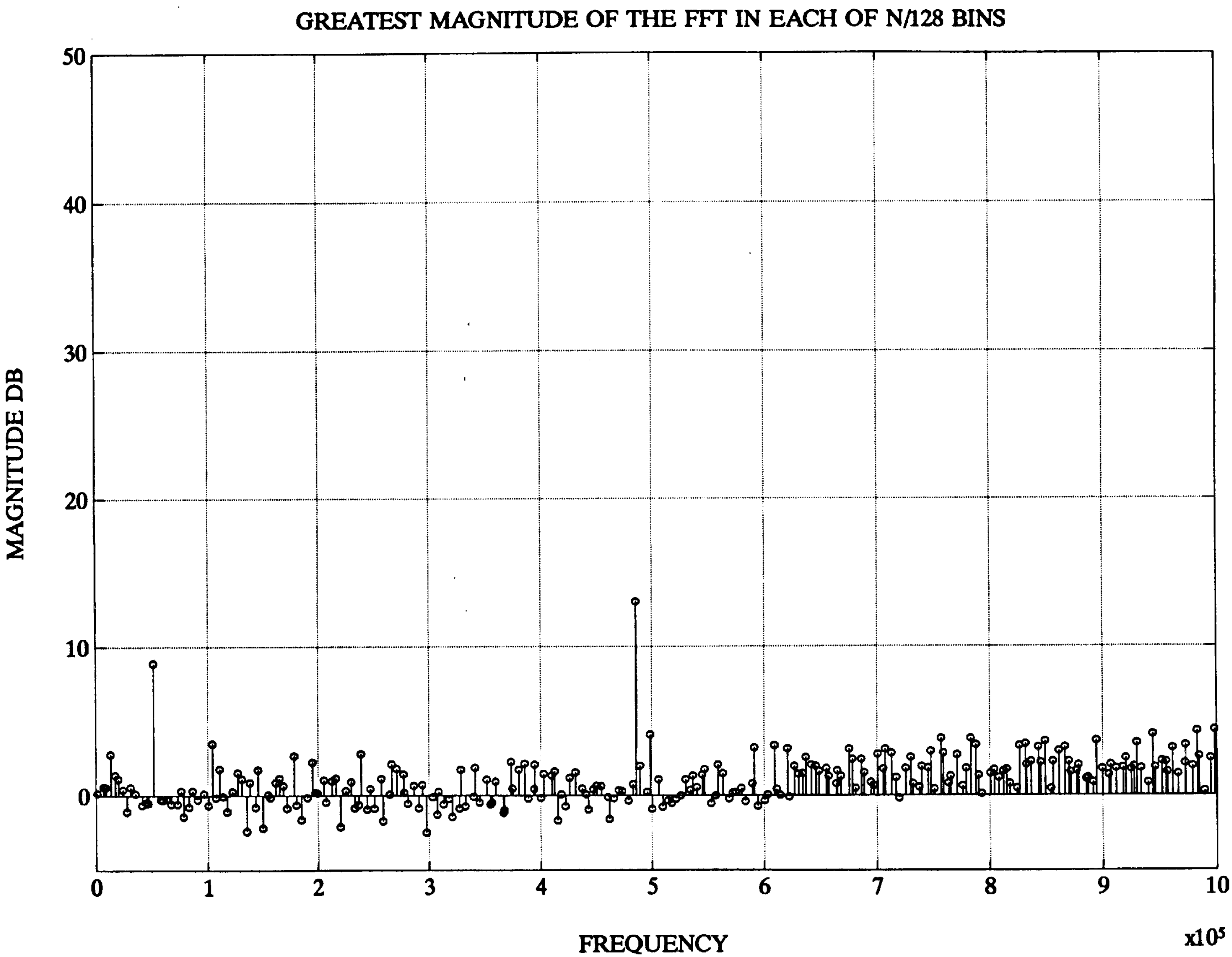


ELE OFFSET: + ≈ 13.3°

GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS

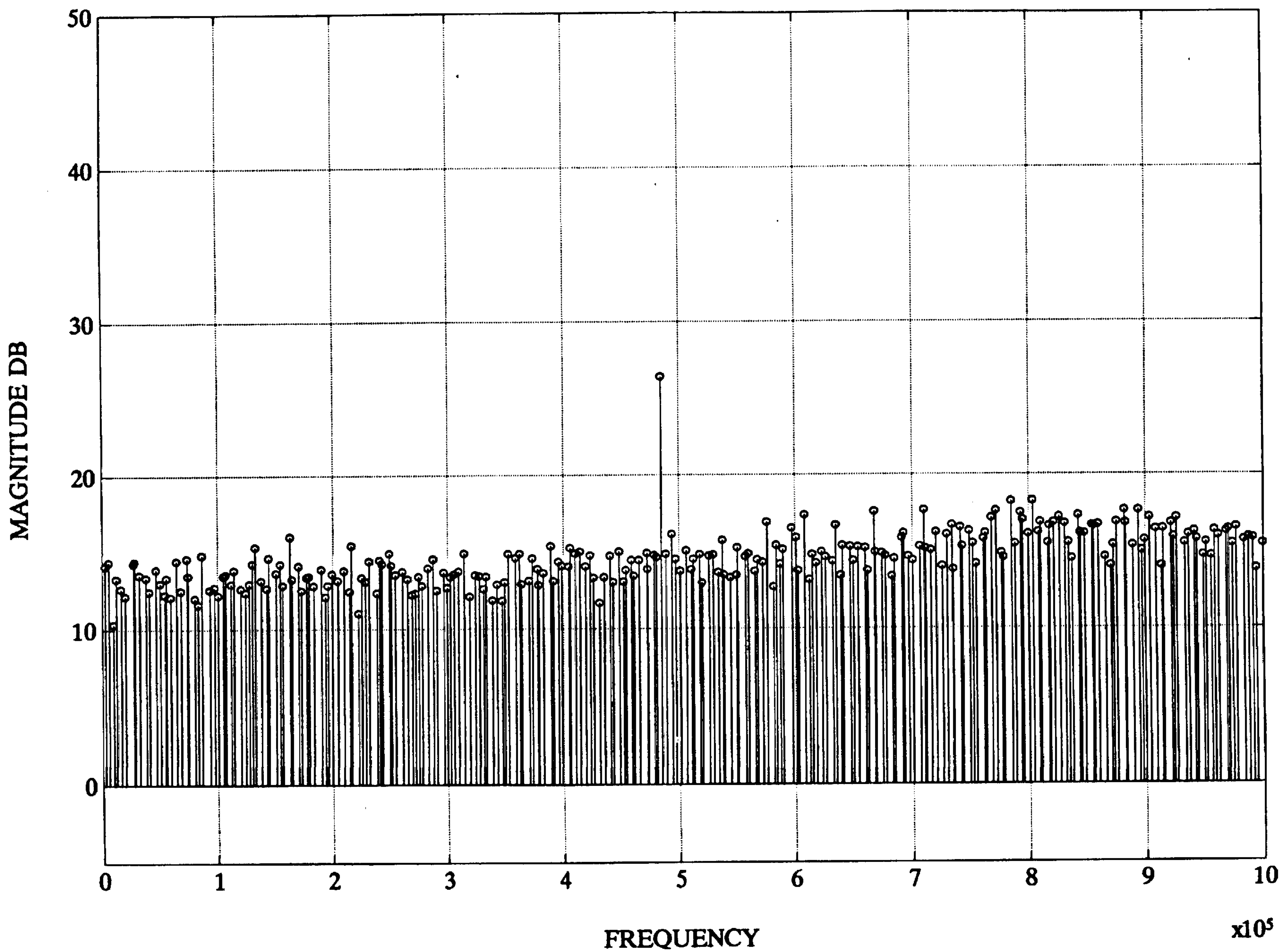


ELF OFFSET: ± 17.3°



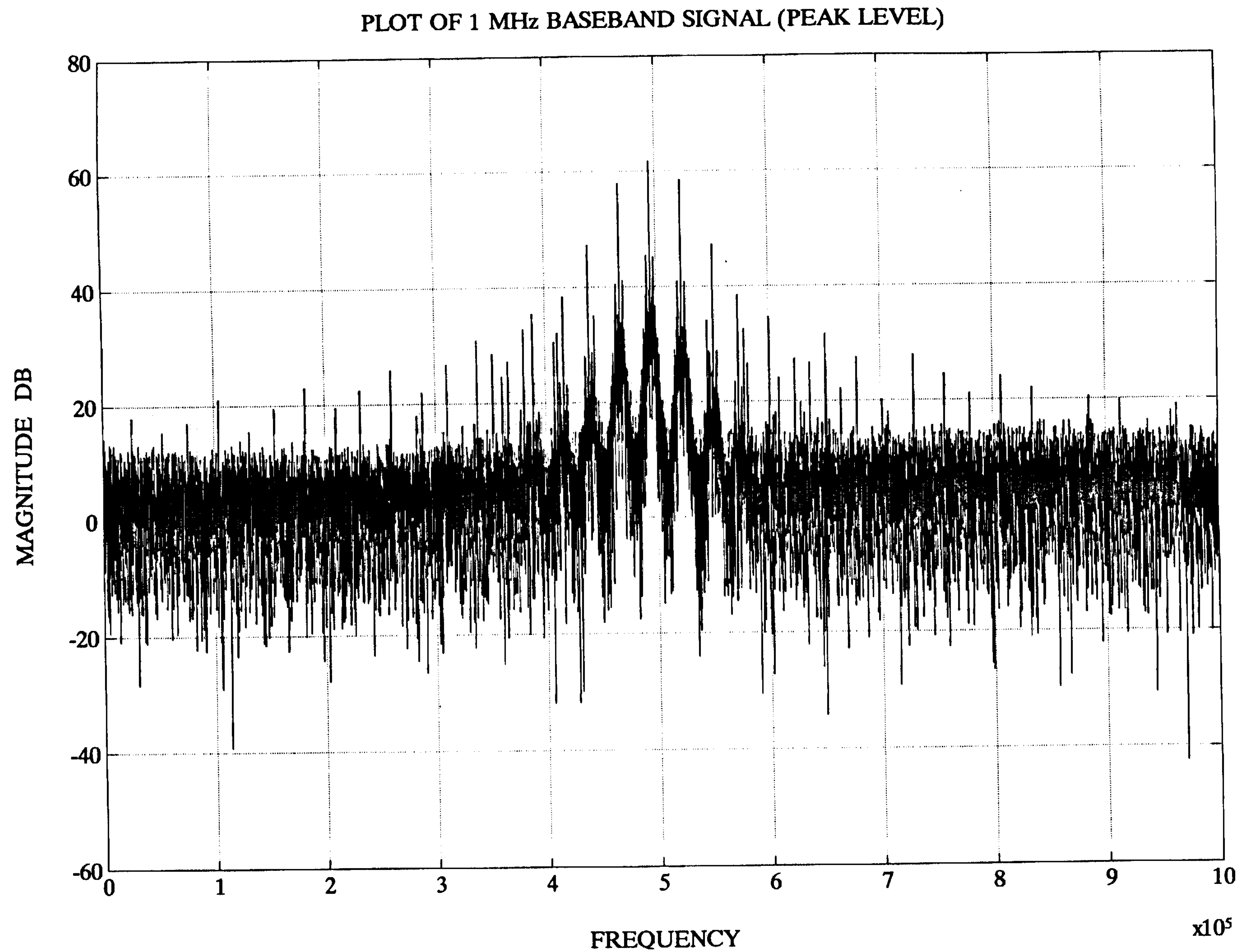
ELE OFFSET: ≈ ±23.3°

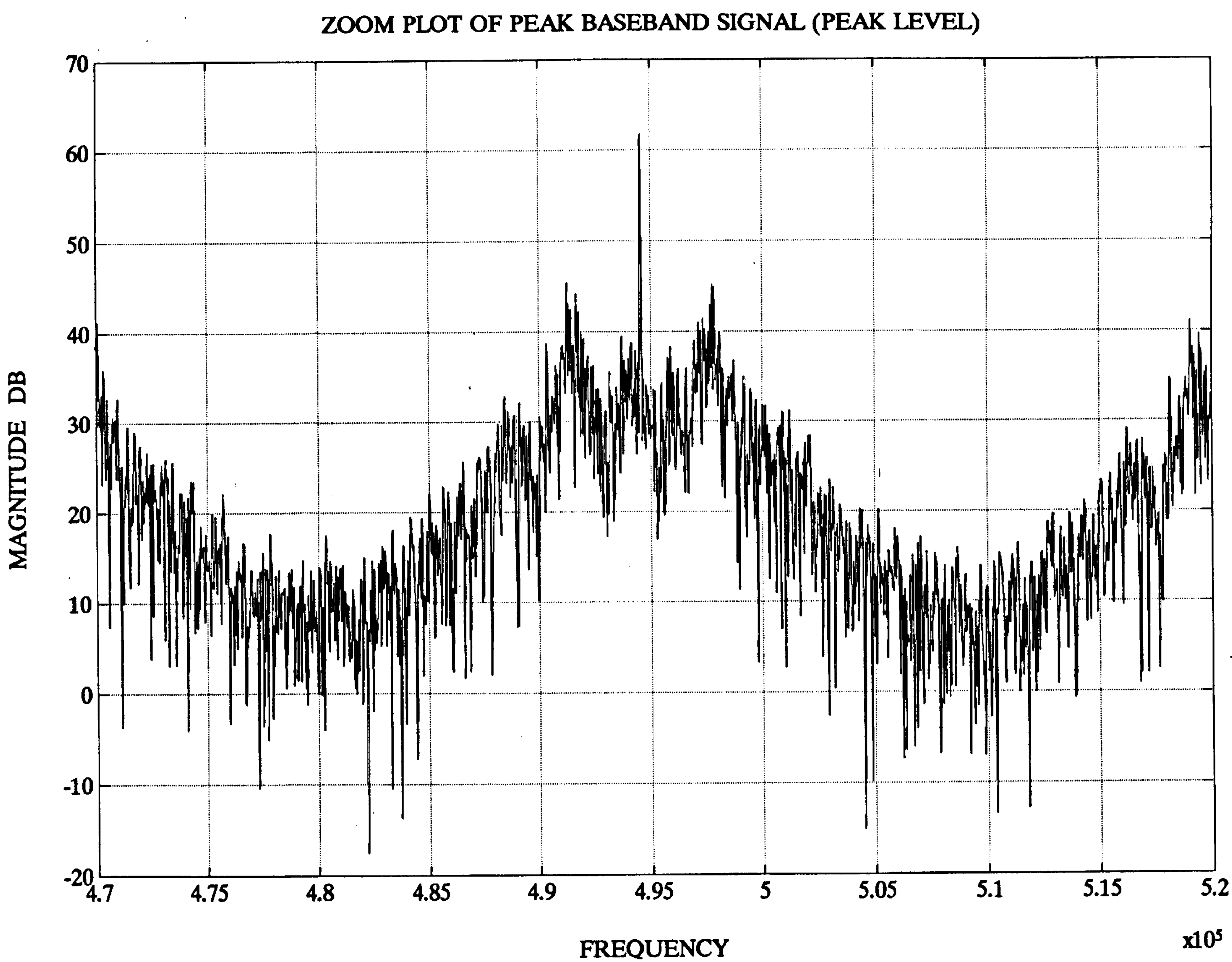
GREATEST MAGNITUDE OF THE FFT IN EACH OF N/128 BINS



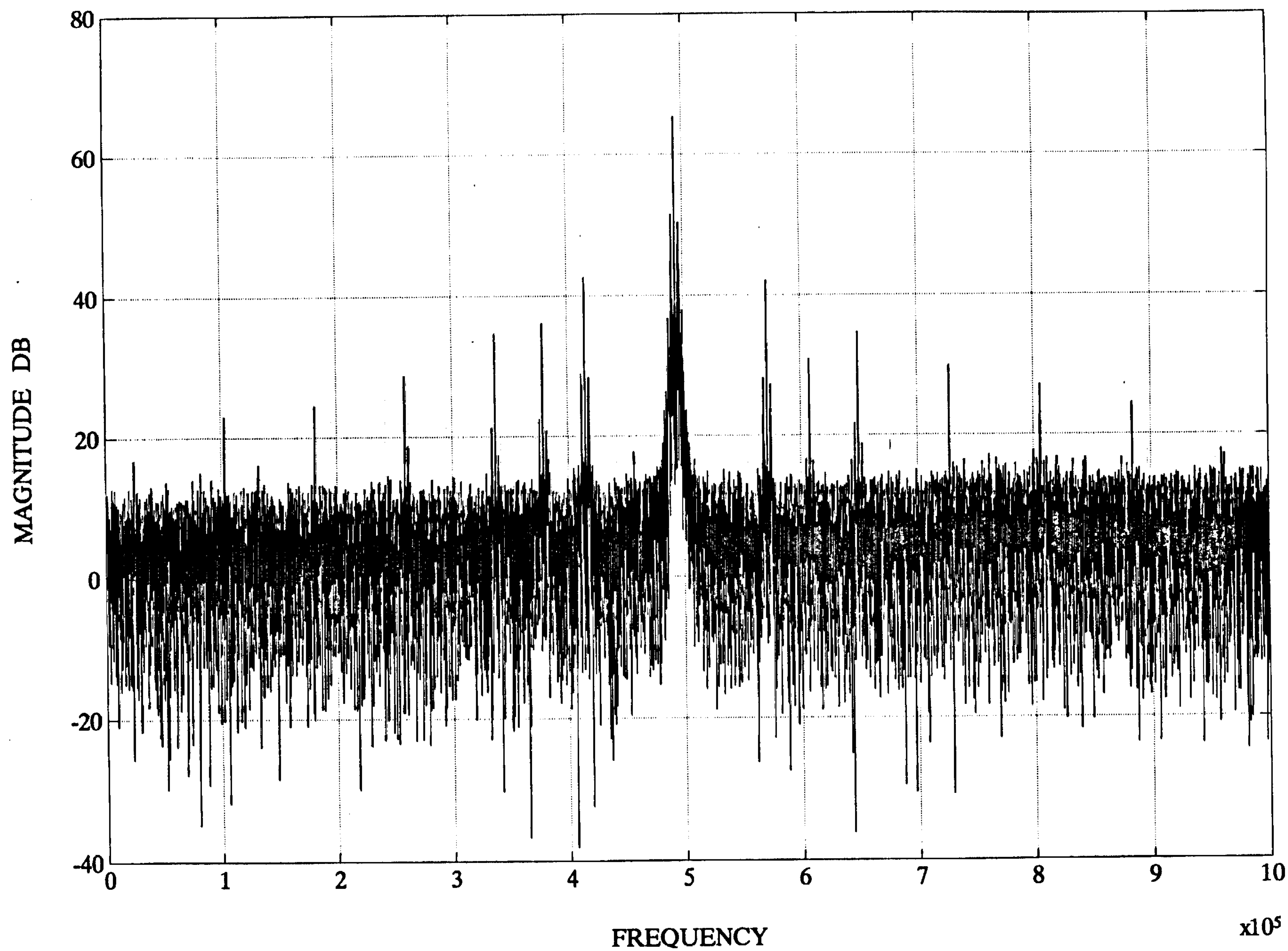
APPENDIX B

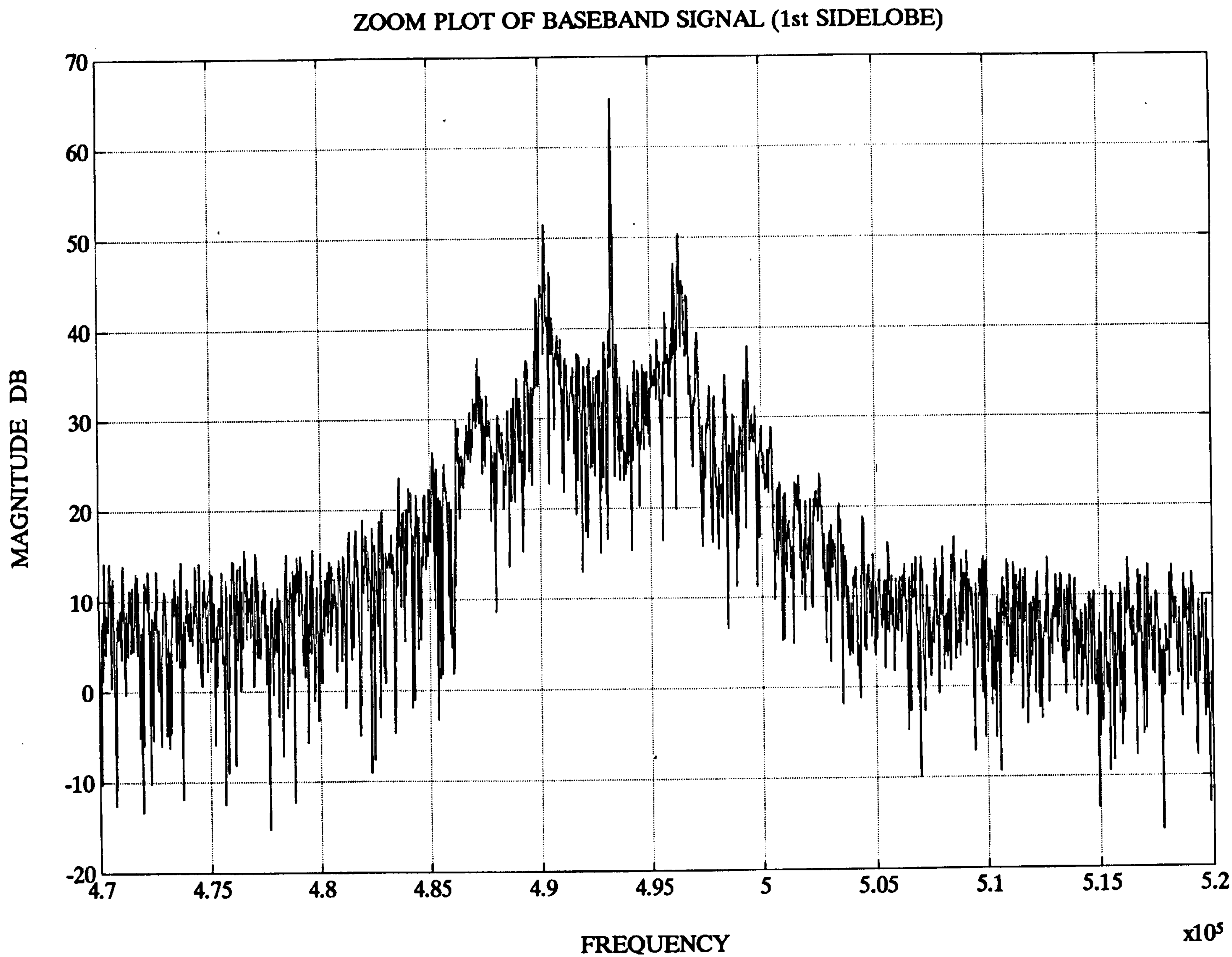
Fullband Spectral Plots of Main Lobe, 1st Side Lobe 2nd Side Lobe, and Antenna Stow Position


PLOT OF 1 MHz BASEBAND SIGNAL (PEAK LEVEL)
MAGNITUDE DB
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY
x10^5

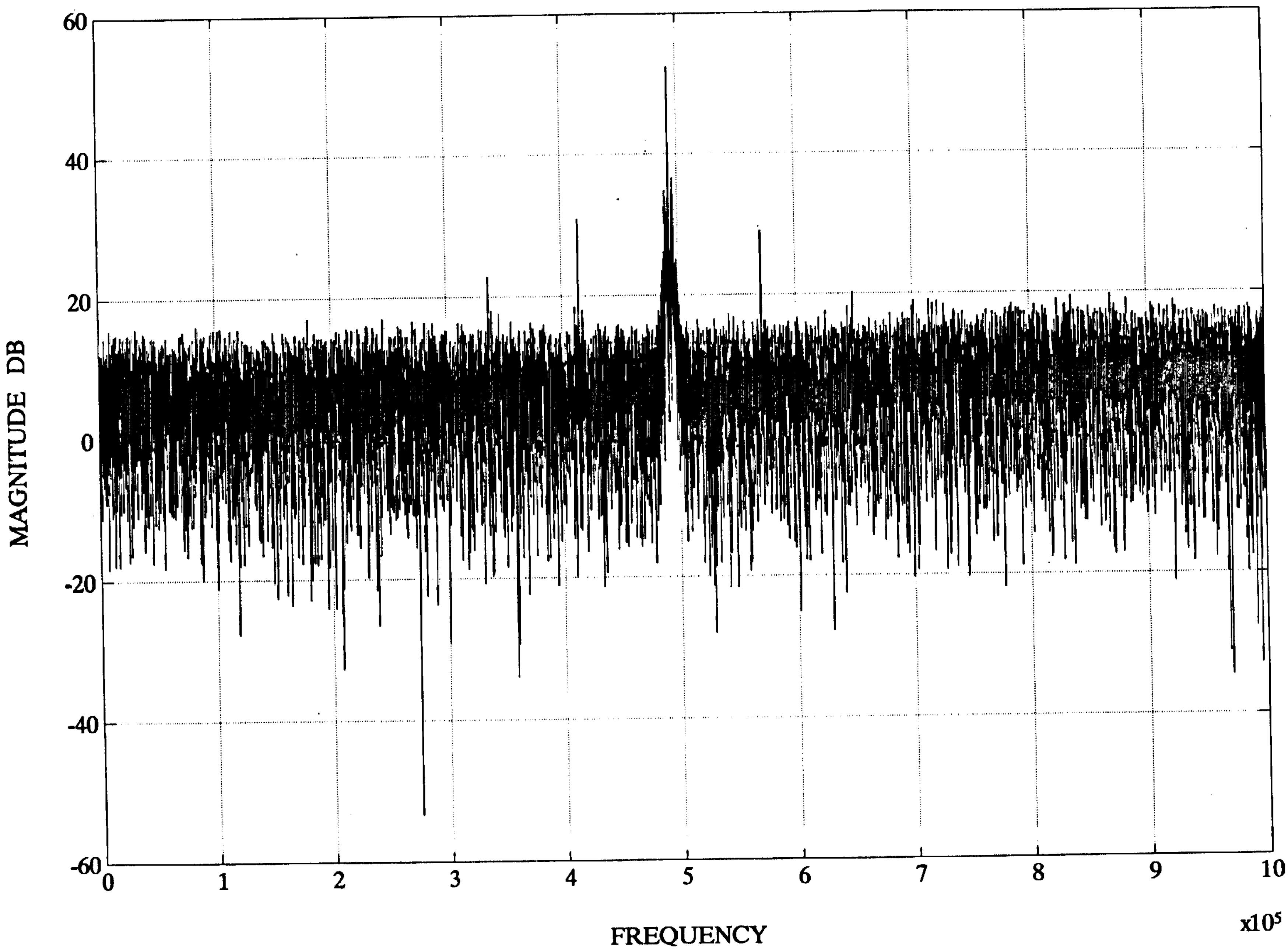

ZOOM PLOT OF PEAK BASEBAND SIGNAL (PEAK LEVEL)
MAGNITUDE DB
70
60
50
40
30
20
10
0
-10
-20
4.7
4.75
4.8
4.85
4.9
4.95
5
5.05
5.1
5.15
5.2
FREQUENCY
x10^5

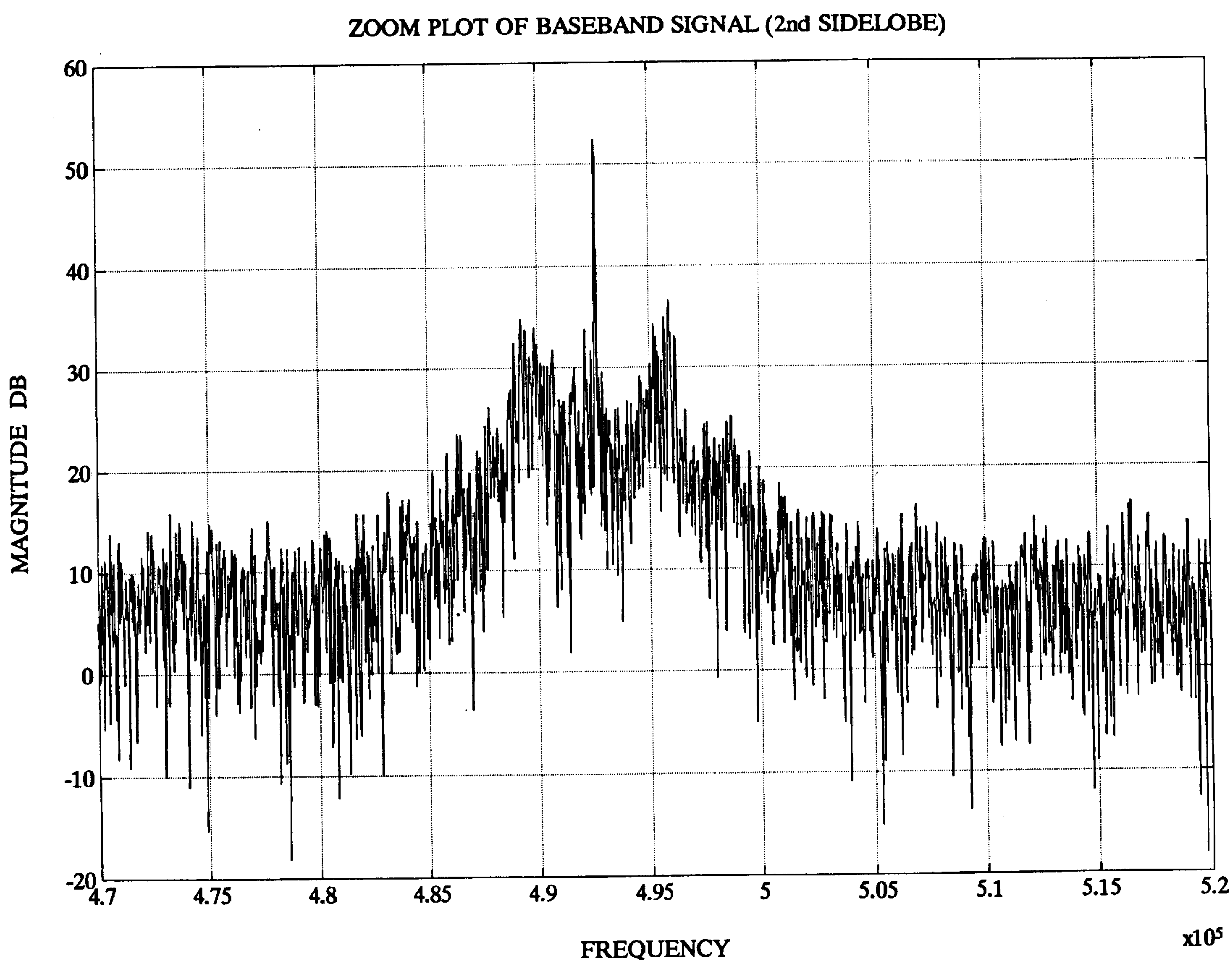
PLOT OF BASEBAND SIGNAL (1st SIDELOBE)




ZOOM PLOT OF BASEBAND SIGNAL (1st SIDELOBE)
MAGNITUDE DB
70
60
50
40
30
20
10
0
-10
-20
4.7
4.75
4.8
4.85
4.9
4.95
5
5.05
5.1
5.15
5.2
x10^5
FREQUENCY

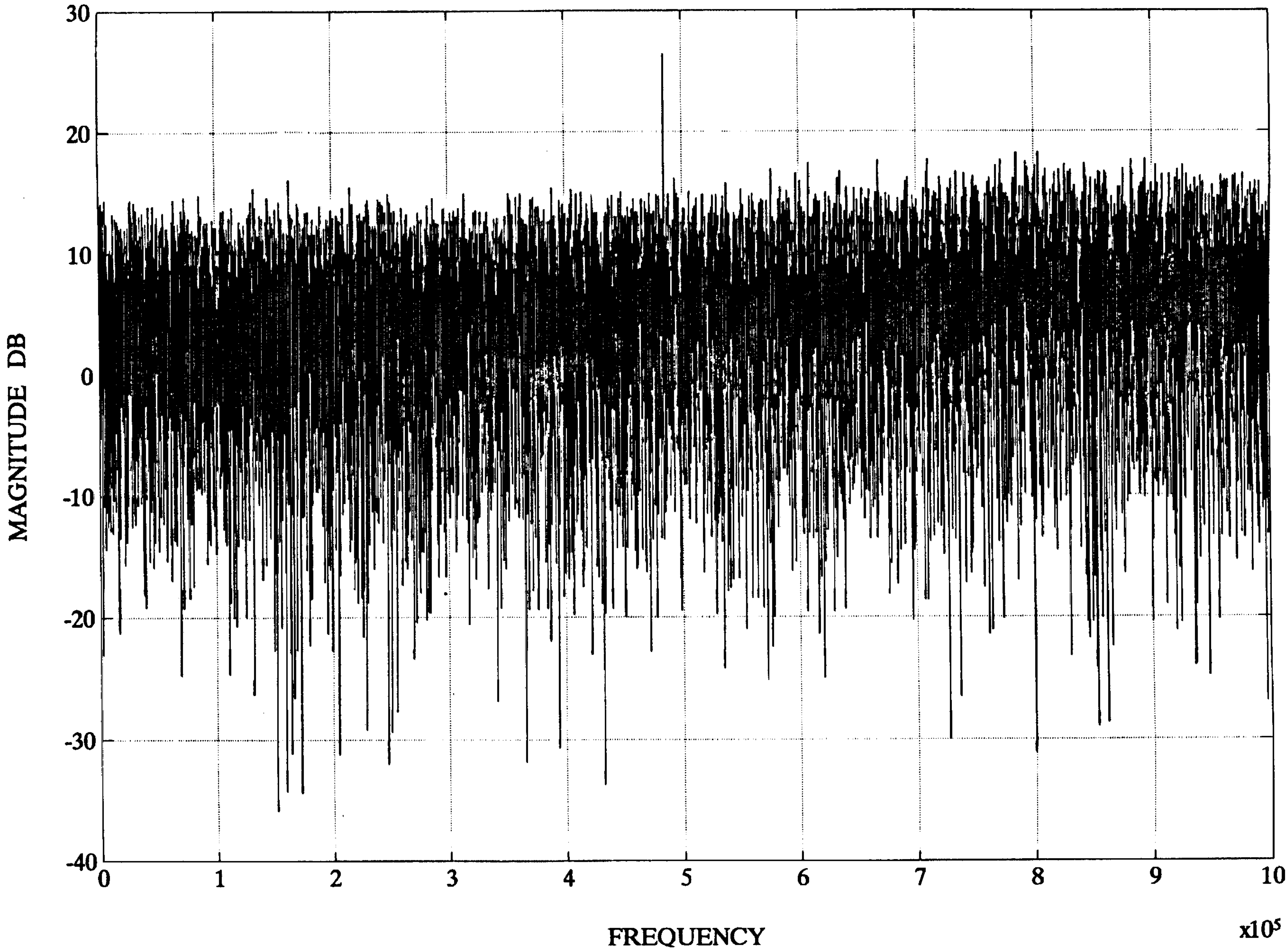
PLOT OF 1 MHz BASEBAND SIGNAL (2nd SIDELOBE)




ZOOM PLOT OF BASEBAND SIGNAL (2nd SIDELOBE)
60
50
40
30
20
10
0
-10
-20
4.7
4.75
4.8
4.85
4.9
4.95
5
5.05
5.1
5.15
5.2
x10^5
MAGNITUDE DB
FREQUENCY

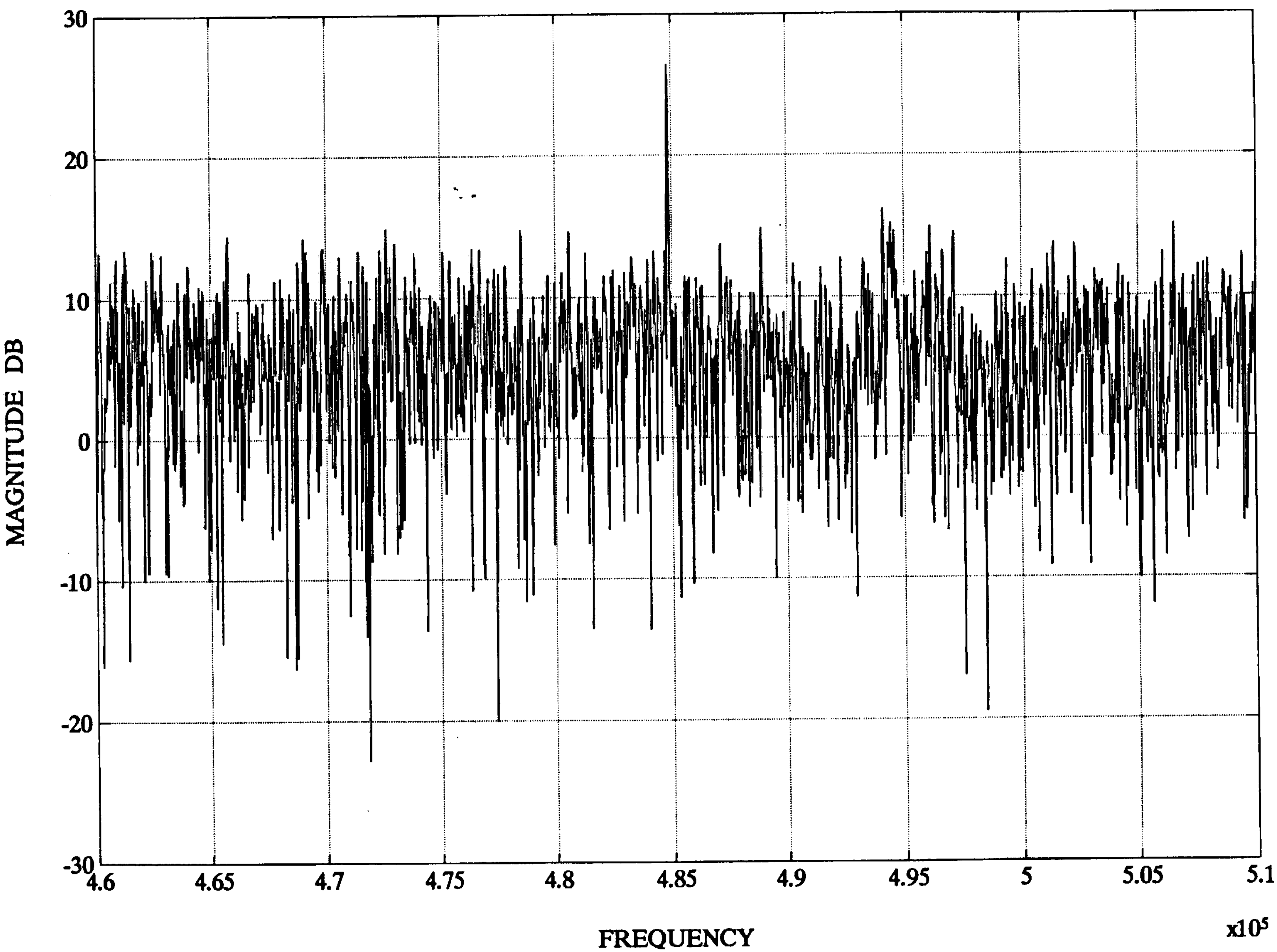
ELE_ OFFSET: +23.3°

PLOT OF 1 MHz BASEBAND SIGNAL (STOW POSITION)



ELE OFFSET: + ≈ 23.3°

ZOOM PLOT OF BASEBAND SIGNAL (STOW POSITION)

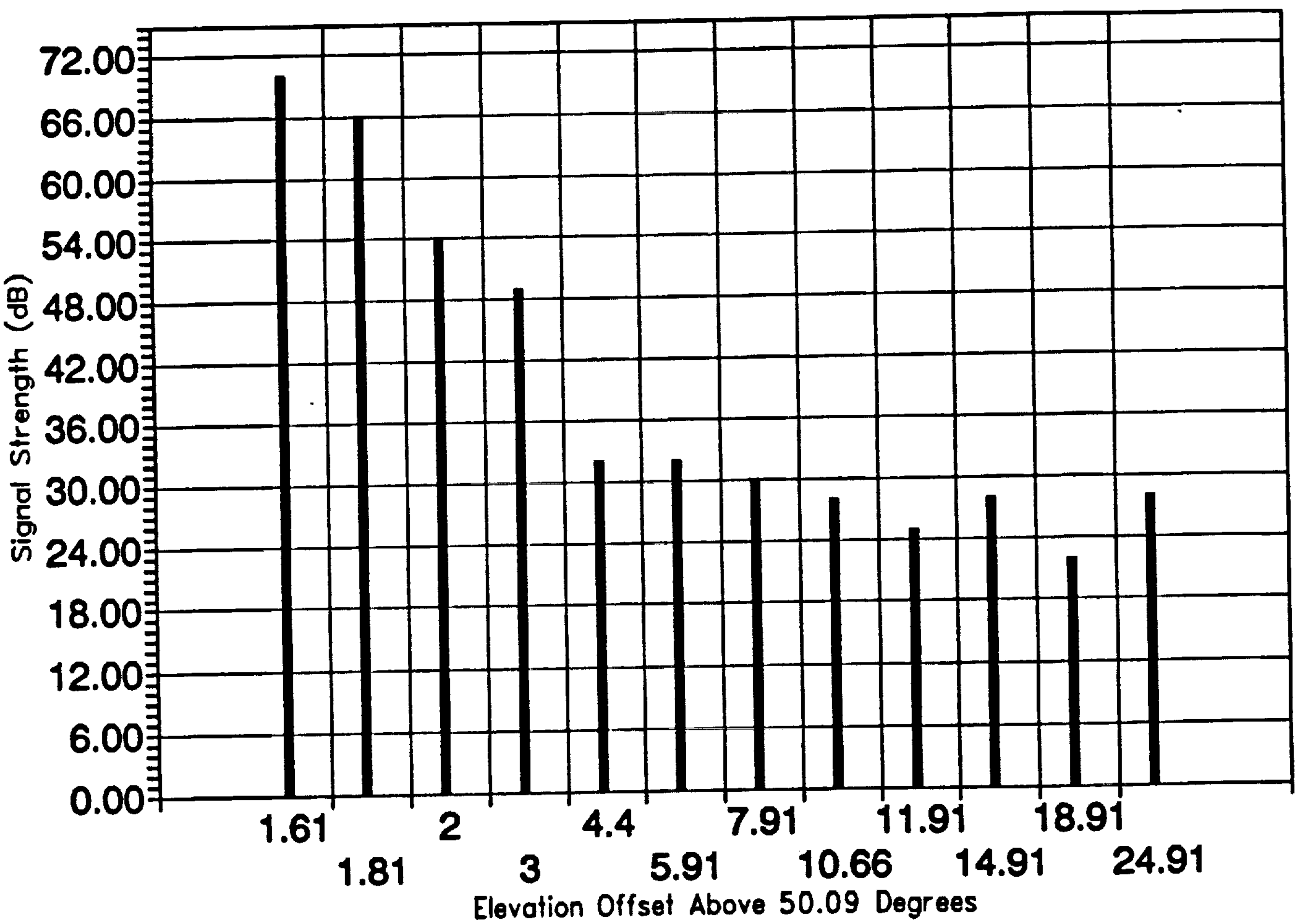


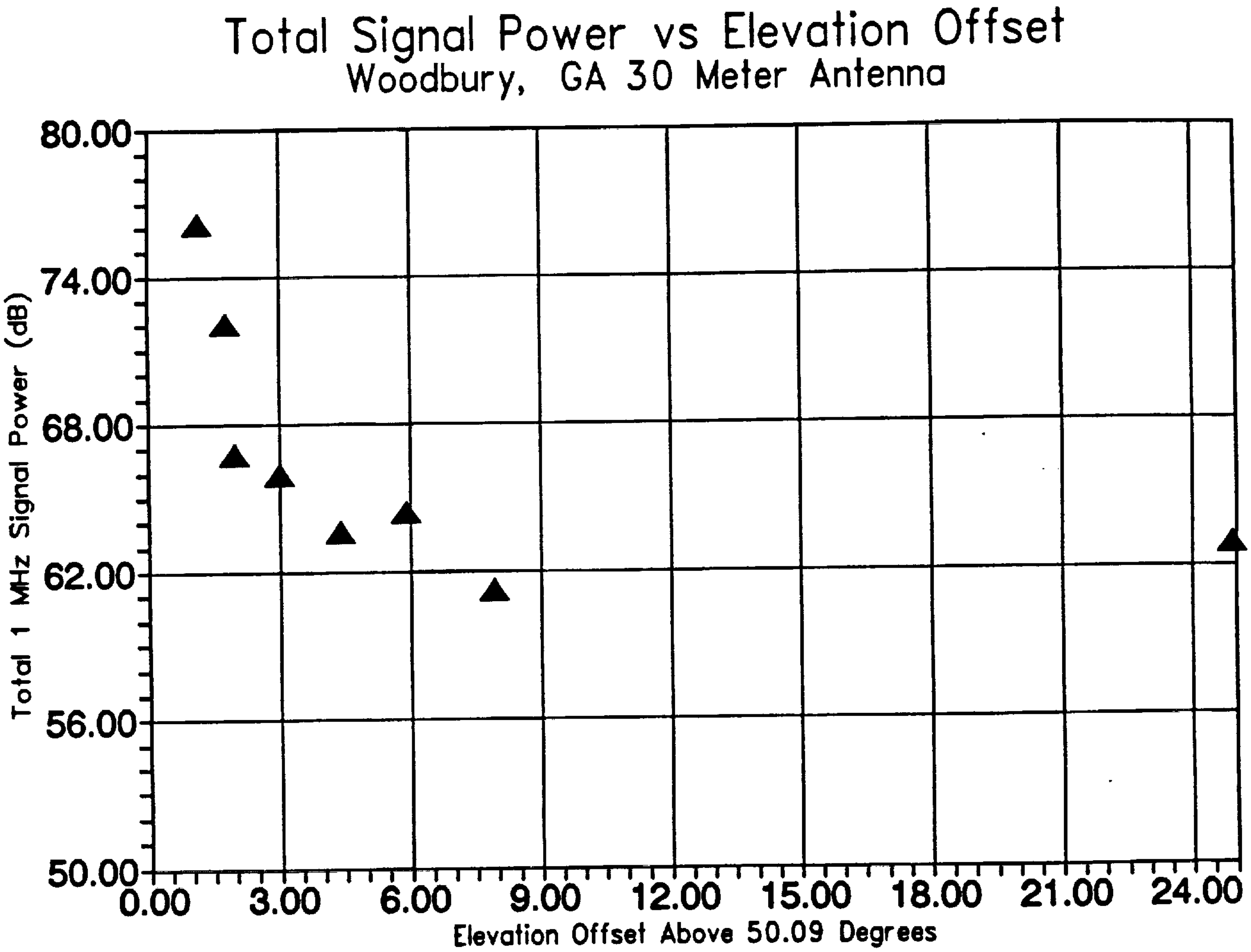
APPENDIX C

Relative RFI Signal Strength Summary Plots

This appendix summarizes the observed signal strengths as a function of antenna elevation offset. The peak signal values in dB were obtained from the 13 spectra plots found in Appendix A. For the main lobe, the observed signal strength appears to be only about 4 dB greater than the first side lobe. We expected a main lobe signal strength approximately 16 dB stronger. This disparity is due to saturation of the Harris 6522 receiver by approximately 16 dB above manufacturer's specification for maximum RF input power.

Signal Strength vs Elevation Offset
Woodbury, GA 30 Meter Antenna



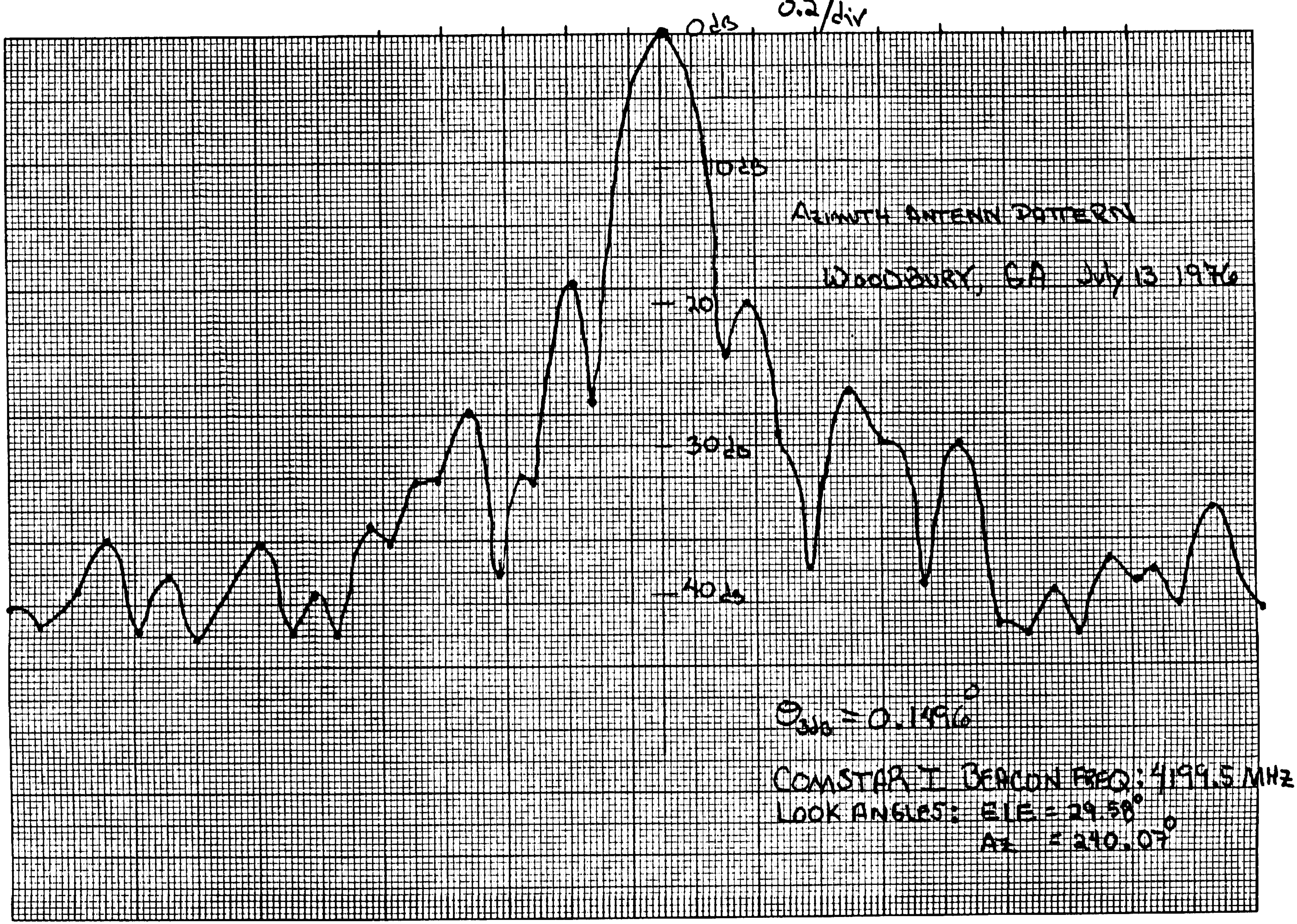

Total Signal Power vs Elevation Offset
Woodbury, GA 30 Meter Antenna
Total 1 MHz Signal Power (dB)
80.00
74.00
68.00
62.00
56.00
50.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
Elevation Offset Above 50.09 Degrees

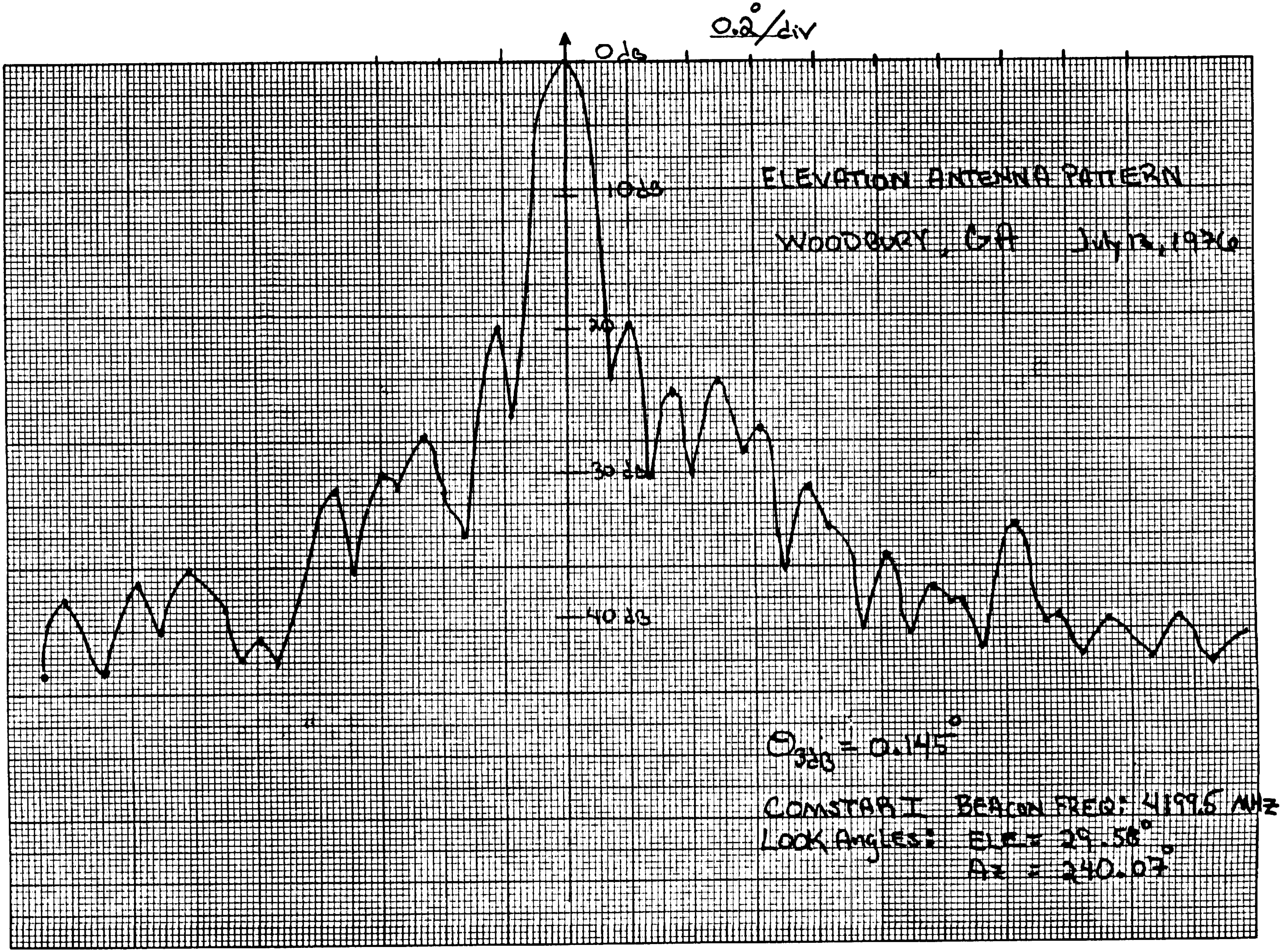
APPENDIX D

Georgia Tech 30 Meter Observation Facility
Antenna Beam Patterns

NO. 340-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.




0.2°/div
0 db
10 db
20
30 db
40 db
ELEVATION ANTENNA PATTERN
WOODBURY, GA July 12, 1976
Θ3dB = 0.145°
COMSTAR I BEACON FREQ: 4199.5 MHz
LOOK ANGLES: ELE = 29.58°
AZ = 240.07°

APPENDIX E

Commercial Summary Sheet of Telstar-302 Specifications

Telstar 302 [U.S.—AT&T],

85 Degrees West

AT&T Communications is the owner and operator of a satellite system designed to complement AT&T's extensive network of terrestrial communications facilities. On August 30, 1984, Telstar 302 was launched into space by the NASA space shuttle Discovery. The satellite transmits voice, data, audio, and TV services to the contiguous U.S., Alaska, Hawaii, and Puerto Rico.

Telstar 301, 302, and 303 transmit AT&T's "Skynet" family of business services, which includes Skynet 1.5, a data transmission service operating at 1.5 megabits per second (Mb/s); Skynet Television and Skynet audio broadcast services for television and radio signals; and Skynet Transponder Service, a program that allows customers to lease transponders on a part- or full-time basis. Major Skynet customers include broadcasters such as the ABC and CBS television networks, Meadowlands Communications, Inc., Keystone Communications, and Hughes Television Network.

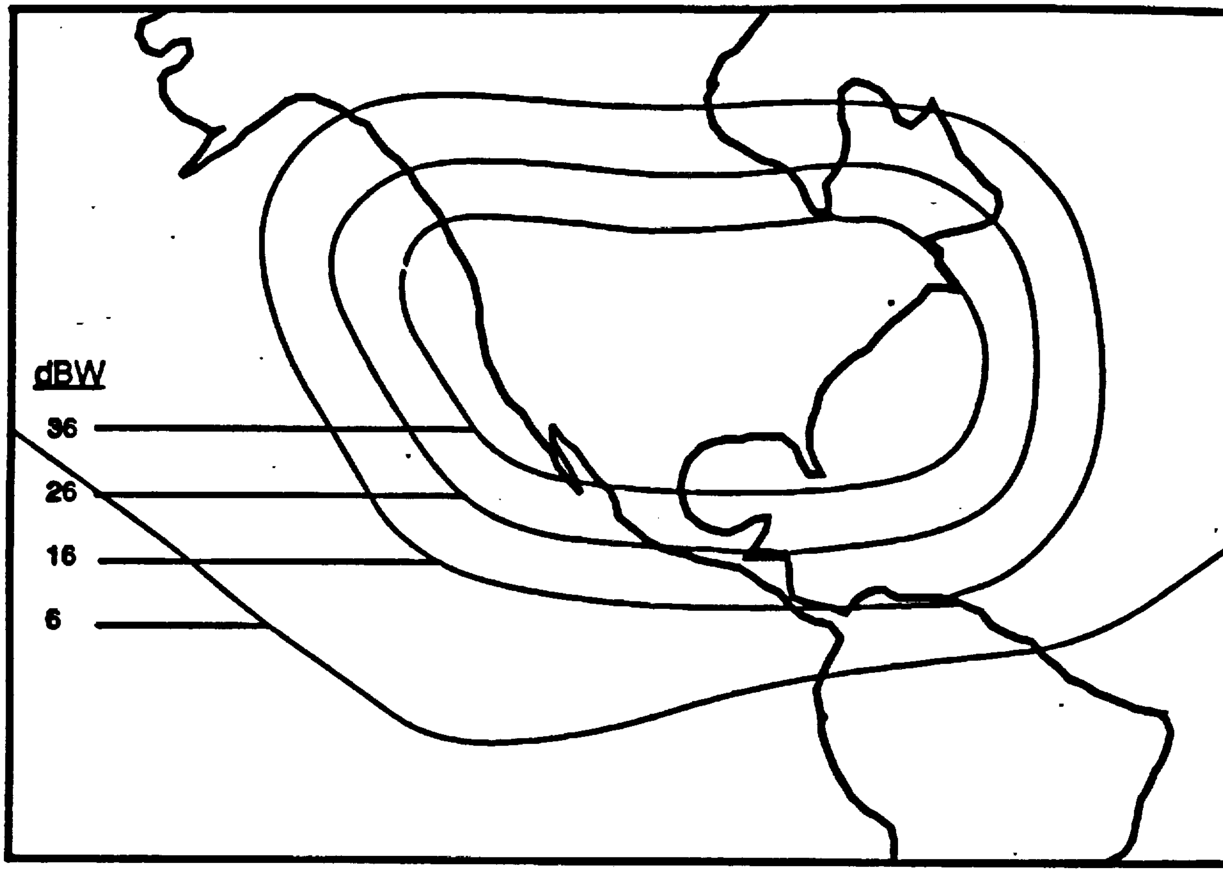
AT&T's Telstar 3 series of satellites were built by the Hughes Aircraft Corp. of El Segundo, California. These satellites conform to specifications developed by AT&T Bell Laboratories.

Telstar 302 at a Glance

Operational History	
Present Orbital Assignment:	85 degrees West Longitude
Launch Date:	August 30, 1984
Launch Vehicle:	NASA space shuttle
Status:	American domestic satellite with AT&T telephony, data, and video services
Design Life:	10 years
Communications Payload	
Frequency Band(s):	Receive: 5.925–6.425 GHz Transmit: 3.700–4.200 GHz
Channels	12 with horizontal polarization 12 with vertical polarization
Signal Power (EIRP):	CONUS: 34 dBW Alaska, Hawaii, or Puerto Rico spot beams: 34 dBW
Antenna Coverage:	CONUS; Alaska spot, Hawaii spot or Puerto Rico spot; or CONUS combined with one of three spot beams.
SSPA & TWTA Power:	8.5 watt SSPAs or 8.5 watt TWTAs
Capacity:	21,600 simultaneous long-distance telephone calls
Spacecraft	
Satellite Type:	Hughes HS 376 spin-stabilized
Initial On-Station Weight:	653kg (1,438 lbs)
Maximum (deployed) Dimensions:	6.8 (22 ft, 3 in) in height 2.2m (7ft, 2in) in diameter
Electrical Power:	670 watts at end of life

TELSTAR 302

Degrees East: -275.0 Degrees West: -85



TELSTAR 302

Degrees East: -275.0 Degrees West: -85

OWNER/OPERATOR: AT&T SKYNET SATELLITE COMMUNICATIONS

PRESENT STATUS:- .... OPERATIONAL
TYPE OF SERVICE :- .... FSS
TYPICAL USES:- .... TELEPHONE, DATA, TV
GEOGRAPHIC COVERAGE:- .... USA
LAUNCH DATE:- .... 31 AUG. 1984
LAUNCH VEHICLE:- .... SHUTTLE DISCOVERY
LAUNCH WEIGHT:- .... 1440 LBS
TYPE OF SATELLITE:- .... HS 376
PRIME CONTRACTORS:- .... HUGHES AIRCRAFT
DESIGN LIFETIME:- .... 10 YEARS
STABILIZATION :- .... SPIN
DIMENSIONS:- .... 22 FT HEIGHT, 7FT DIAMETER
BANDWIDTH:- .... 34 dBW
NO. OF - C BAND:- .... 24 \6 BACKUP
NO. OF - K BAND:- .... NONE
NO. OF - OTHER:- .... NONE
FREQUENCY BAND:- .... RECEIVE (5.925-6.425) TRANSMIT (3.7-4.2) GHz
EIRP - MAIN BEAM:- .... 34 dBW - 36 dBW
TWTA POWER:- .... 8.5 WATTS
ELECTRIC POWER:- .... 670 WATT EOL