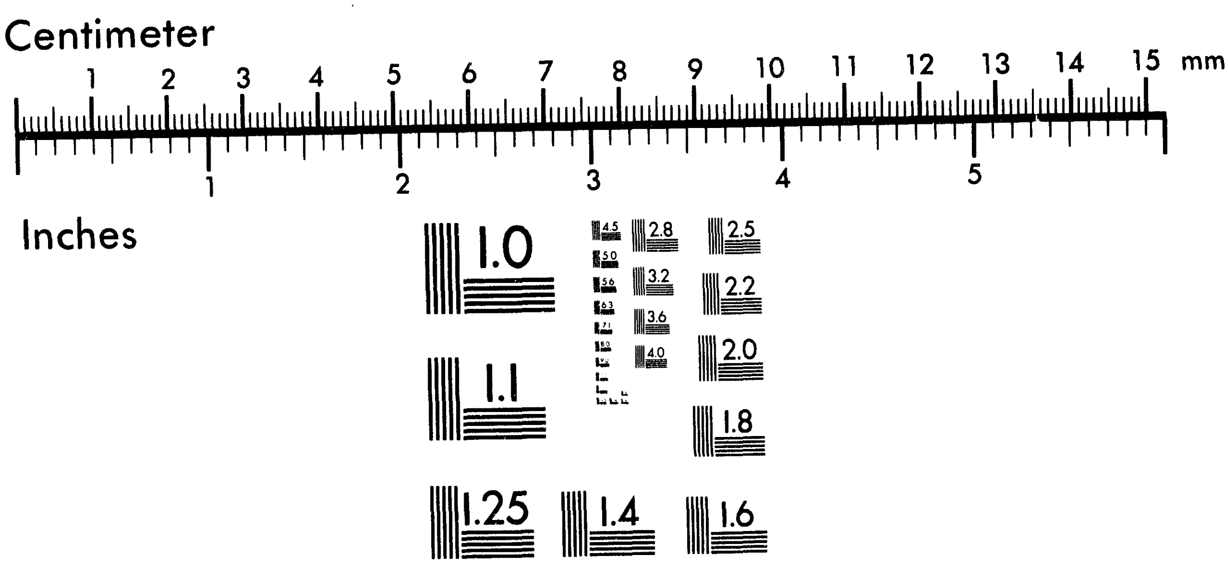


Centimeter
mm
Inches

1 of 1

ANL/APS/CP-- 83263
Conf-940531--2

FIELD CONFIGURATION OF BEAM EXCITED MODES IN THE ADVANCED PHOTON SOURCE (APS) STORAGE RING WAVEGUIDES*

S.O. Brauer, R.L. Kustom
Advanced Photon Source
Argonne National Laboratory
9700 S. Cass Ave, Argonne, IL 60439, USA

P.L.E. Uslenghi
Department of Electrical Electrical Engineering and Computer Science
University of Illinois at Chicago
Box 4348, Chicago, IL 60680, USA

ABSTRACT

Argonne National Laboratory (ANL) is in the process of building a positron accelerator and storage ring, the Advanced Photon Source (APS). The RF system for the APS storage ring uses 16 cylindrical TM010-like, reentrant cavities operating at 351.93 MHz to resupply energy lost by the beam due to synchrotron radiation. The stored beam will have approximately 60 bunches, 5 mA per bunch, for a total beam current of 300 mA. Calculations of the threshold current for coupled-bunch instabilities in the storage ring have indicated that several beam-induced higher-order modes (HOMs) will reduce the threshold for beam stability and therefore should be damped. Previous data taken using a pillbox cavity showed that it is likely that some of these modes couple, through the coupling loop, from the storage ring cavity into the waveguide[1]. This study investigates the electric and magnetic field configuration of each HOM present in the waveguide. A pillbox and a prototype storage ring cavity, together with various WR2300 waveguide components, are used to obtain the measurements needed for the determination of the mode configuration of the HOMs at the frequencies of interest. To avoid the development of beam instabilities due to the existence of these HOMs in the rf cavity, damping of the modes will be required. The HOMs present in the rf cavity coupling into the loop coupler and traveling through the coupler into the waveguide, may allow damping of some of the HOMs by insertion of dampers into the waveguide adjacent to each cavity.

*Work supported by U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. W-31-109-ENG-38.

INTRODUCTION

When a particle bunch from a stored beam travels through an rf cavity, the electrical charge and current of the bunch generate electric and magnetic fields in the cavity[2], much of which is deposited in resonant HOMs which are determined by the geometry of the rf cavity. These HOMs of rf cavities can cause coupled-bunch instabilities.

In a multibunch operation of a storage ring, the stability limit is reached at a threshold current value which is inversely proportional to the shunt impedance, R_S, of the driving HOM[3]. The threshold current value for instabilities is determined by the synchrotron radiation damping rate and the growth rate of the instabilities. During the synchrotron acceleration process the amplitude of small phase oscillations and transverse oscillations of the bunch are reduced as energy is emitted by the positrons; this is known as synchrotron radiation damping. The radiation damping rate is independent of stored current, while the instability growth is proportional to the stored current. The current at which the instability growth is equal to the damping rate is the stability threshold. Since the maximum beam current for the APS is 300 mA, the threshold current for a HOM with a value less than 300 mA may cause coupled-bunch instabilities. Twelve HOMs of concern are listed in Table I[4].

Table I

Longitudinal Modes (Monopoles)		Transverse Modes (Dipoles)	
freq HOM (MHz)	Ithresh (mA)	freq HOM (MHz)	Ithresh (mA)
536.7	80	588.7	80
922.5	130	761.1	43
939.0	340	962.0	190
1173.2	340	1017.4	435
1210.8	130	1145.1	410
1509.1	130	1219.2	315

E-probe and H-loop dampers will be used for damping some HOMs in the cavity. To insure the possibility of damping all HOMs that can cause beam instabilities, the feasibility of using waveguide dampers is being investigated and therefore the HOMs which couple into the waveguide from the rf cavities must be determined.

PROCEDURES

The modes corresponding to the HOMs in the single-cell cavity were first studied in an equivalent (348 MHz) aluminum pillbox cavity. The mode configuration for several of the HOMs under consideration and corresponding frequencies for the single-cell cavity and the pillbox are listed in Table II.

Table II

Mode	f pillbox	f cavity	fcav/fpillbox	Δ
TM110	554.0	588.7	1.0626	0.0626
TM012	872.0	922.5	1.0579	0.0579
TM112	973.0	962.0	0.9887	0.0113
TM120	1014.0	1145.0	1.1293	0.1293
TM013	1249.0	1210.8	0.9684	0.0305
TM122	1292.0	1219.2	0.9437	0.0563

Verification of the HOMs' field configuration in the pillbox and actual single-cell cavity was done by performing bead-pull measurements. According to perturbation theory, the resonant frequency of a mode in a cavity is shifted when an object is placed inside the cavity by[5]:

$$\frac{\delta\omega}{\omega} = \frac{\iiint_{v_1} \left[\left(\underline{E}_1\underline{D}_0 - \underline{E}_0\underline{D}_1\right) - \left(\underline{H}_1\underline{B}_0 - \underline{H}_0\underline{B}_1\right)\right] dv}{\iiint_{v_0} \left(\underline{E}_0\underline{D}_0 - \underline{H}_0\underline{B}_0\right) dv} \tag{1}$$

where: ω = frequency, subscripts 0 and 1 refer to unperturbed and perturbed fields, respectively.

The bead-pull measurement setup consisted of the cavity, a small conducting needle epoxied to a silk string, an apparatus to suspend the string through the beam axis of the conducting cavity, a stepper motor to step the needle through the cavity, a Hewlett Packard 8753 C Network Analyzer to take measurements of the phase shift of the resonant frequency due to the needle, and an IBM PC for automated control of the HP 8753 C. From the results of the bead-pull measurements the frequencies and configuration of the HOMs of both the pillbox and the prototype single-cell rf cavity were confirmed.

To obtain measurements needed for the determining of the mode configuration of the HOMs in the waveguide at the frequencies of interest, the cavity, analyzer, and WR2300 waveguide components were arranged as shown in Figure 1.

The various waveguide components--hybrid (power splitter), waveguide transitions, and 200 KW coaxial loads--were used in the experimental setup to simulate conditions that would be found in the rf system of the APS. Rectangular waveguide components are not broadband devices and the impedance of the component varies substantially at frequencies other than the designed fundamental frequency. Those modes which couple into the waveguide and are not damped by loads on the hybrids become resonant and must be damped in the waveguide.

When the loop coupler, used to couple rf power from the waveguide into the cavity, was inserted into the cavity, it was matched to 50 ohms using the Smith chart on the network analyzer. This optimized the transmission of power through the loop into the cavity. Small E-probe antennas were inserted around the perimeter of a straight section of waveguide, parallel to the flanges. They were evenly spaced along the broad-walls and side-walls for measurement of any E-field that would be perpendicular to the wall of the guide. An H-probe was used to exite the HOMs in the cavity.

At each HOM frequency the H-probe was adjusted to determine the Q (stored energy/energy lost in the cavity per cycle) of each mode. At the same time a reflection measurement (S_{11} on the 8753 C) of the H-probe was taken to note that β (coupling coefficient) was as close to zero as possible to insure that there was minimum coupling of the H-probe to the cavity. Finally, a transmission measurement (S_{21} on the 8753 C) was taken from the H-probe in the cavity to each E-probe in the waveguide.

MEASUREMENTS IN WAVEGUIDE

Measurements taken using the pillbox did show that out of six frequencies generated in the cavity, all six were found in the waveguide and three out of the six had E-field measured on the side-walls of the guide.

Measurements taken using the prototype single-cell rf cavity showed that out of the twelve HOMs of interest, two frequencies (585.763 and 1144.108 MHz) were not found in the waveguide. Three additional frequencies (538.548, 1021.275, and 1232.375 MHz) were found but the strength of the measured E-field was lower than expected. These results may be due to the construction of the prototype cavity, which was copper-plated stainless steel. Additional measurements are being taken with an all-copper prototype single-cell cavity to further verify the data. The seven remaining remaining HOMs were found in the waveguide. E-field was measured on both the broad-wall and side-wall of the waveguide as shown in Figures 2 through 5.

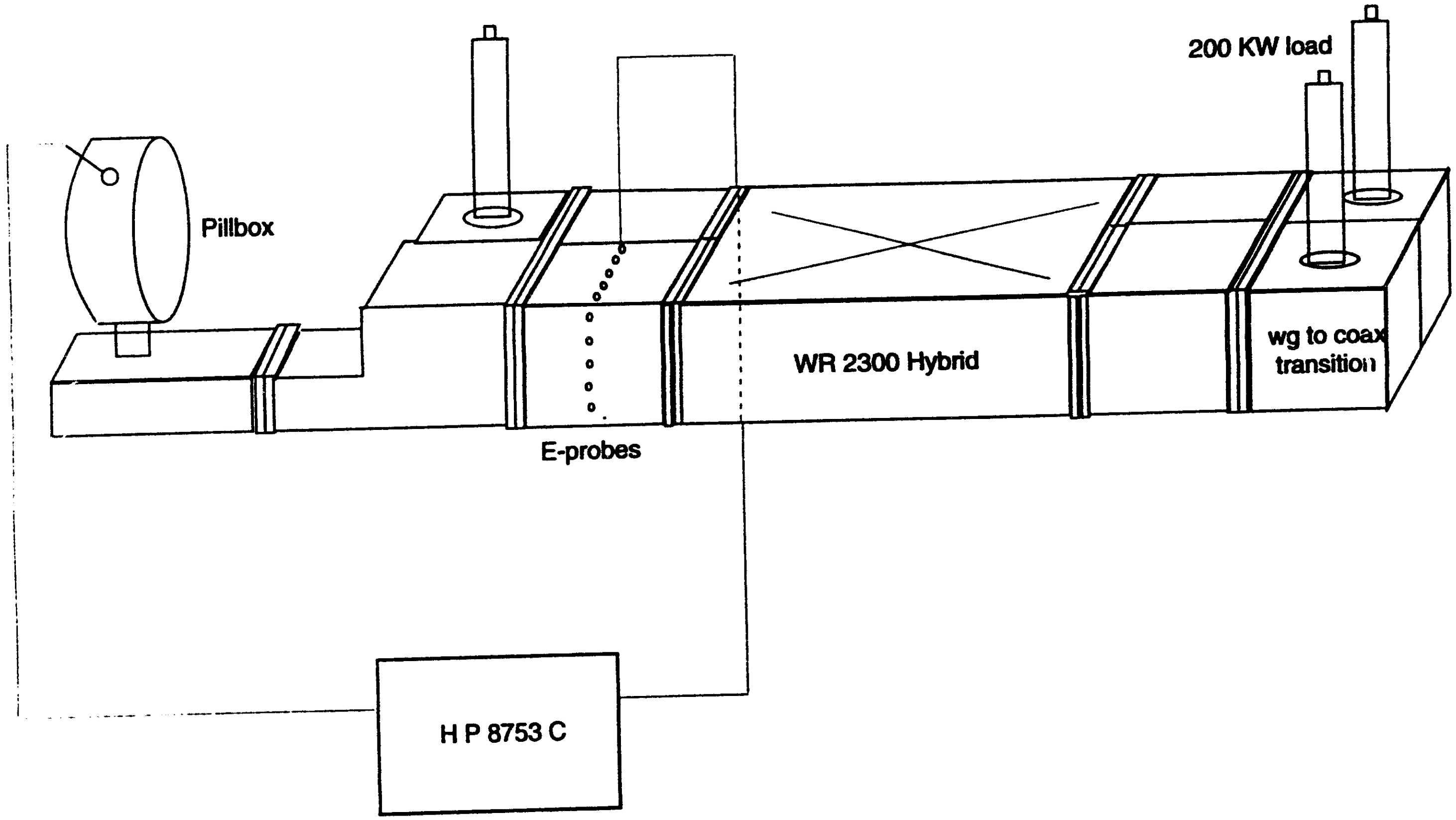


Figure 1. Measurement setup for HOMs in waveguide.

Fig. 2

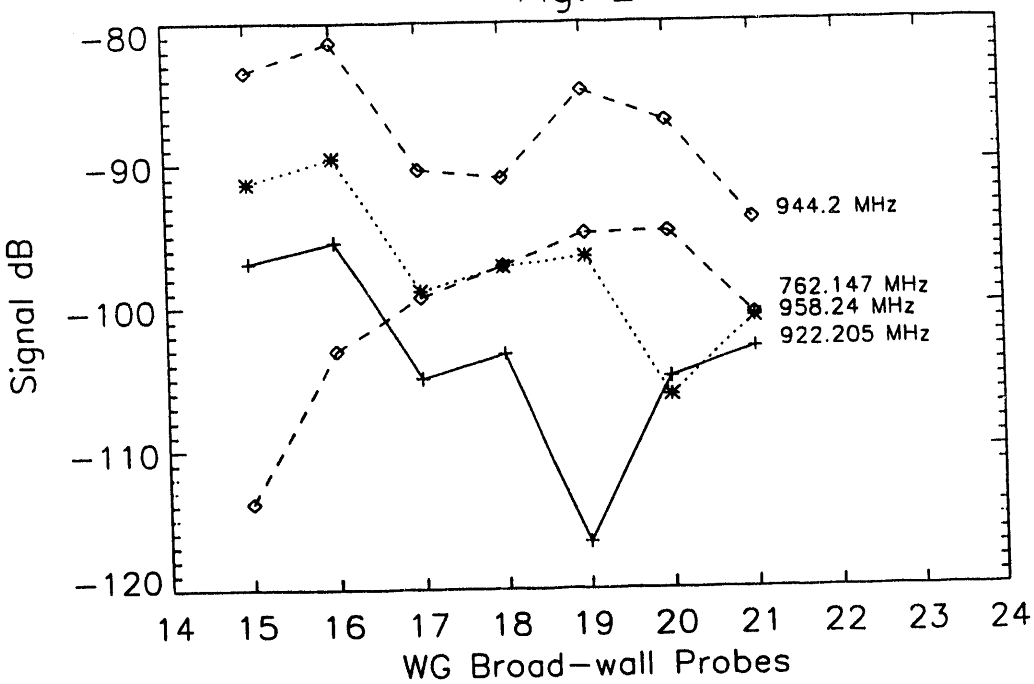

-80
-90
-100
-110
-120
Signal dB
14
15
16
17
18
19
20
21
22
23
24
WG Broad-wall Probes
944.2 MHz
762.147 MHz
958.24 MHz
922.205 MHz

Fig. 3

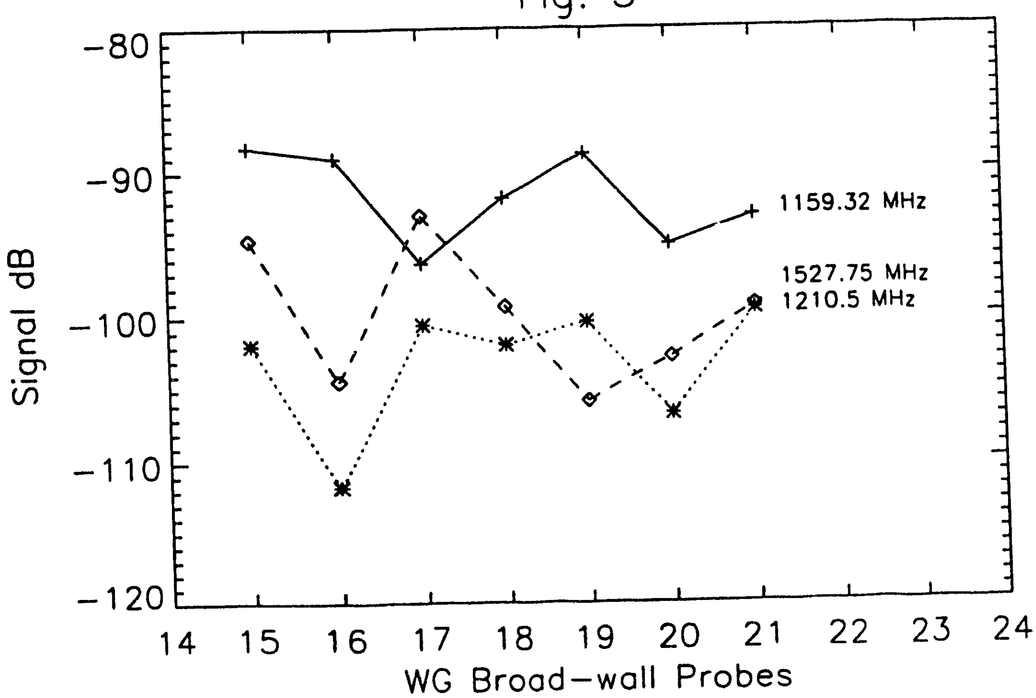
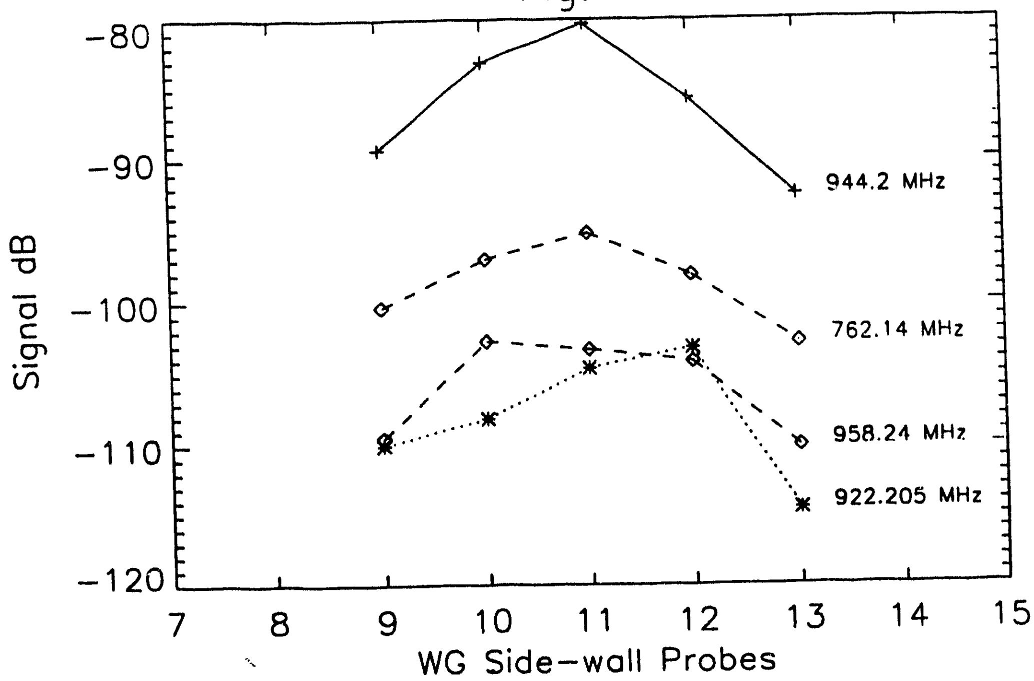
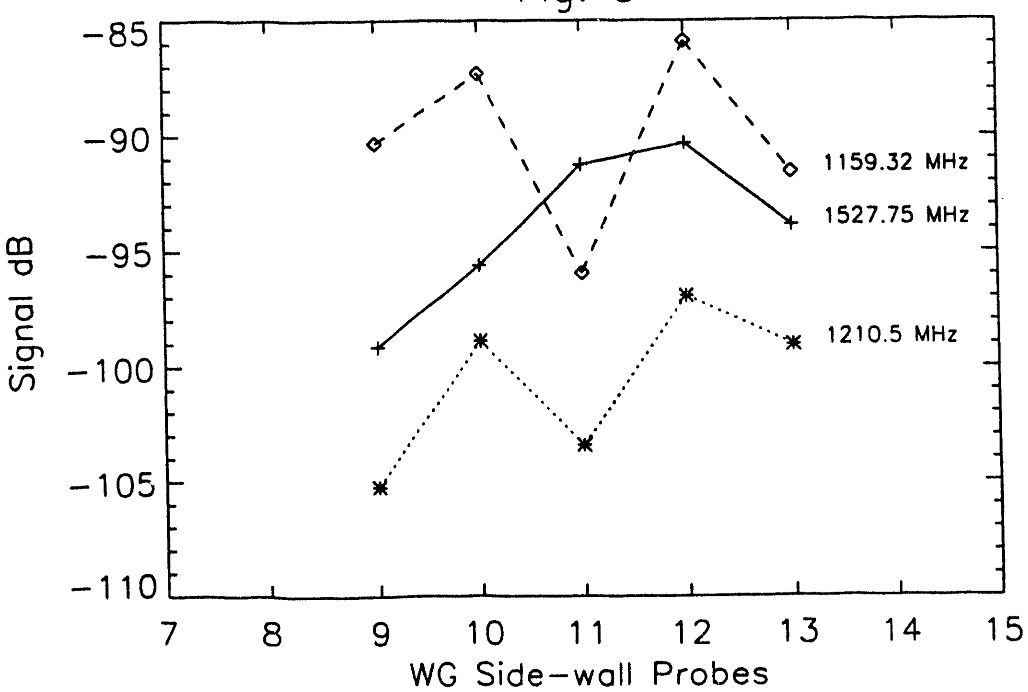

-80
-90
-100
-110
-120
Signal dB
14
15
16
17
18
19
20
21
22
23
24
WG Broad-wall Probes
1159.32 MHz
1527.75 MHz
1210.5 MHz

Fig. 4



Signal dB
-80
-90
-100
-110
-120
7
8
9
10
11
12
13
14
15
WG Side-wall Probes
944.2 MHz
762.14 MHz
958.24 MHz
922.205 MHz

Fig. 5



Signal dB
-85
-90
-95
-100
-105
-110
7
8
9
10
11
12
13
14
15
WG Side-wall Probes
1159.32 MHz
1527.75 MHz
1210.5 MHz

CONCLUSION

Seven of the twelve modes that are being investigated have measured E-fields on the side-wall of the waveguide. The E-fields at this location on the wall are the result of higher-order waveguide modes created by a hybrid, which is only a good match at the fundamental frequency. These modes can be damped by using a simple antenna placed inside the waveguide through the side-wall of the guide without coupling into the TE01, fundamental mode, at the fundamental frequency since no E-fields exist at the location of the antenna. These antennas have successfully been used in waveguides at CERN/LEP to damp second harmonic signals generated by klystrons (rf amplifiers)[6]. The effect of the side-wall antennas as dampers for the HOMs present in the waveguide is being tested.

REFERENCES

1. S.O. Brauer and R.L. Kustom, "Higher-Order Modes in the APS Storage Ring Waveguides," *Proceedings of the 1993 Particle Accelerator Conference,* Washington, D.C., pp.1217-1219, May, 1993.
2. M. Sands and J. Rees, "A Bench Measurement of the Energy Loss of a Stored Beam to Cavity," PEP-95, Stanford, CA, August 8, 1974.
3. J. Jacob, "Measurement of the Higher Order Mode Impedances of the LEP Cavities," ESRF-RF/88-02, Grenoble, pp. 2-12, January 1988.
4. L. Emery, "Coupled-Bunch Instabilities in the APS Ring," *Proceedings of the 1991 Particle Accelerator Conference,* San Francisco, CA, pp. 1713-1715, 1991.
5. R.A. Rimmer, "High Power Microwave Window Failures," Thesis for the Degree of Doctor of Philosophy, Lanchaster University, Lanchaster, England, October 1988.
6. H. Frischholz, "The LEP Main Ring High Power RF System," *Proceedings of the 1989 Particle Accelerator Conference,* Chicago, IL, March 1989.

DATE FILMED

8/24/94

END