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# Optimization of Accelerator System Performance at the NSLS*

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Abstract

There is an active program of accelerator development at the NSLS aimed at improving reliability, stability and brightness. Work is primarily focused on providing improved performance for the NSLS user community, however, important elements of our work have a generic character and should be of value to other synchrotron radiation facilities. In particular, we have successfully operated a small gap undulator with a full vertical beam aperture of only 3.8 mm, with no degradation of beam lifetime. This provides strong support for the belief that small gap, short period devices will play an important role in the future.



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## Introduction

At the NSLS we are pursuing a program of development of the accelerator systems aimed at increasing their reliability, stability and brightness. Key to the enhancement of reliability are upgrades to the computer control and injection systems. These upgrades have already produced a large reduction in downtime, and we expect work over the next year will significantly improve performance. Global orbit feedback systems, first introduced at the NSLS, have provided a high degree of orbit stability for all users, a task which would have been difficult using local orbit feedback. Machine studies on the X-Ray ring have demonstrated that an increase of brightness by one order of magnitude is achievable, by increasing the operating current and decreasing the vertical emittance. R&D aimed at advancing the state-of-the-art in insertion devices is proceeding, with the successful operation in the X13 straight of a small-gap, short-period undulator achieved in July 1994 and installation of a polarized wiggler scheduled for December 1994. On the VUV-Ring a fourth harmonic RF cavity has been used to lengthen the bunches to provide an increase in Touschek lifetime. Work on the optimization of the operation of this cavity has culminated in present user operation being carried out with the cavity actively powered. Further improvements in VUV-Ring operation could include increasing the operating energy from 750 MeV to 850 MeV and/or operating in a top-off mode.

## Reliability

When the NSLS was originally built, the computer control system was based upon a Data General computer and multibus micros. Later, as demands on the computer system increased, a VAX computer was added. More recently, it became clear that the control system should be

replaced by more modern hardware, but the difficult question was how to do this without an extended shutdown of facility operations. The Computer Group, led by John Smith with major contributions from Susila Ramamoorthy and Yong Tang, solved this problem by identifying a transition path which allowed simultaneous control of devices by the existing system and the new system under development. This approach [1] has been successful, and recently we have converted our computer control to a modern system based on Ethernet communications, VME micros and HP workstations. This has already eliminated most downtime due to computer control problems, and has made possible the development of improved state-of-the-art application programs, improved error monitoring and alarms, and on-line real-time diagnostics.

Another great improvement in reliability has been achieved by the injector upgrade program headed by Eric Blum. The injector upgrade is on-going and in the near future new power supplies will be installed for the Booster magnets, allowing the repetition rate to be increased toward 2 Hz. New modulators will be installed for the Linac RF, replacing very old equipment. New electron beam diagnostics [2] are under development. Tune measurements [3] are now available continuously throughout the Booster ramp and an orbit measurement system will be installed in the near future. Eventually, we hope to automate the tuning of the transport lines. As a result of this program, we expect to significantly increase the charge rate of the storage rings.

## Orbit Stability

Of major importance has been the improvement of the orbit stability of both the X-Ray and VUV storage rings. New RF receivers designed by Jack Bittner [4] for the beam position monitors (capacitively coupled pick-up electrodes) were developed, yielding high precision orbit measurements with a low noise level of 5 $\mu$m in a 300 Hz bandwidth. The design of the receivers provides orbit position measurements independent of electron beam intensity. Ongoing development work [5] is aimed at further increasing the dynamic range of the receivers.

A group led by Li Hua Yu at the NSLS developed the first global orbit feedback systems. [6] These systems are very successful [7] and reduce orbit variations below 30 Hz by a factor of 5 to 10 from ambient values, as shown in Figure 1. Recent work on orbit correction algorithms by Eva Bozoki, Aharon Friedman [8] and Yong Tang [9] has allowed significant improvement in the initial placement of the electron beam at the beginning of a fill. Work is now proceeding on the design of a digital global orbit feedback system.[10] On the X-Ray ring we also have local orbit feedback systems for each of the insertion devices, providing an improvement in orbit stability below 30 Hz over the global system results by an additional factor of 5-10. Recent developments by Om Singh have provided a decoupling of the local and global systems making them insensitive to orbit glitches, which in the past occasionally resulted in the feedback systems going into oscillation.

Brightness Enhancement

In the X-Ray ring we are working toward increasing the source brightness by an order of magnitude.[11] The increase of brightness will be achieved by increasing the current from 250 ma to 430 ma and reducing the vertical emittance from 1 nm down to 0.2 nm. In December 1992, the RF group installed an additional RF cavity in the X-Ray ring [12], increasing the total number of cavities to four. Under Manny Thomas' guidance a new RF amplifier chain was added to drive this cavity. Together with Norman Fewell and Richard Heese, the RF group then was able to increase the stored current to 430 ma at 2.58 GeV, with the insertion devices turned off (500 ma has been achieved at 2.50 GeV). We are now working to provide the protection of the vacuum chamber necessary to allow operation at the increased current with the insertion devices operating. Through the work of James Safranek [11], a lower emittance of 0.2 nm has been achieved. When we increase the current, we will be able to move to an operational schedule with only one injection per day.

Plans for longer term improvements include replacing the existing RF cavities in the X-Ray ring by new cavities designed by Payman Mortazavi. The present rf cavities suffer from two major design flaws. These are due to presence of water to vacuum joints and use of unsuitable copper clad steel. The new design addresses these problems. The use of all OFHC copper along with improved heat transfer capabilities should increase their reliability. Also, the wiggler magnets for X21 and X25 may be replaced by new devices with half the period length and half the vertical gap. By maintaining the peak magnetic field strength we could increase the brightness of these sources by a factor of two in this manner. Another possibility in the long term is reducing the horizontal emittance of the X-Ray ring down to 30 nm from the present value of 110 nm.

Thinking further into the future, Eric Blum [13] has shown that B-Factory technology could be used to obtain an order of magnitude more flux by increasing the X-Ray ring current to 2.4 Amp and the energy to 3 GeV. Of course such an upgrade would require a major modification to the facility and a significant shutdown. The major changes to the storage ring would be a higher frequency RF system and a copper vacuum chamber. The development of high flux x-ray optics would be an important component of this upgrade. To assure rapid filling and minimize thermal cycling of beamline optics, a full energy injector would be constructed.

R&D Straight Section X13

Returning to work taking place on a shorter timescale, development programs for two new insertion devices are underway utilizing the R&D straight section X13: a small gap undulator[14] and an elliptically polarized wiggler[15]. The small-gap undulator built by George Rakowsky is situated at the center of a low-$\beta$ insertion (Figure 2), where the electron beam is focussed down to a very small size ($\sigma_y = 7\ \mu$m). Utilizing a variable gap vacuum chamber (Figure 3) designed by Peter Stefan we have been able to operate [16] with a 7 mm magnet gap and a vertical beam aperture of only 3.8 mm, with no loss of lifetime at an electron current of 300 ma. The undulator has a period length of 16 mm and is comprised of twenty periods. Operating with K = 0.7, it produces a very high brightness beam ($10^{17}$ ph/sec, mm$^2$, mrad$^2$, 0.1% $\Delta\lambda/\lambda$) from the first harmonic at 3 KeV, and copious x-rays at 9 KeV from the third harmonic. Details of the small gap undulator experiment will be published in the near future [16]. Our results indicate that the vertical beam aperture can be reduced below the present hardware limit of 3.8 mm before the lifetime will be reduced. This raises the possibility of operating an undulator with a period length of 8 mm and a K value near unity, by utilizing an in-vacuum type undulator such as that developed by Yamamoto et al [17].

The elliptically polarized wiggler, [18] analyzed by Aharon Friedman [14], is being built in collaboration with Argonne and BINP in Novosibirsk. The vertical wiggler field is produced by a hybrid permanent magnet and the horizontal field by an electromagnet capable of either AC or DC operation. In AC operation, the device will produce radiation with an oscillating circular polarized component. Installation is scheduled for December 1994.

Bunch Lengthening Cavity in VUV Ring

In the VUV-Ring the electron beam lifetime has been extended by utilizing a fourth harmonic RF cavity operating at 211 MHz to lengthen the bunches. This cavity has been in operation for several years in a passive mode [19] whereby the field induced in the cavity by the electron beam acts back on the bunch in such a manner as to lengthen it (Figure 4). In this passive mode of operation, conditions for optimum bunch lengthening only occur at a single current. Recently, Richard Biscardi [20] has successfully driven the harmonic cavity by an external transmitter providing increased bunch lengthening over the full range of operating currents. This active mode of operation provides longer lifetime (Figure 5), and a more constant longitudinal bunch profile versus current than does the passive operation. Normal VUV ring operations are now carried out with the 211MHz cavity powered. Bunch length monitoring under development by Steve Kramer [21], will be an important diagnostic for the harmonic cavity operation.

In the future, increasing the operating energy of the VUV-Ring from 750 to 850 MeV may prove advantageous, providing an increase in lifetime and a hardening of the spectrum. Also, the idea of providing a top-off mode of operation continues to be of interest. Steve Kramer, Manager of the VUV Ring, is leading the analysis of these possibilities.

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Figure Captions

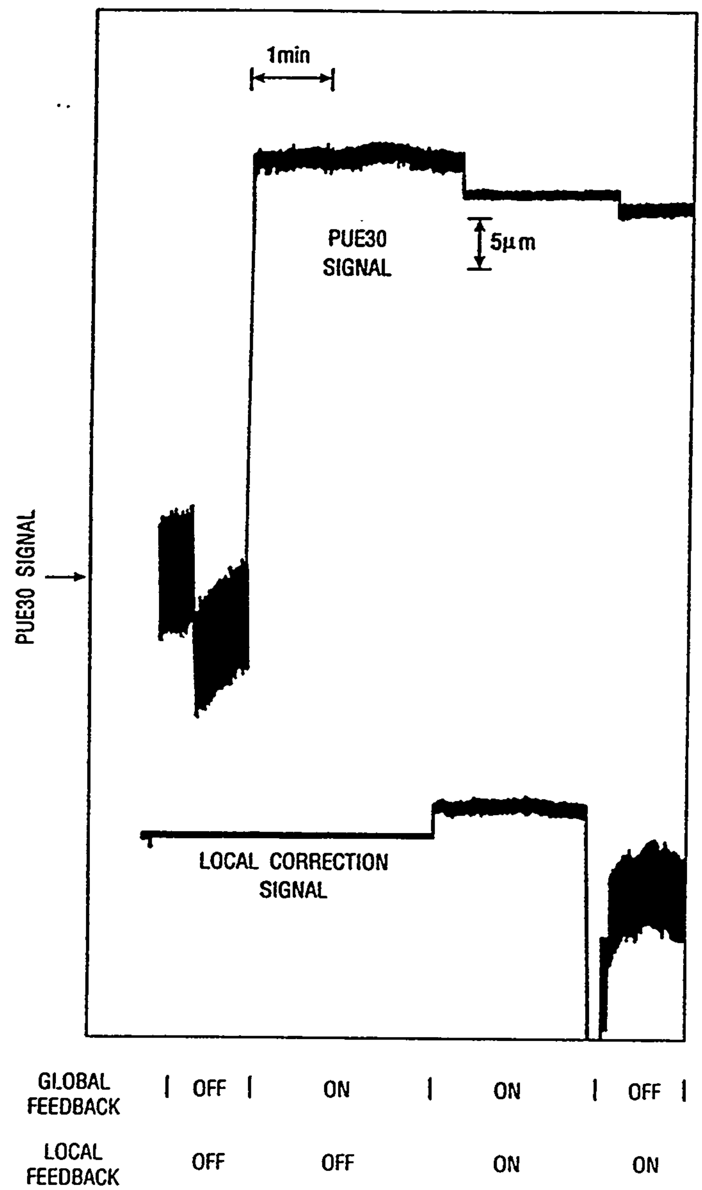
Fig. 1. Results of combined global-local orbit feedback system.

Fig. 2. The beta-functions and dispersion function for the Xray ring. The value of the vertical beta-function at the insertion center is 0.33 m.

Fig. 3. Small gap undulator vacuum chamber concept.

Fig. 4. Longitudinal bunch profile in VUV-Ring with the harmonic RF cavity (a) operating and (b) shorted.

Fig. 5. Current versus time with the fourth harmonic cavity shorted, passive, and powered.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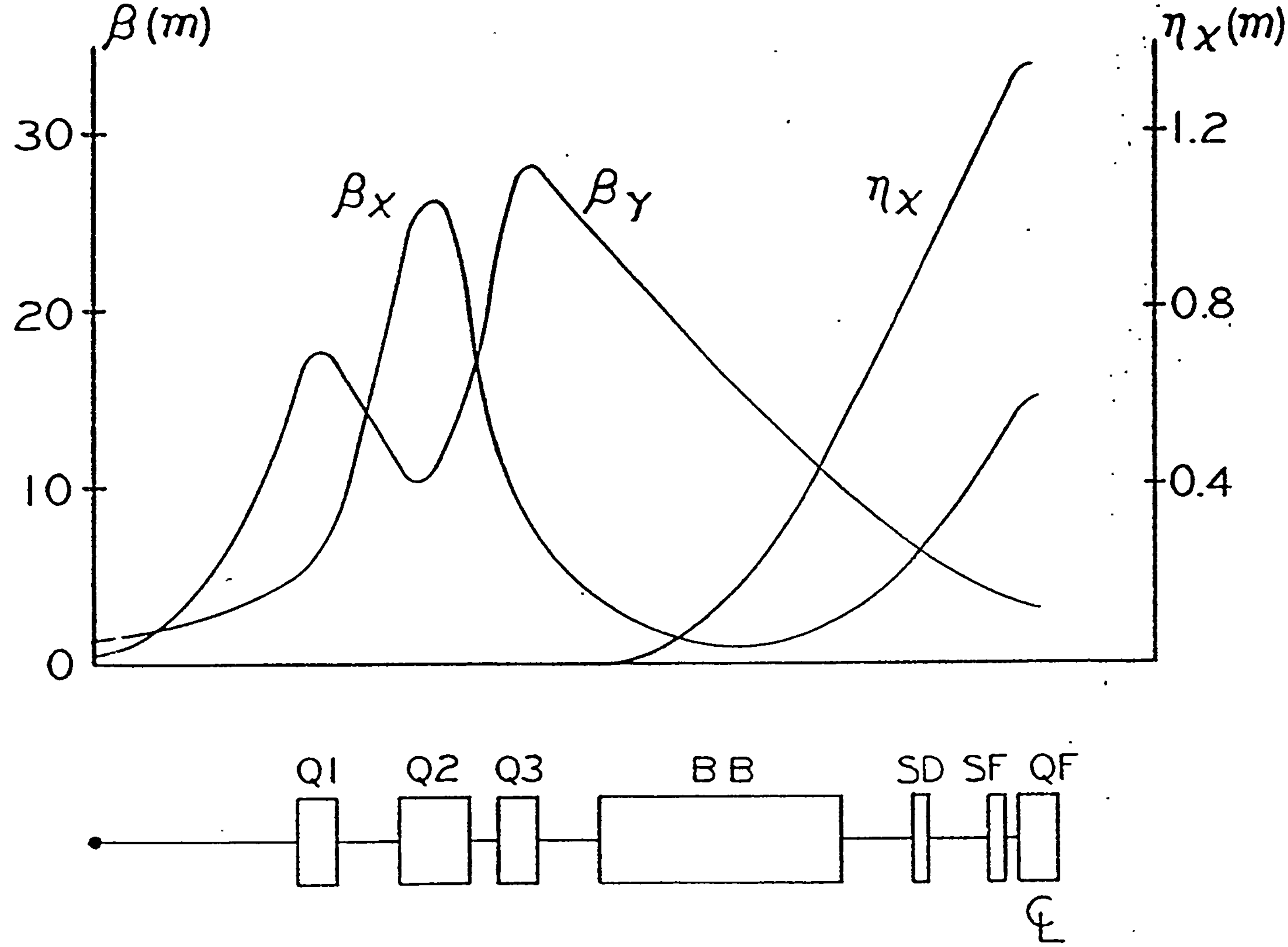

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20
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β x
β y
η x
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Q2
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B B
SD
SF
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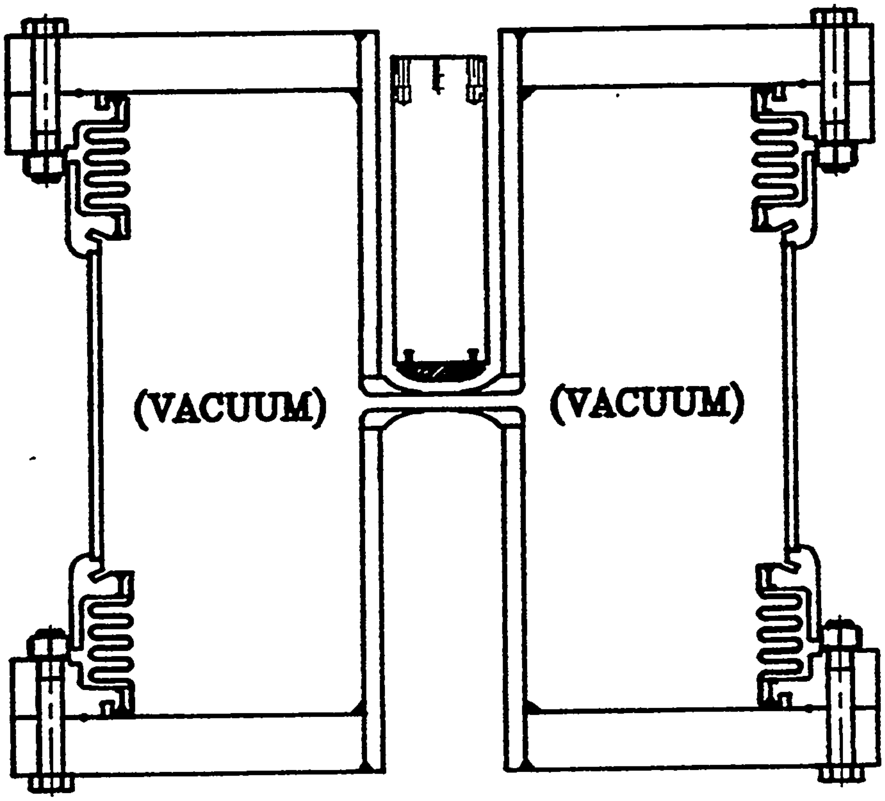
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Time:
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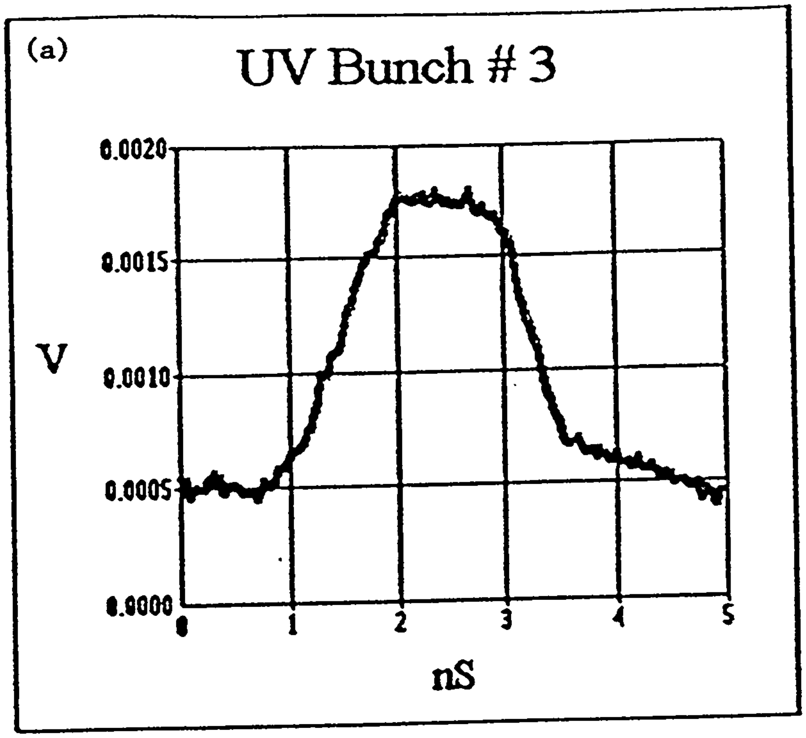
65 mA single bunch

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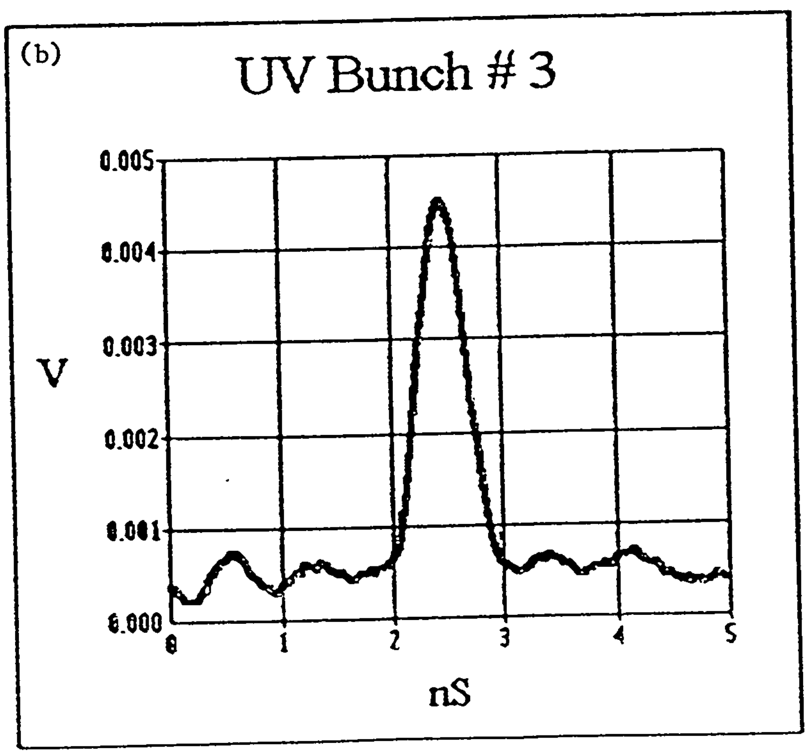

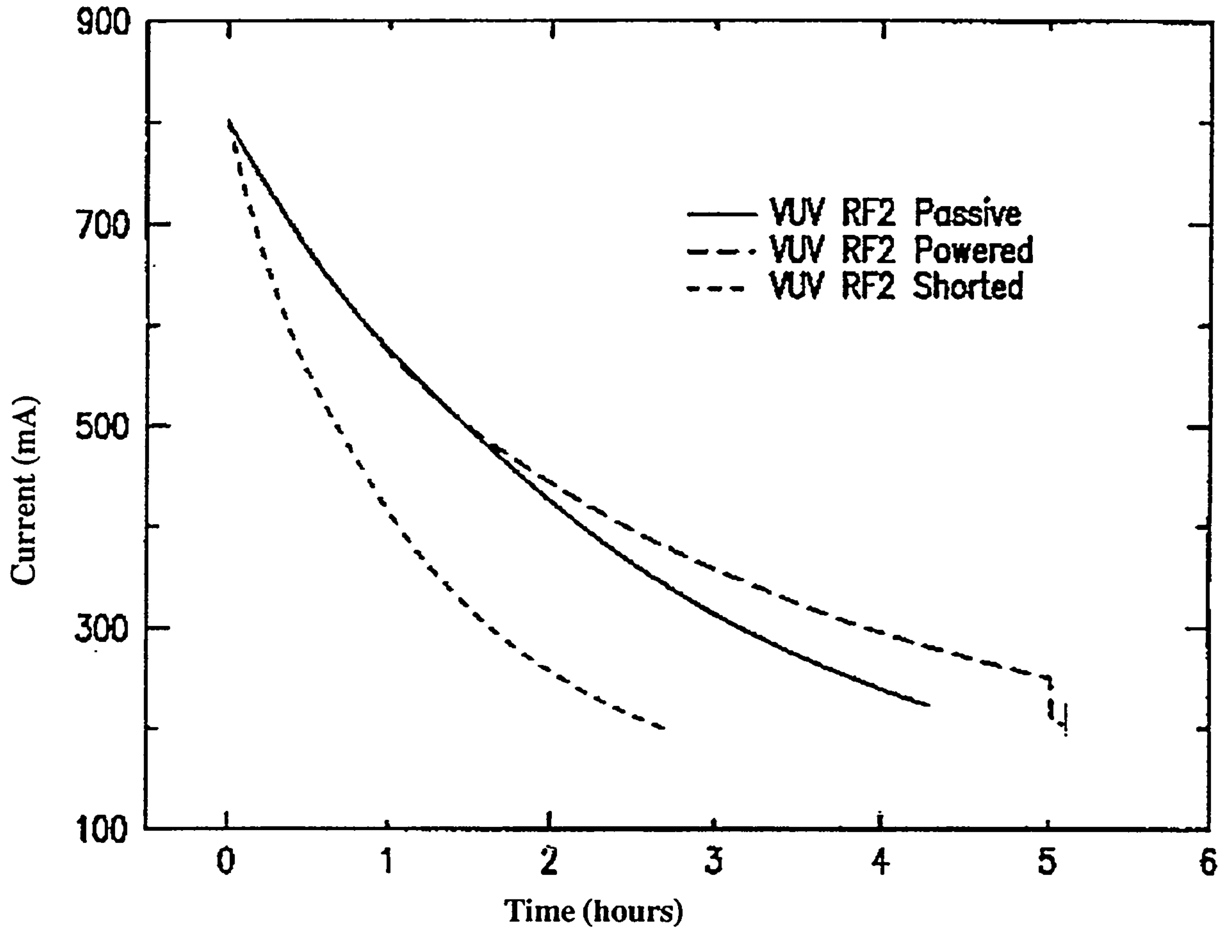

900
700
500
300
100
Current (mA)
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1
2
3
4
5
6
Time (hours)
VUV RF2 Passive
VUV RF2 Powered
VUV RF2 Shorted