NONLINEAR EFFECTS OF A ROTATING MAGNETIC FIELD ERROR PERTURBATION

Poster presented at the
38th Annual Meeting
APS Division of Plasma Physics
11-15 November 1996
Denver, Colorado

K.A. Mirus
J.C. Sprott

Department of Physics
University of Wisconsin-Madison
Madison, WI 53706

PLP 1192

November 1996

Abstract Submitted
for the DPP96 Meeting of
The American Physical Society

Sorting Category: 5.1.3 (experimental)

Nonlinear Effects of a Rotating Magnetic Field Error Perturbation † K.A. MIRUS, J.C. SPROTT, *University of Wisconsin-Madison* — Periodic perturbations applied to chaotic systems have been illustrated both numerically and experimentally to control the systems' dynamics or change their dimensionality. Such a perturbation has been applied as a rotating n=6 radial magnetic field error to the toroidal gap of the MST reversed-field pinch. Low power experiments done at fixed frequencies of 11 and 22 kHz show a shift in the peak of the power spectrum of edge magnetic fluctuations, but do not seem to lower their immeasurably high dimension. However, there is some evidence of stochastic resonance (the amplification of a weak periodic signal applied to a nonlinear system in the presence of an optimal amount of noise). Future experiments using greater perturbation amplitudes and different perturbation frequencies should provide clearer results.

†This work was supported by the USDOE.

[ ] Prefer Oral Session
[X] Prefer Poster Session

Kevin A. Mirus
mirus@juno.physics.wisc.edu
University of Wisconsin-Madison

Special instructions: Please place in the MST reversed-field pinch poster grouping.

Date submitted: July 10, 1996

Electronic form version 1.1

Revised Abstract

Periodic perturbations applied to chaotic systems have been illustrated both numerically and experimentally to control the systems' dynamics or change their dimensionality. Such a perturbation has been applied as a rotating n=6 and n=1 radial magnetic field error to the toroidal gap of the MST reversed field pinch. Low power experiments done at fixed frequencies of 11 and 22 kHz show a shift in the peak of the power spectrum of edge magnetic fluctuations, but do not seem to lower their immeasurably high dimension. However, there is some evidence of stochastic resonance (the amplification of a weak periodic signal applied to a nonlinear system in the presence of an optimal amount of noise). Future experiments using greater perturbation amplitudes and different perturbation frequencies should provide clearer results.

This work was supported by the U.S. Department of Energy.

Outline

I. Motivation

II. Experimental Apparatus

III. General Effects on Mode Rotation and Locking

IV. Nonlinear Effects I: Stochastic Resonance

V. Nonlinear Effects II: Correlation Dimension

VI. Summary

VII. Future Work

I. Motivation

- Motivation from a standard mode rotation point of view:
    - Rotating field errors are known to help prevent locking through entrainment of resonant islands to the rotating perturbation. The perturbation essentially serves as an asynchronous induction motor.
    - The m=1, n=6 mode is a dominant mode in the MST. Thus, an n=6 perturbation was initially chosen to be applied.
    - An m=0, n=1 mode is dominant at the reversal surface, so an n=1 perturbation has also been applied.

- Motivation from a nonlinear dynamics point of view:
    - Control of some simple chaotic systems with small system perturbations has been established.
    - The "induction motor" provides a good starting point to search for similar effects in the MST.

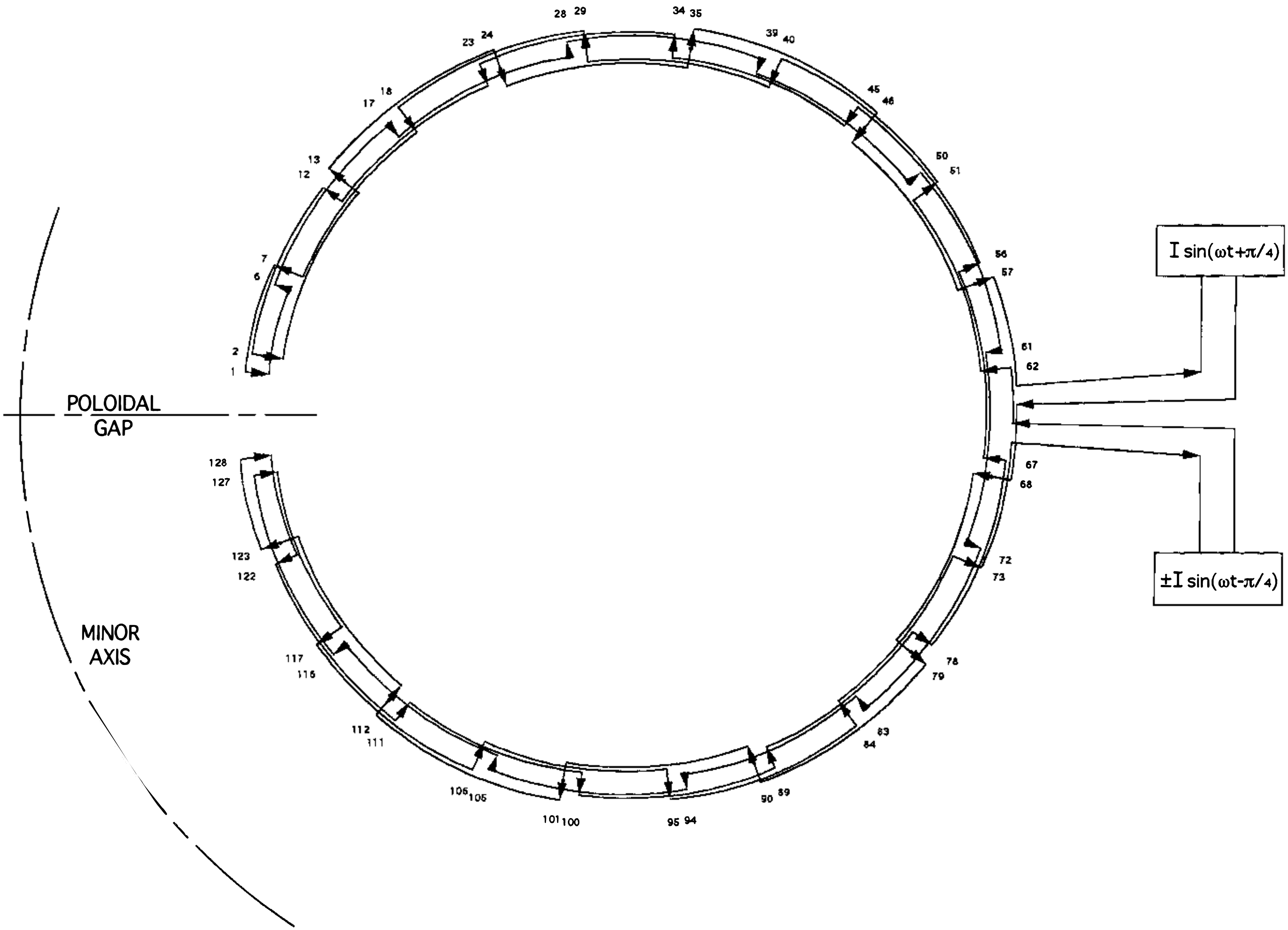
II. Experimental Apparatus

- The n=6 and n=1 induction motors each consist of two sets of coils which thread the toroidal gap of MST in appropriate locations to yield the desired mode structure.

- The two coil sets for each induction motor are driven in quadrature with resonant RLC circuits to give a rotating field error (see poster 2S.10 for further details).

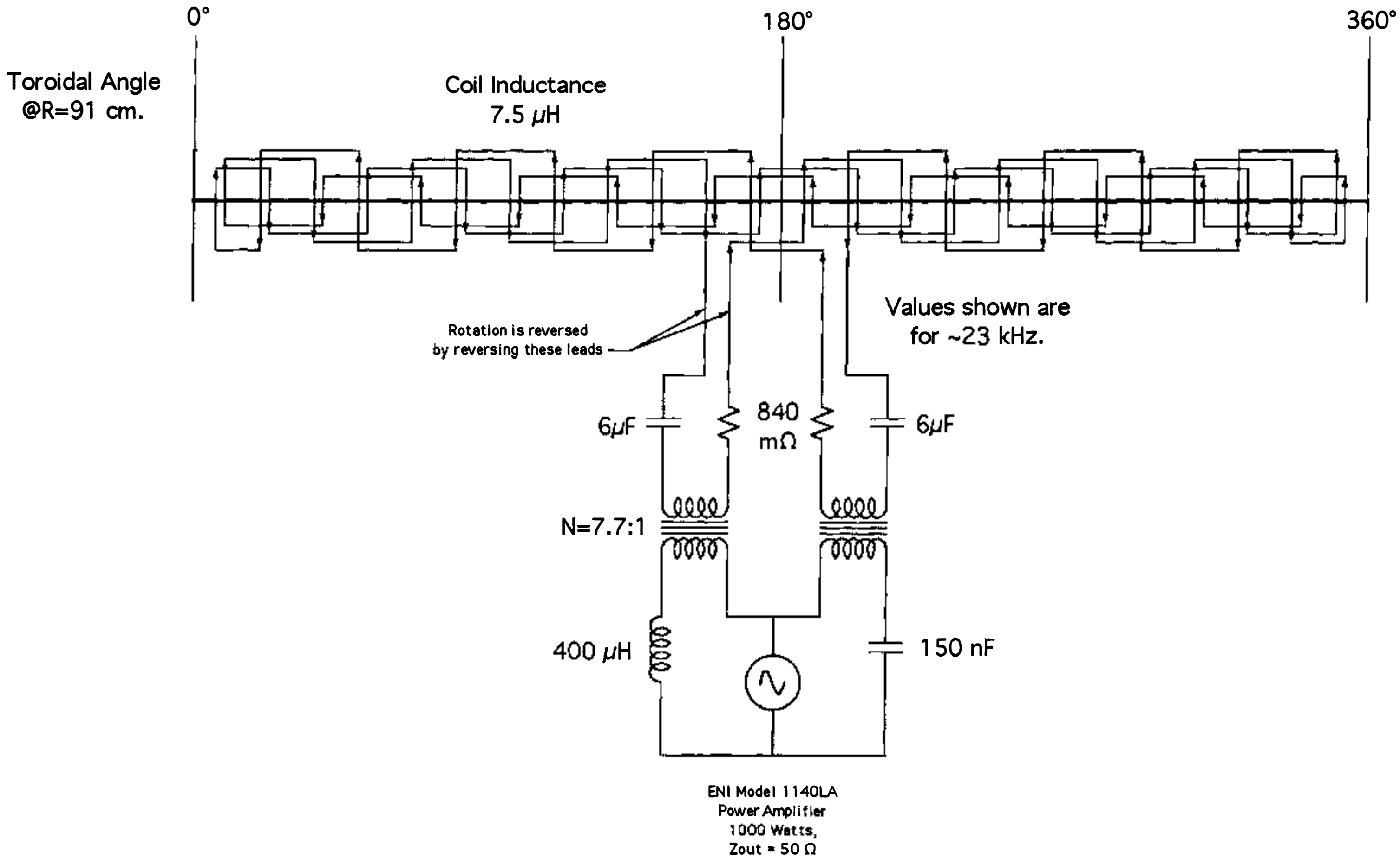
- Due to present circuit limitations, no more than ~80A P-P has been driven in the induction motors.

MST n=6 coils, Top View



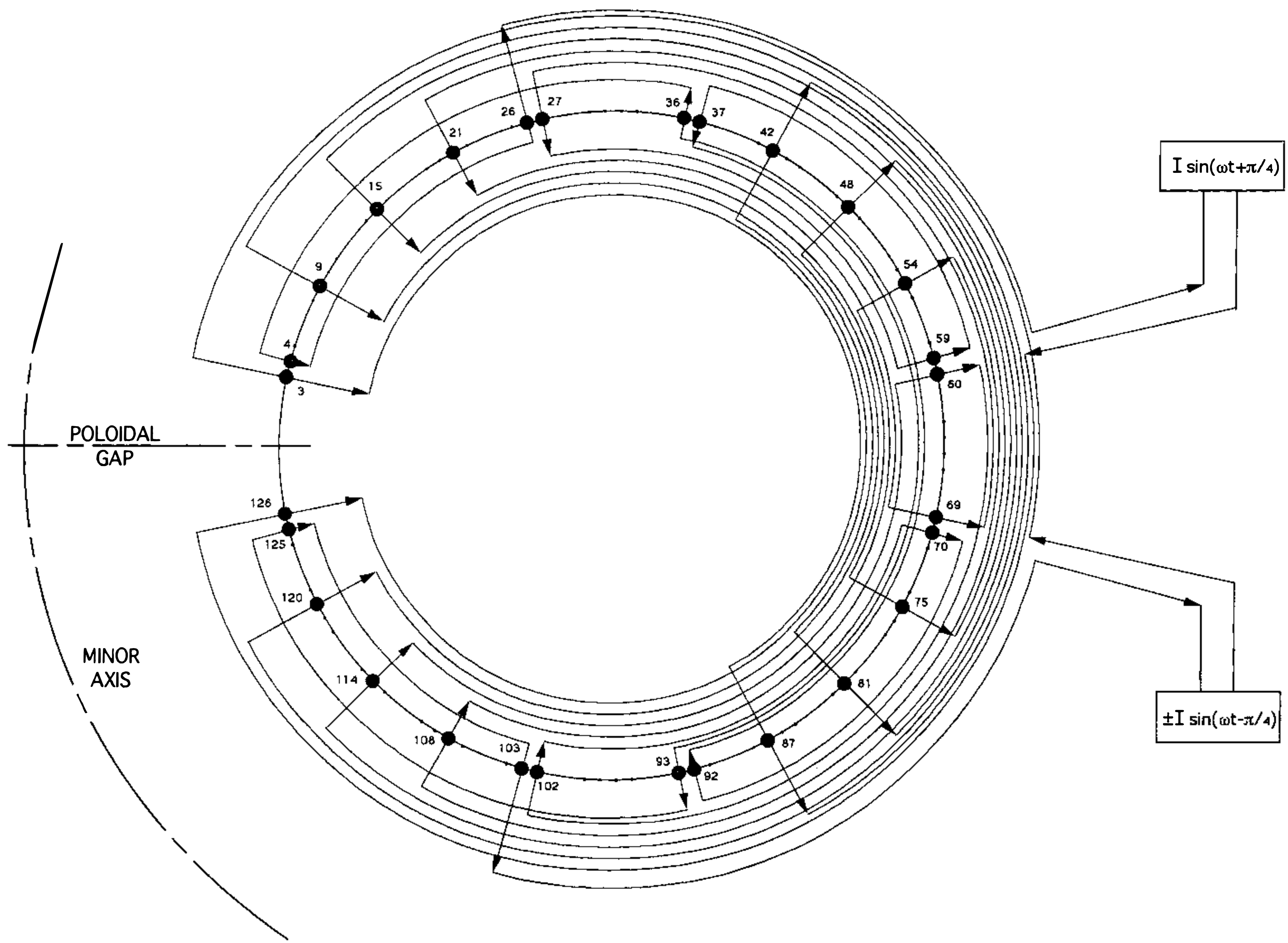
M. Thomas 09/09/96

MST n=6 coils, Schematic



M. Thomas 09/09/96

MST n=1 coils, Top View



M. Thomas 11/04/96

III. General Effects on Mode Rotation and Locking

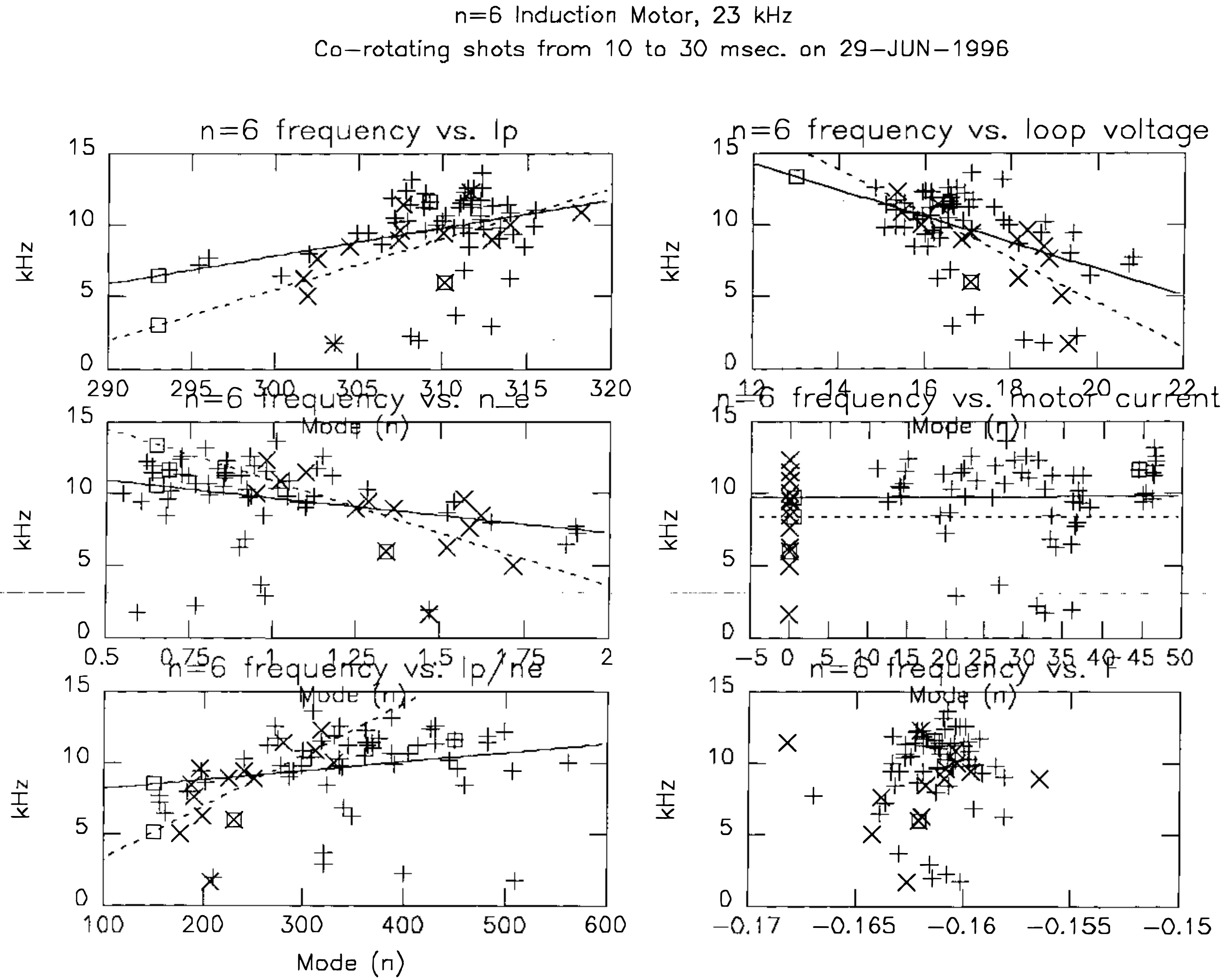
• The n=6 induction motor seems to increase the rotation frequency of the m=1, n=5,6,7,8 modes a bit, but it does not increase the n=6 mode amplitude.

• The n=1 induction motor does not seem to have any effect on the usually locked m=0, n=1 mode.

• For a couple anomalous shots, the plasma locked or unlocked with the application of a 10 msec gated n=6 perturbation.

• Summary of the overall occurance of locked shots with the induction motors:

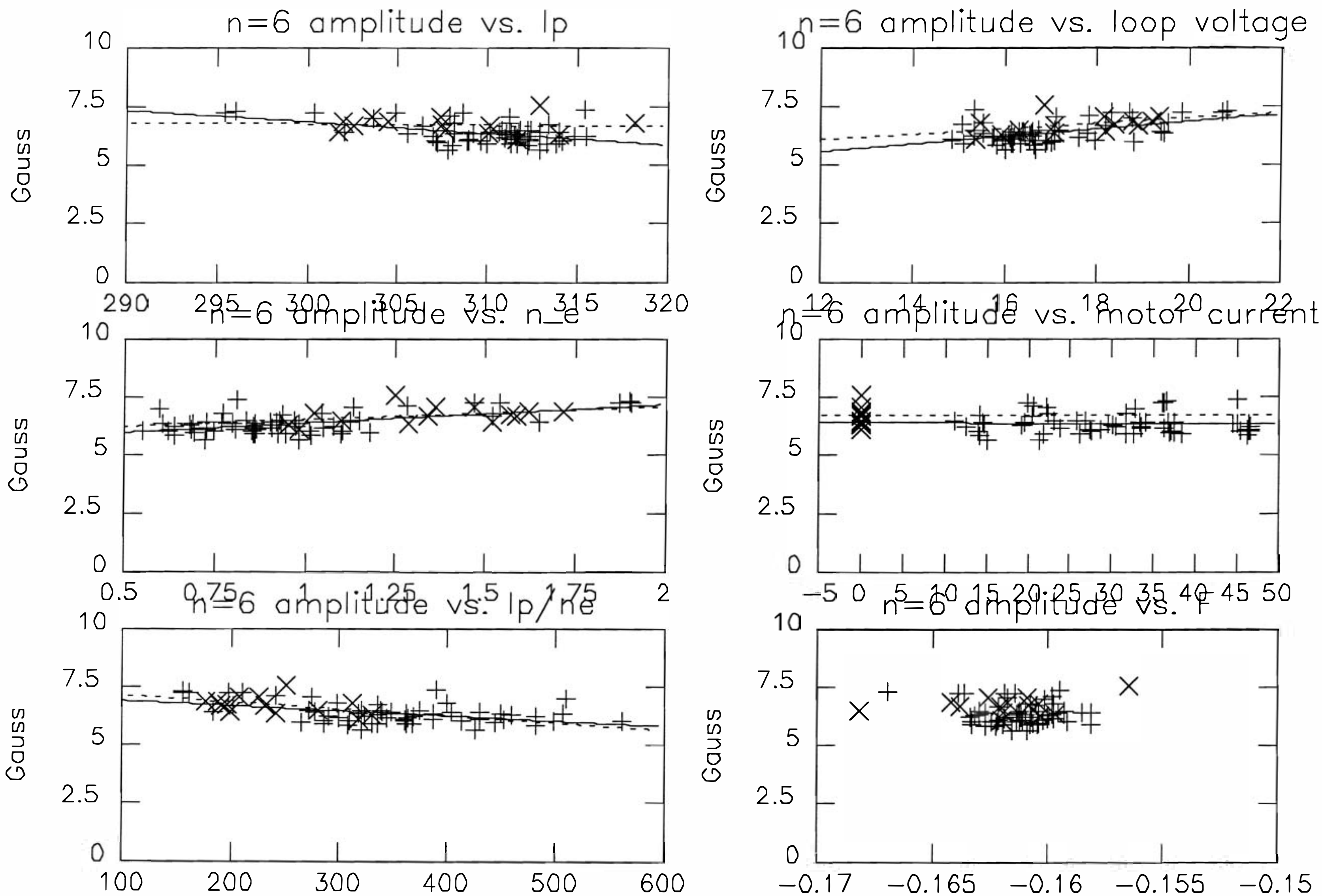
number of poles in "motor"	drive frequency (kHz)	co- or counter-rotating	percent unlocked shots
no motor	----	----	68%
n=6	23.0	co-	65%
n=6	23.0	counter-	80%
n=6	10.9	co-	52%
n=6	10.9	counter-	62%
n=1	10.0	co-	69%
n=1	10.0	counter-	50%



n=6 Induction Motor, 23 kHz
Co-rotating shots from 10 to 30 msec. on 29-JUN-1996
n=6 frequency vs. Ip
n=6 frequency vs. loop voltage
n=6 frequency vs. n_e
n=6 frequency vs. motor current
n=6 frequency vs. Ip/ne
n=6 frequency vs. F
kHz
Mode (n)

n=6 Induction Motor, 23 kHz

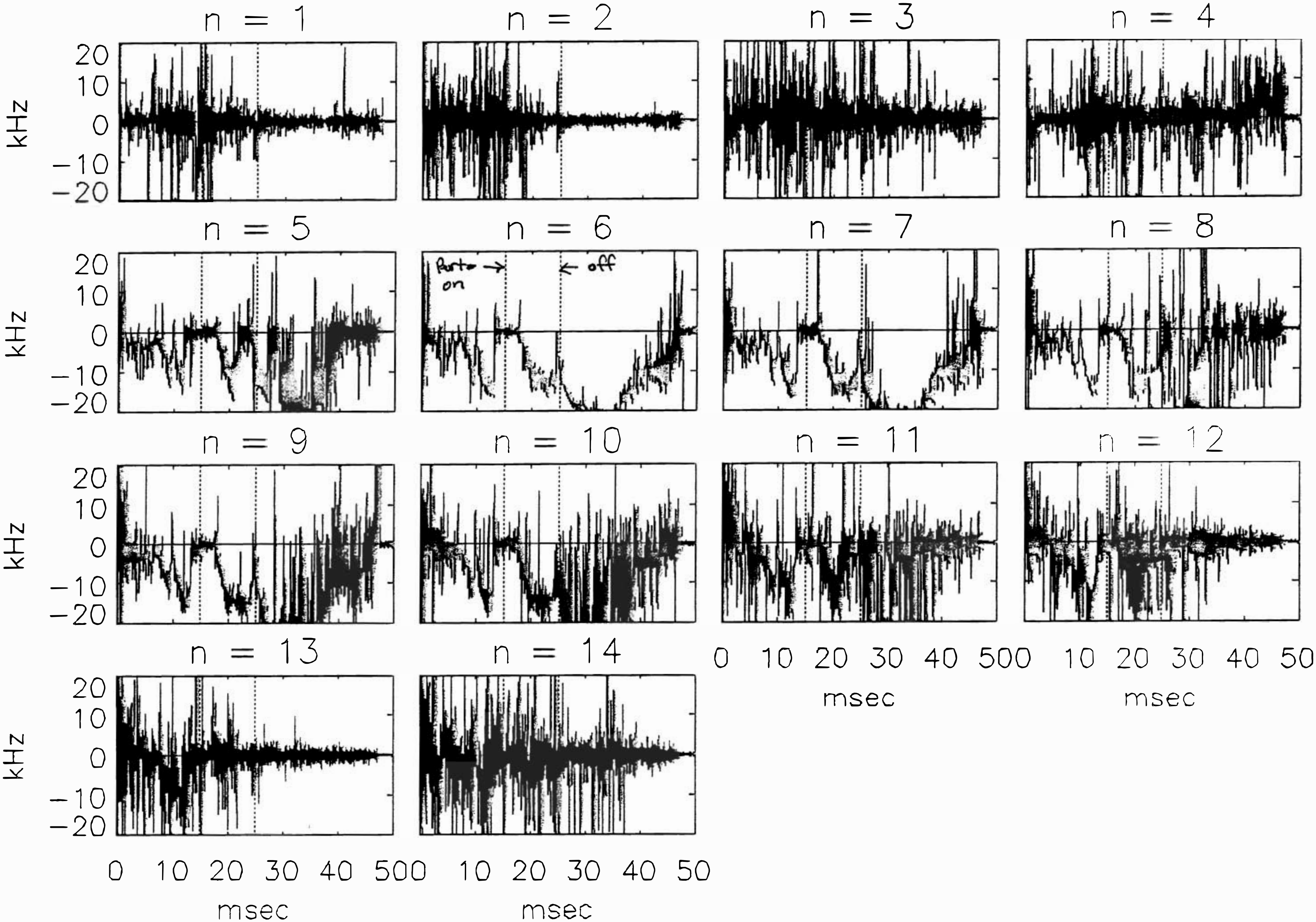
Co–rotating shots from 10 to 30 msec. on 29–JUN–1996



Co-Rotating Perturbation

Mode Rotation Frequencies, SHOT # 82 7-JUL-1996

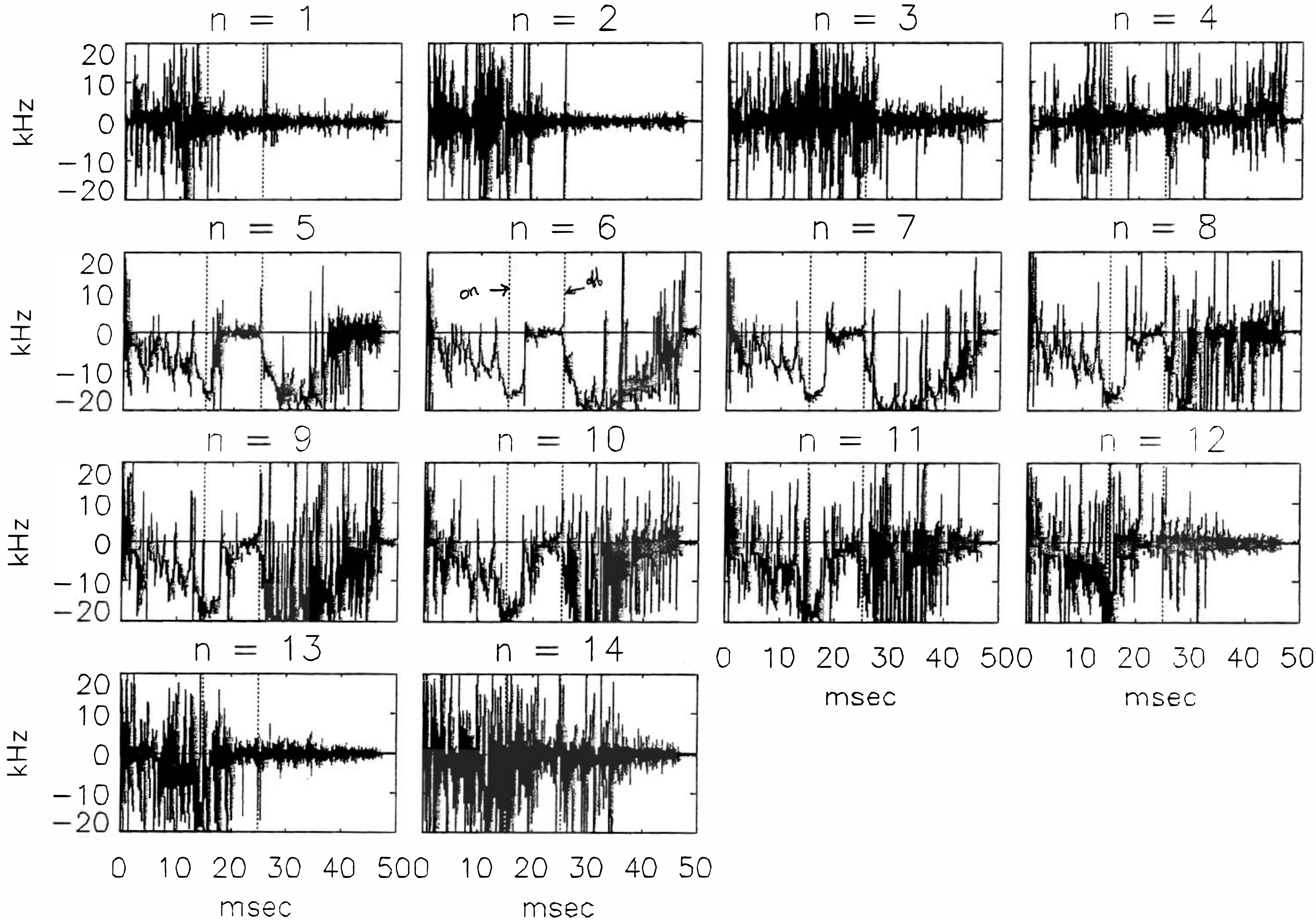
Smoothed 1 time(s) over 10 points



Counter-Rotating Perturbation

Mode Rotation Frequencies, SHOT # 86 7-JUL-1996

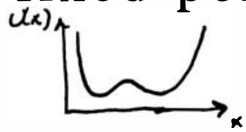
Smoothed 1 time(s) over 10 points



IV. Nonlinear Effects I: Stochastic Resonance

• Stochastic resonance is the phenomenon of generating "coherent motion" in a dynamical system in the presence of an optimum amount of noise.

• This coherent motion is generally seen in periodically forced systems with bistable states or fixed-point to limit-cycle bifurcations.



• Signatures of stochastic resonance are peaks in the power spectra of fluctuating quantities at the drive frequency and its harmonics, and a peaking in the signal-to-noise ratio (SNR) at an optimum amount of fluctuation noise.

• Stochastic Resonance has been observed in weakly ionized rf plasmas by L. I and J.-M. Liu[1]:

[1] L. I and J.-M. Liu, Phys. Rev. Lett. **74**, 3161 (1995).

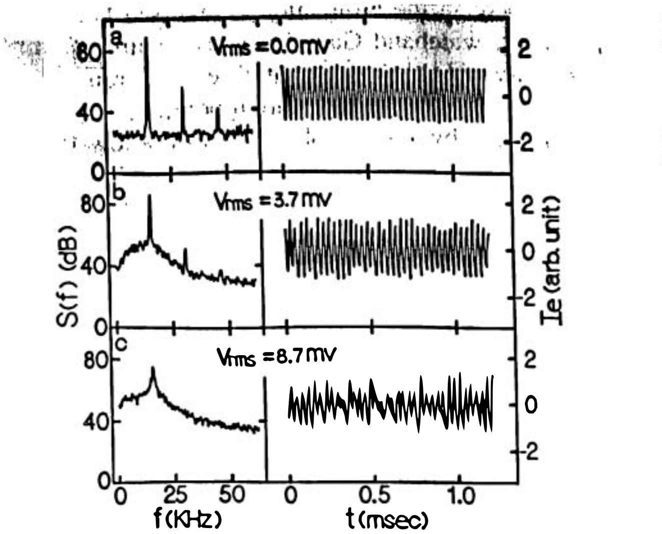


FIG. 2. The power spectra and time evolutions of probe current at point A ($V_0 = 75$ mV) with different V_{rms}.

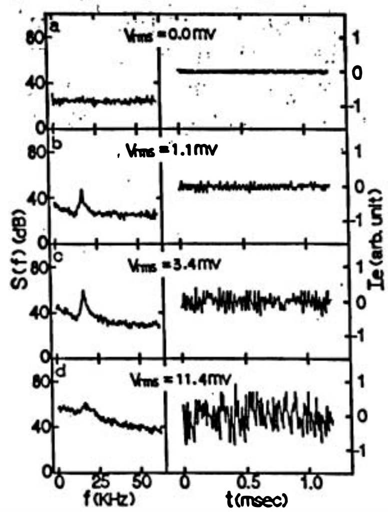


FIG. 3. The power spectra and time evolutions of probe current at point B ($V_0 = 75.7$ mV) with different V_{rms}.

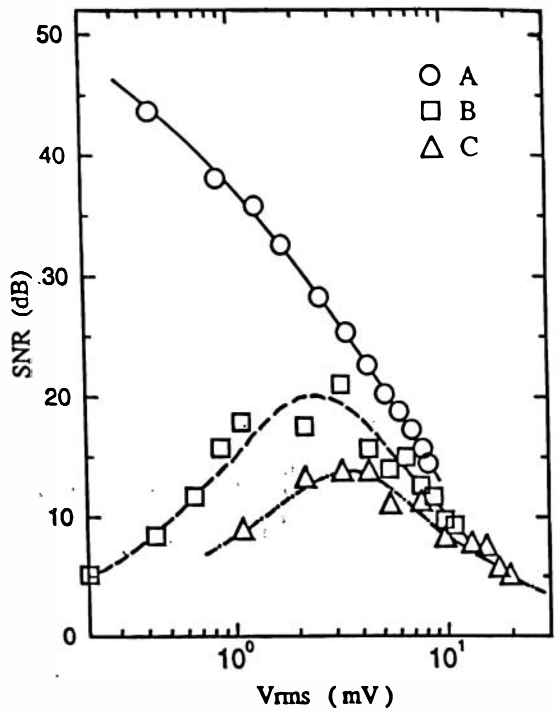
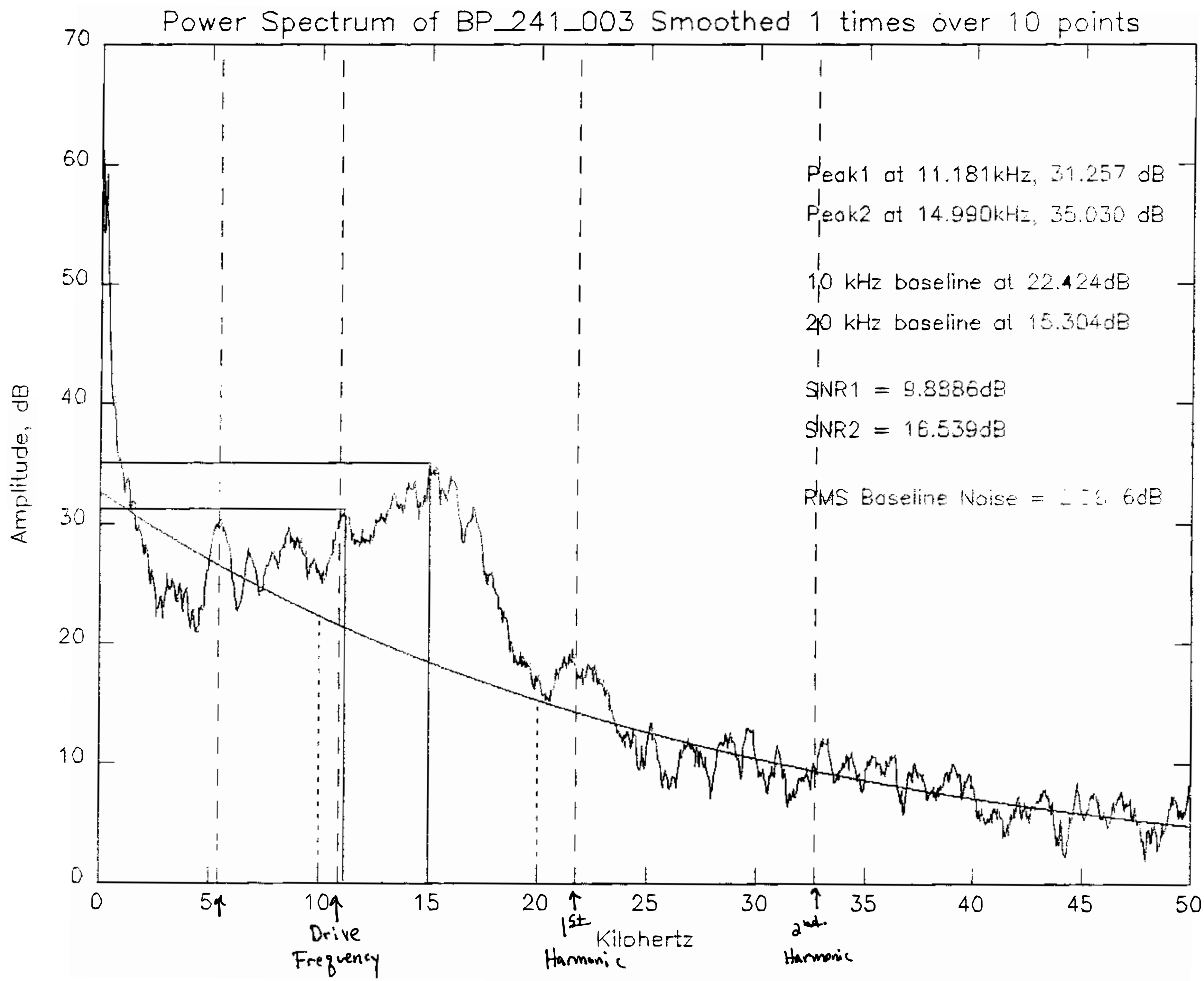


FIG. 5. The SNR vs V_{rms} at points A, B, and C.

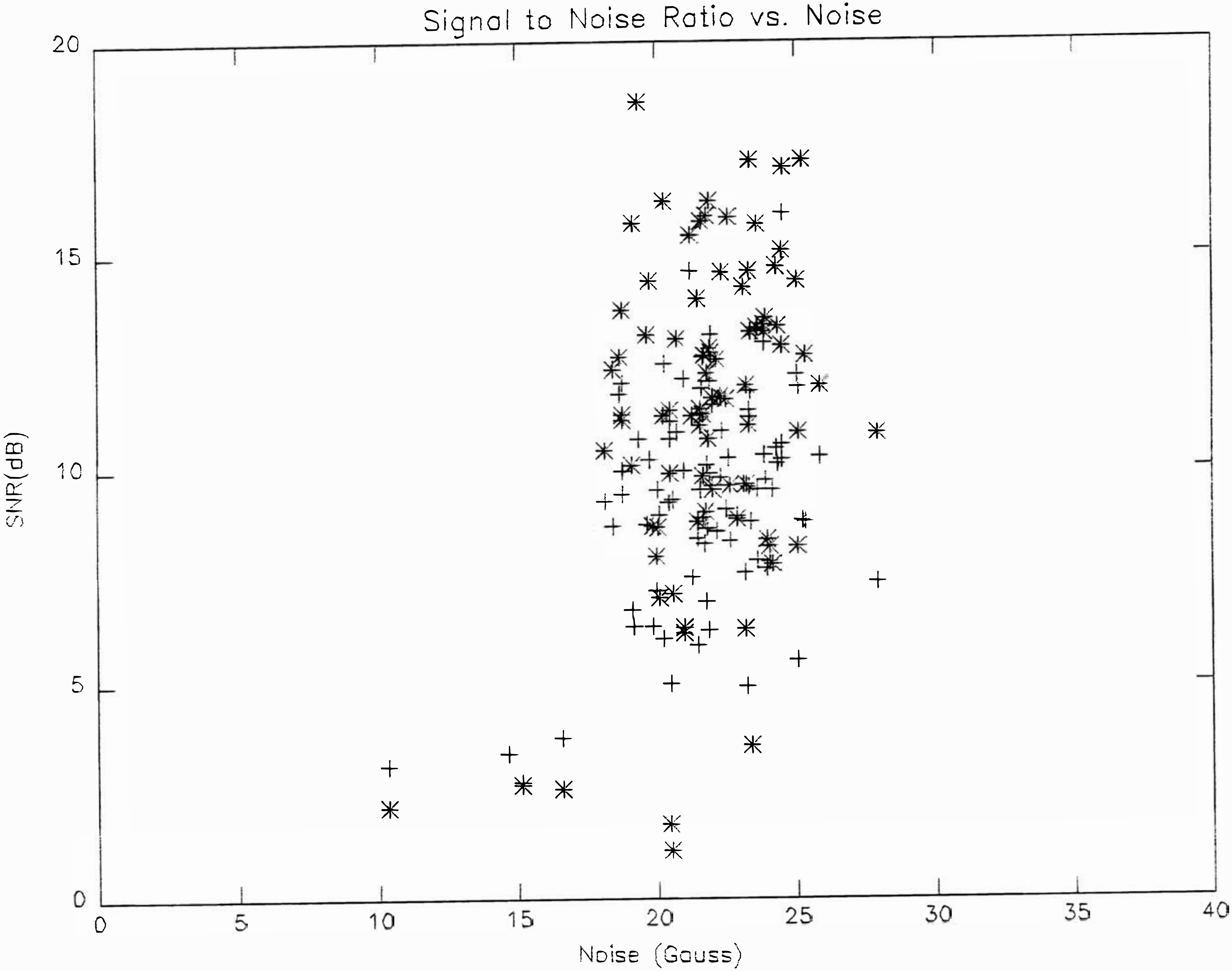
- Power spectra of fluctuations in poloidal field pick-up coils at the wall of MST sometimes revealed peaks at the induction motor driving frequency and its harmonics. Thus, it was supposed that the fluctuation noise may have been enhancing the induction motor drive.

- However, when the SNR for these peaks were plotted against the RMS values of the fluctuations (i.e. the noise), the standard curve characteristic of stochastic resonance was not seen.

SHOT # 55 14-JUL-1996



STOCHASTIC RESONANCE STUDIES FOR 14-JUL-1996



V. Nonlinear Effects II: Correlation Dimension

• The correlation dimension is used to calculate the fractal dimension of chaotic systems. It is the probability that any two points on the trajectory of the system will occupy the same "hypersphere", and is defined by:

$$D_c = \lim_{r \to 0} \frac{d\left(\lim_{N \to \infty} \frac{1}{N^2} \sum_{i,j} \Theta(r - |x_i - x_j|) \right)}{dr}$$

• C. Watts has claimed that the fractal dimension of MST is immeasurably high.[2]

• Numerical work suggests that simple periodic perturbations to even high-dimensional systems can significantly lower their dimension.

• Such a decrease in the dimensionality of fluctuations in the pickup coil data was not observed for any of the perturbations applied with the induction motor.

[2] C. Watts, PhD. Thesis, University of Wisconsin-Madison, 1993.

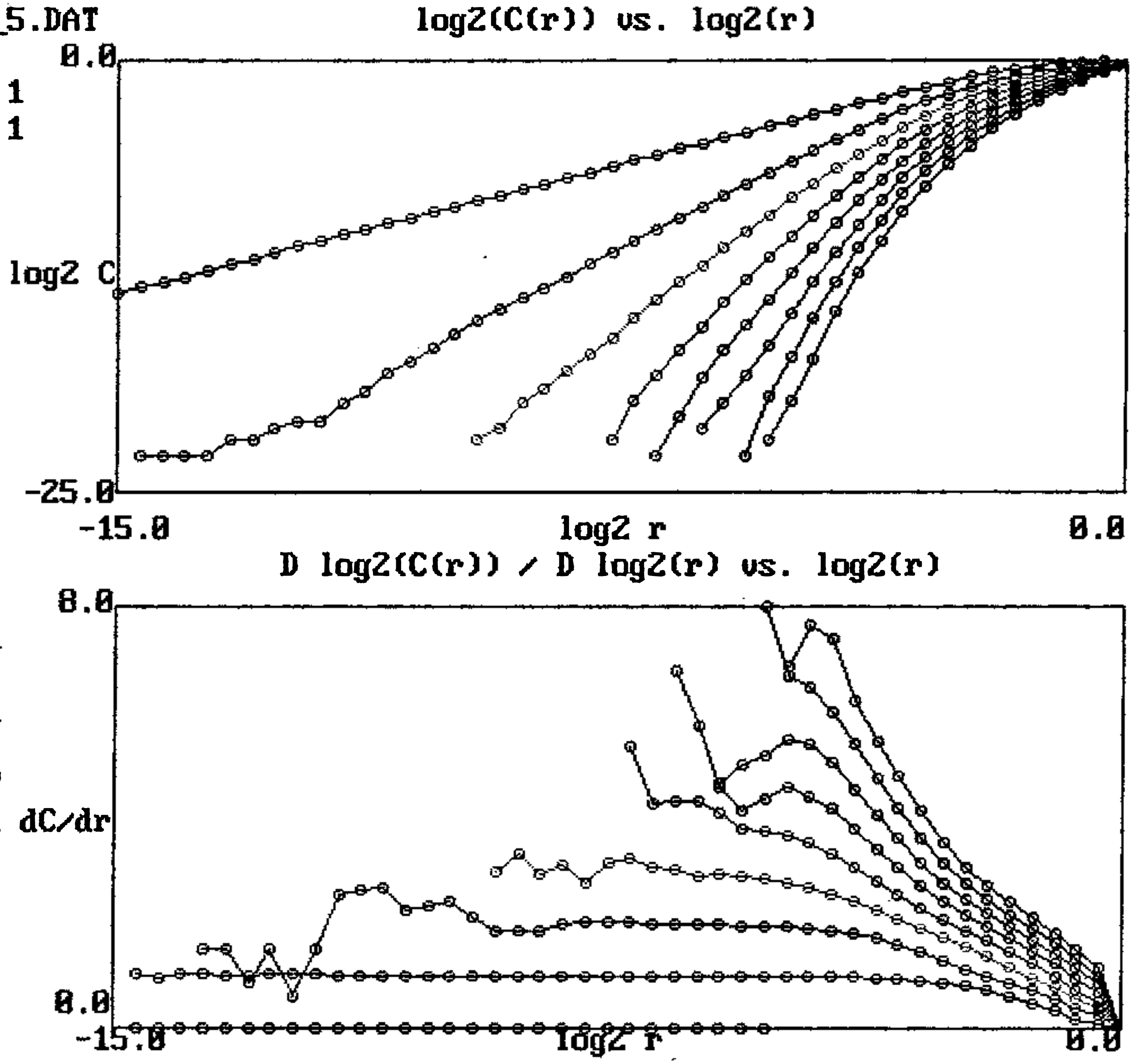
Unperturbed Case

D:\WWD2\UTIL\24JUN_5.DAT
N = 4001
Component delay = 1
Vector delay = 1
xmax = 54.853300

m(1) = 0
m(2) = 0
m(3) = 0
m(4) = 0
m(5) = 0
m(6) = 0
m(7) = 0
m(8) = 0

Dc(1) = .932184
Dc(2) = 1.849351
Dc(3) = -.525019
Dc(4) = -.6527151
Dc(5) = -.780683
Dc(6) = -.9134107
Dc(7) = -1.048851
Dc(8) = -1.186208

CPU time = 0.165



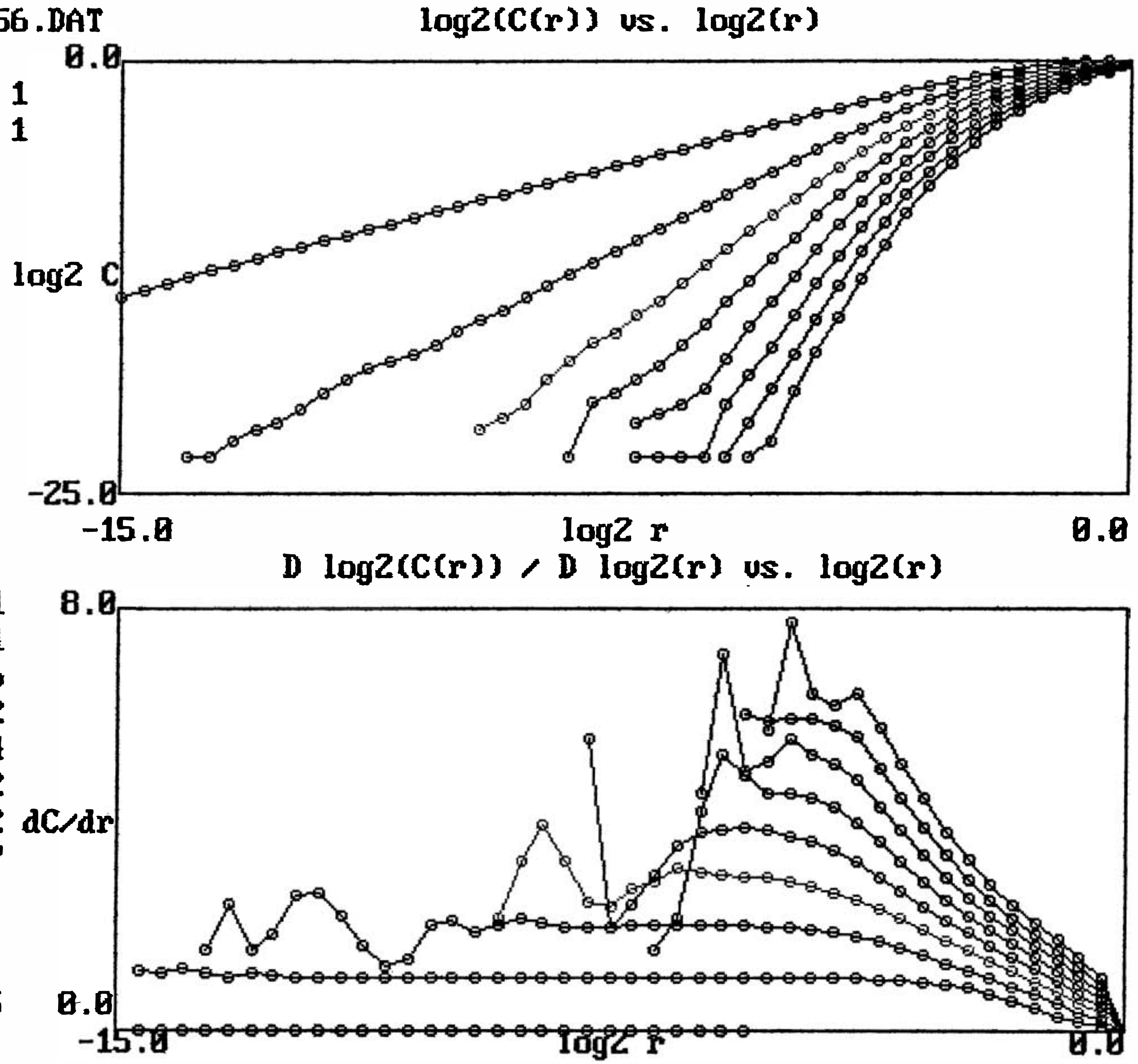
Perturbed Case

D:\WWD2\UTIL\29JUN56.DAT
N = 4001
Component delay = 1
Vector delay = 1
xmax = 49.594400

m(1) = 0
m(2) = 0
m(3) = 0
m(4) = 0
m(5) = 0
m(6) = 0
m(7) = 0
m(8) = 0

Dc(1) = .9308861
Dc(2) = 1.813151
Dc(3) = -.5099906
Dc(4) = -.6424442
Dc(5) = -.7762154
Dc(6) = -.9138582
Dc(7) = -1.057142
Dc(8) = -1.202527

CPU time = 0.165



VI. Summary

- The rotating field errors applied to MST by the n=6 and n=1 induction motors show signs of affecting the plasma mode rotation and locking, but currently lack the power to make a definitive effect.

- MST plasmas do not seem to exhibit stochastic resonance, but a wider range of plasma parameters and driving amplitudes have yet to be explored.

- The perturbations applied so far have not had the effect of decreasing the overall dimensionality of the system.

VII. Future Work

- Increase the power to the n=6 and n=1 field coils.

- Look for evidence of stochastic resonance under a broader range of plasma parameters and stronger driving (e.g., the Cold Biased Probe, or plasma guns).

- Examine a broader range of perturbation frequencies and amplitudes in a search to decrease the plasma dimensionality.