VLBA Correlator Memo No. 92

(871016)

SIMULATION RESULTS FOR THE VLBA CORRELATOR

by John Benson, Chuck Broadwell, and Ray Escoffier

Oct. 16, 1987

The attached figures give the results of two programs developed to simulate the performance of the VLBA correlator. These simulators, and early results, were described in VLBA Correlator memos 74, 76, and 84. Further results were deemed desirable at this time because none of the earlier results used quantization levels now planned for the system. This memo will present the results of simulations that were made using the currently planned details of the correlator.

In addition to using current correlator quantization levels, this memo presents the results of experiments not simulated in earlier runs. For example, one-bit sample simulations, absorption line simulations and a three station run to check closure performance were performed and the result of these experiments are presented here.

The two simulation programs will still be distinguished from each other as was done in correlator memo 84 by the terms "hardware simulator" and "software simulator". The software simulator was written by John Benson and runs on a Cray computer and the hardware simulator runs on hardware built using TMS 32020 digital signal processing system.

The table below gives results of the simulations presented in this memo. Experiments labeled as narrow line observation used cw signals (not narrow bandwidth gaussian signals) to generate input data.

EXPERIMENT 1:

observation	3-station continuum
simulator	software
correlation coefficient	0.5
integration length	32 Msamples
figures (none)	

COMMENT ON EXPERIMENT 1:

The software simulator was used to run a closure phase test for a point source model that is offset from the phase center. Each of the three baselines was integrated for 32 Msamples. The initial station phase and phase rates are shown below;

$P1 = 25.20$ deg., $\dot{P}1 = 23641.71$ Hz.

$P2 = -41.20$ deg., $\dot{P}2 = 35121.99$ Hz.

$P3 = -13.70$ deg., $\dot{P}3 = 17229.78$ Hz.

The measured closure phase was, PC = 0.02deg. $\pm$ 0.09deg. averaged across the spectrum.

EXPERIMENT 2:

observation	continuum
simulator	hardware
correlation coefficient	0.5
integration length	957 Msamples
figure 2A	station 1
figure 2B	station 2
figure 2C	cross power
figure 2D	station 1 rms deviation
figure 2E	cross power real rms deviation
figure 2F	cross power imaginary rms deviation

EXPERIMENT 3:

observation	continuum
simulator	software
correlation coefficient	0.5
integration length	128 Msamples
figure 3	station 1 and cross power

EXPERIMENT 4:

observation	wide line
simulator	hardware
correlation coefficient	0.95
integration length	200 Msamples
figure 4A	station 1
figure 4B	station 2
figure 4C	cross power

EXPERIMENT 5:

observation	narrow line
simulator	software
correlation coefficient	0.5
integration length	128 Msamples
figure 5A	station 1
figure 5B	cross power

EXPERIMENT 6:

observation	narrow line
simulator	hardware
correlation coefficient	0.5
integration length	438 Msamples
figure 6A	station 1
figure 6B	cross power

EXPERIMENT 7:

observation	narrow line
simulator	software
correlation coefficient	0.95
integration length	32 Msamples
figure 7A	station 1
figure 7B	cross power

EXPERIMENT 8:

observation	narrow line
simulator	hardware
correlation coefficient	0.95
integration length	103 Msamples
figure 8A	station 1
figure 8B	station 2
figure 8C	cross power

EXPERIMENT 9:

observation	absorption line
simulator	software
correlation coefficient	0.5
integration length	128 Msamples
figure 9A	station 1
figure 9B	cross power

EXPERIMENT 10:

observation	absorption line
simulator	hardware
correlation coefficient	0.7
integration length	238 Msamples
figure 10A	station 1
figure 10B	station 2
figure 10C	cross power

EXPERIMENT 11:

observation	absorption line
simulator	hardware
correlation coefficient	0.95
integration length	152 Msamples
figure 11A	station 1
figure 11B	station 2
figure 11C	cross power
figure 11D	high precision FFT

COMMENTS ON ABSORPTION LINE EXPERIMENTS:

Two single station integrations were run in order to put the station spectrum results of experiments 9, 10, and 11 in perspective. The output of the hardware simulators station signal was Fourier transformed by a high precision commercial FFT package both before and after quantization. The reason for these integrations was to compare which part of the degradation of the station spectrum was due to the low precision FFT and which to the sampling process. The results of these two runs are given in figure 11D.

EXPERIMENT 12:

observation	continuum, one bit sampling
simulator	hardware
correlation coefficient	0.5
integration length	200 Msamples
figure 12A	station 1
figure 12B	station 2
figure 12C	cross power

EXPERIMENT 13:

observation	narrow line. one bit sampling
simulator	software
correlation coefficient	0.5
integration length	128 Msamples
figure 13A	station 1
figure 13B	cross power

EXPERIMENT 14:

observation	narrow line, one bit sampling
simulator	hardware
correlation coefficient	0.5
integration length	127 Msamples
figure 14A	station 1
figure 14B	station 2
figure 14C	cross power

EXPERIMENT 15:

observation	narrow line, low relative fringe rate
simulator	hardware
correlation coefficient	0.5
fringe rate, antenna 1	1007.85 Hz
fringe rate, antenna 2	1000.00 Hz
integration length	95 Msamples
figure 15A	station 1
figure 15B	station 2
figure 15C	cross power

EXPERIMENT 16:

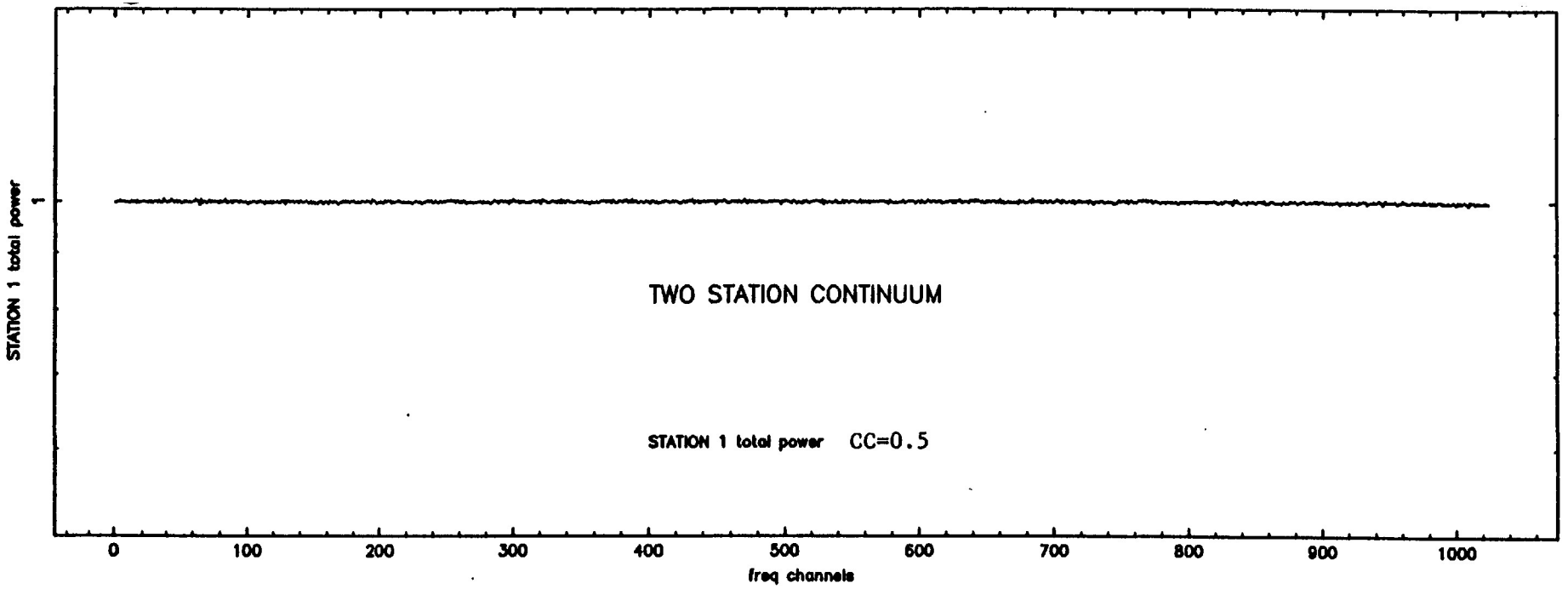
observation	narrow line, low fringe rate
simulator	hardware
correlation coefficient	0.5
fringe rate, antenna 1	7.8542 Hz
fringe rate, antenna 2	1000.00 Hz
integration length	54 Msamples
figure 16A	station 1
figure 16B	station 2
figure 16C	cross power

COMMENTS ON LOW FRINGE RATE EXPERIMENTS PERFORMED ON THE SOFTWARE SIMULATOR:

Three runs with the software simulator were used to measure errors in the cross-correlation phase when the baseline fringe rates are very low. In the case of a geocentric coordinate system, however, the individual station lobe rotator rates generally remain high. The simulator runs were for 128 Msamples each. The baseline phase error along with the baseline and station rates are shown below;

baseline phase error	station fringe rate	baseline fringe rate
-10.98 deg. ± 0.02 deg.	2345.84 Hz	0.17 Hz
0.40 deg. ± 0.02 deg.	2345.84 Hz	0.50 Hz
0.08 deg. ± 0.02 deg.	2345.84 Hz	1.70 Hz

The large phase error of 11 deg. at 0.17 Hz decreases to 0.4 deg as difference between the fringe rate of the two stations increases to 0.5 Hz. The worst case for low fringe rates will be the Pie Town to VLA baseline at 327 MHz. a detailed model of that baseline has shown that the fringe rate remains between + and - 0.5 Hz. for under 10 minutes. For such a short time interval in the most extreme case we can just flag the low fringe rate recorders at a cost of minimal data loss.



9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffts 550_32e '** 774 data **'

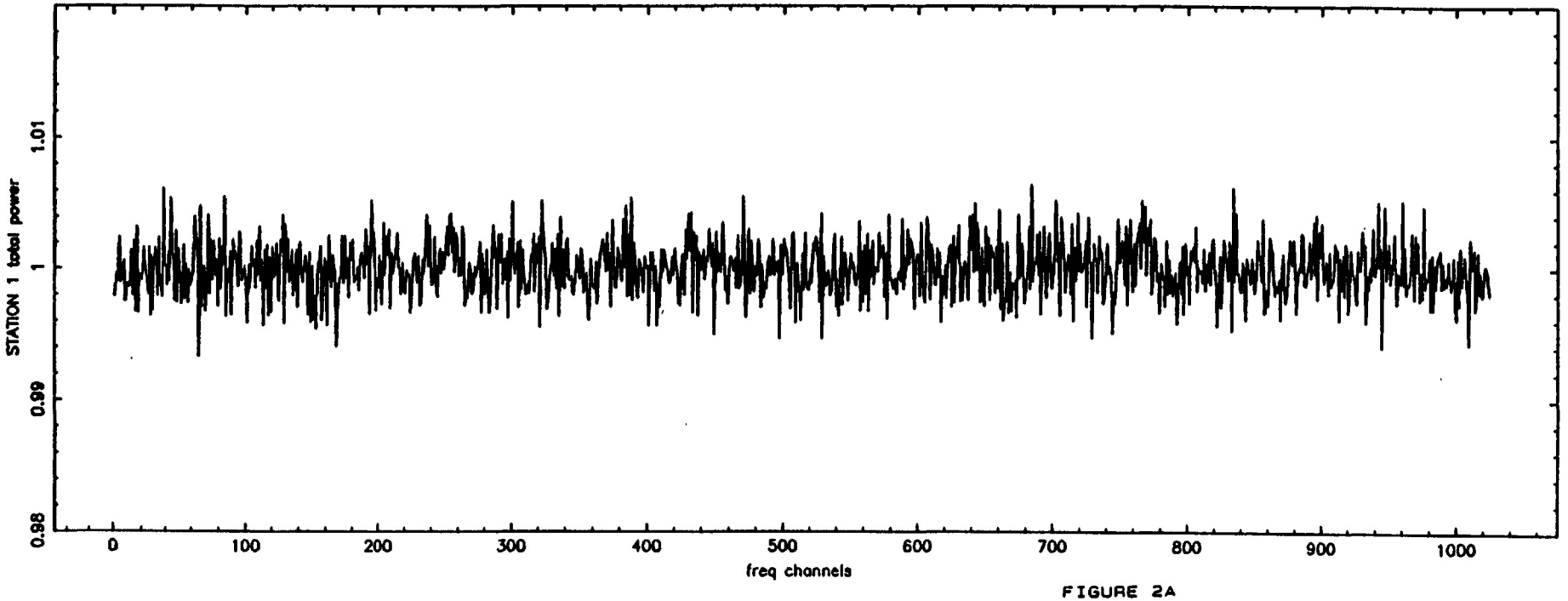
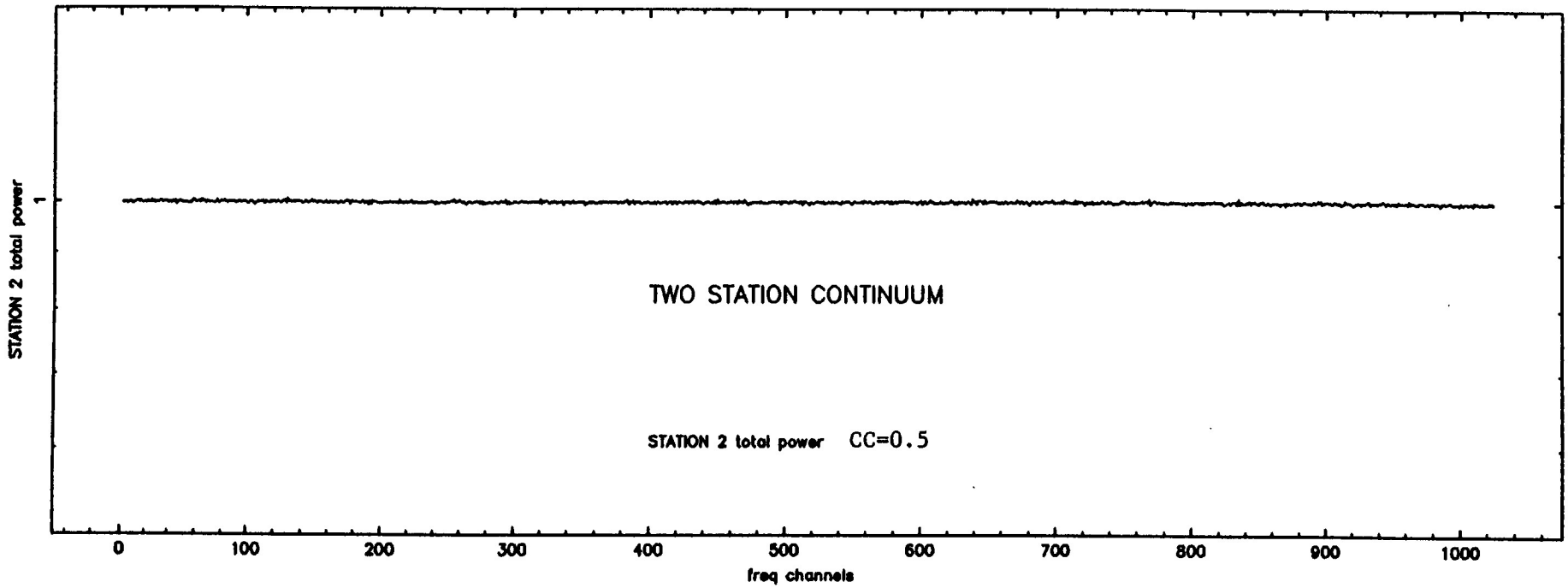


FIGURE 2A



9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffts 550_32e '** 774 data **'

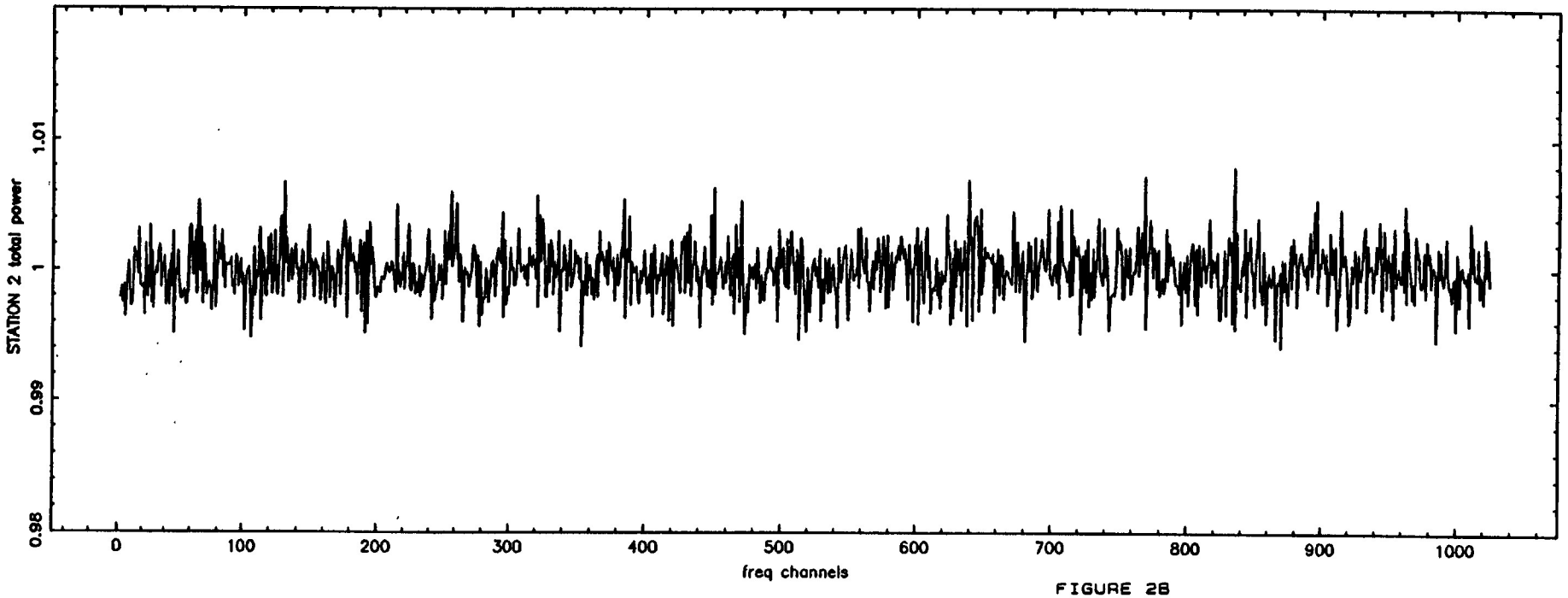
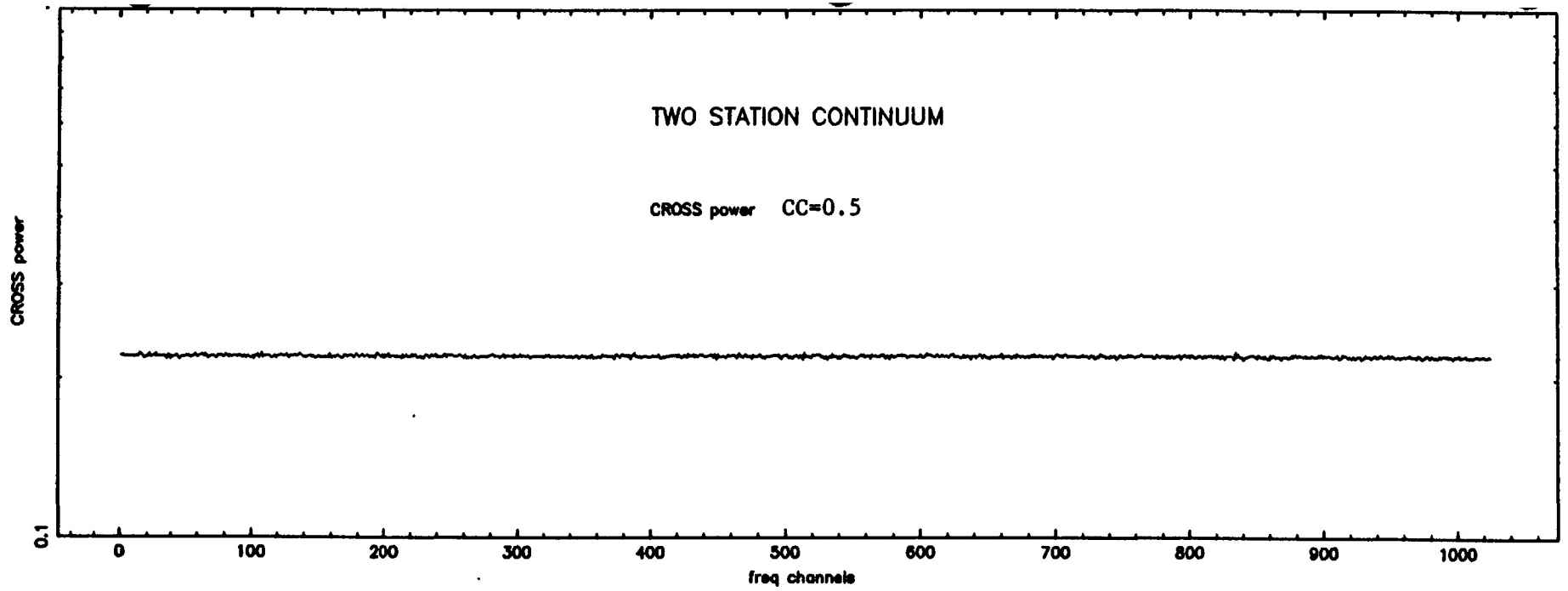


FIGURE 28



9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffte 550_32e '** 774 data **'

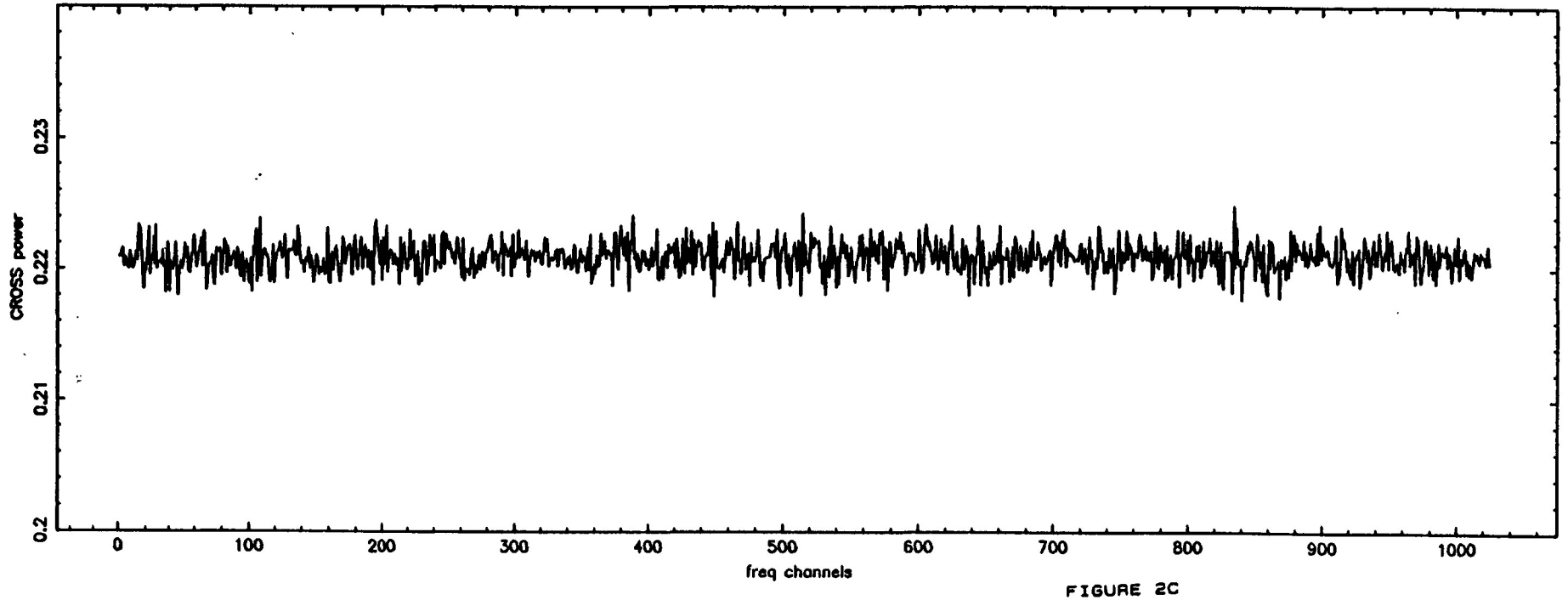


FIGURE 2C

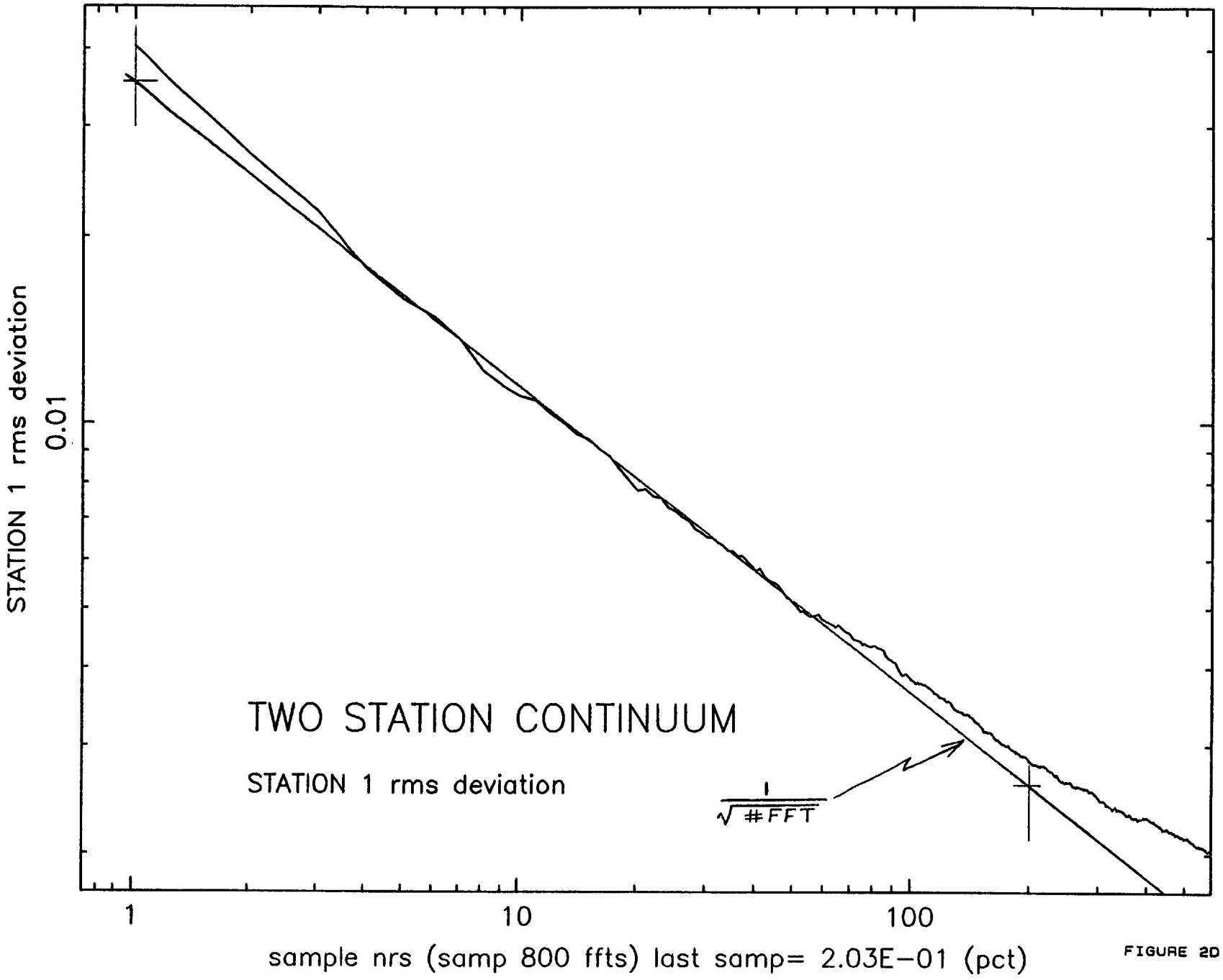

9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffts 550_32e '** 774 data **'
STATION 1 rms deviation
0.01
TWO STATION CONTINUUM
STATION 1 rms deviation
1/√#FFT
1
10
100
sample nrs (samp 800 ffts) last samp= 2.03E-01 (pct)

FIGURE 2D

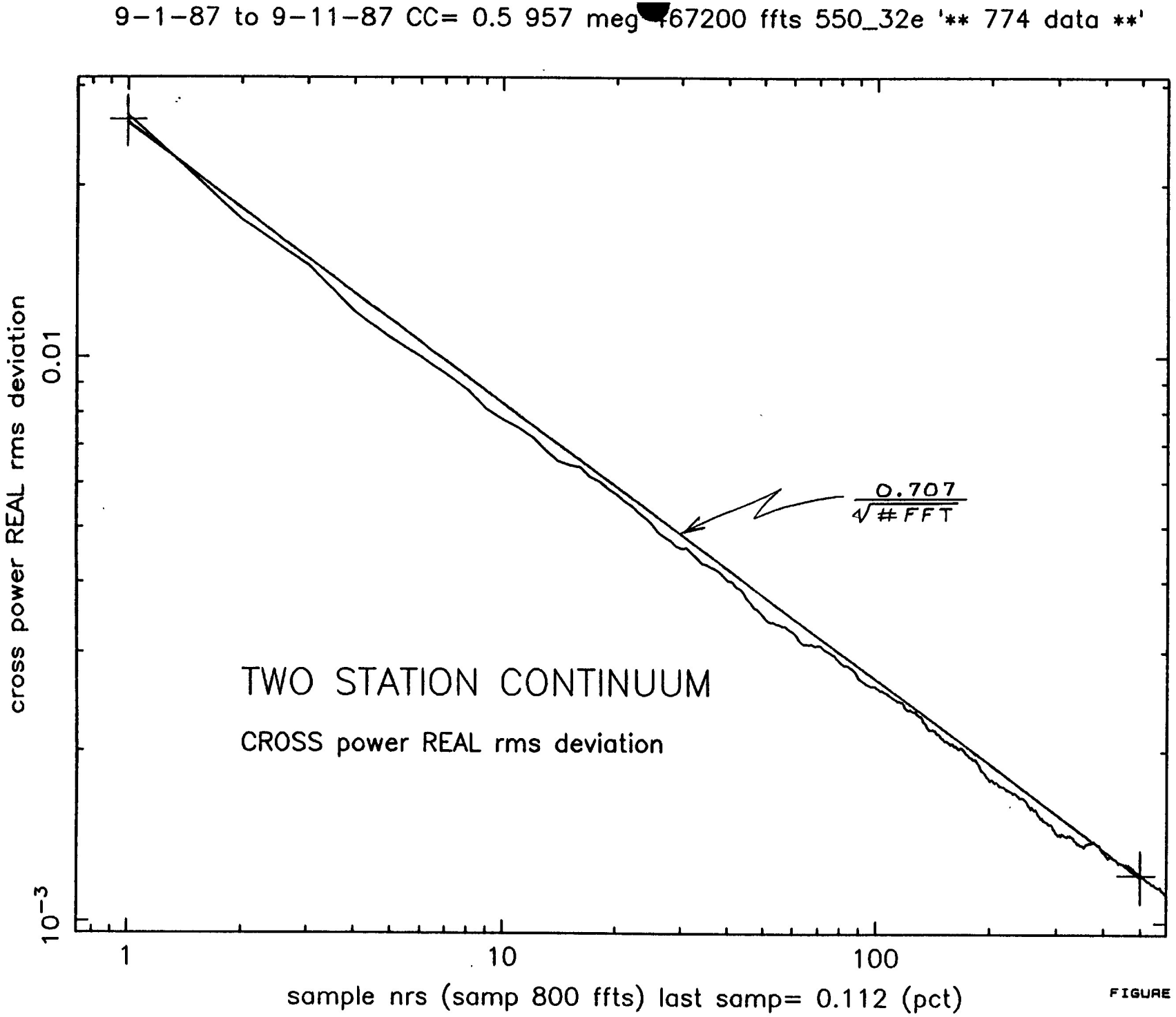

9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffts 550_32e '** 774 data **'
cross power REAL rms deviation
0.01
10^{-3}
0.707
$\sqrt{\#FFT}$
TWO STATION CONTINUUM
CROSS power REAL rms deviation
1
10
100
sample nrs (samp 800 ffts) last samp= 0.112 (pct)

FIGURE 2E

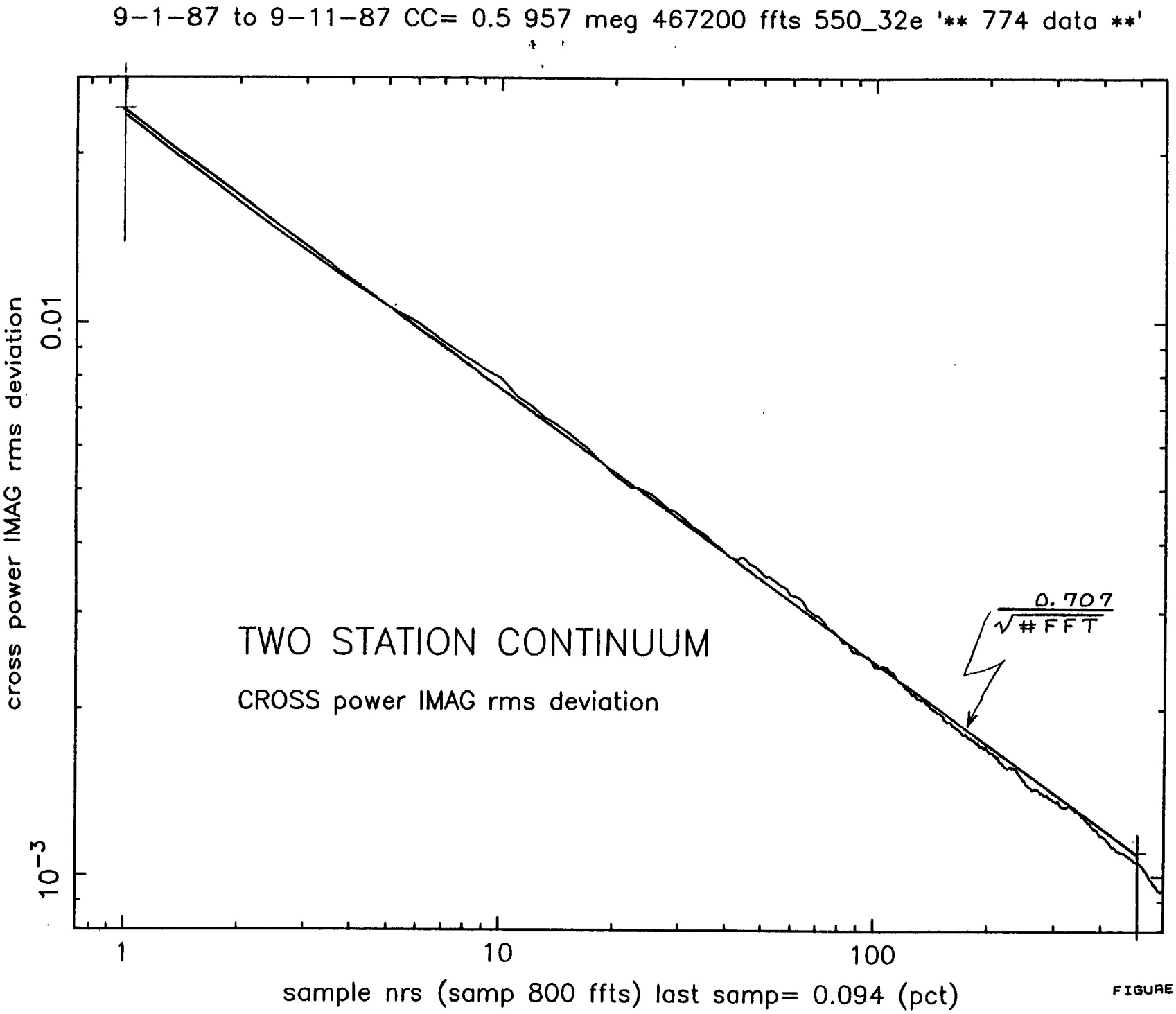
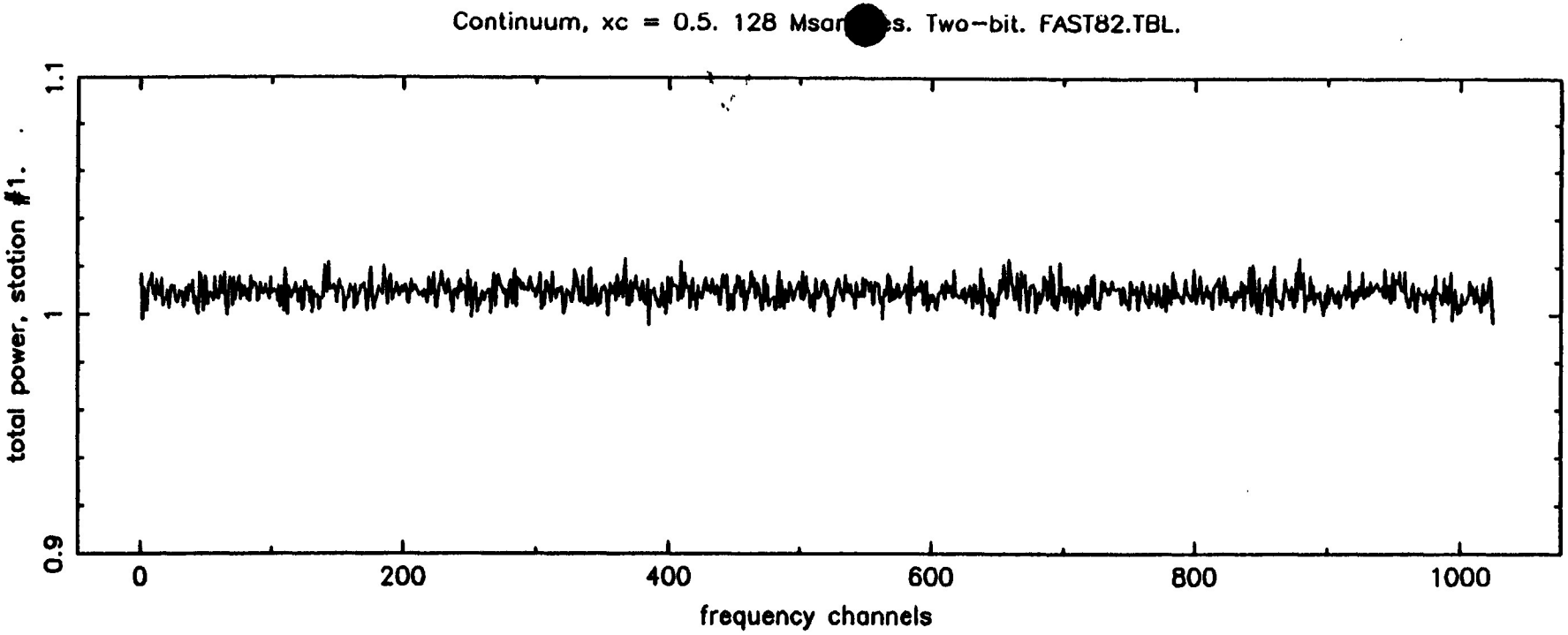

9-1-87 to 9-11-87 CC= 0.5 957 meg 467200 ffts 550_32e '** 774 data **'
cross power IMAG rms deviation
0.01
10^{-3}
TWO STATION CONTINUUM
CROSS power IMAG rms deviation
$\frac{0.707}{\sqrt{\#FFT}}$
1
10
100
sample nrs (samp 800 ffts) last samp= 0.094 (pct)

FIGURE 2F


Continuum, xc = 0.5. 128 Msamples. Two-bit. FAST82.TBL.
total power, station #1.
1.1
1
0.9
0
200
400
600
800
1000
frequency channels

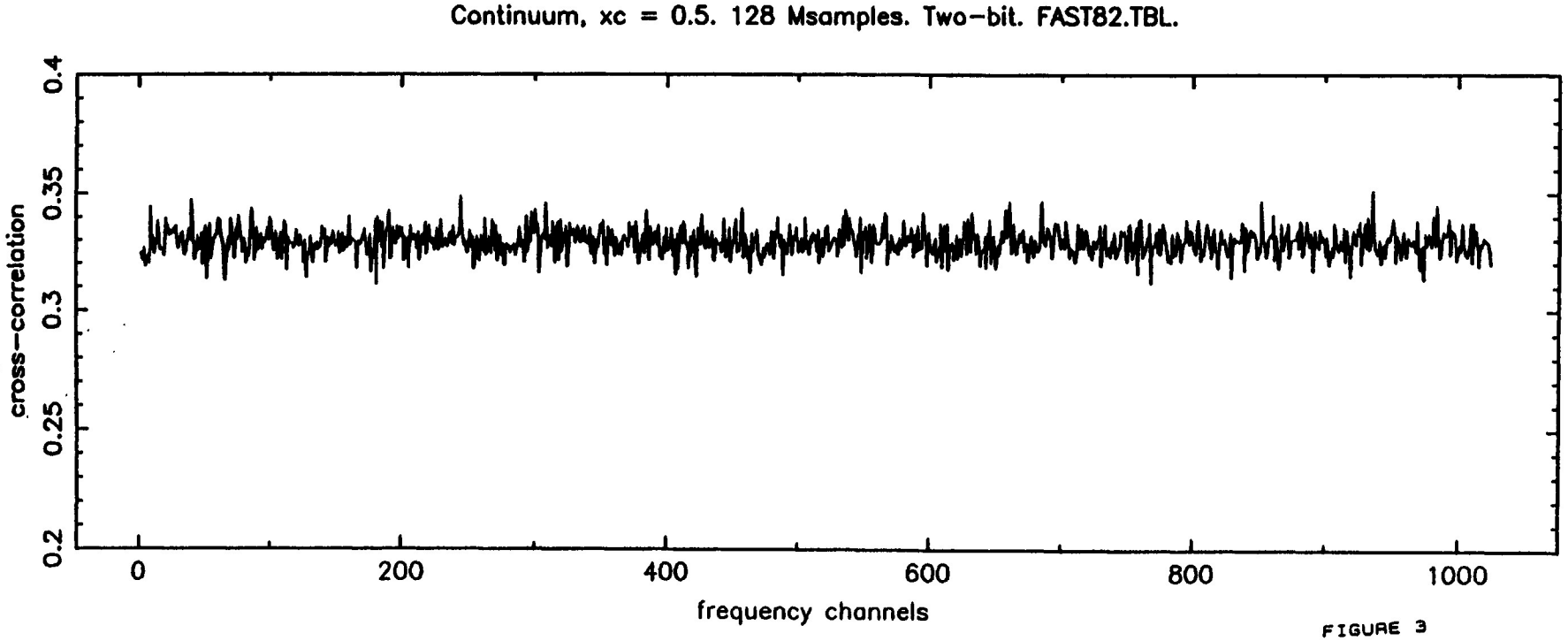
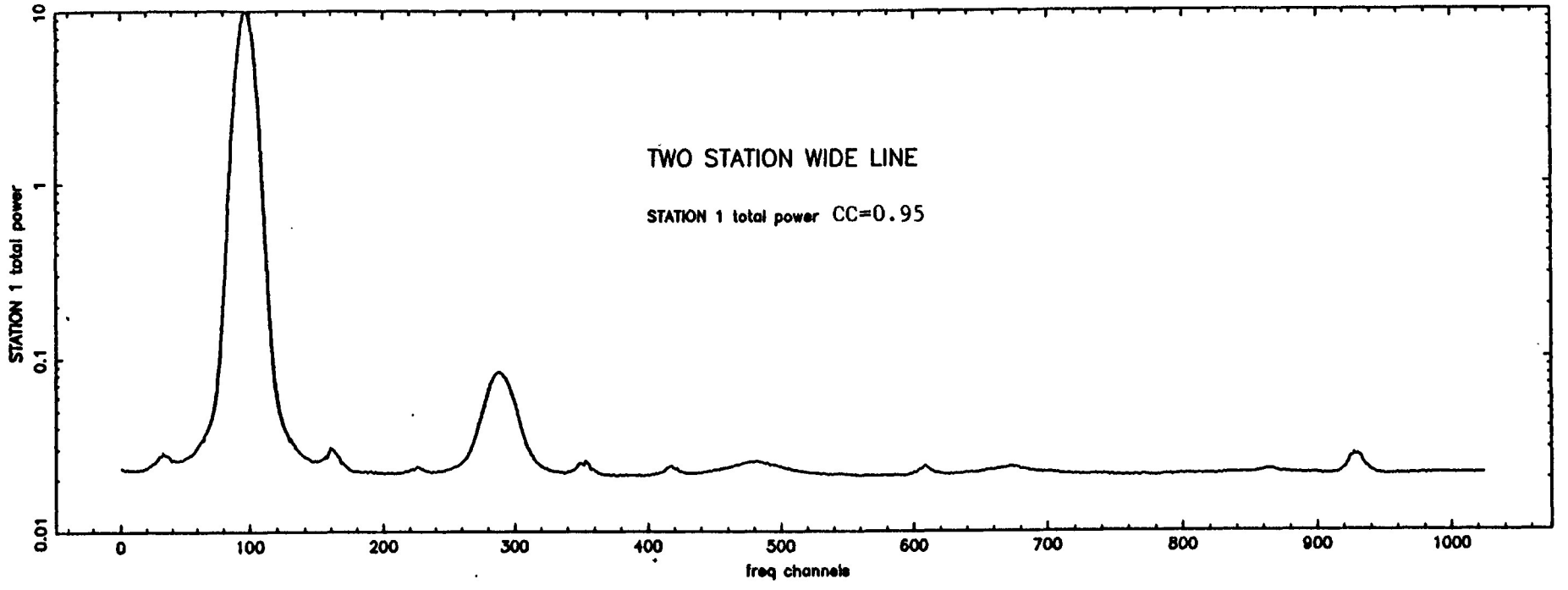

Continuum, xc = 0.5. 128 Msamples. Two-bit. FAST82.TBL.
cross-correlation
0.4
0.35
0.3
0.25
0.2
0
200
400
600
800
1000
frequency channels

FIGURE 3


TWO STATION WIDE LINE
STATION 1 total power CC=0.95
STATION 1 total power
freq channels

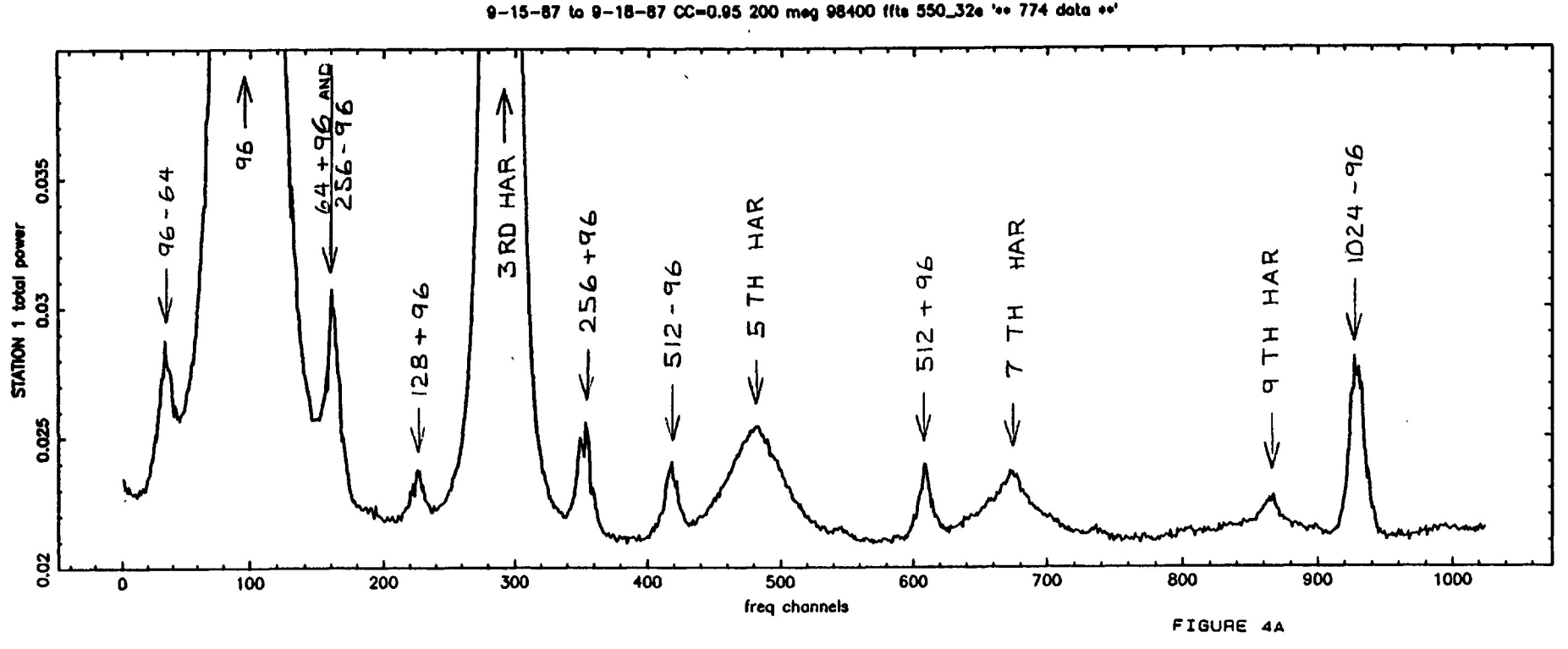
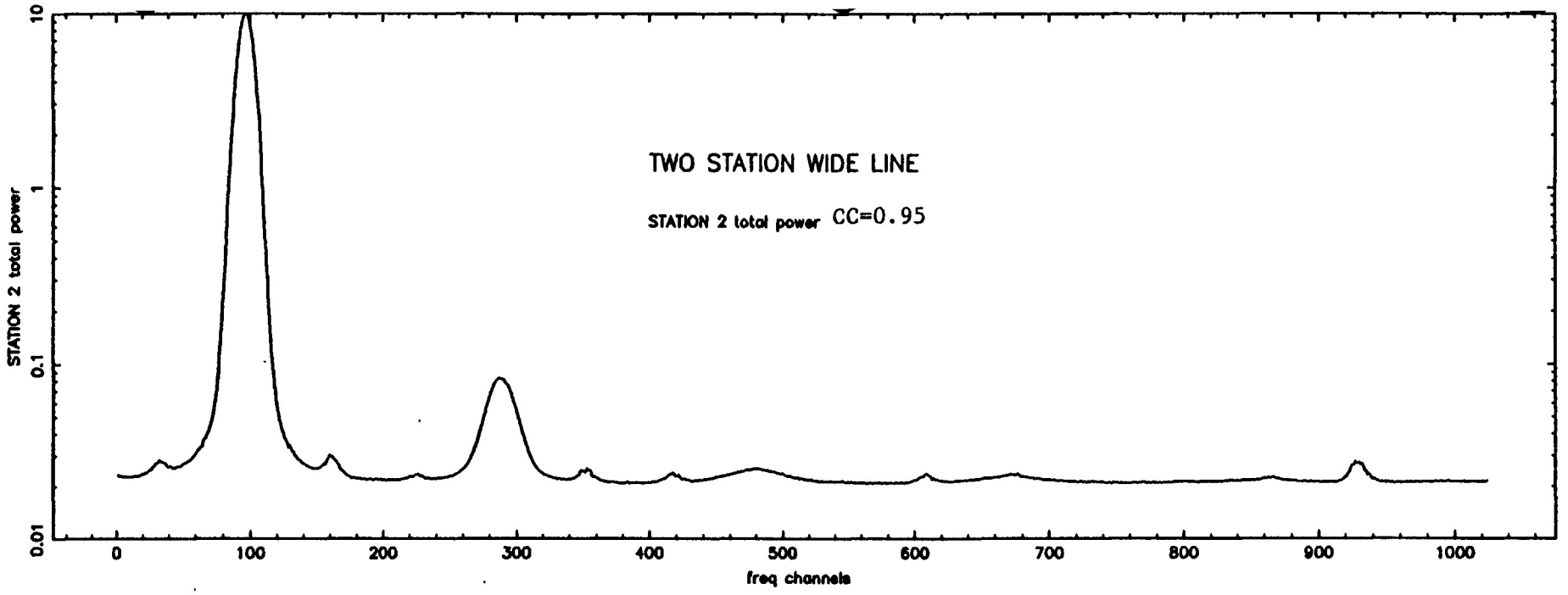

9-15-87 to 9-18-87 CC=0.95 200 meg 98400 ffts 550_32e '** 774 data **'
STATION 1 total power
freq channels
96 - 64
96
64 + 96 AND 256 - 96
128 + 96
3RD HAR
256 + 96
512 - 96
5 TH HAR
512 + 96
7 TH HAR
9 TH HAR
1024 - 96

FIGURE 4A



9-15-87 to 9-18-87 CC=0.95 200 meg 98400 ffts 550_32e '** 774 data **'

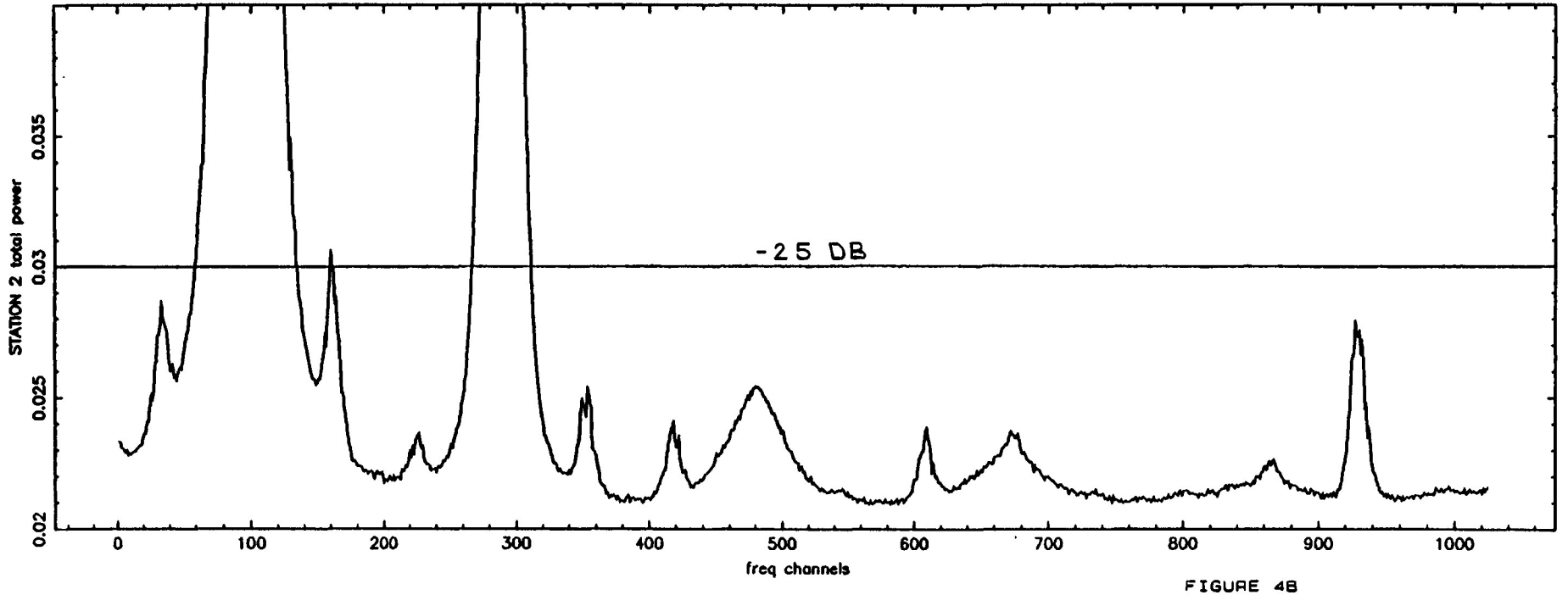
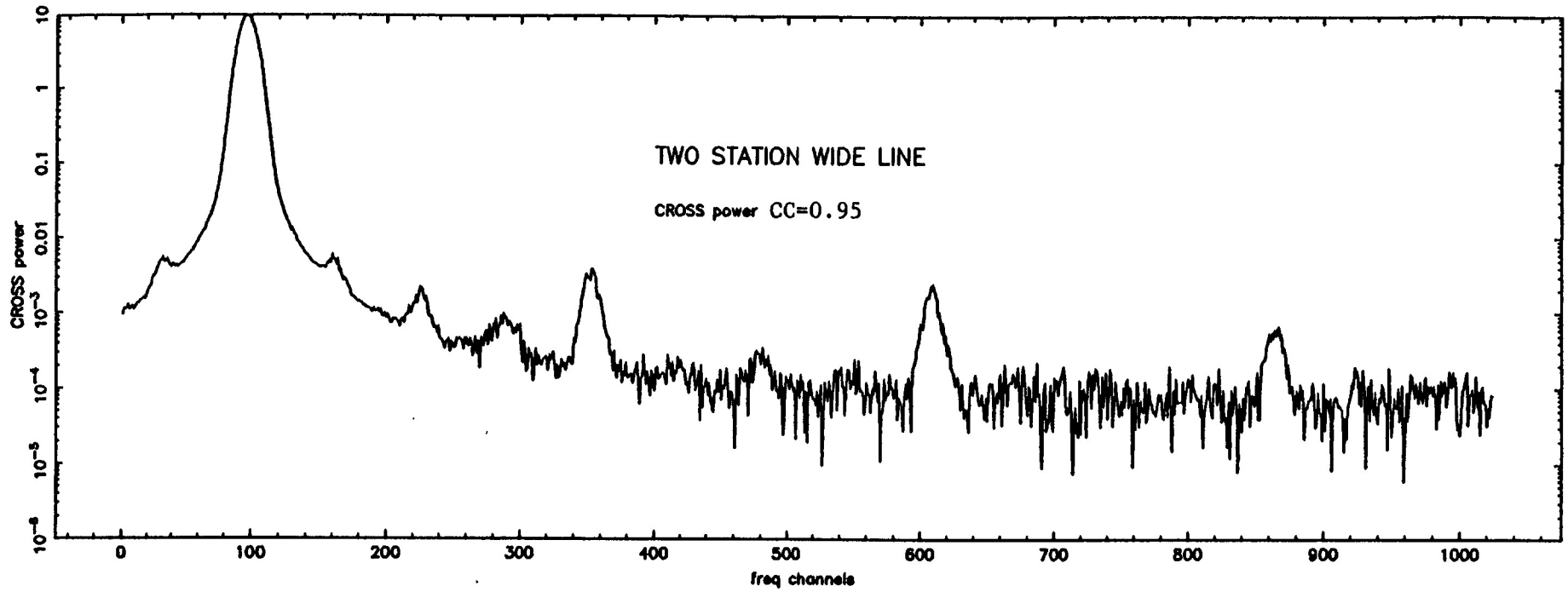


FIGURE 48



9-15-87 to 9-18-87 CC=0.95 200 meg 98400 ffts 550_32e '**774 data**'

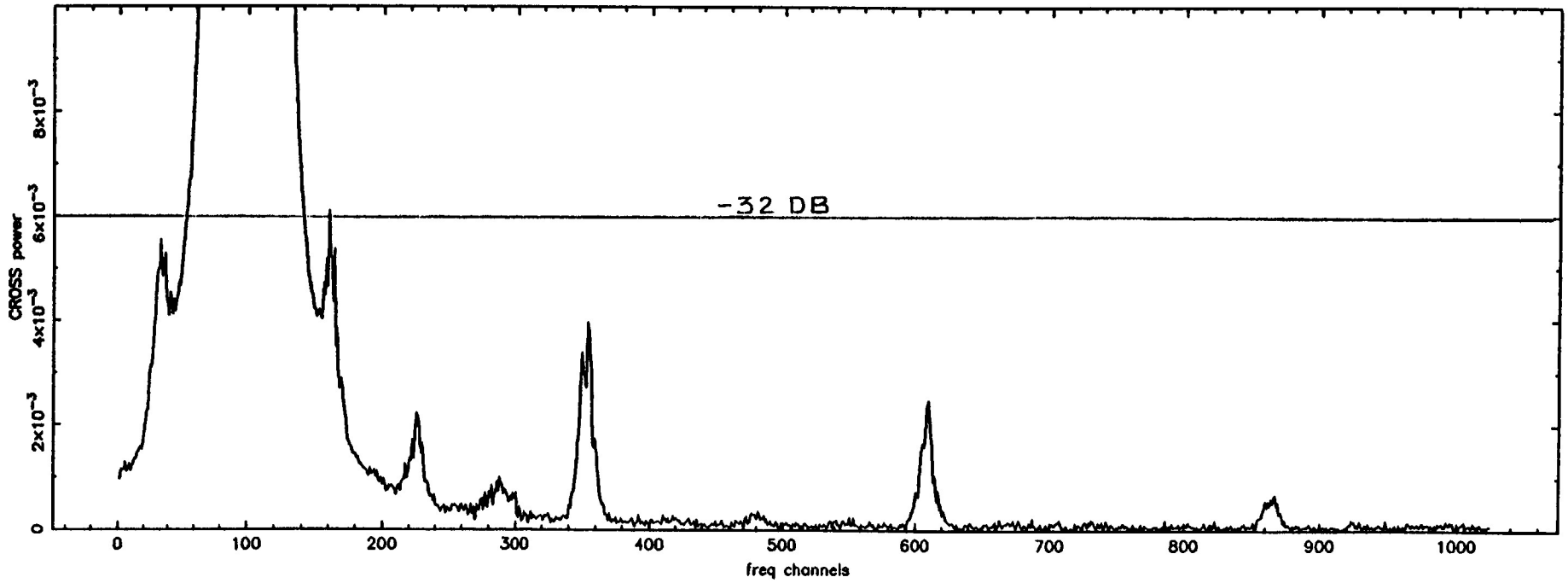
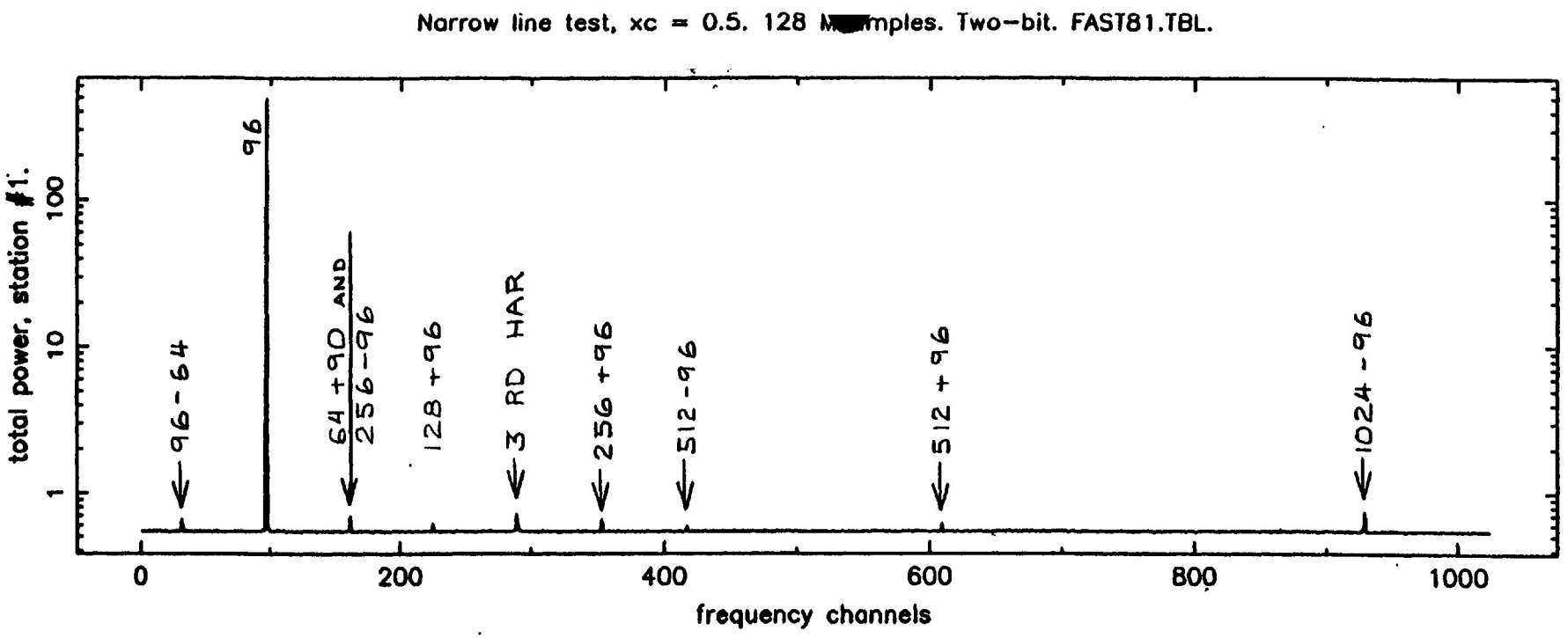


FIGURE 4C


Narrow line test, xc = 0.5. 128 Msamples. Two-bit. FAST81.TBL.
total power, station #1.
1
10
100
96
96-64
64+90 AND 256-96
128+96
3 RD HAR
256+96
512-96
512+96
1024-96
0
200
400
600
800
1000
frequency channels

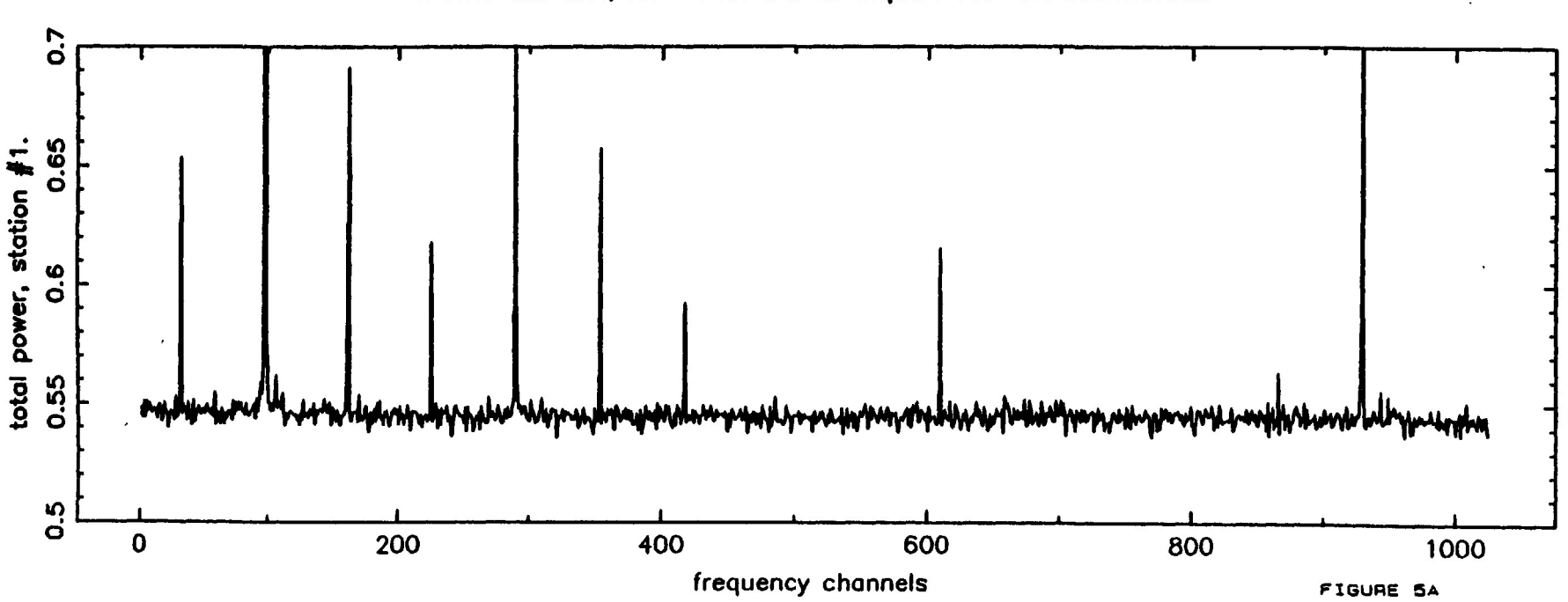
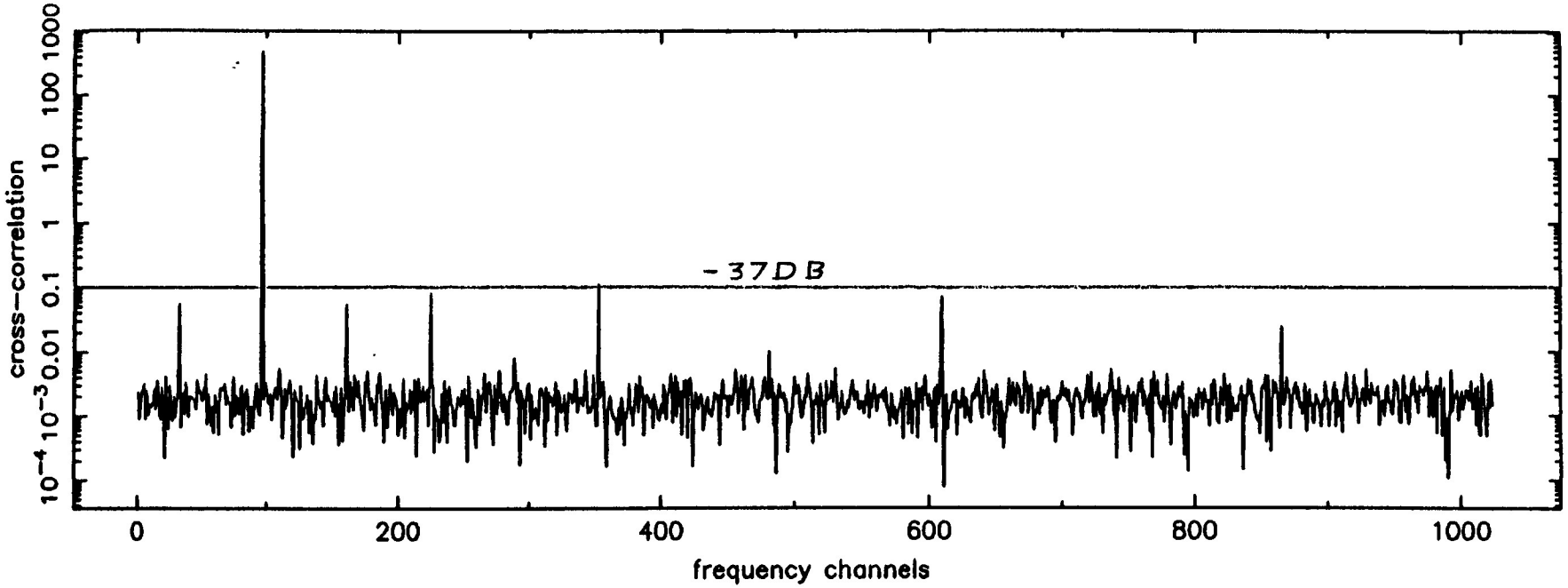

Narrow line test, xc = 0.5. 128 Msamples. Two-bit. FAST81.TBL.
total power, station #1.
0.5
0.55
0.6
0.65
0.7
0
200
400
600
800
1000
frequency channels

FIGURE 5A


Narrow line test, xc = 0.5. 128 Msamples. Two-bit. FAST81.TBL.
cross-correlation
10^-4 10^-3 0.01 0.1 1 10 100 1000
-37DB
0
200
400
600
800
1000
frequency channels

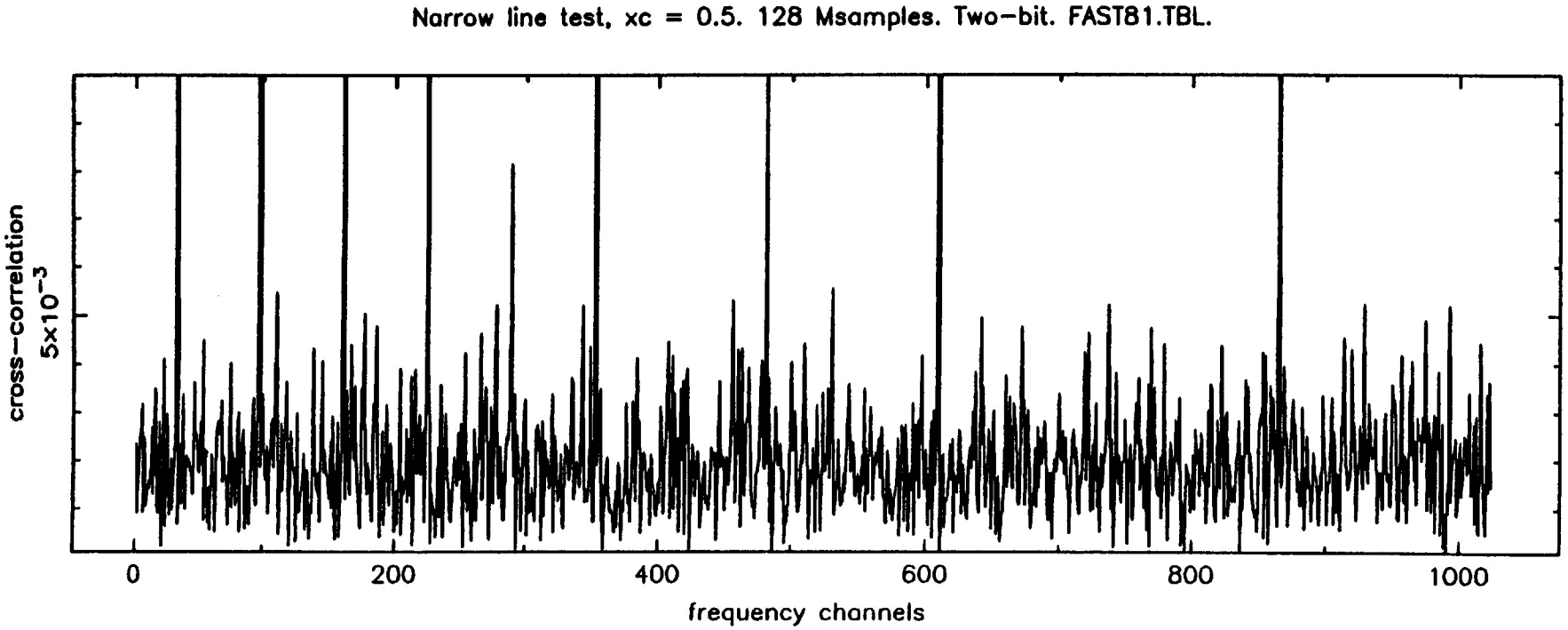
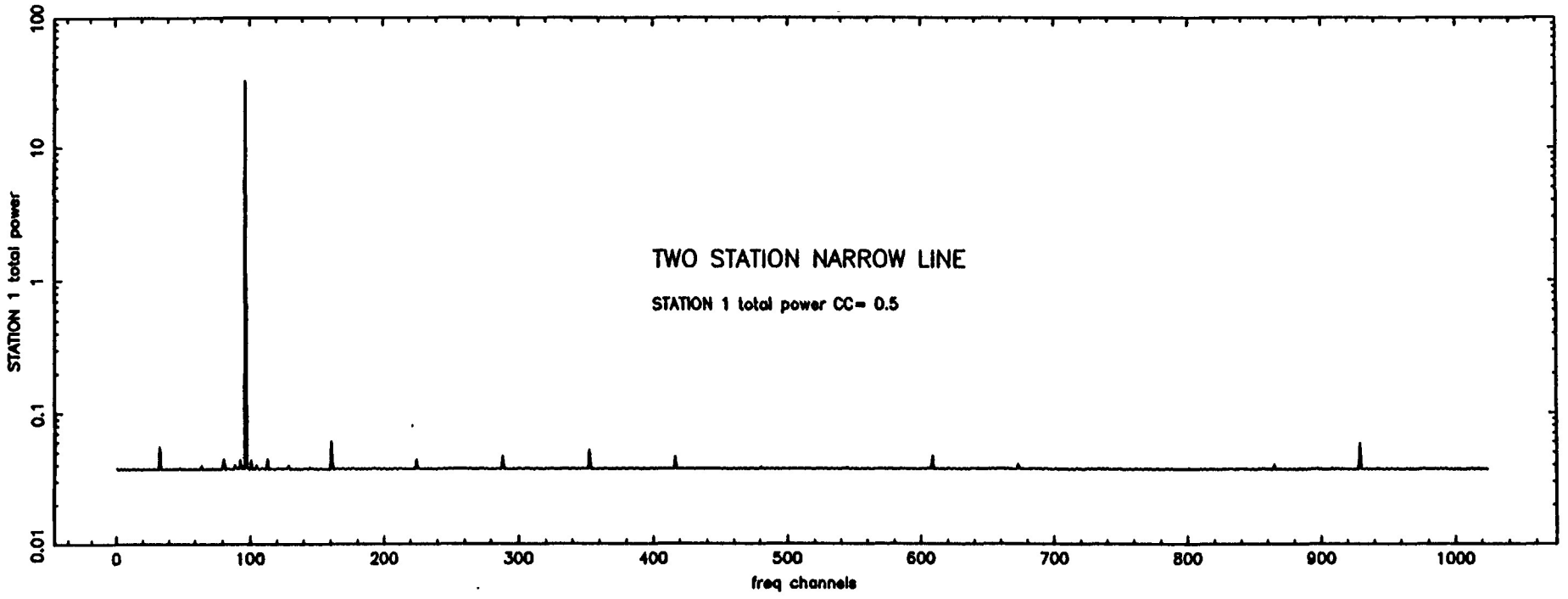

Narrow line test, xc = 0.5. 128 Msamples. Two-bit. FAST81.TBL.
cross-correlation
5x10^-3
0
200
400
600
800
1000
frequency channels

FIGURE 5B



9-18-87 to 9-24-87 CC=0.5 438 meg 213600 ffts 550_32e '** 774 data **'

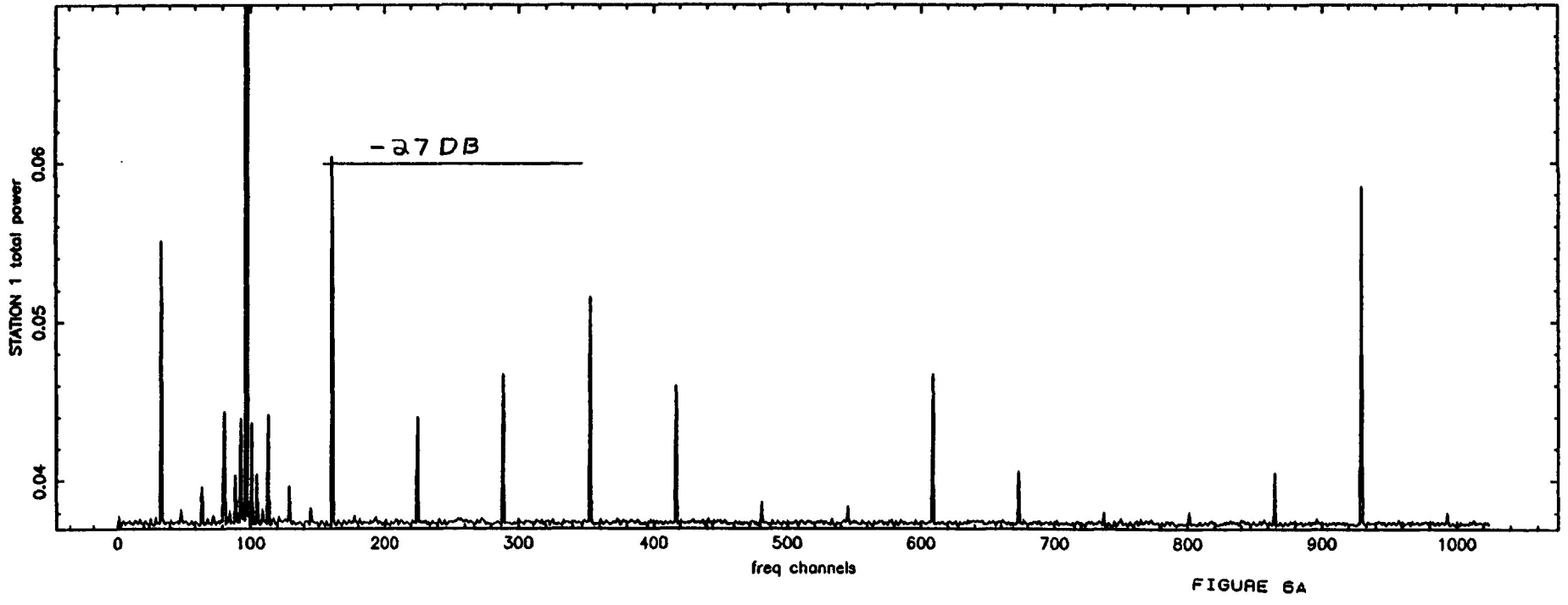
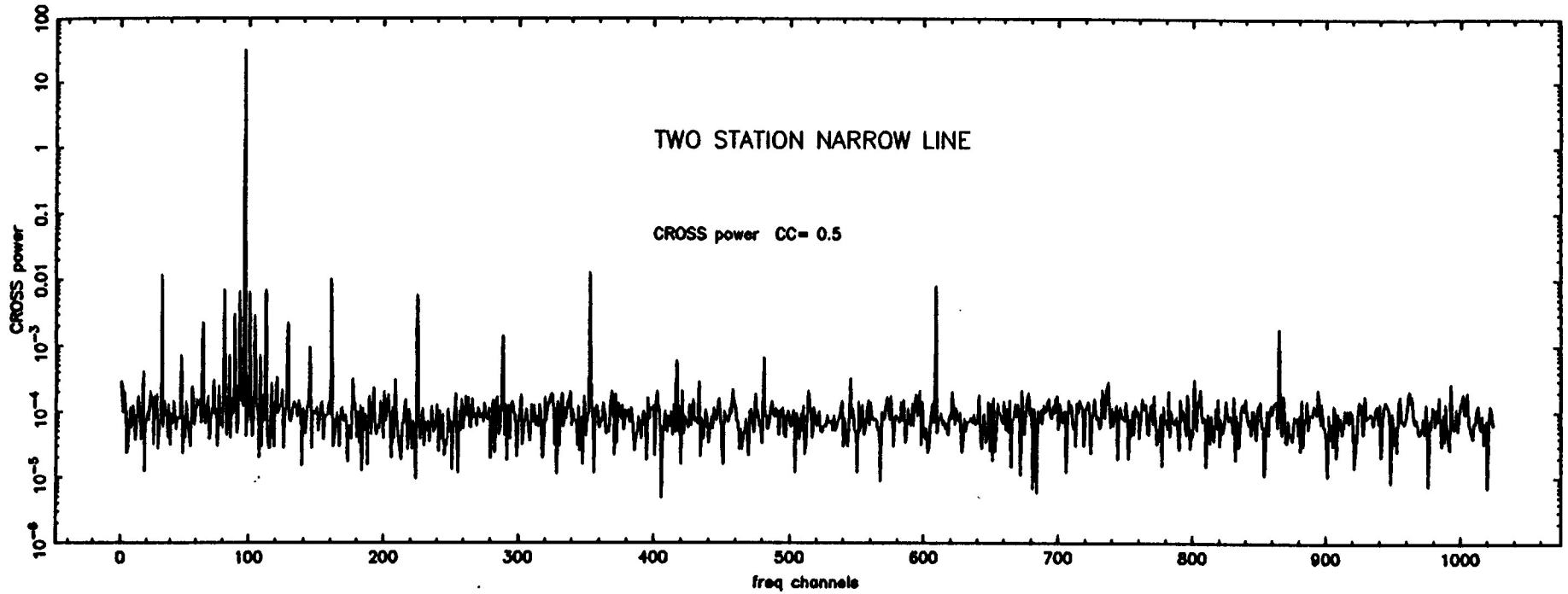


FIGURE 6A



9-18-87 to 9-24-87 CC=0.5 438 meg 213600 ffts 550_32e '** 774 data **'

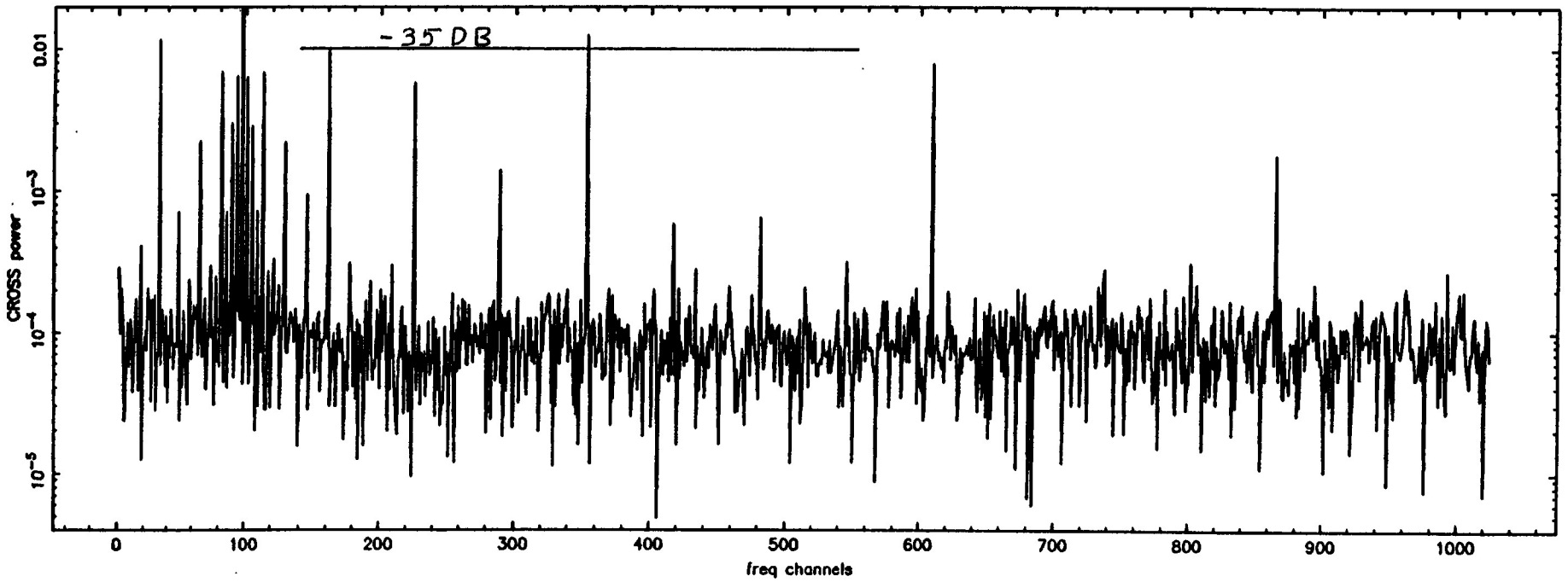
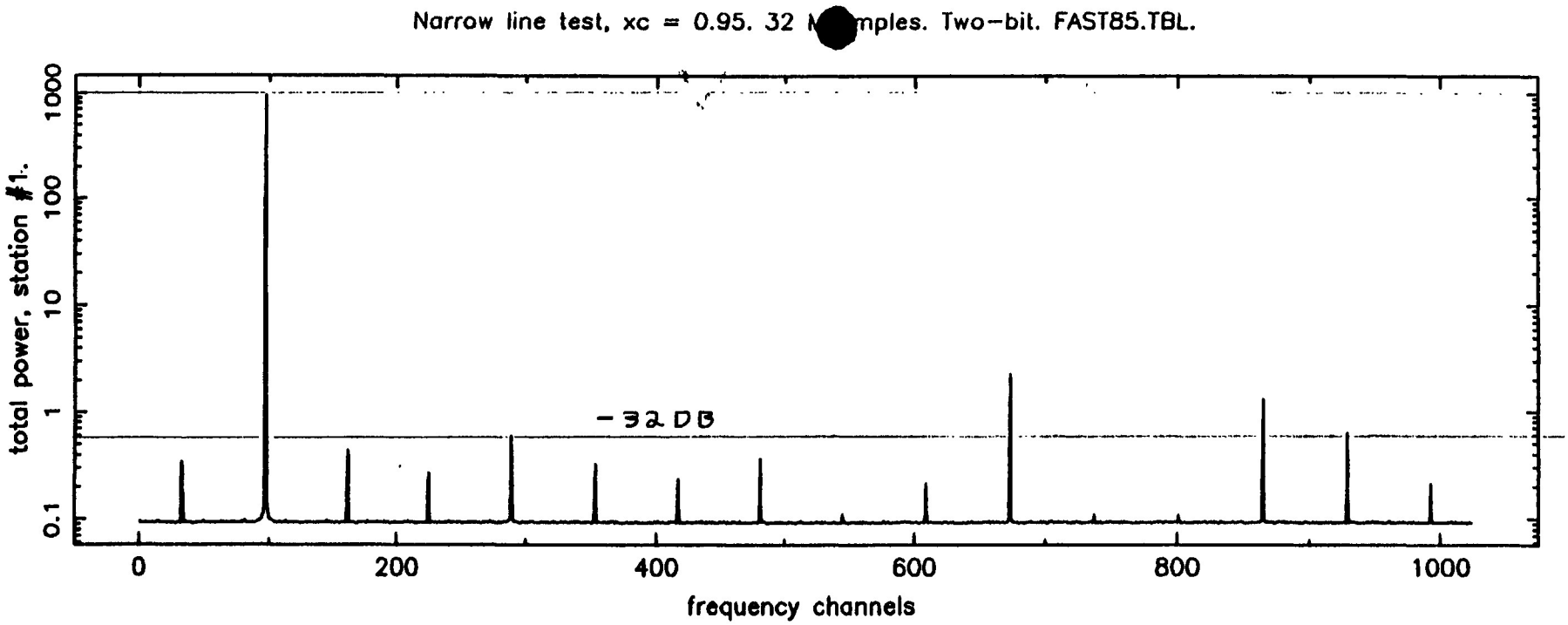


FIGURE 68


Narrow line test, xc = 0.95. 32 Msamples. Two-bit. FAST85.TBL.
total power, station #1.
1000
100
10
1
0.1
-32 DB
0
200
400
600
800
1000
frequency channels

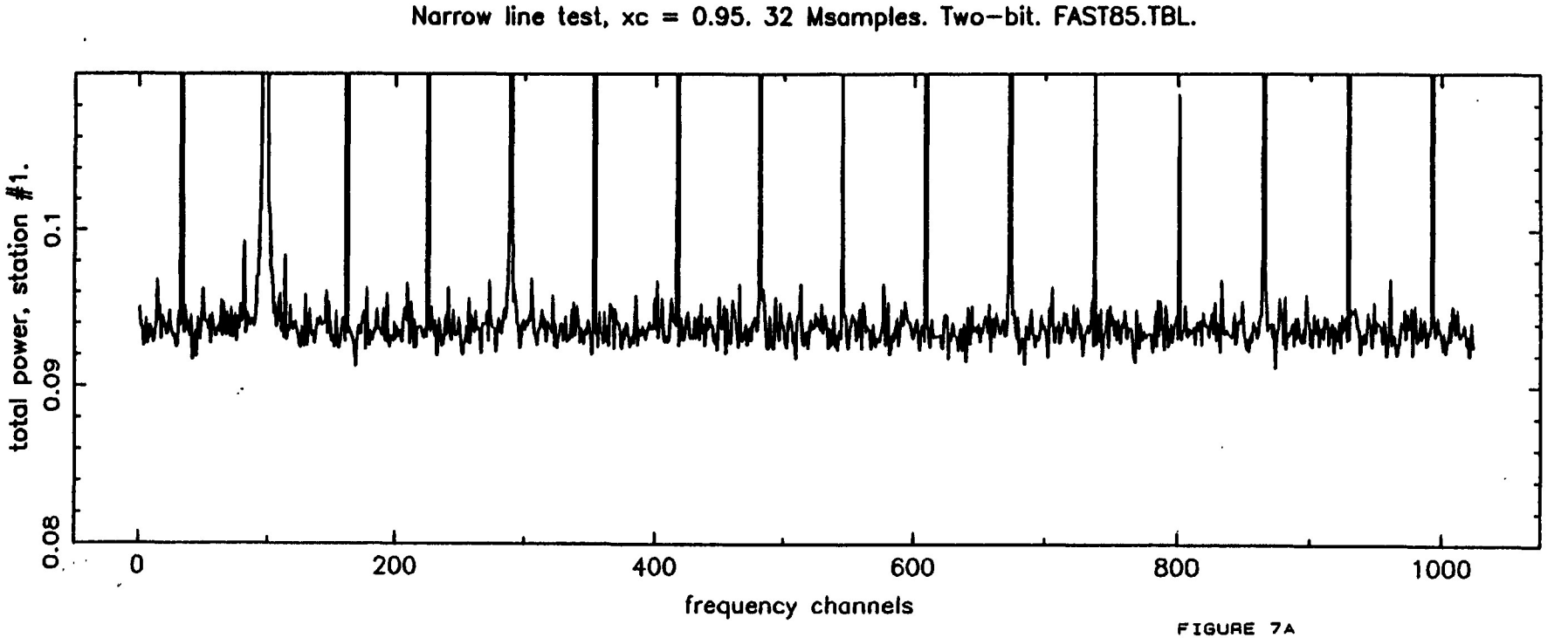
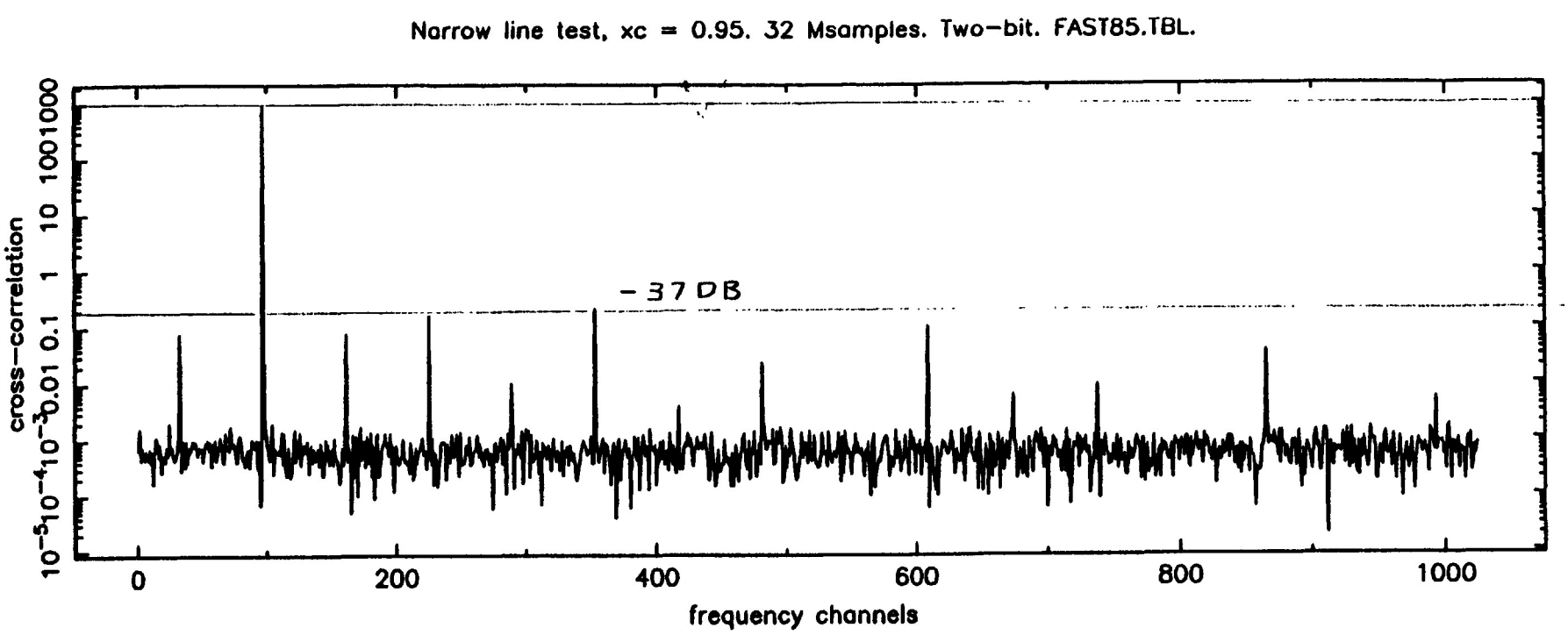

Narrow line test, xc = 0.95. 32 Msamples. Two-bit. FAST85.TBL.
total power, station #1.
0.1
0.09
0.08
0
200
400
600
800
1000
frequency channels

FIGURE 7A


Narrow line test, xc = 0.95. 32 Msamples. Two-bit. FAST85.TBL.
cross-correlation
10^-5 10^-4 10^-3 0.01 0.1 1 10 100 1000
-37 DB
0
200
400
600
800
1000
frequency channels

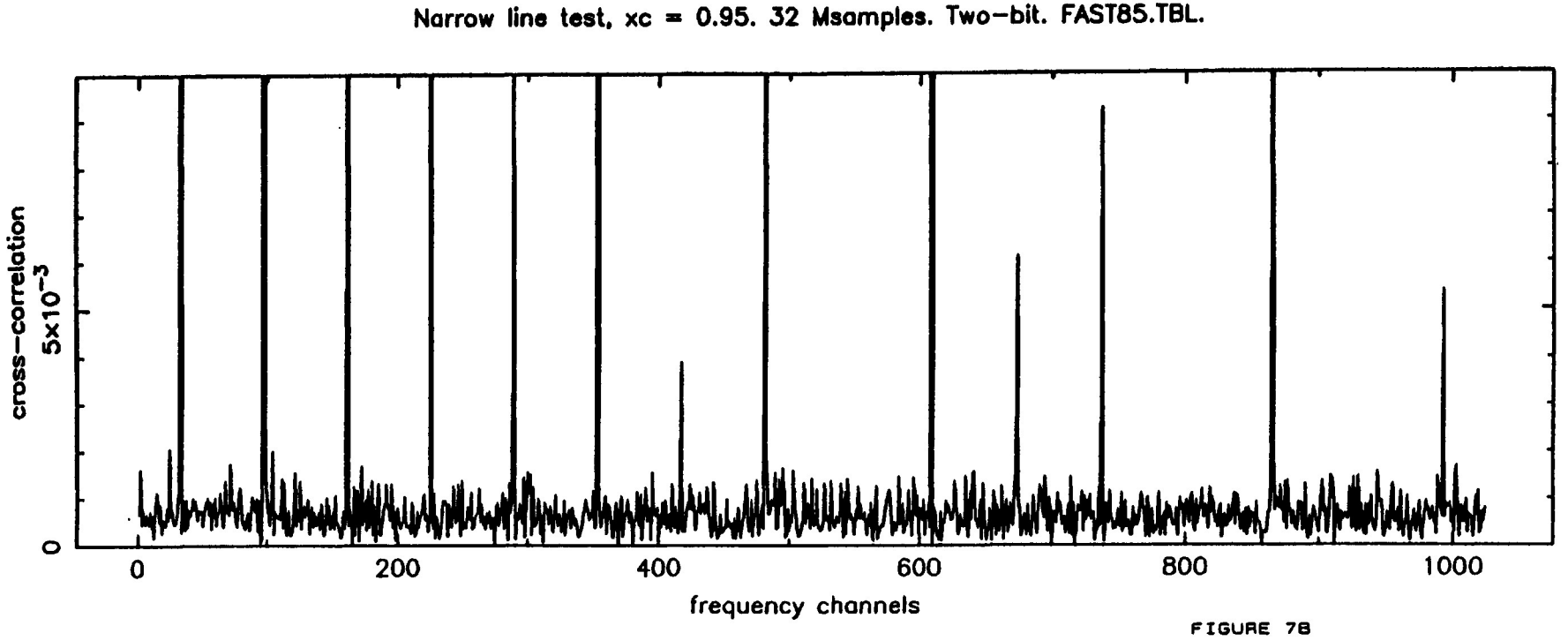
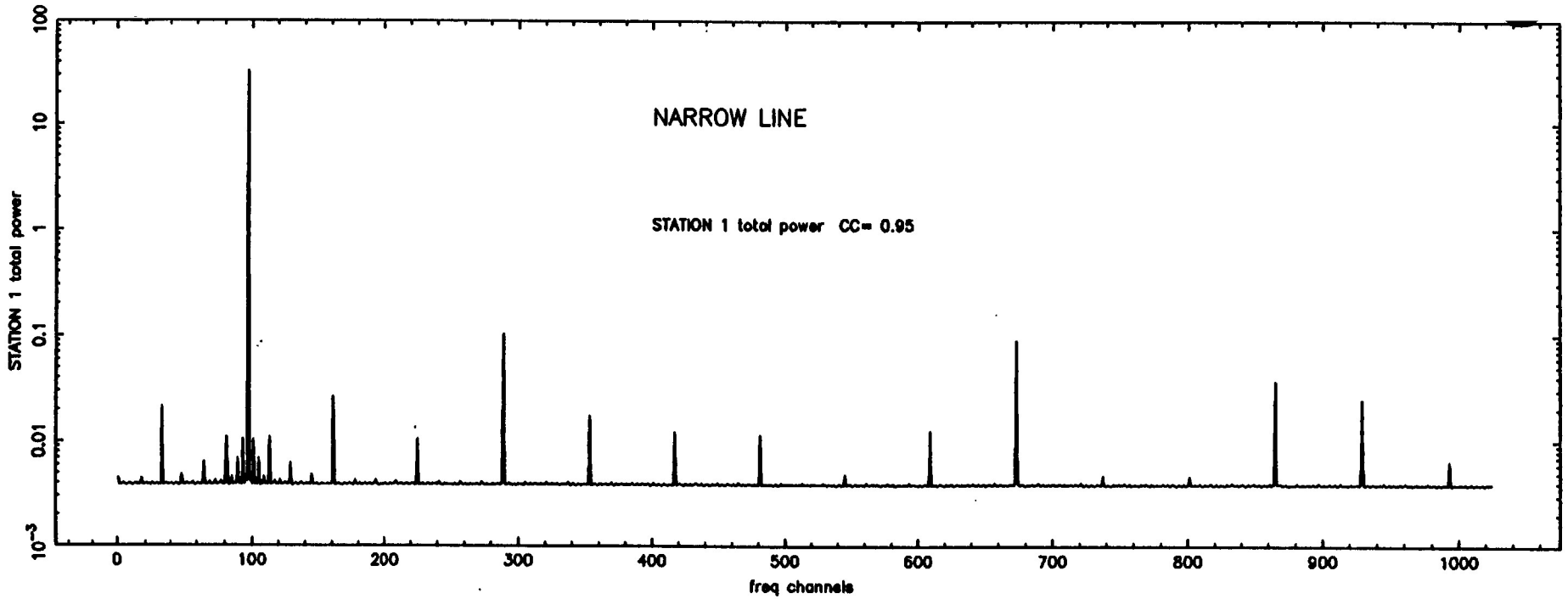

Narrow line test, xc = 0.95. 32 Msamples. Two-bit. FAST85.TBL.
cross-correlation
5x10^-3
0
0
200
400
600
800
1000
frequency channels

FIGURE 78



10-7-87 to 10-8-87 CC=0.95 103 meg 50400 ffts 550_32e '** 774 data **'

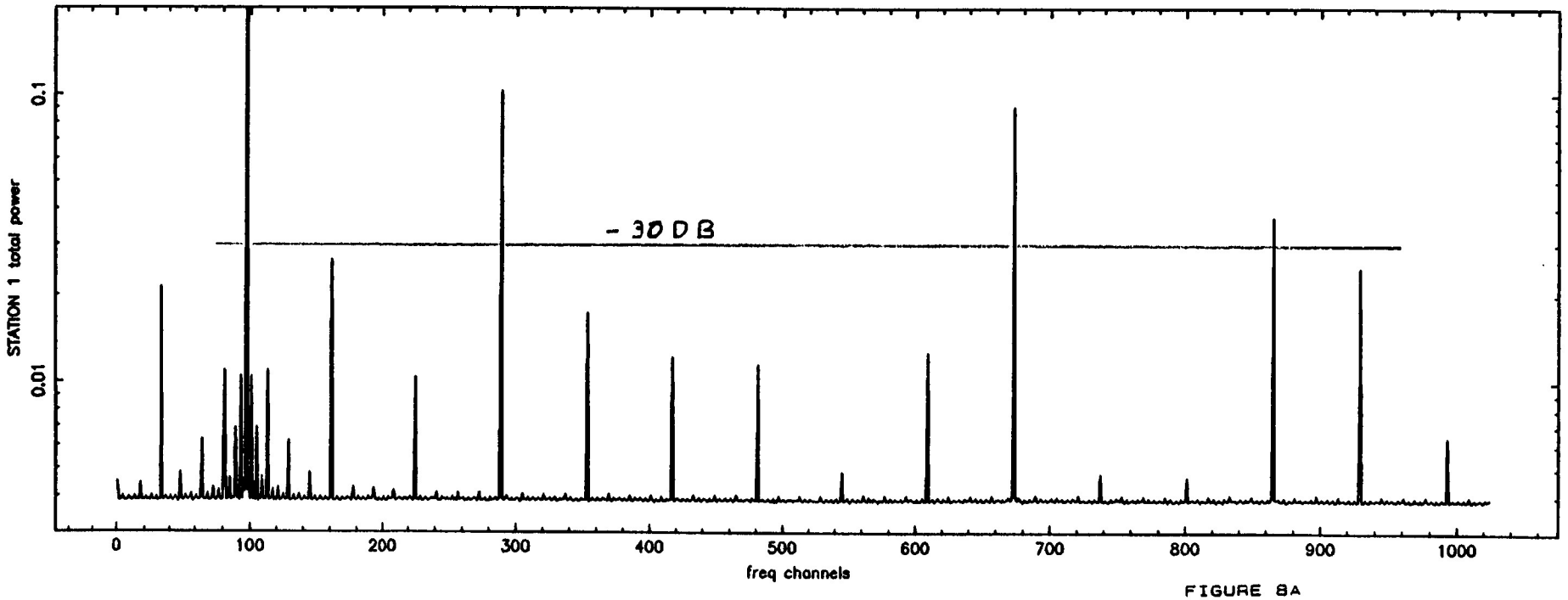
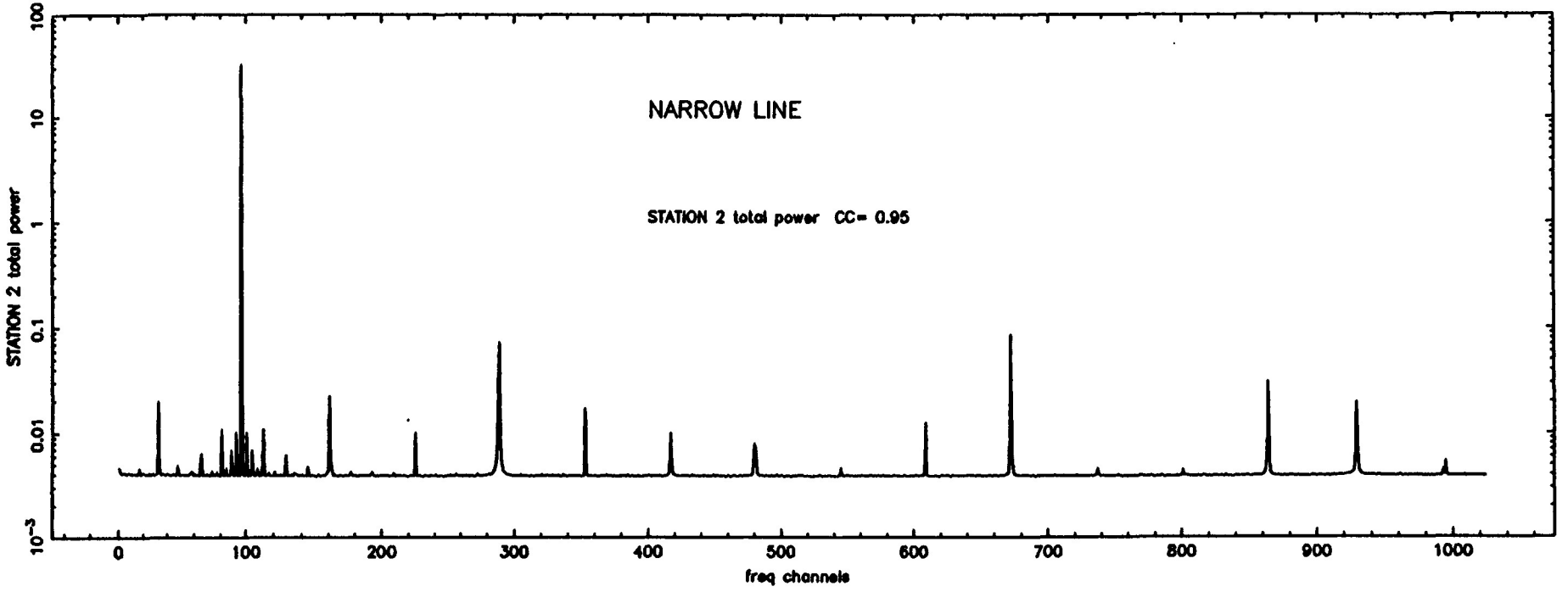


FIGURE 8A



10-7-87 to 10-8-87 CC=0.95 103 meg 50400 ffts 550_32e '** 774 data **'

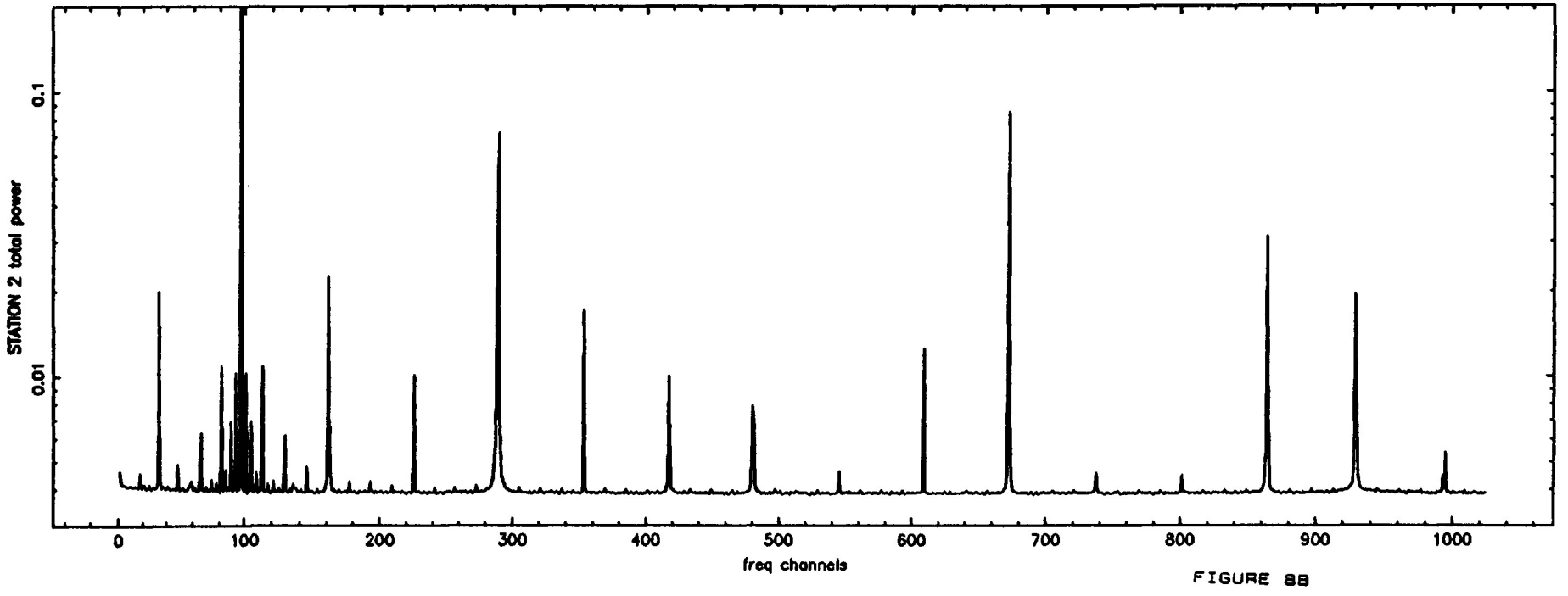
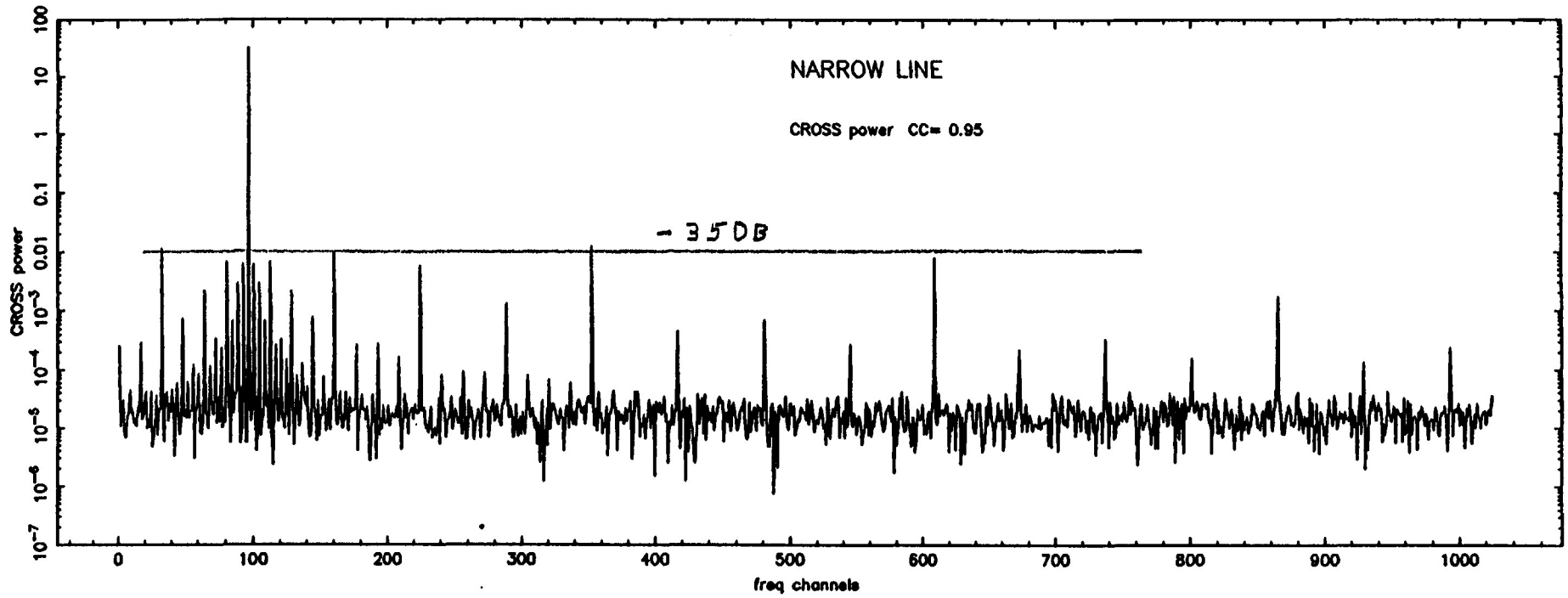


FIGURE 88



10-7-87 to 10-8-87 CC=0.95 103 meg 50400 ffts 550_32e '** 774 data **'

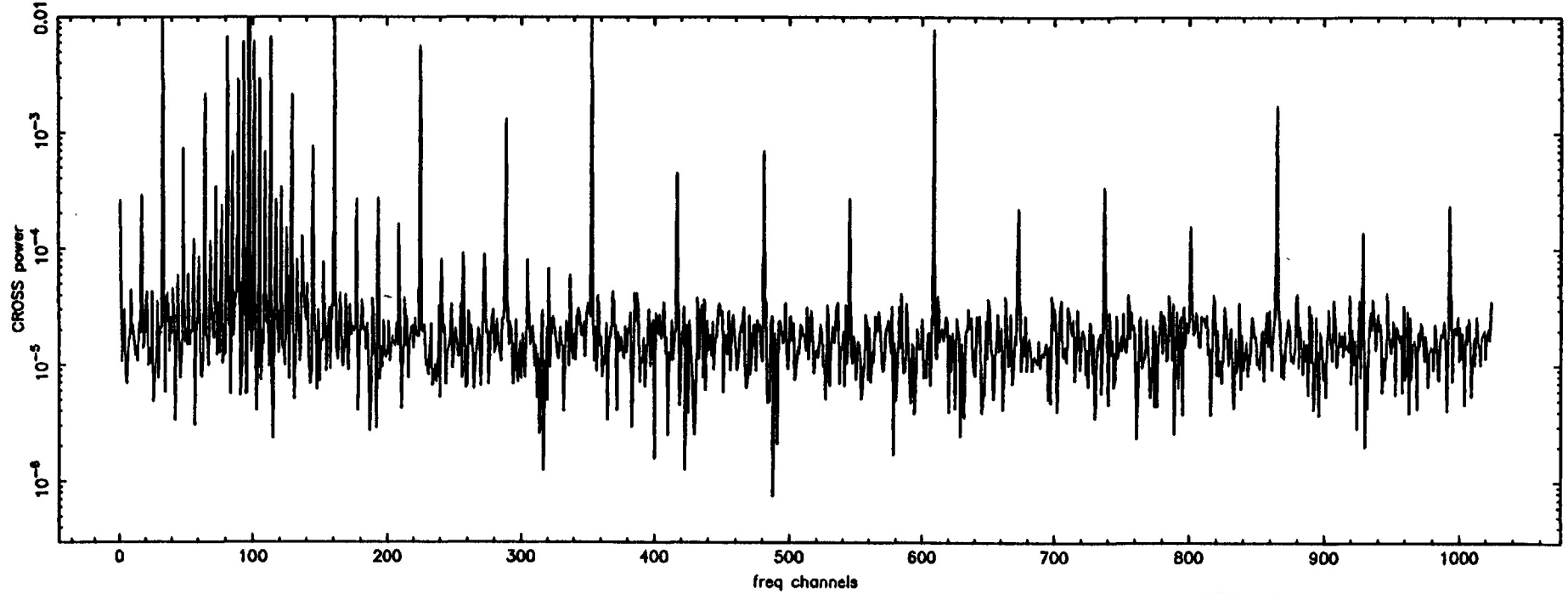
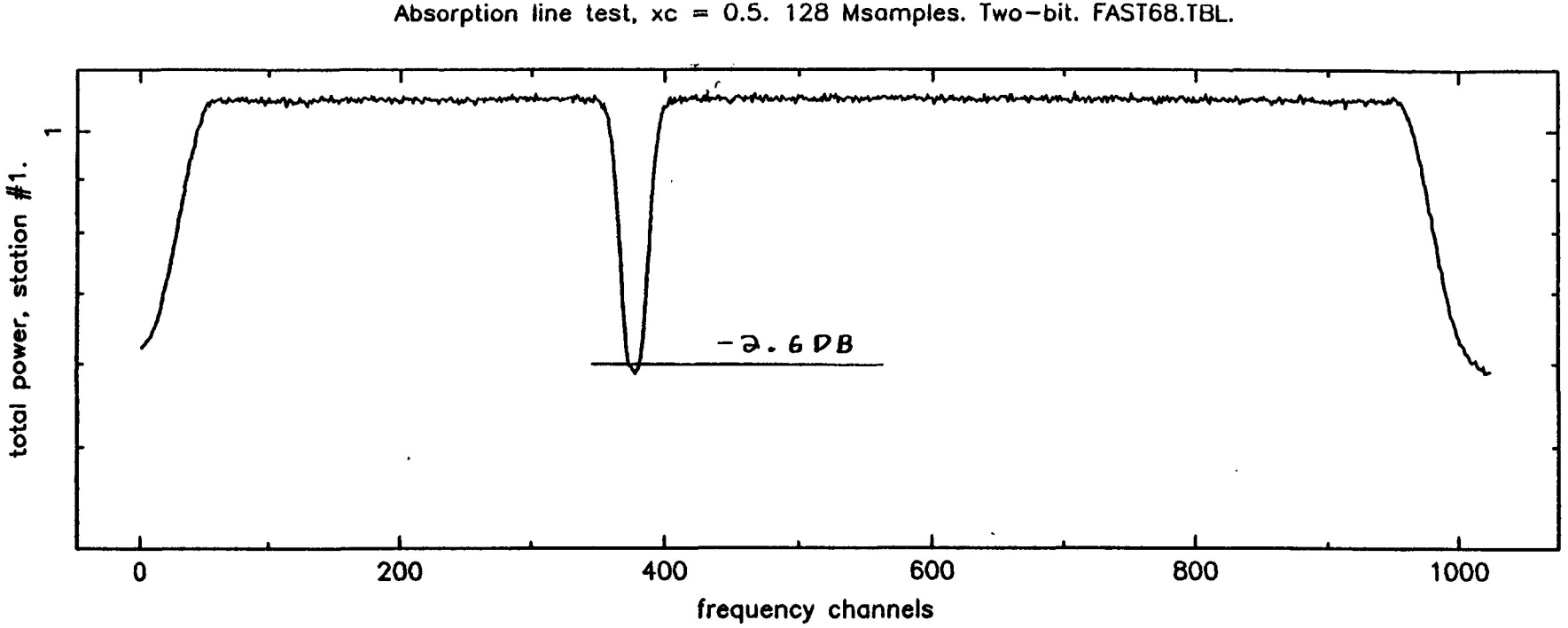


FIGURE 8C


Absorption line test, xc = 0.5. 128 Msamples. Two-bit. FAST68.TBL.
total power, station #1.
1
-2.6DB
0
200
400
600
800
1000
frequency channels

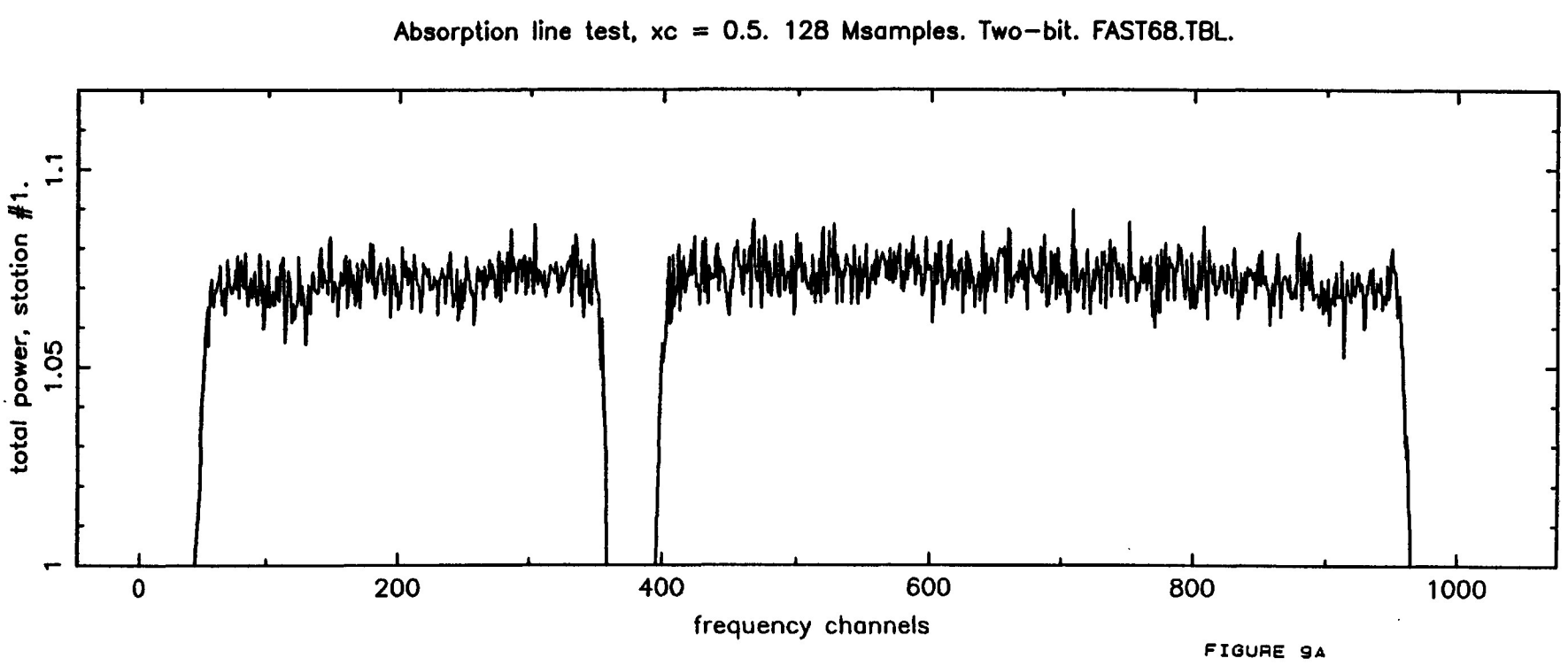
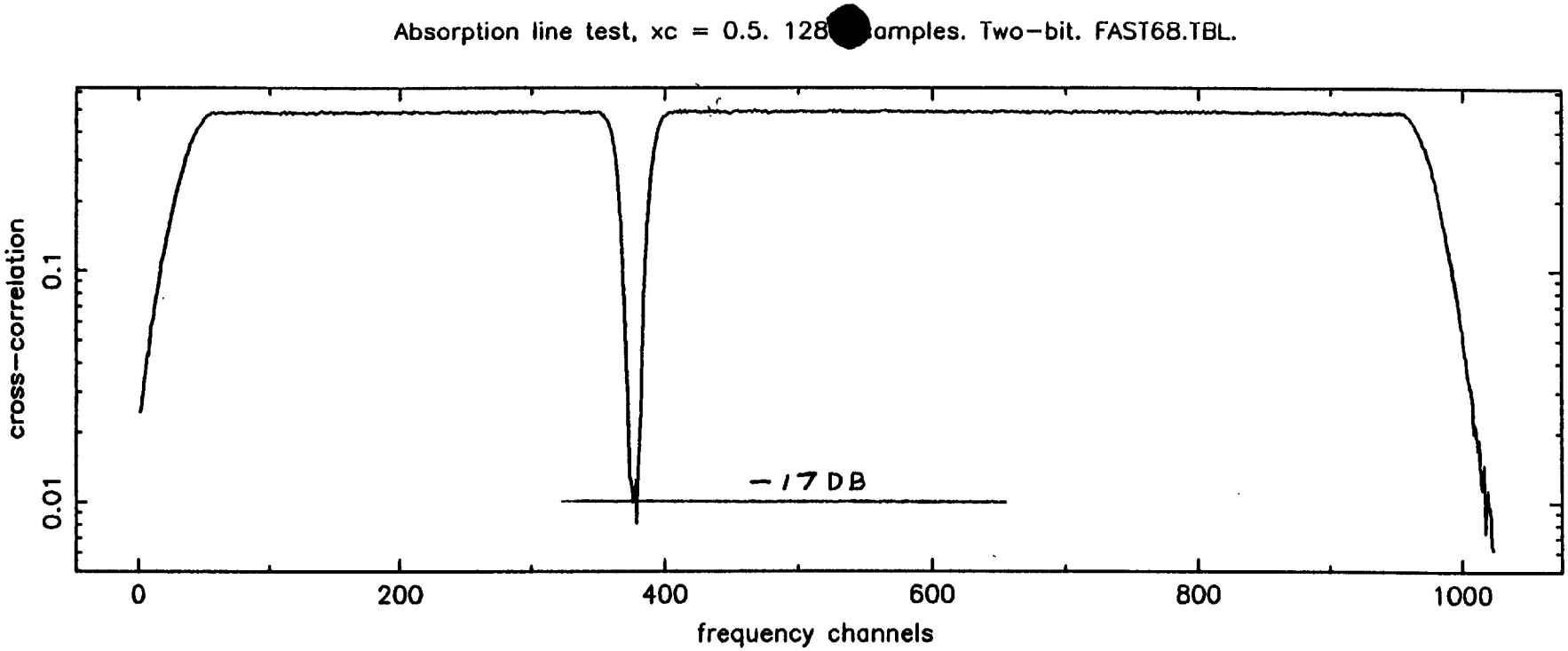

Absorption line test, xc = 0.5. 128 Msamples. Two-bit. FAST68.TBL.
total power, station #1.
1.1
1.05
1
0
200
400
600
800
1000
frequency channels

FIGURE 9A


Absorption line test, xc = 0.5. 128 samples. Two-bit. FAST68.TBL.
cross-correlation
0.1
0.01
-17 DB
0
200
400
600
800
1000
frequency channels

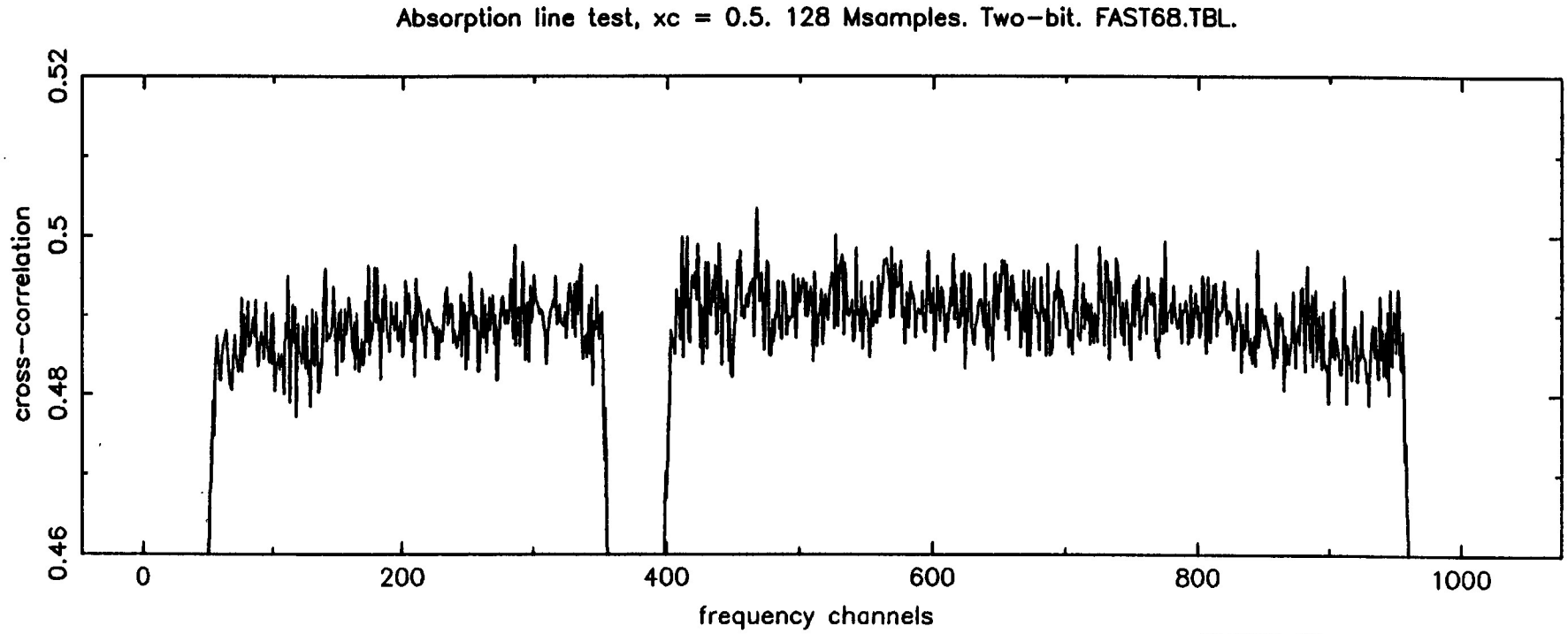
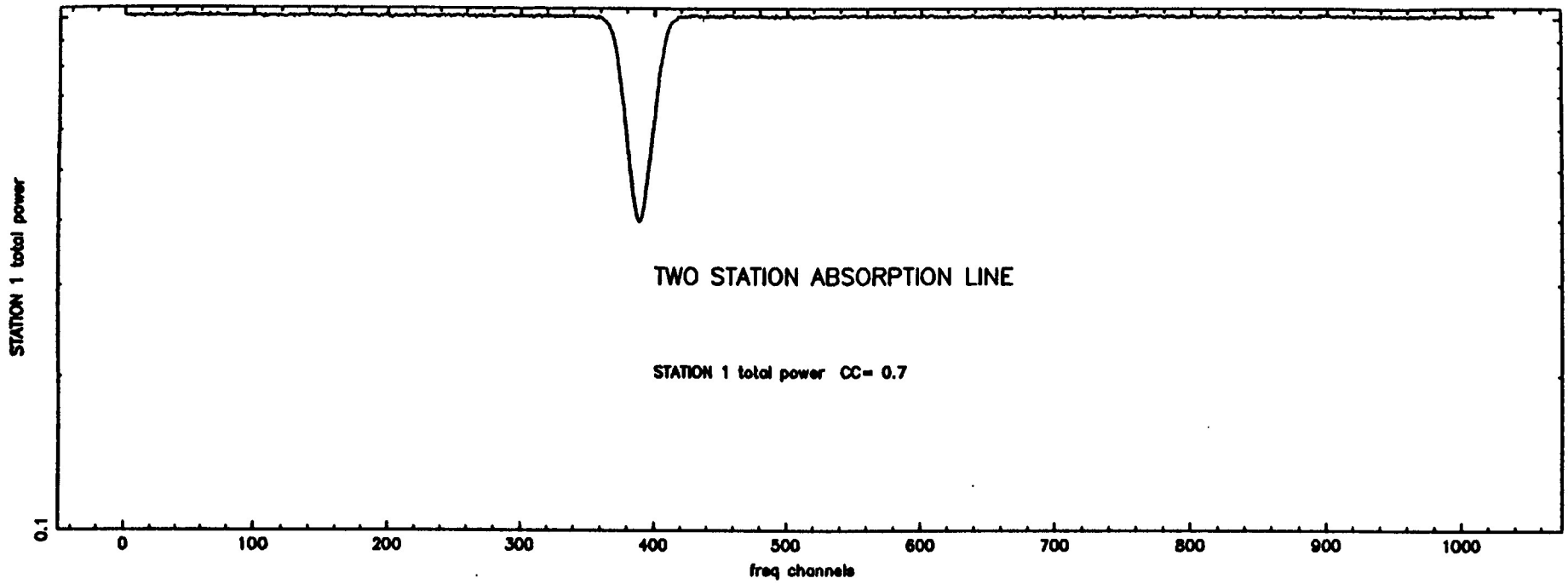

Absorption line test, xc = 0.5. 128 Msamples. Two-bit. FAST68.TBL.
cross-correlation
0.52
0.5
0.48
0.46
0
200
400
600
800
1000
frequency channels

FIGURE 98


STATION 1 total power
0.1
TWO STATION ABSORPTION LINE
STATION 1 total power CC= 0.7
0
100
200
300
400
500
600
700
800
900
1000
freq channels

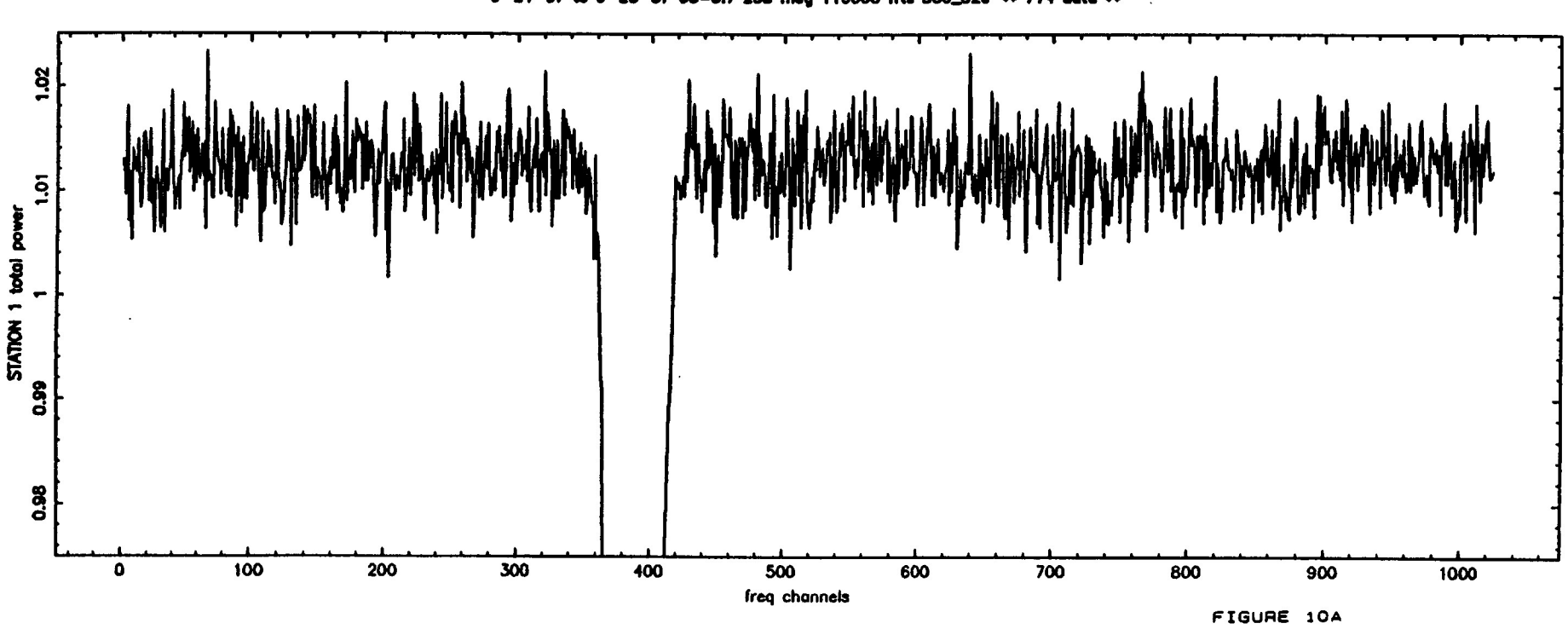
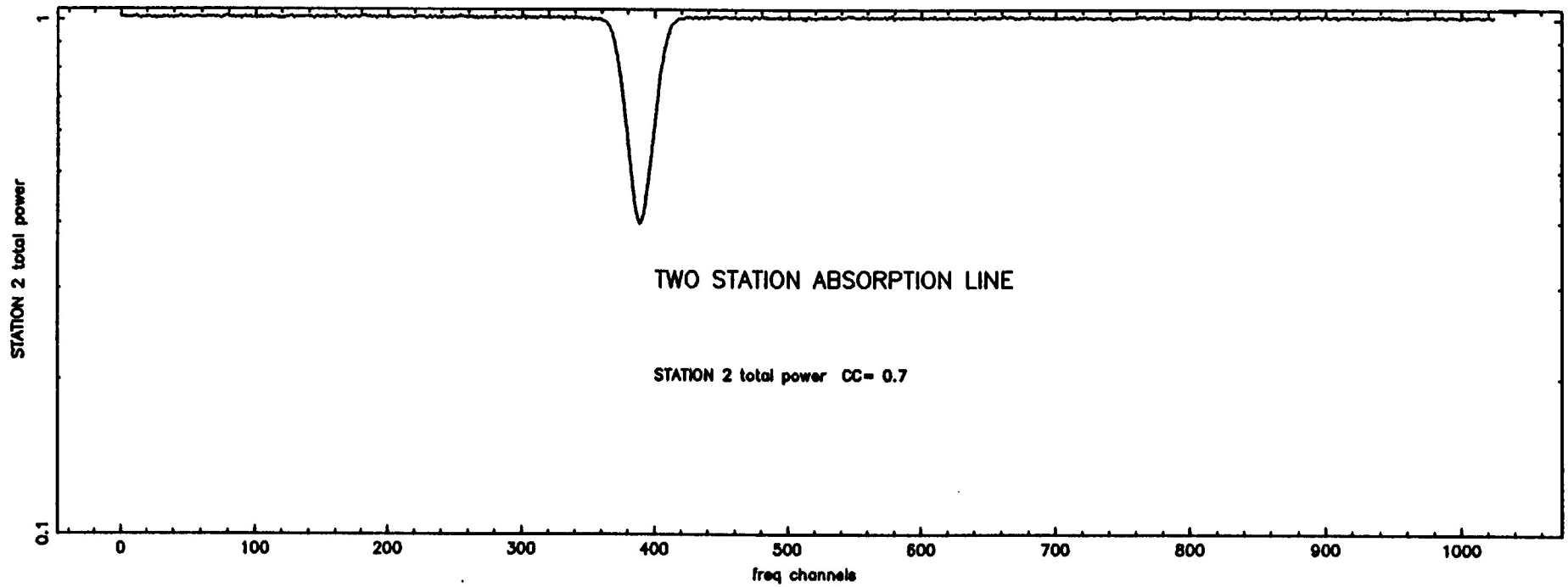

9-24-87 to 9-28-87 CC=0.7 238 meg 116000 ffts 550_32e '** 774 data **'
STATION 1 total power
0.98
0.99
1
1.01
1.02
0
100
200
300
400
500
600
700
800
900
1000
freq channels

FIGURE 10A



9-24-87 to 9-28-87 CC=0.7 238 meg 116000 ffts 550_32e '** 774 data **'

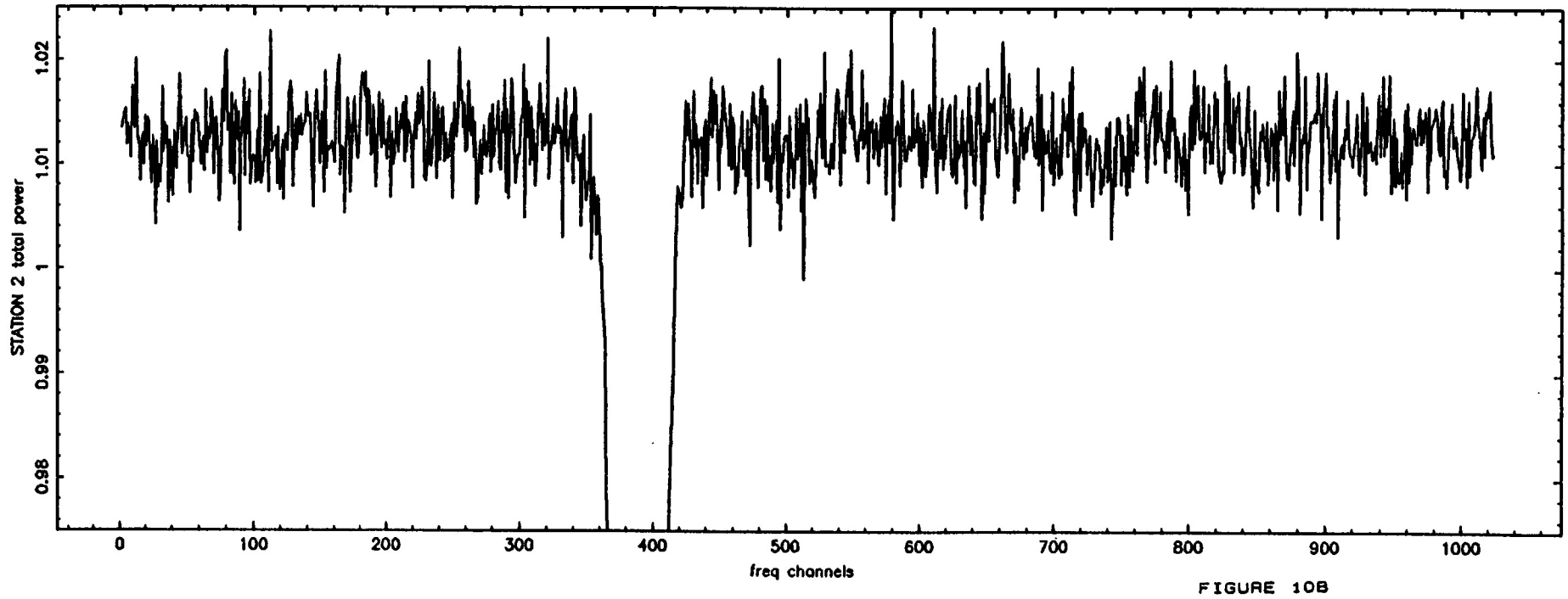
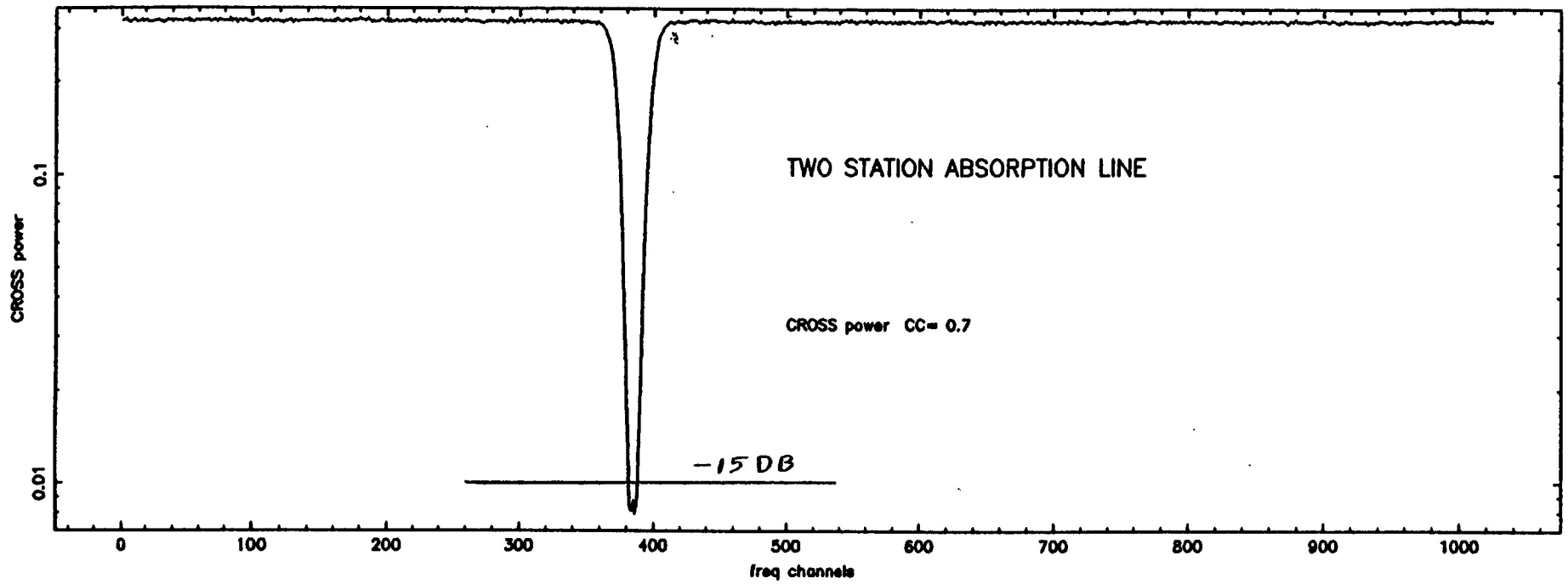


FIGURE 10B



9-24-87 to 9-28-87 CC=0.7 238 meg 116000 ffts 550_32e '** 774 data **'

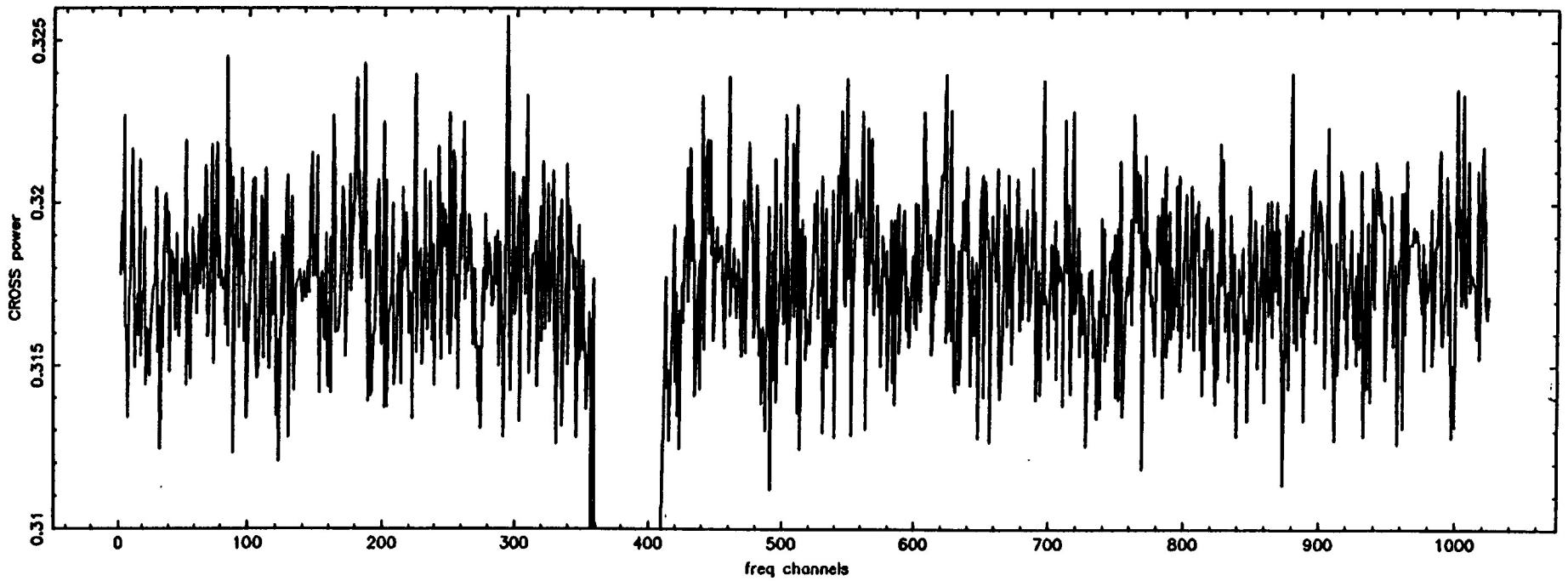
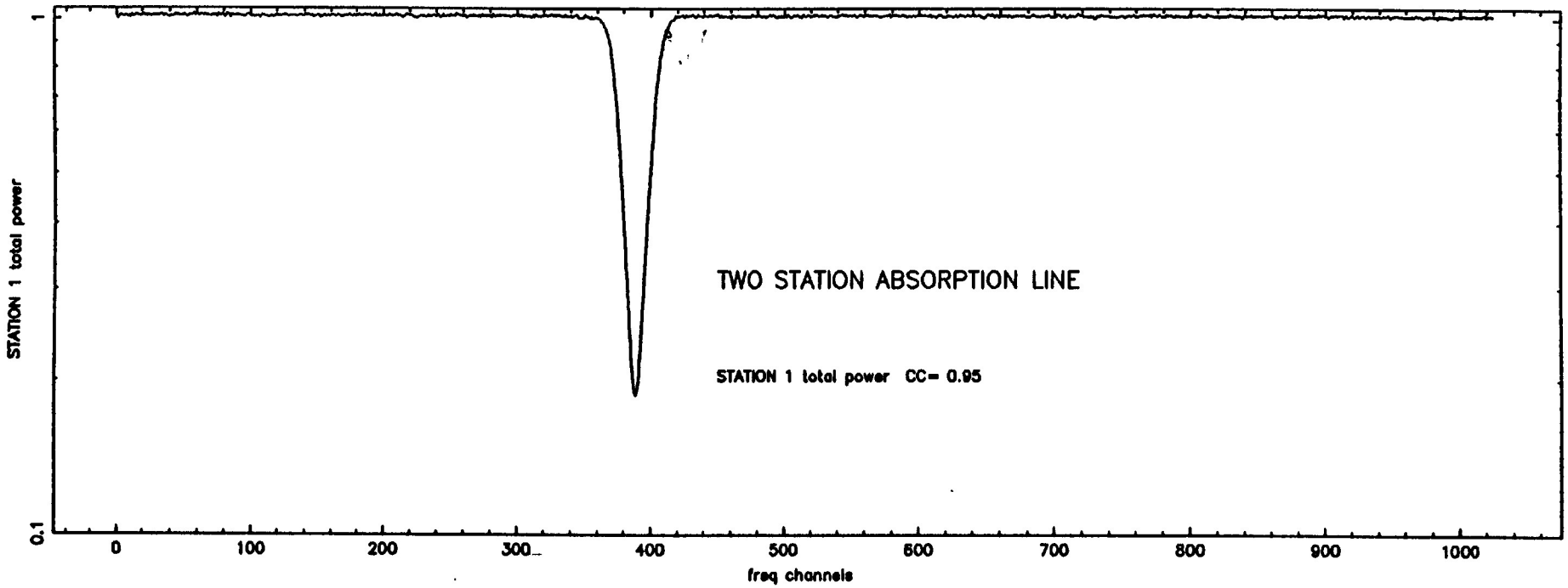


FIGURE 10C



10-10-87 to 10-12-87 CC=0.95 152 meg 73600 ffts 550_32e '** 774 data **'

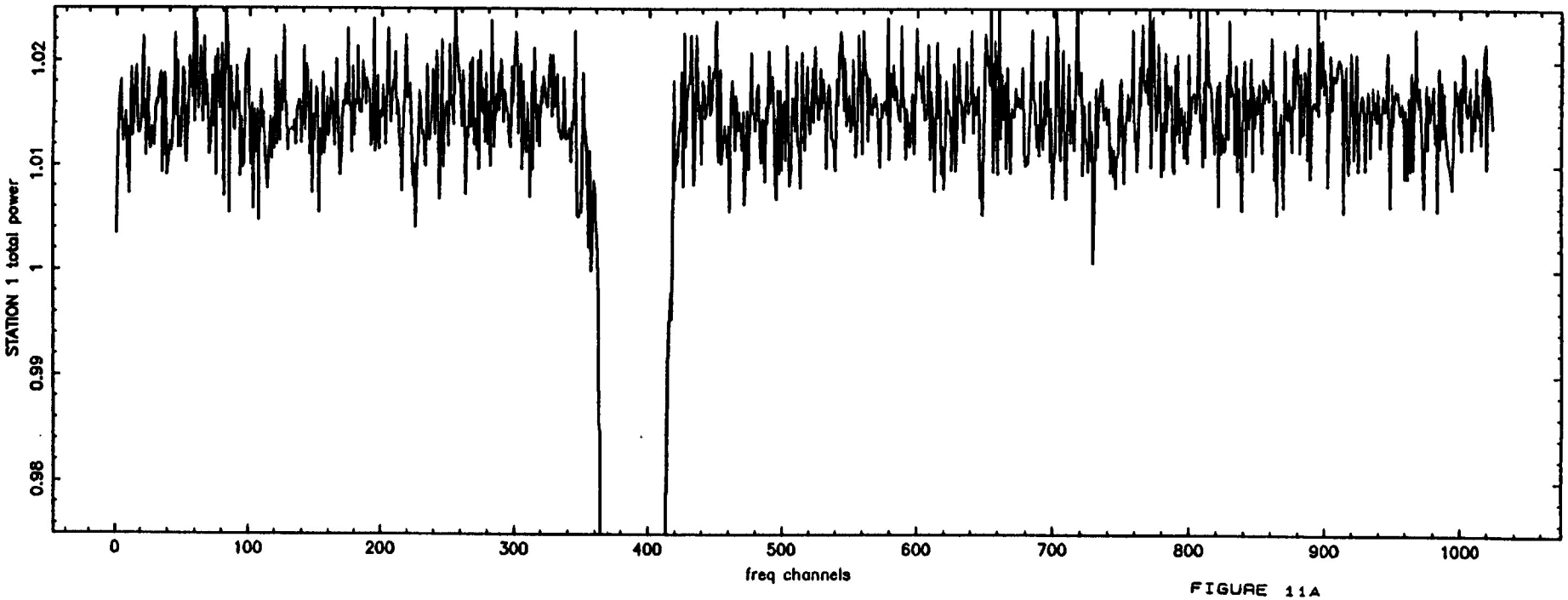
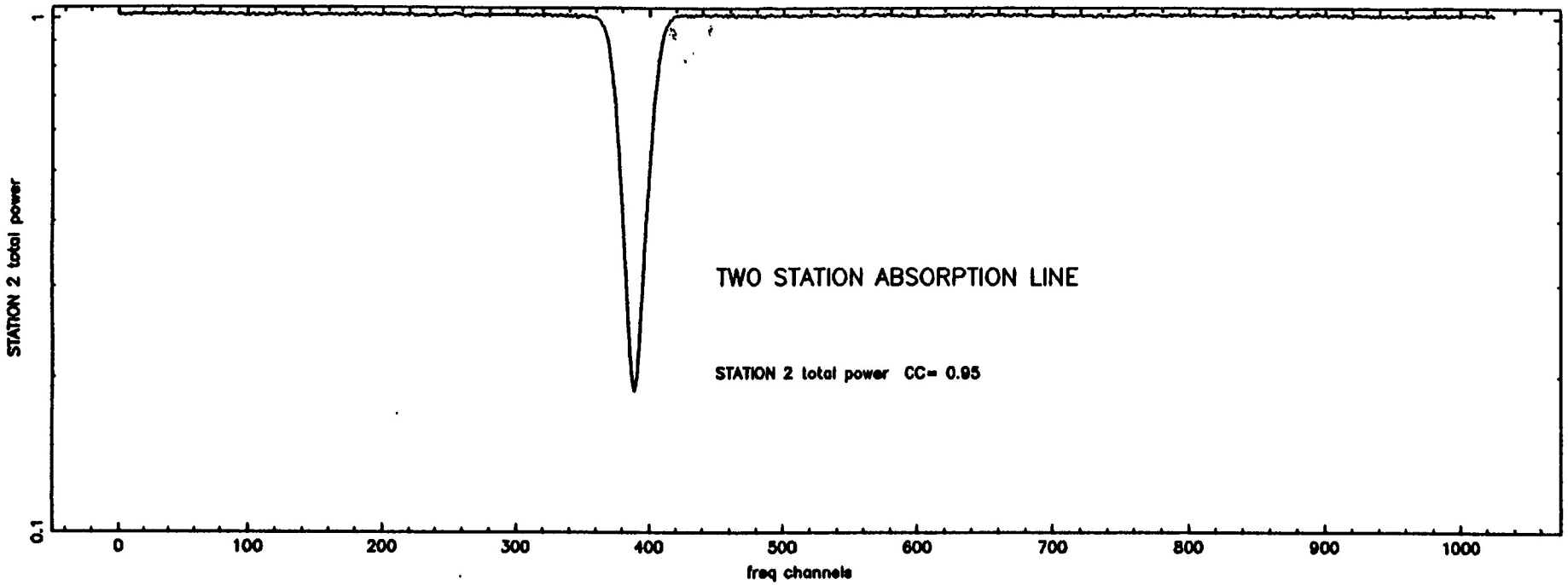


FIGURE 11A



10-10-87 to 10-12-87 CC=0.95 152 meg 73600 ffts 550_32e '** 774 data **'

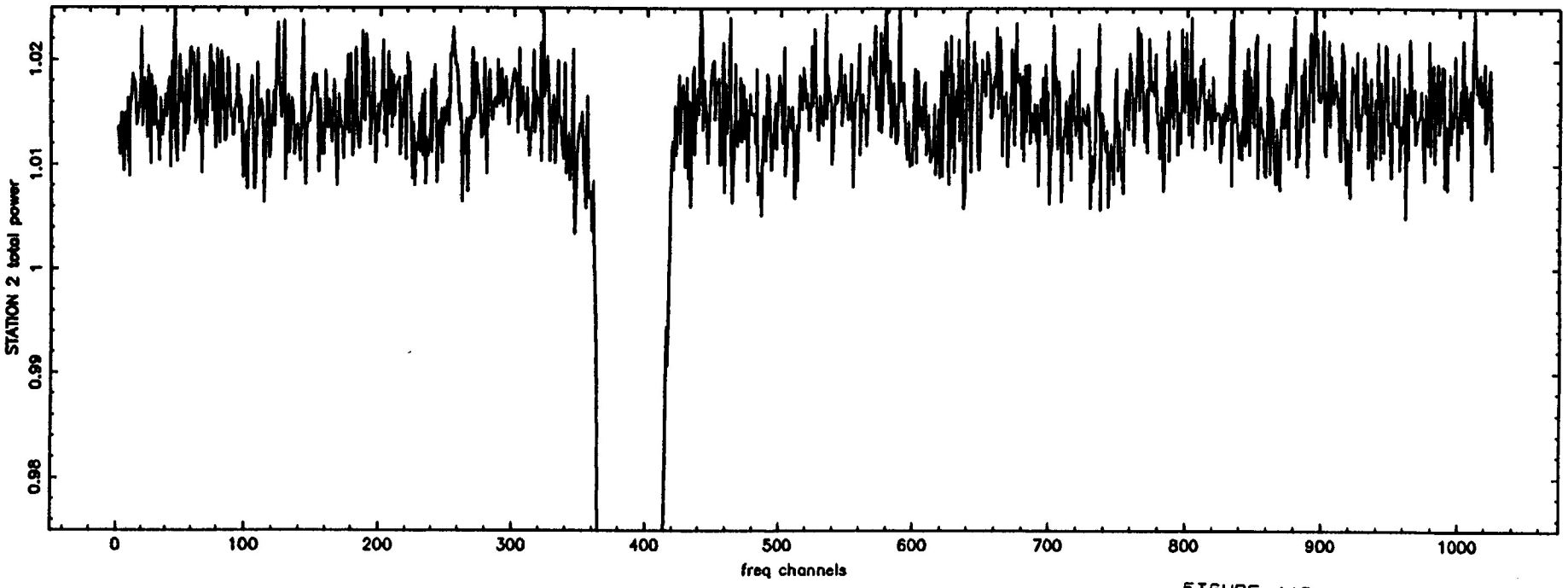
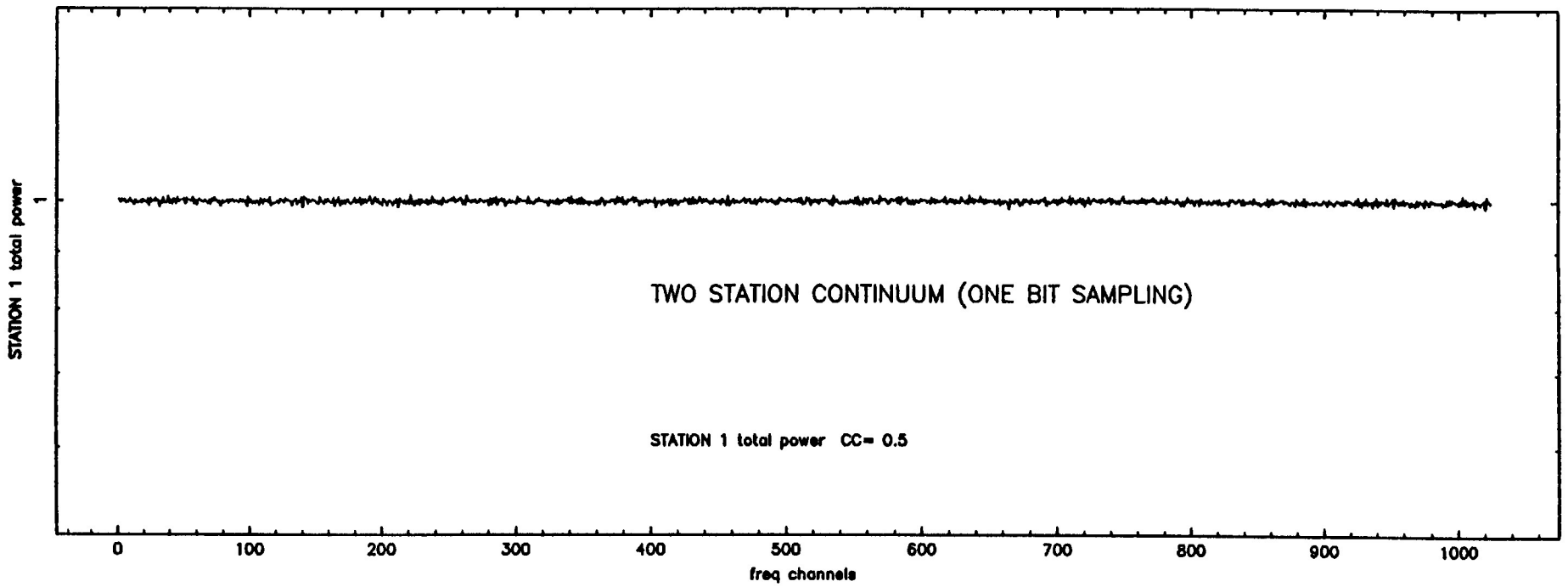


FIGURE 11B



10-4-87 to 10-7-87 CC=0.5 200 meg 97600 ffts 550_32e '** 774 data **'

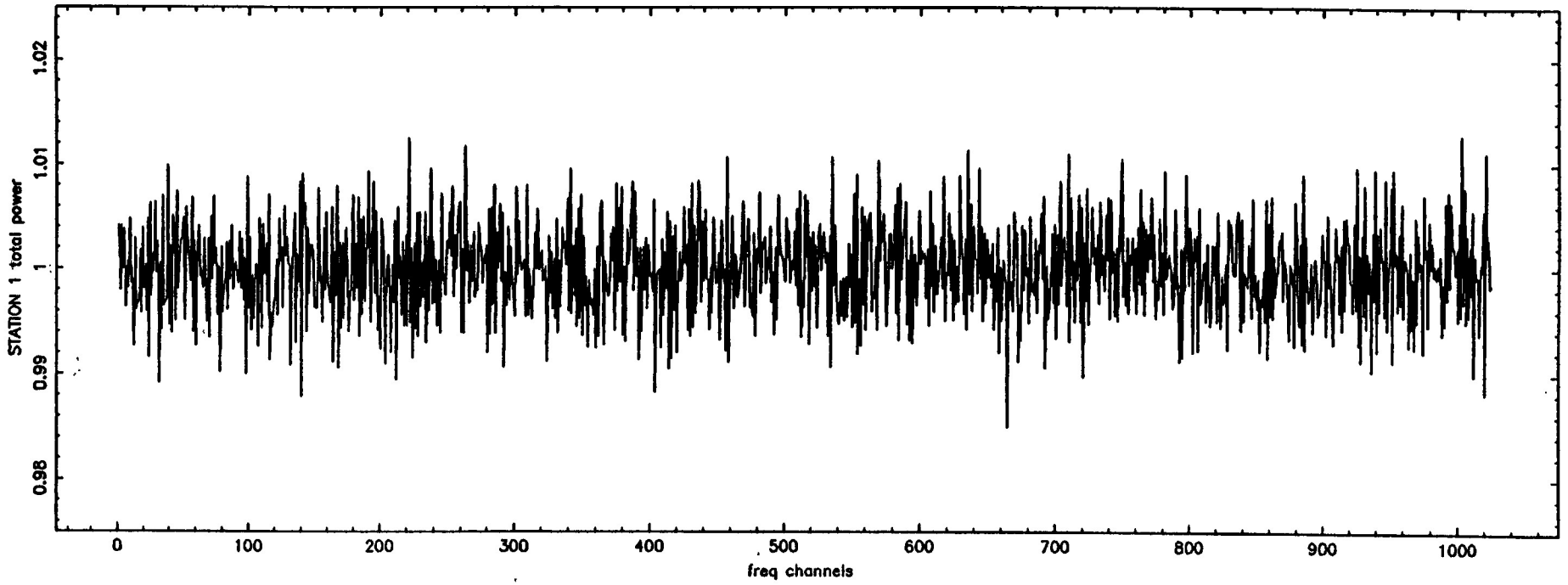
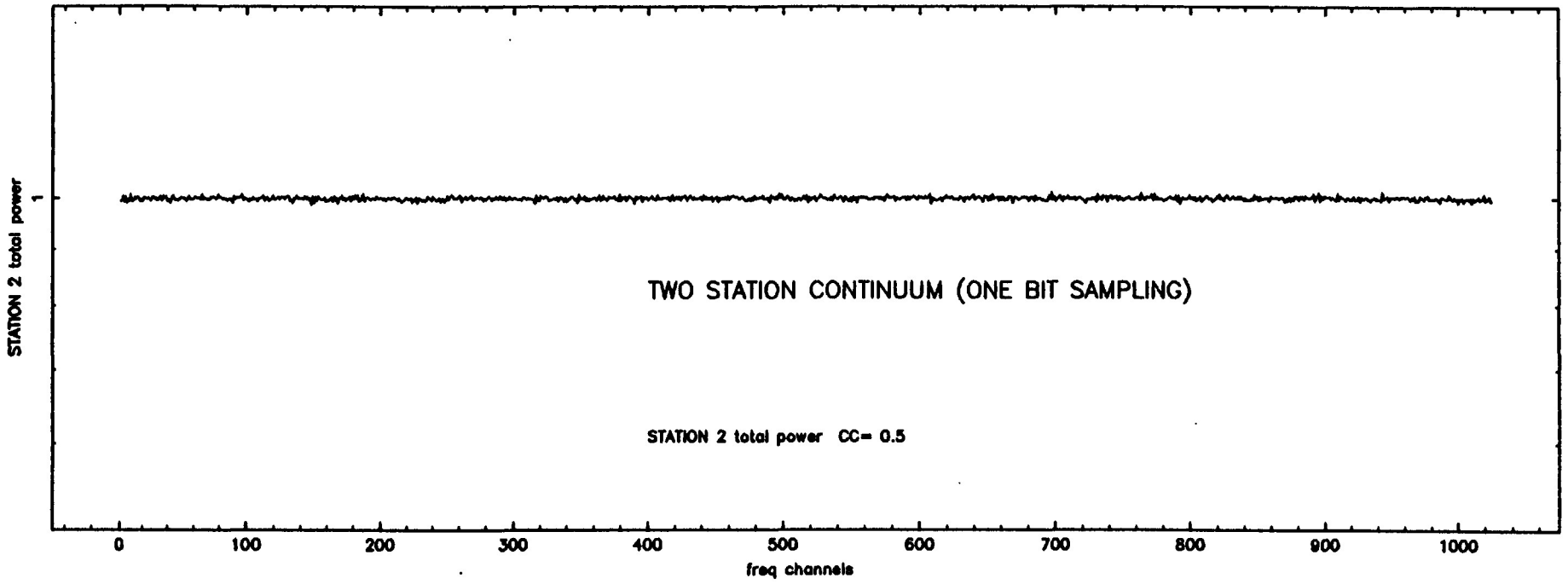


FIGURE 12A



10-4-87 to 10-7-87 CC=0.5 200 meg 97600 ffts 550_32e '** 774 data **'

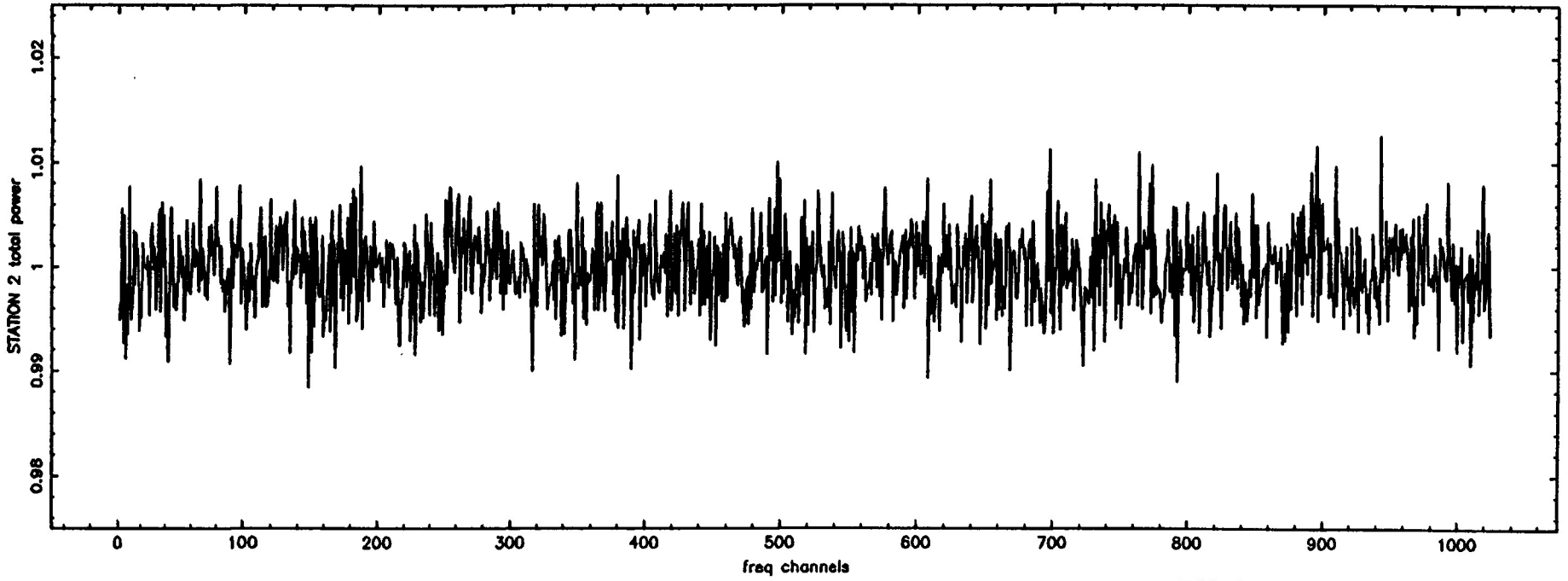
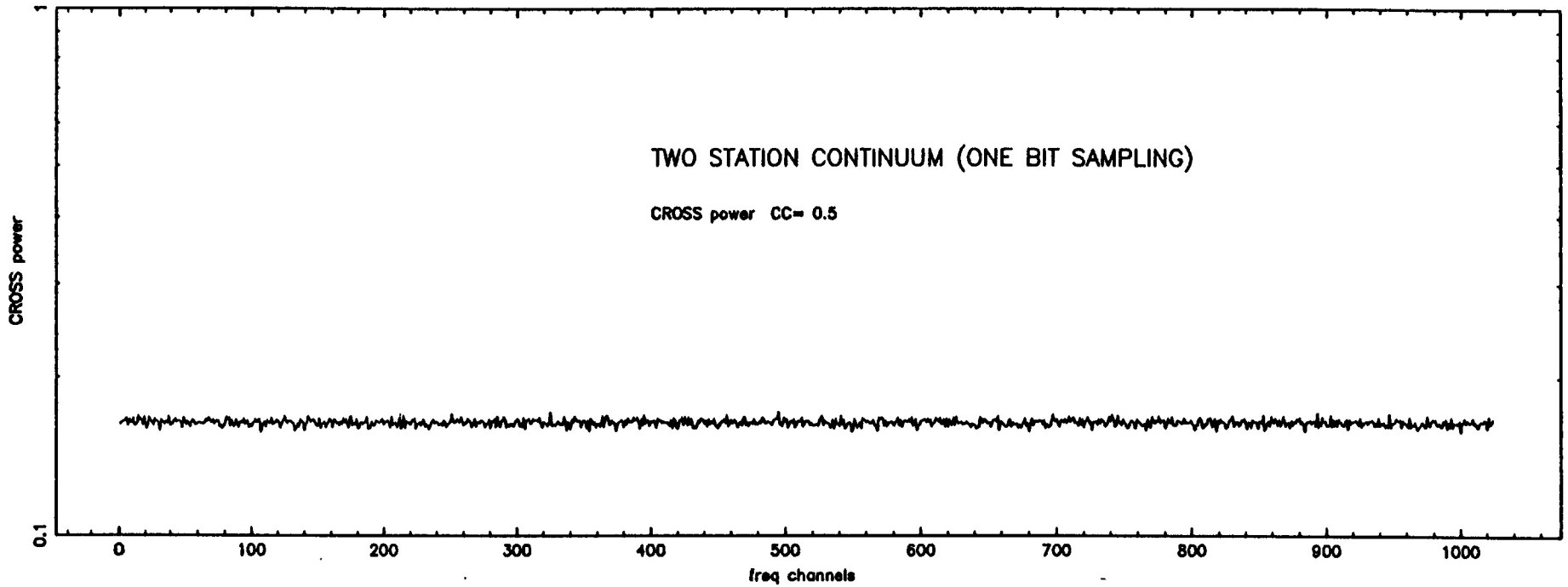


FIGURE 12B



10-4-87 to 10-7-87 CC=0.5 200 meg 97600 ffts 550_32e '** 774 data **'

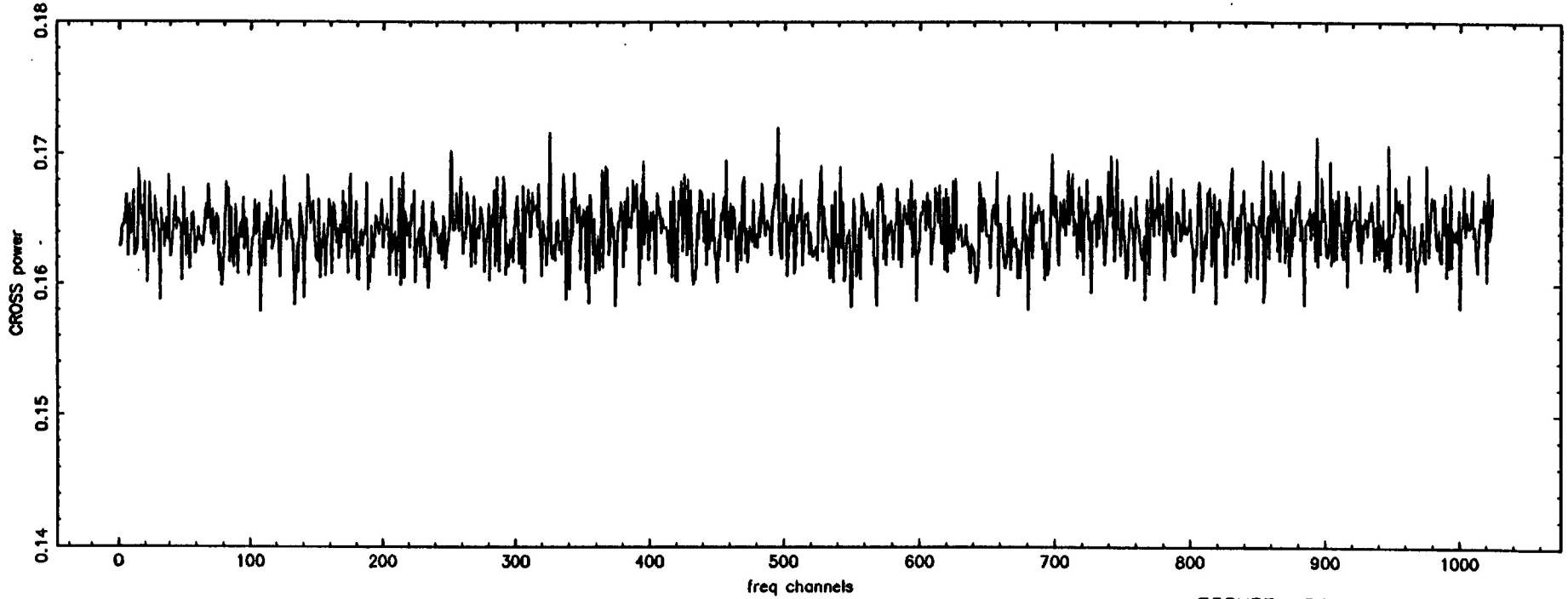
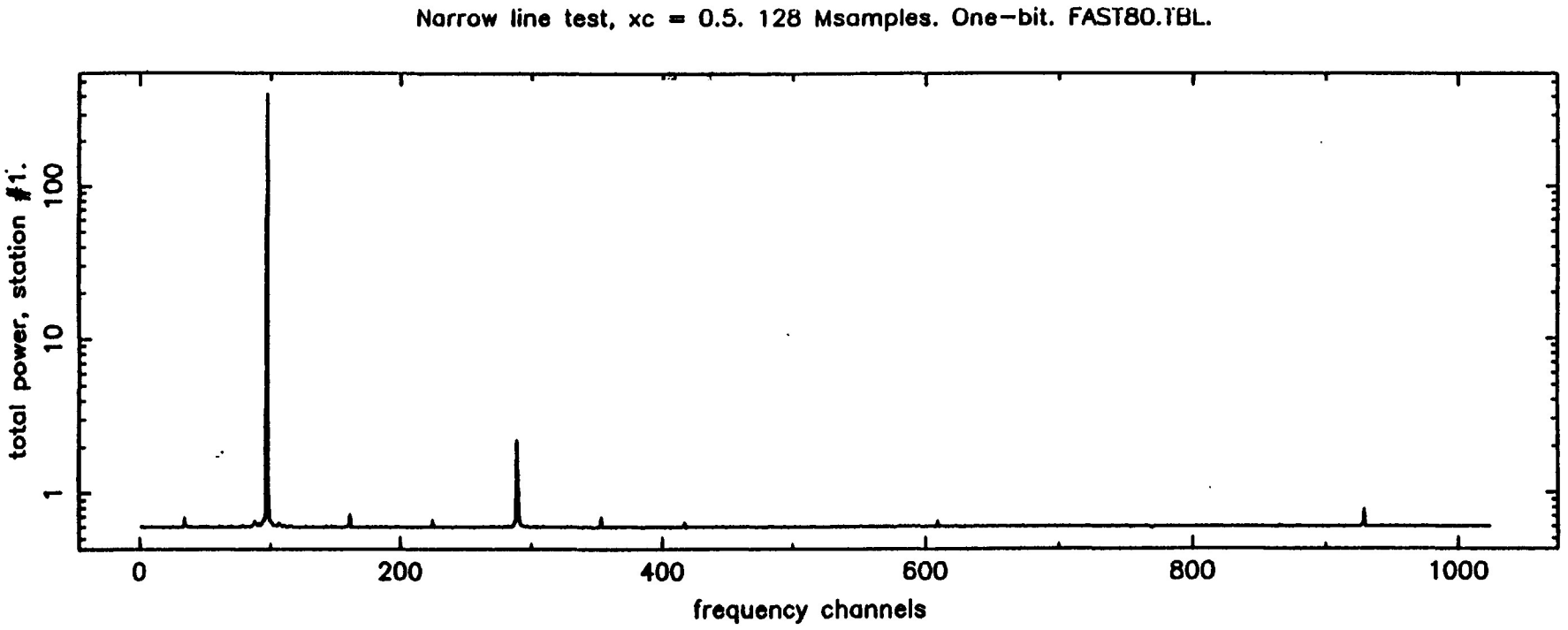


FIGURE 12C


Narrow line test, xc = 0.5. 128 Msamples. One-bit. FAST80.TBL.
total power, station #1.
1
10
100
0
200
400
600
800
1000
frequency channels

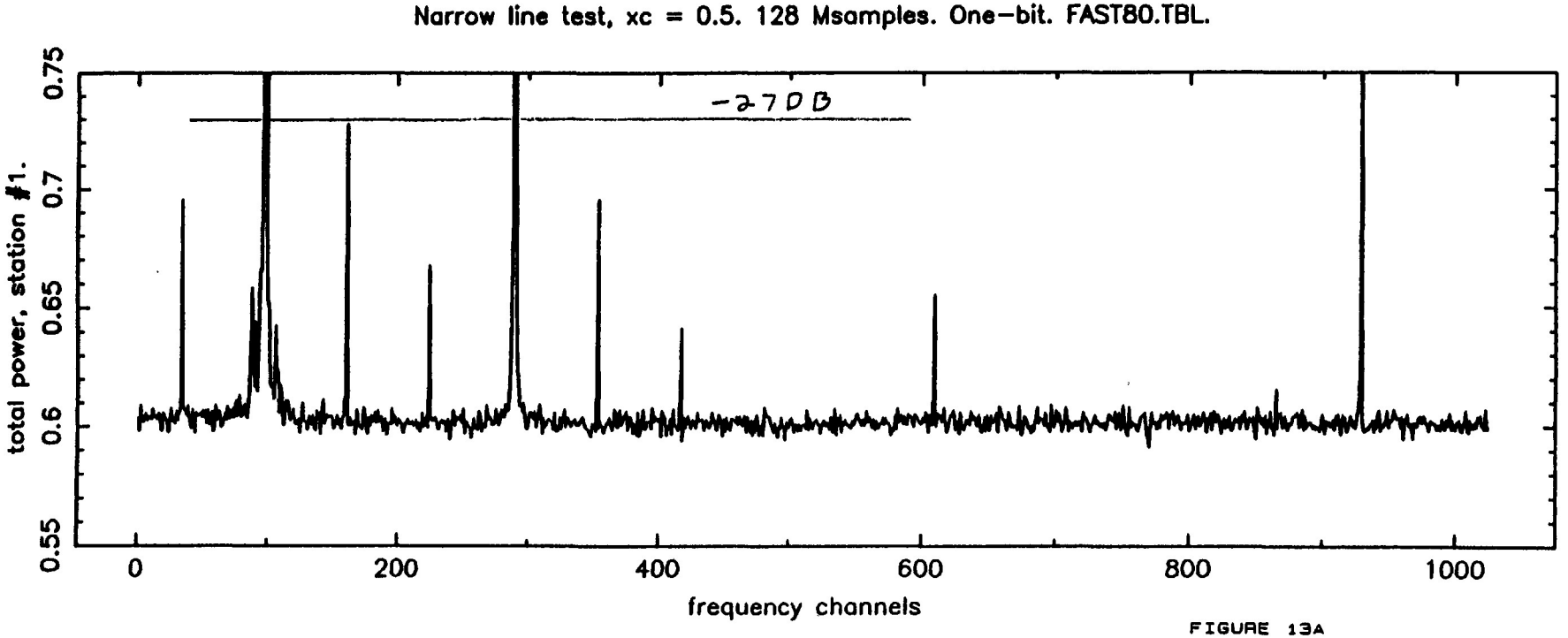
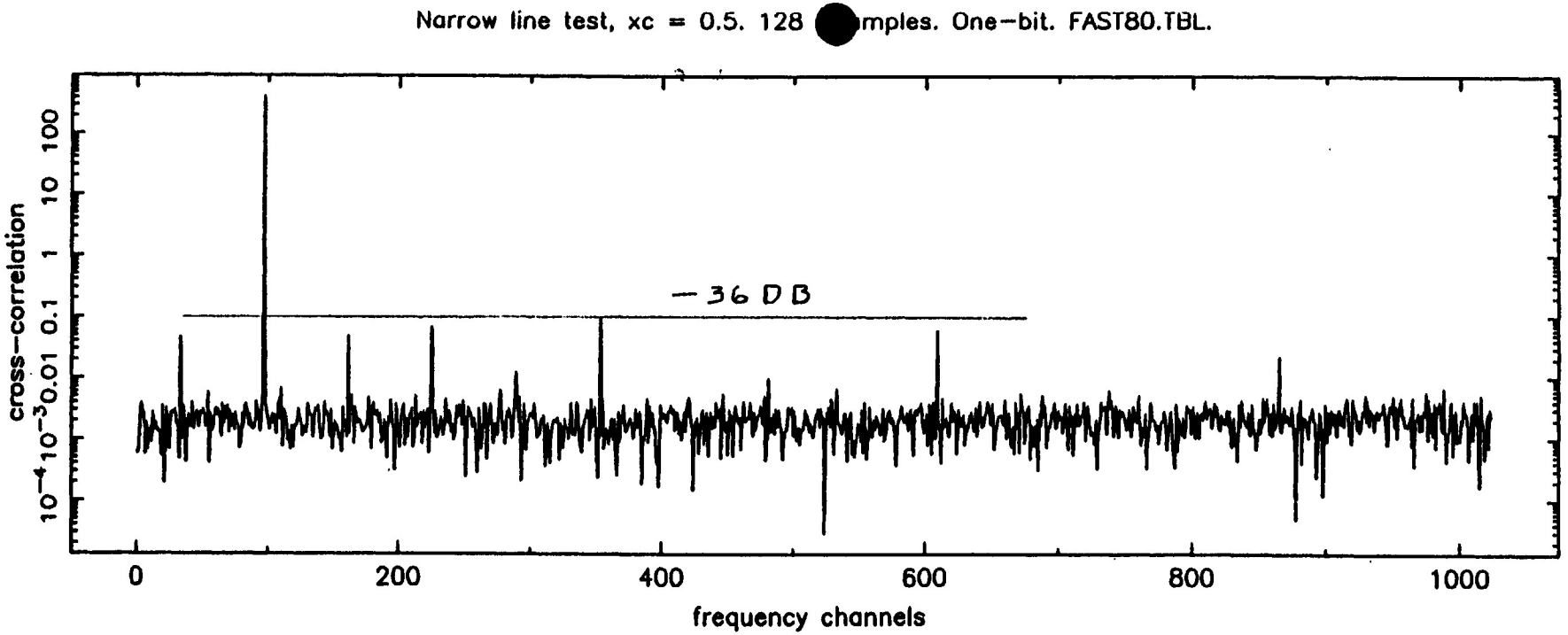

Narrow line test, xc = 0.5. 128 Msamples. One-bit. FAST80.TBL.
-27DB
total power, station #1.
0.55
0.6
0.65
0.7
0.75
0
200
400
600
800
1000
frequency channels

FIGURE 13A


Narrow line test, xc = 0.5. 128 Msamples. One-bit. FAST80.TBL.
cross-correlation
10^{-4} 10^{-3} 0.01 0.1 1 10 100
−36 DB
0
200
400
600
800
1000
frequency channels

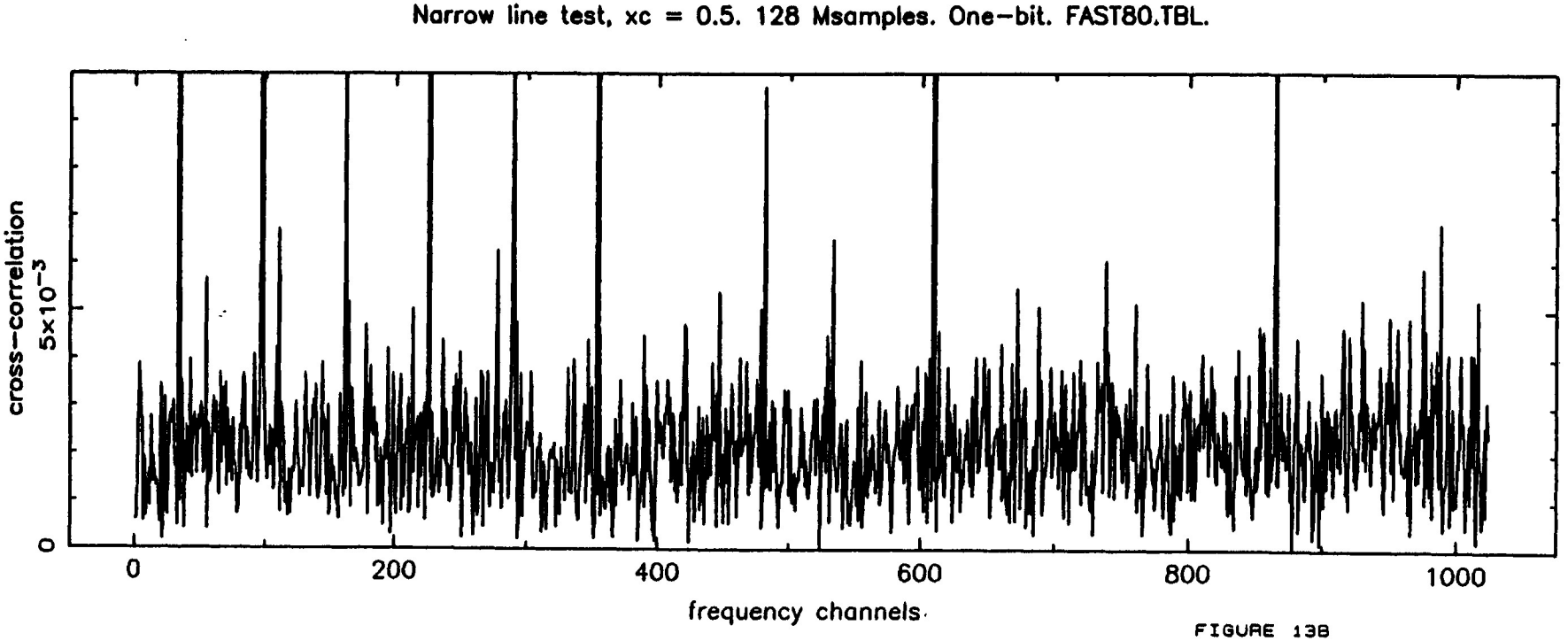
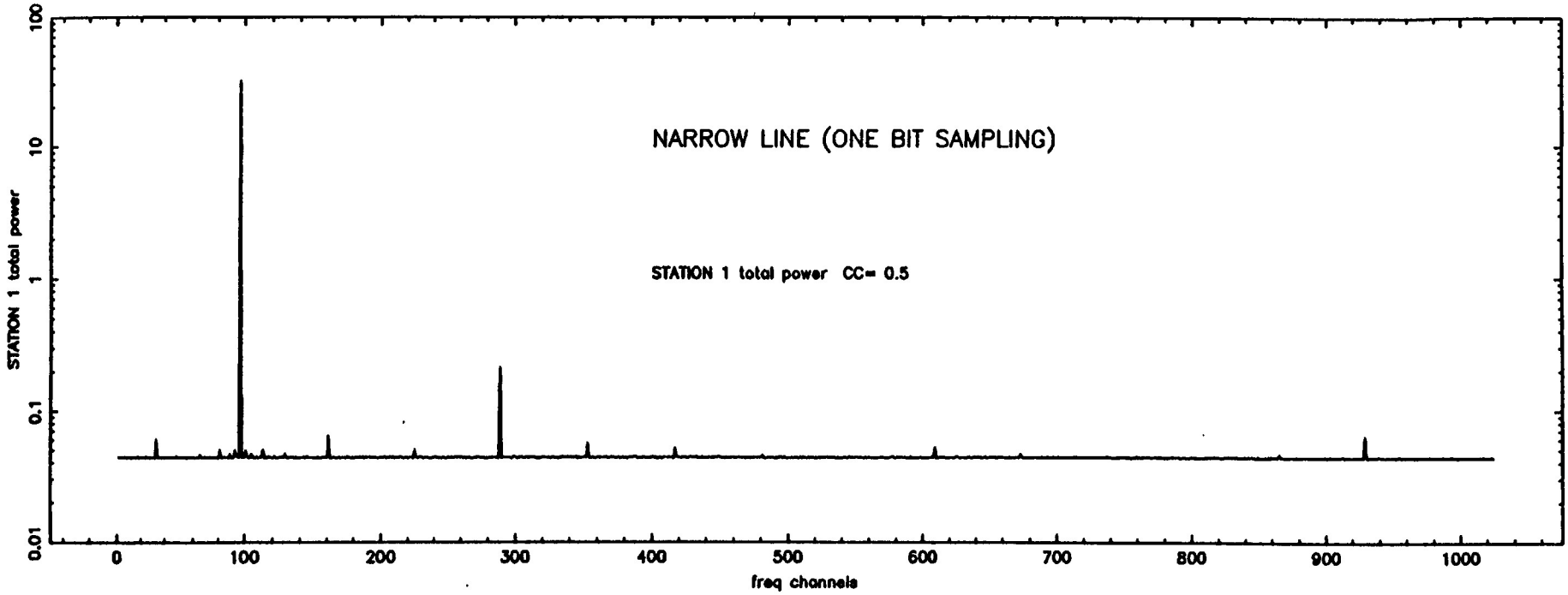

Narrow line test, xc = 0.5. 128 Msamples. One-bit. FAST80.TBL.
cross-correlation
5×10^{-3}
0
0
200
400
600
800
1000
frequency channels

FIGURE 13B



10-8-87 to 10-10-87 CC=0.5 127 meg 61600 ffts 550_32e '** 774 data **'

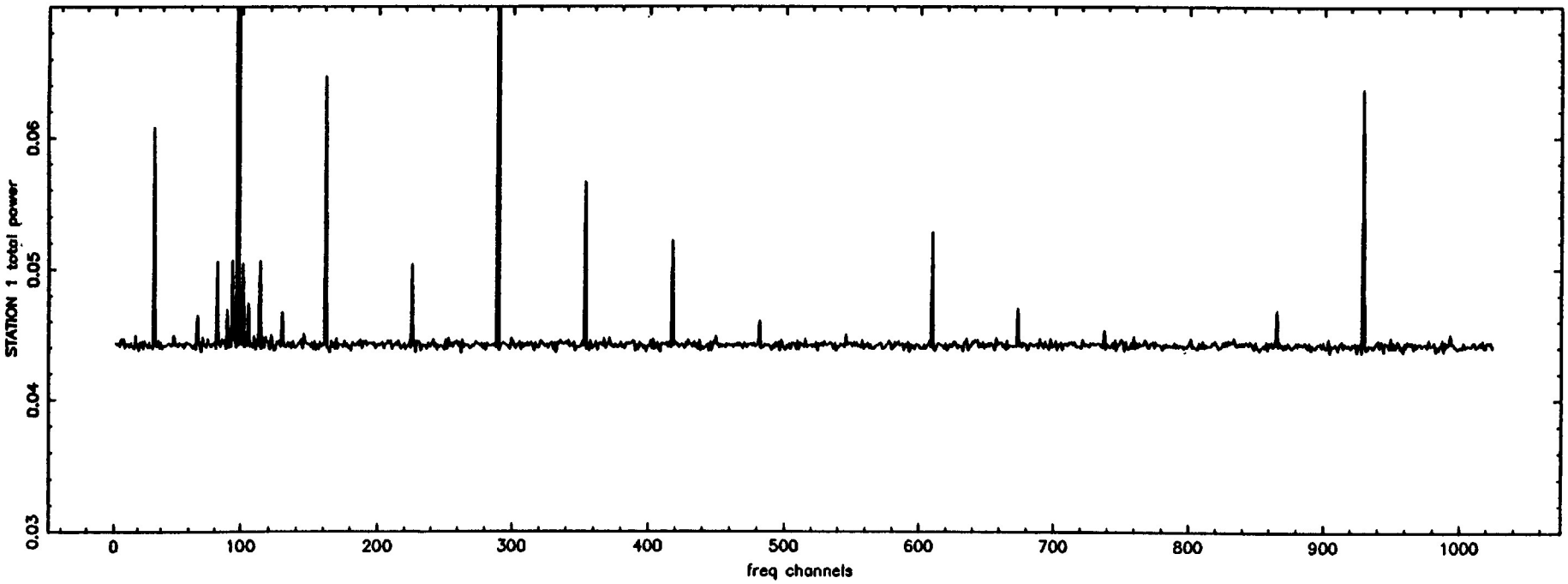
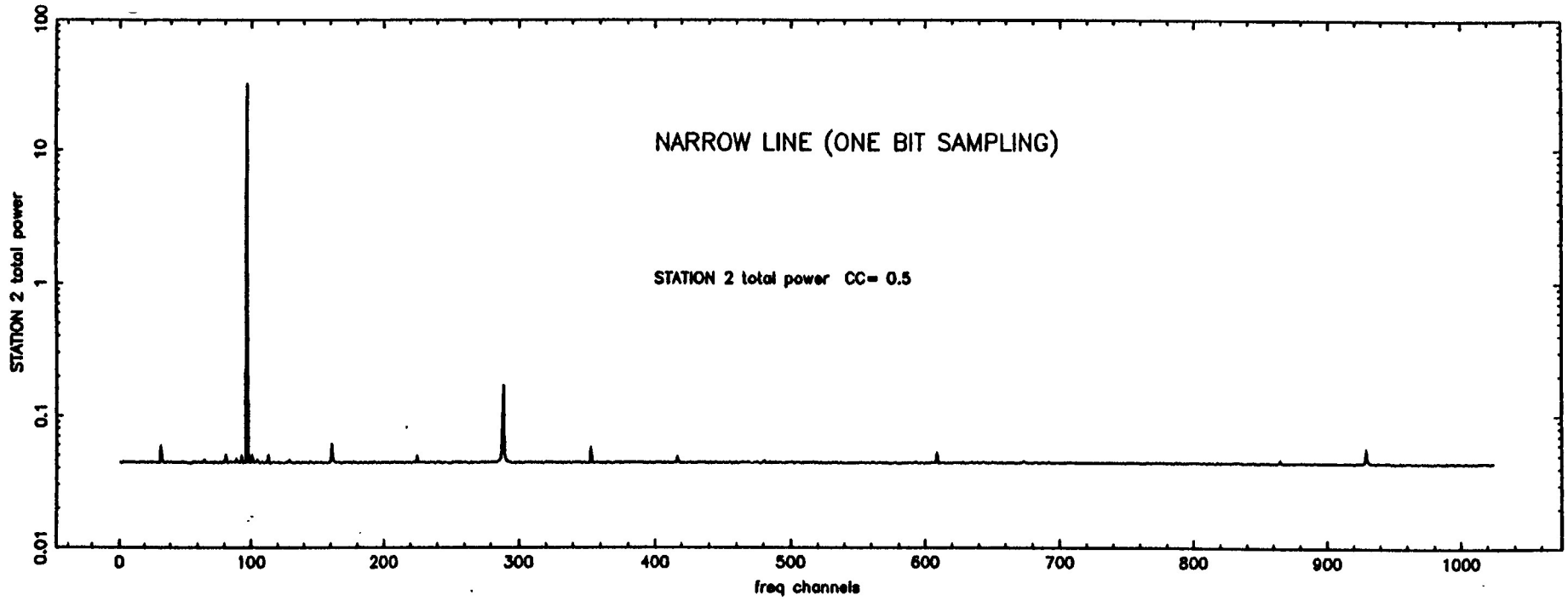


FIGURE 14A



10-8-87 to 10-10-87 CC=0.5 127 meg 61600 ffts 550_32e '** 774 data **'

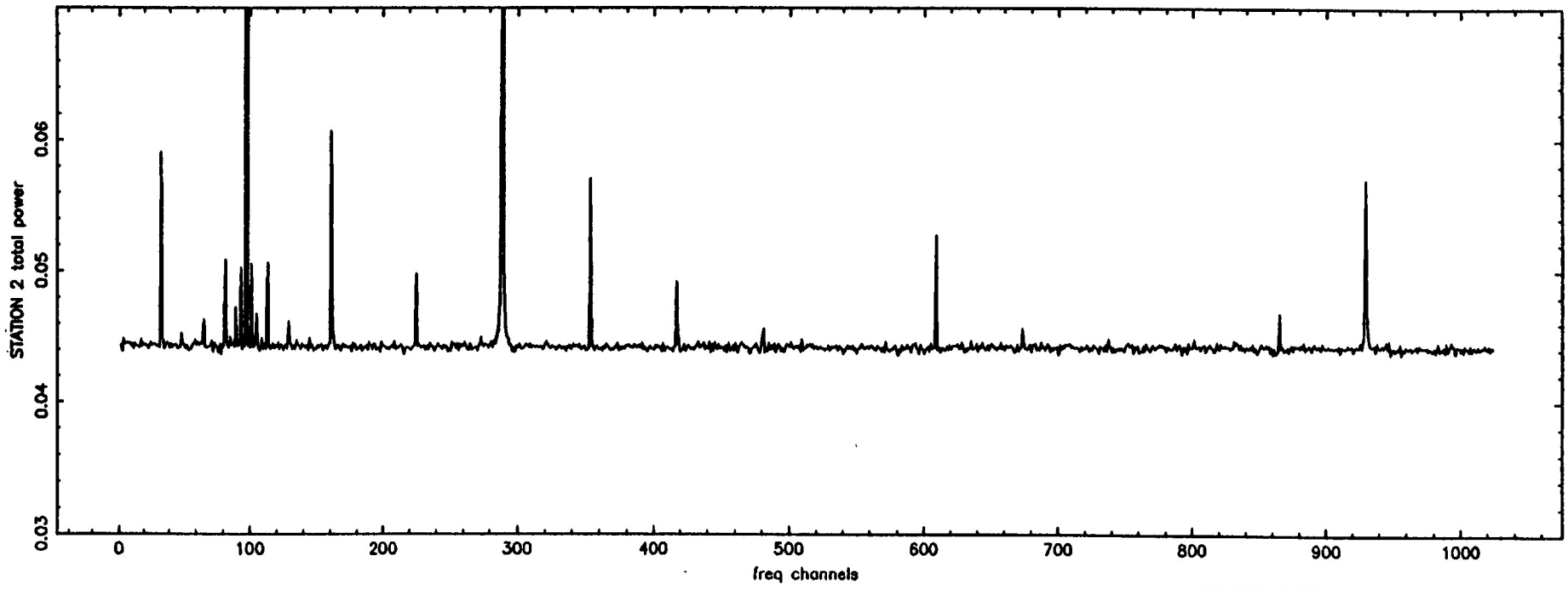
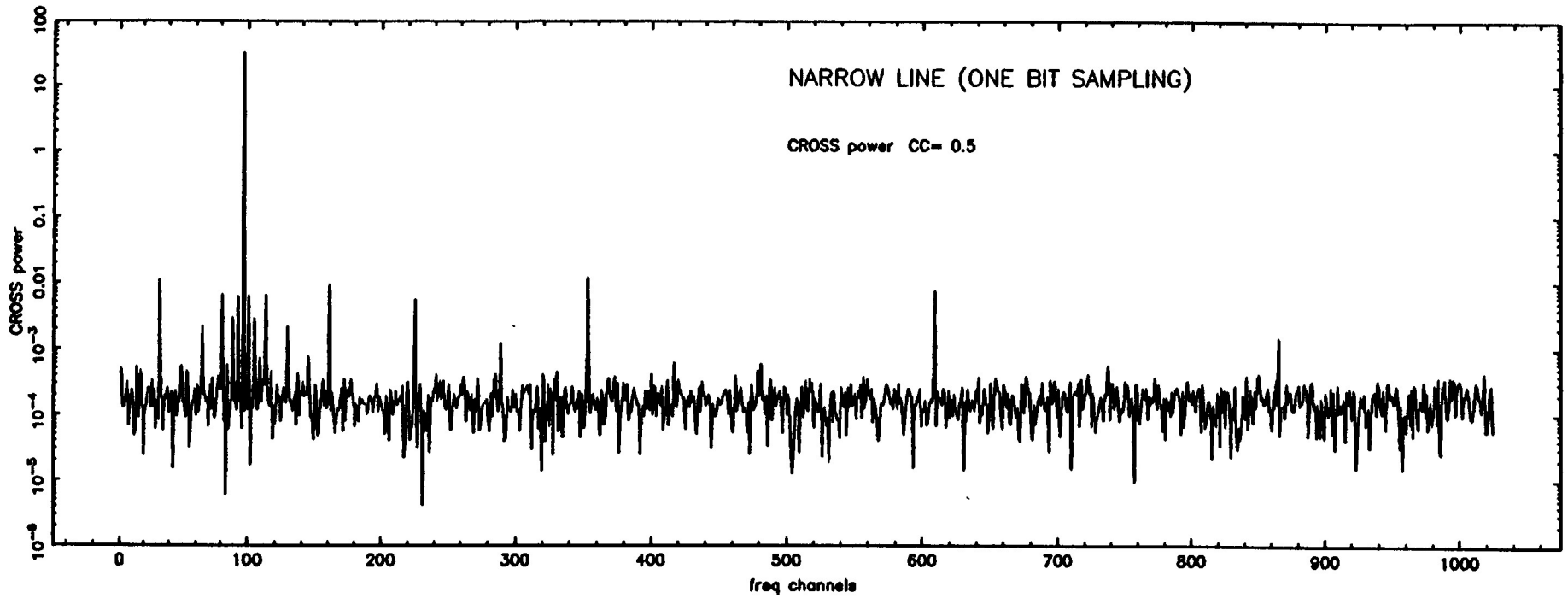


FIGURE 14B


NARROW LINE (ONE BIT SAMPLING)
CROSS power CC= 0.5
CROSS power
freq channels

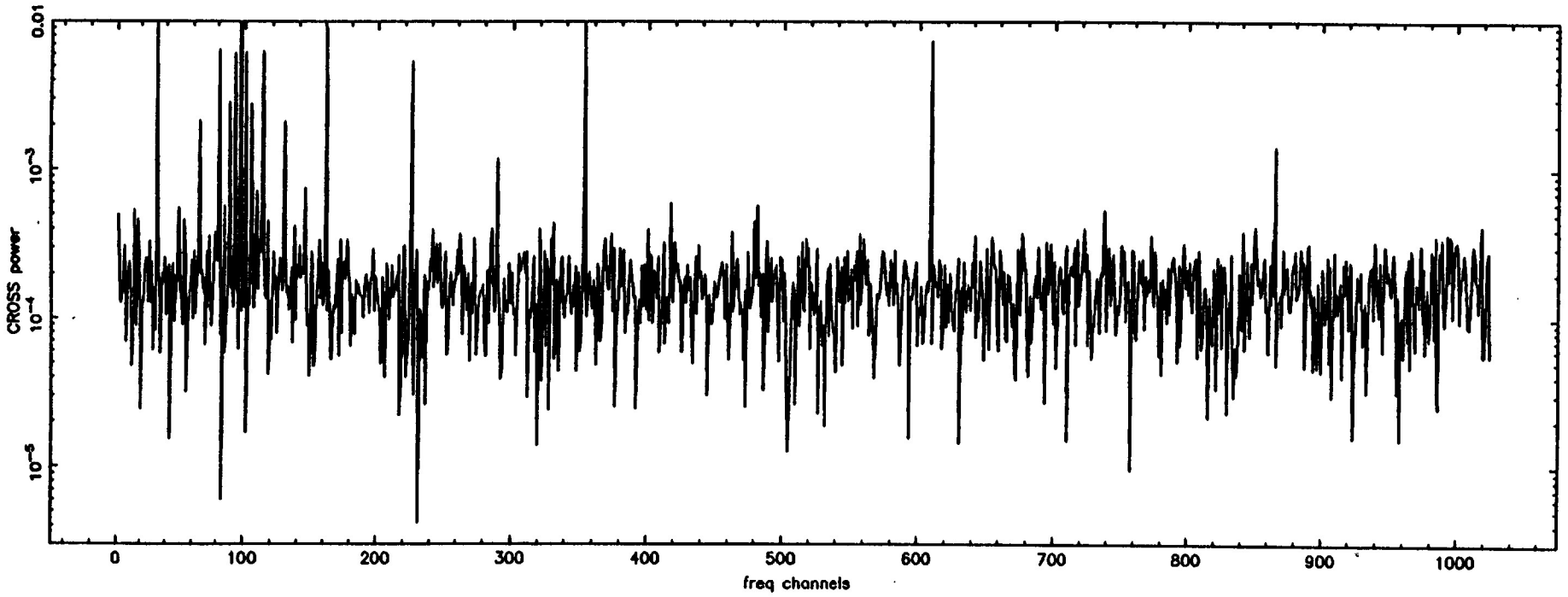
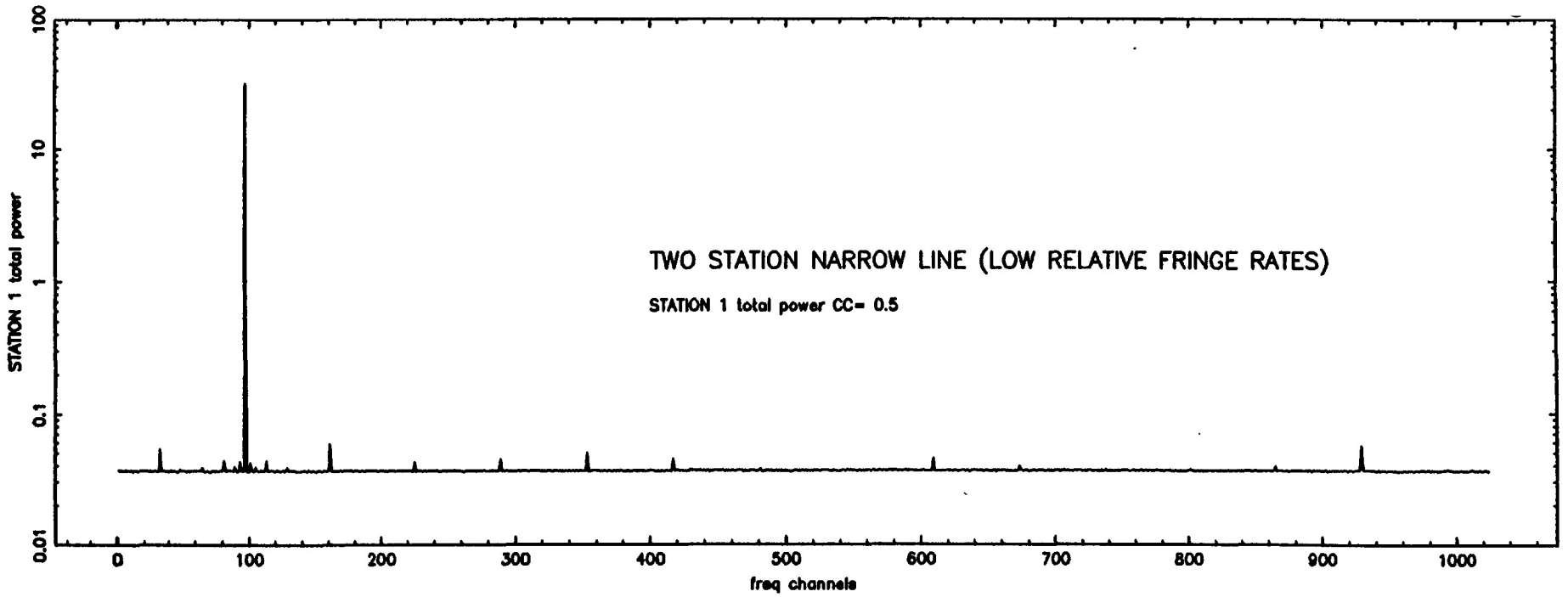

10-8-87 to 10-10-87 CC=0.5 127 meg 61600 ffts 550_32e '** 774 data **'
CROSS power
freq channels

FIGURE 14C



10-12-87 to 10-13-87 CC=0.5 95 meg 46400 ffts 550_32e '** 774 data **'

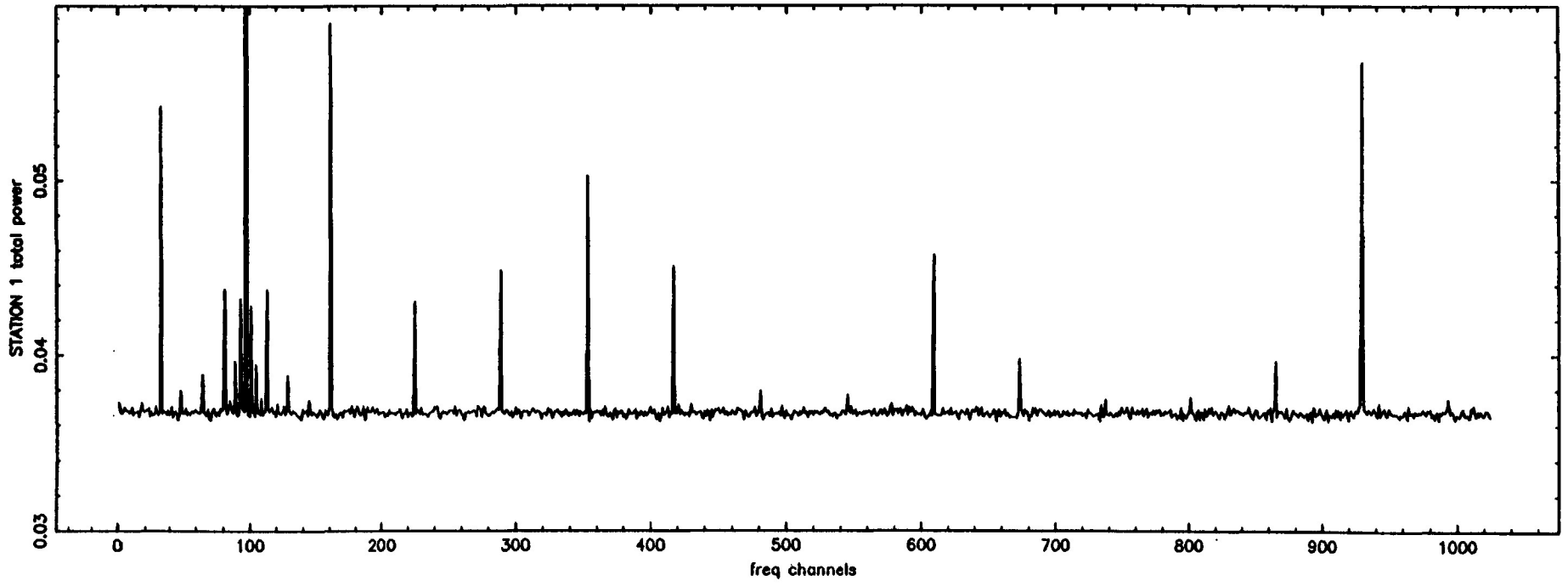
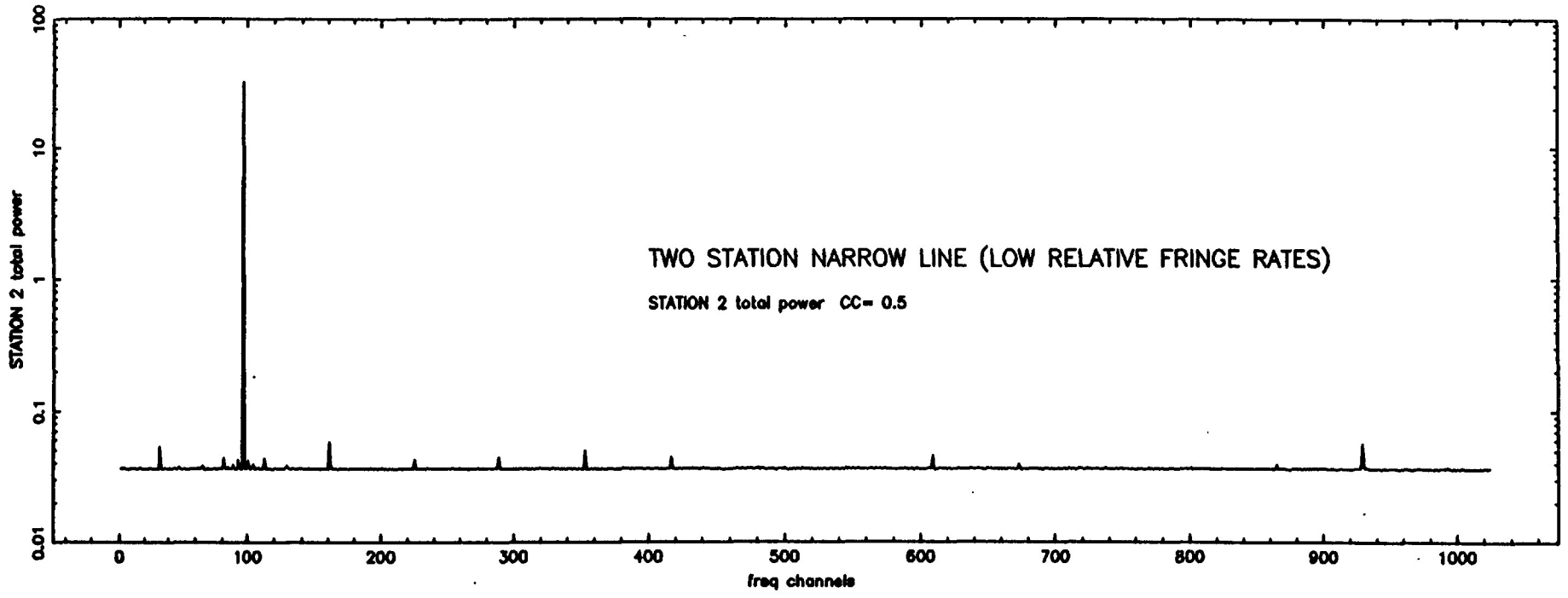


FIGURE 15A



10-12-87 to 10-13-87 CC=0.5 95 meg 46400 ffts 550_32e '** 774 data **'

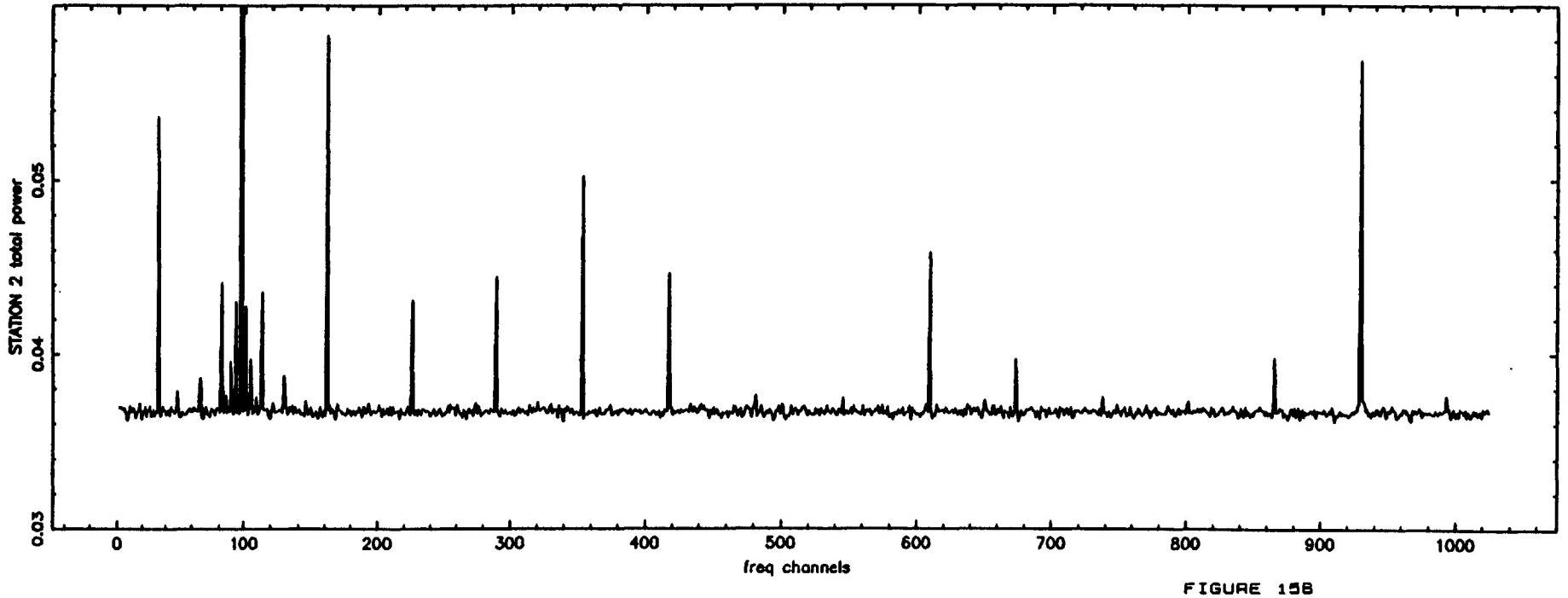
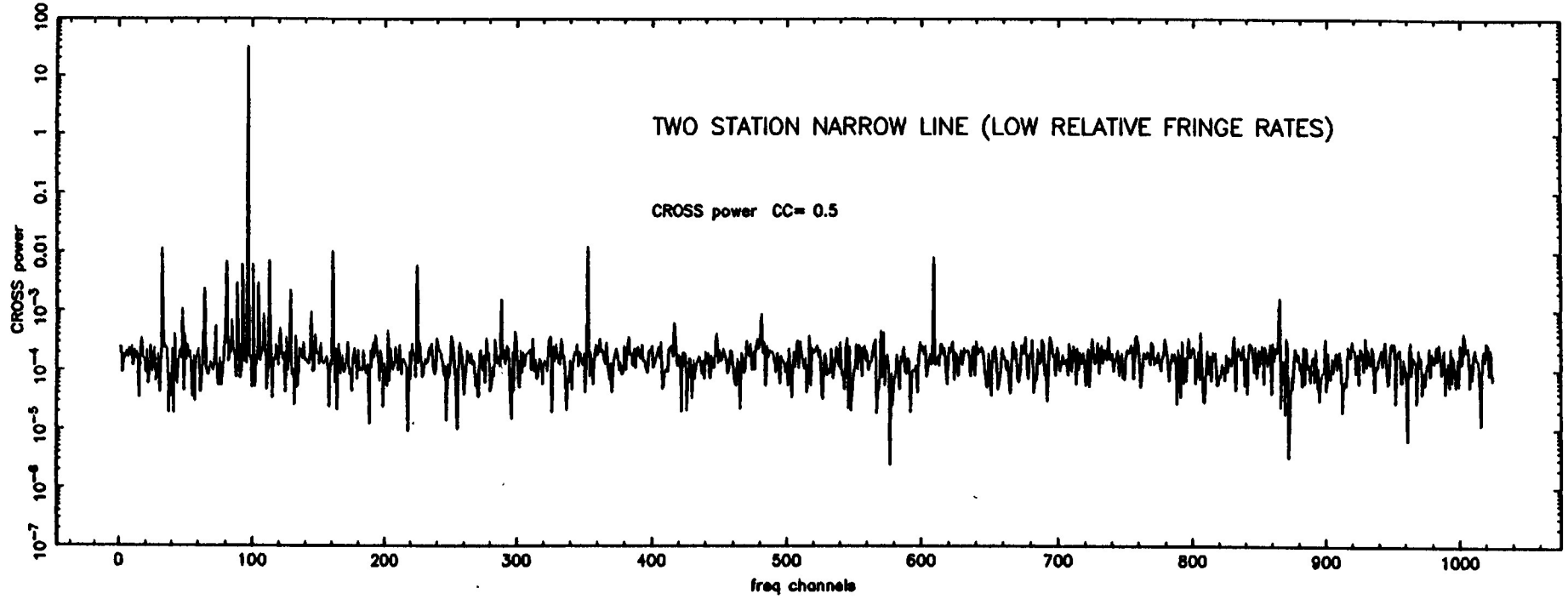


FIGURE 158



10-12-87 to 10-13-87 CC=0.5 95 meg 46400 ffts 550_32e '** 774 data **'

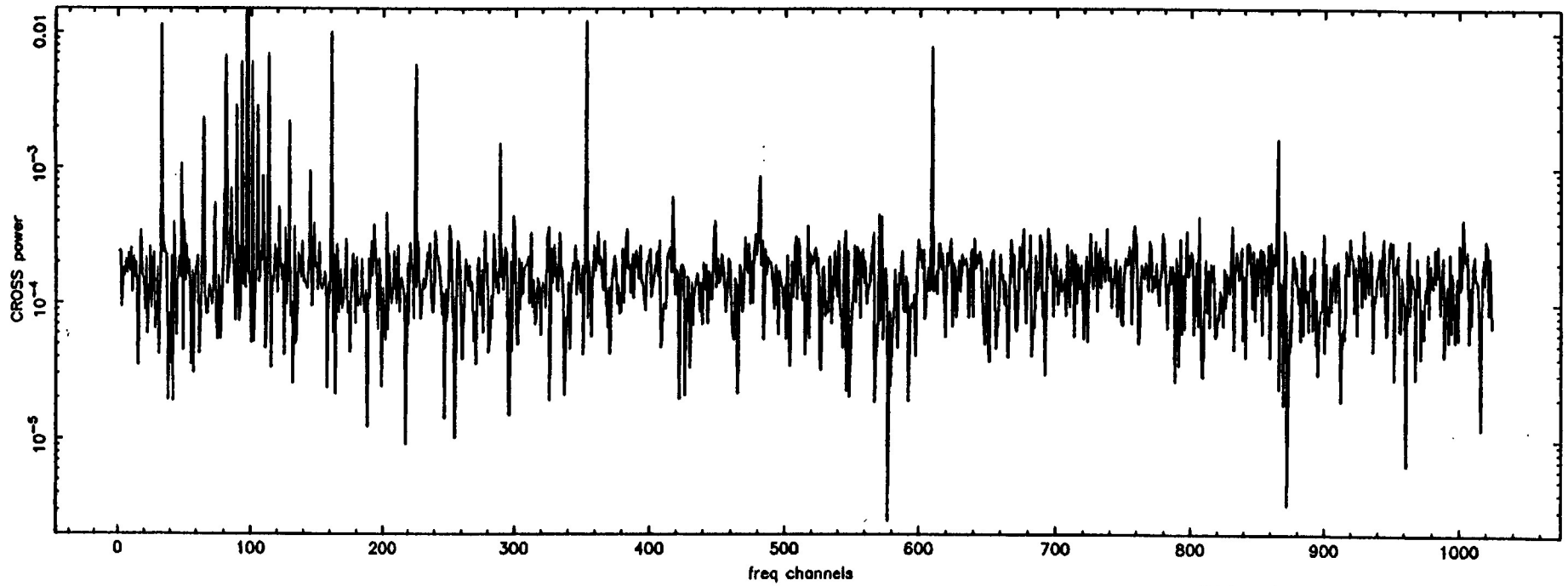
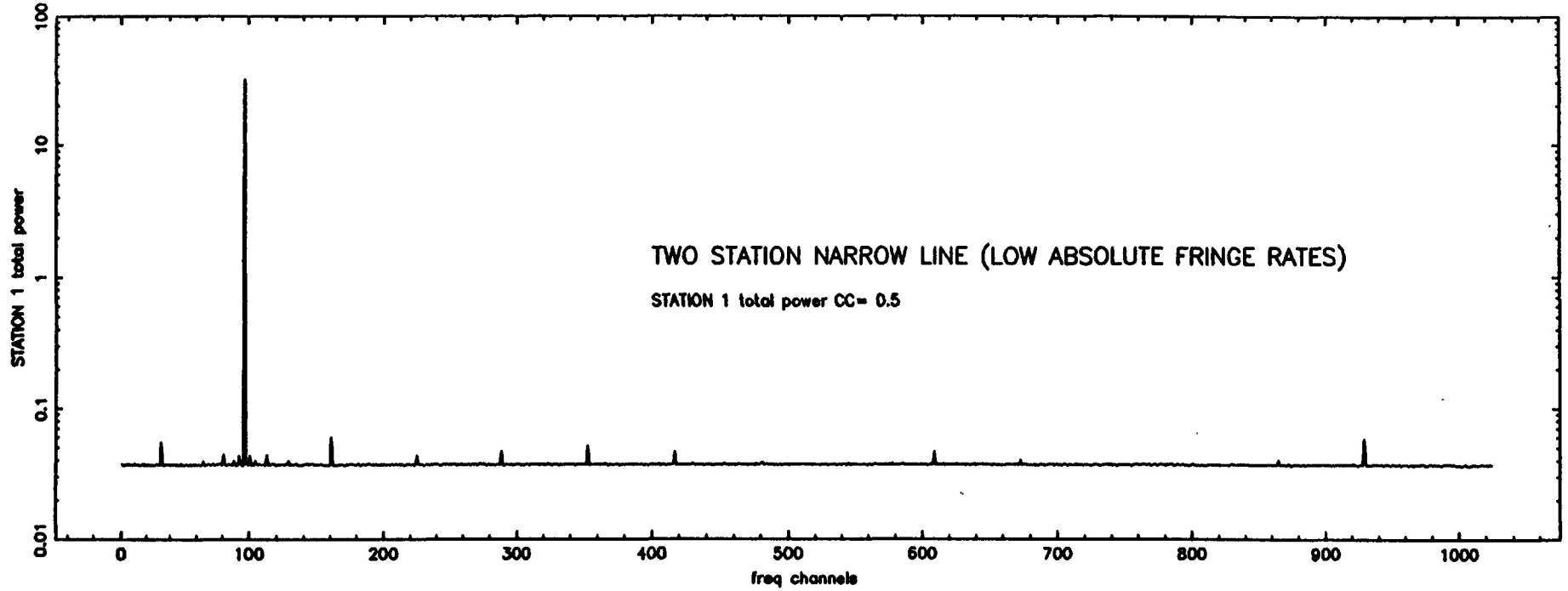


FIGURE 15C



10-13-87 to 10-14-87 CC=0.5 54 meg 26400 ffts 550_32e '** 774 data **'

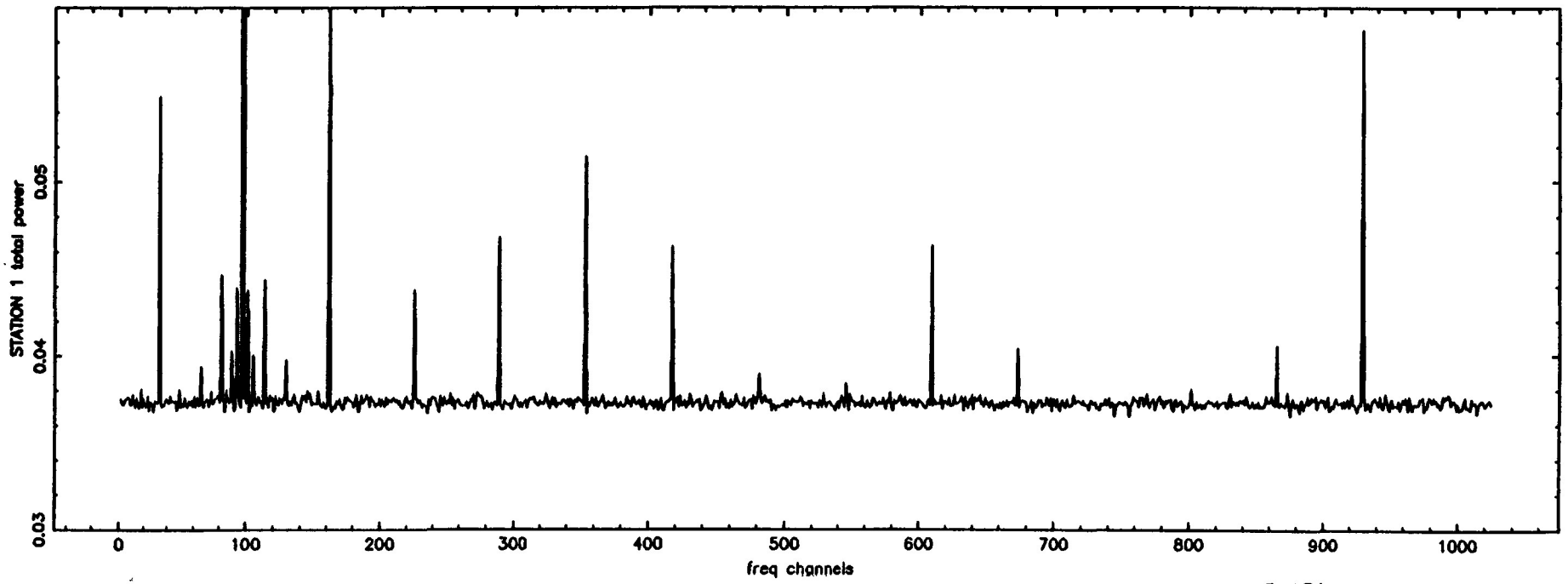
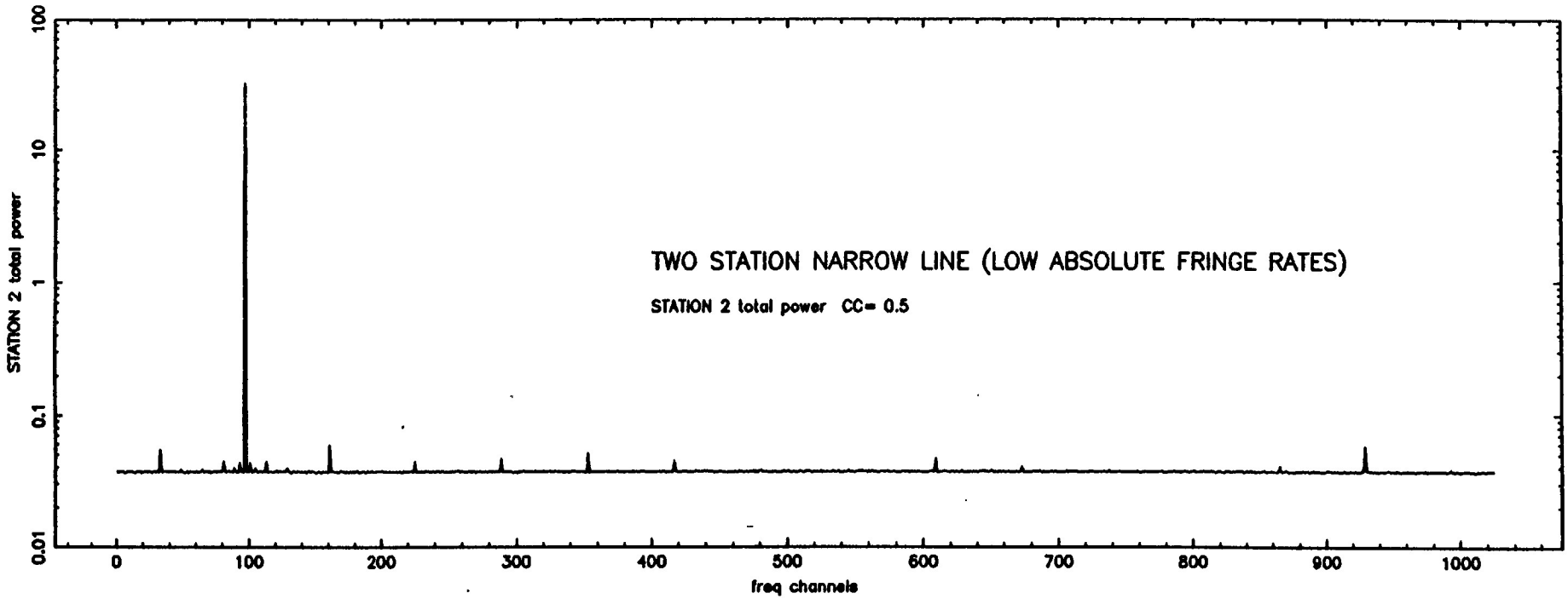


FIGURE 16A



10-13-87 to 10-14-87 CC=0.5 54 meg 26400 ffts 550_32e '** 774 data **'

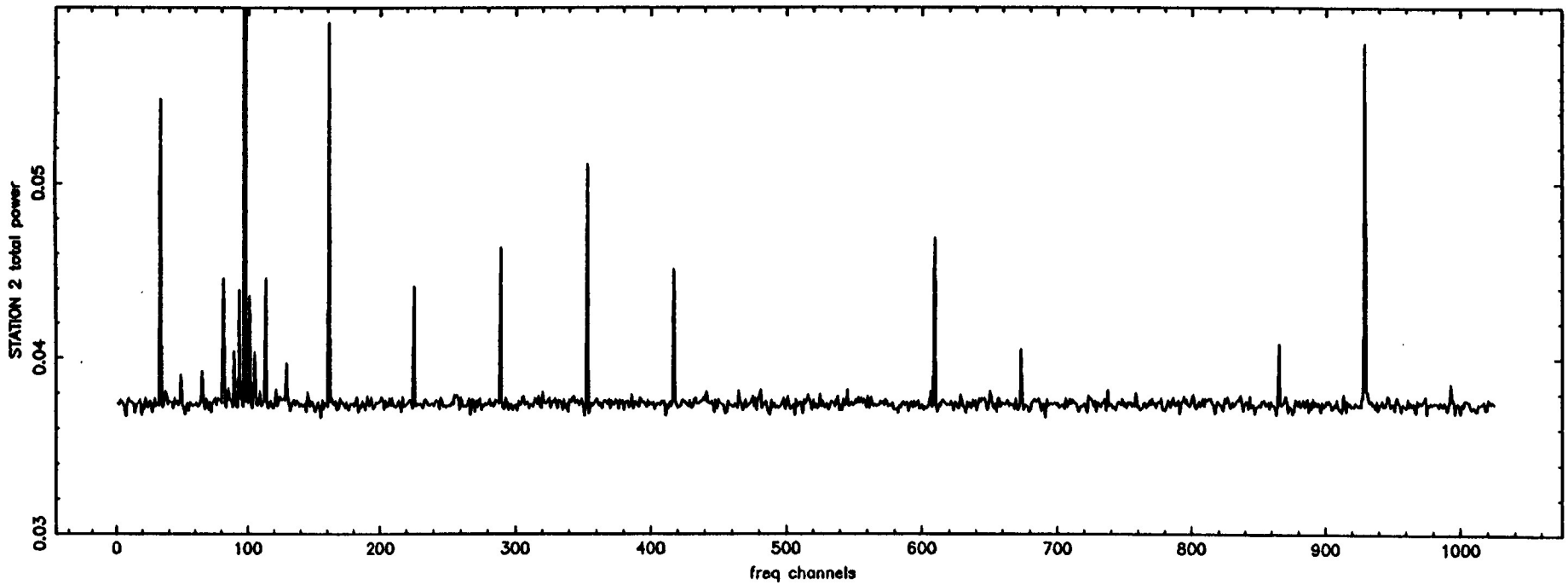
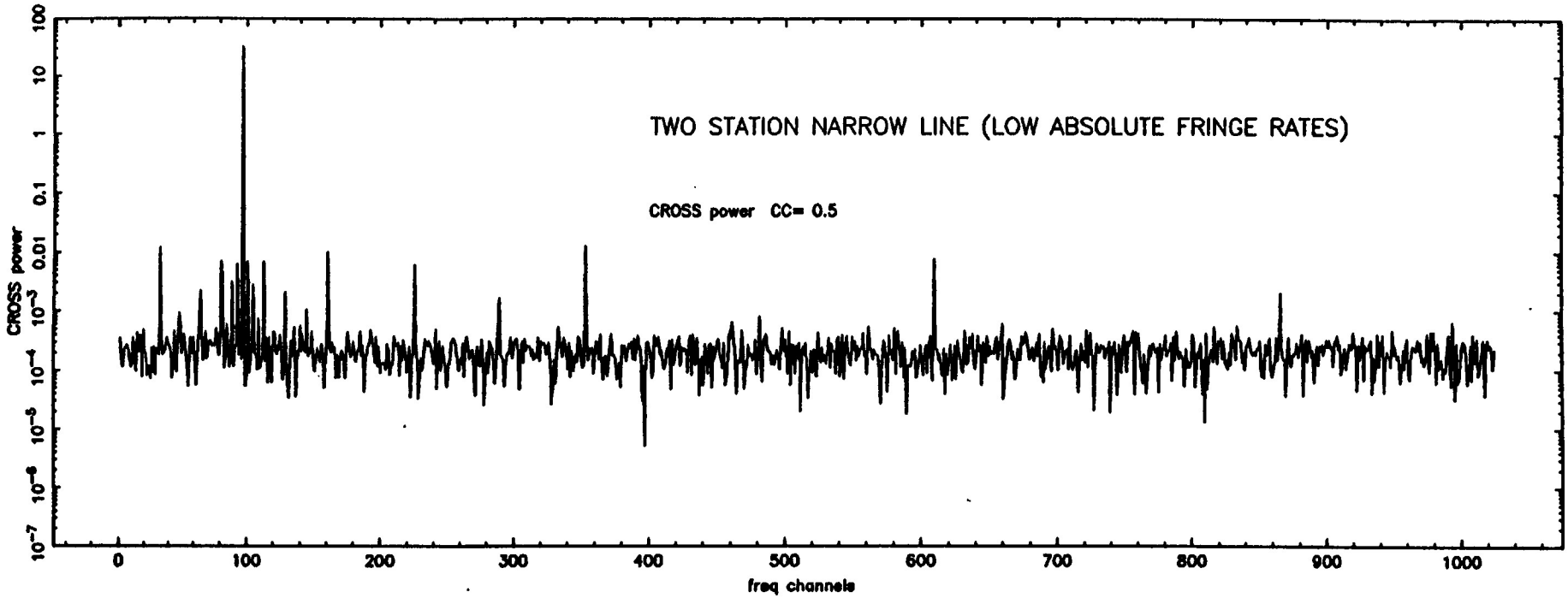


FIGURE 168



10-13-87 to 10-14-87 CC=0.5 54 meg 26400 ffts 550_32e '** 774 data **'

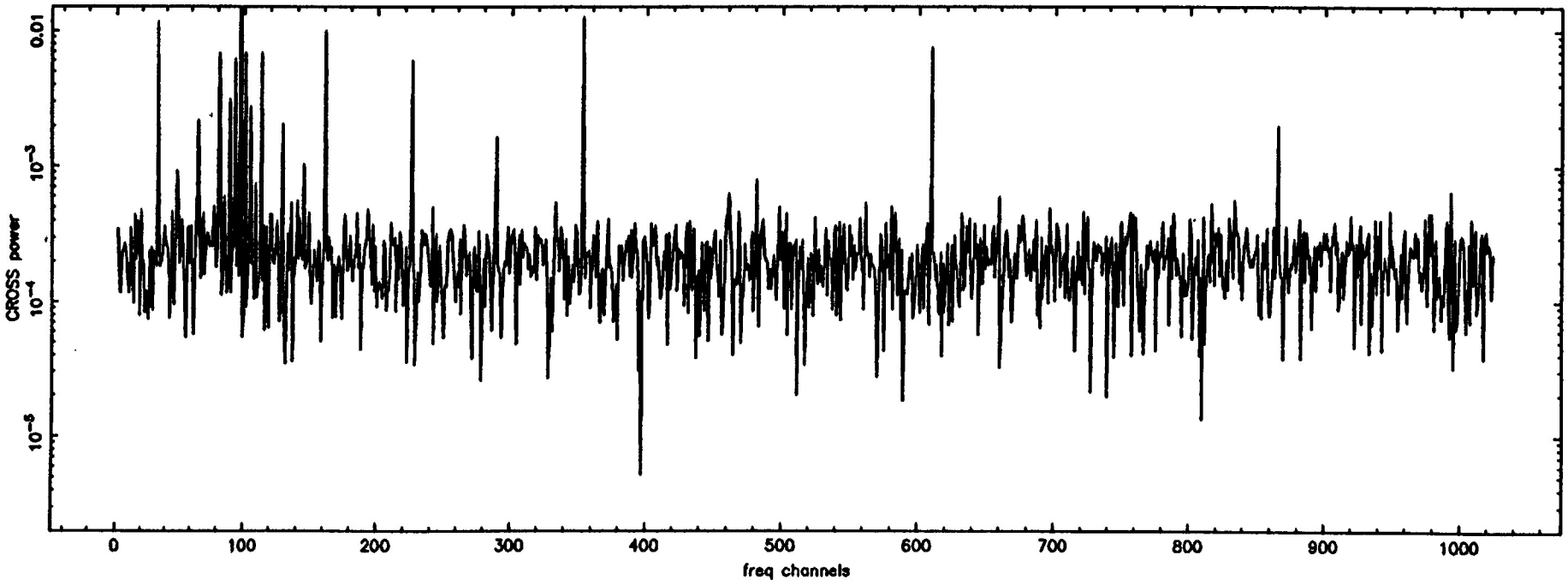


FIGURE 16C