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MAIN ACCELERATOR QUADRUPOLE TRANSISTORIZED REGULATORS FOR IMPROVED TUNE STABILITY THROUGH TRANSISTION

R. J. Yarema

May 5, 1976

INTRODUCTION

Two power supplies have been designed and built to regulate the Main Ring quadrupole magnets during injection and provide active filtering during initial beam acceleration through the transistion region of the Main Ring ramp. Each power supply uses 320 parallel power transistors, which are connected directly into the main high-power bus system, to provide the close current control which is required. By precise control of the transistorized supplies, substantial improvements have been obtained in reducing the Main Accelerator's tune fluctuations due to quad current variations, over use of the conventional Main Ring, SCR-controlled, quadrupole power supplies.

GENERAL OPERATION

Each of the two Main Ring quadrupole buses are comprised of a series connection of power supplies and magnets. During the initial part of each Main Ring cycle, each bus is regulated by one of the two new quadrupole transistorized power supplies (see Figure 1). When beam is injected into the Main Ring, all of the remaining quadrupole supplies are off and power is supplied to the quadrupole bus from the transistorized quad supply.

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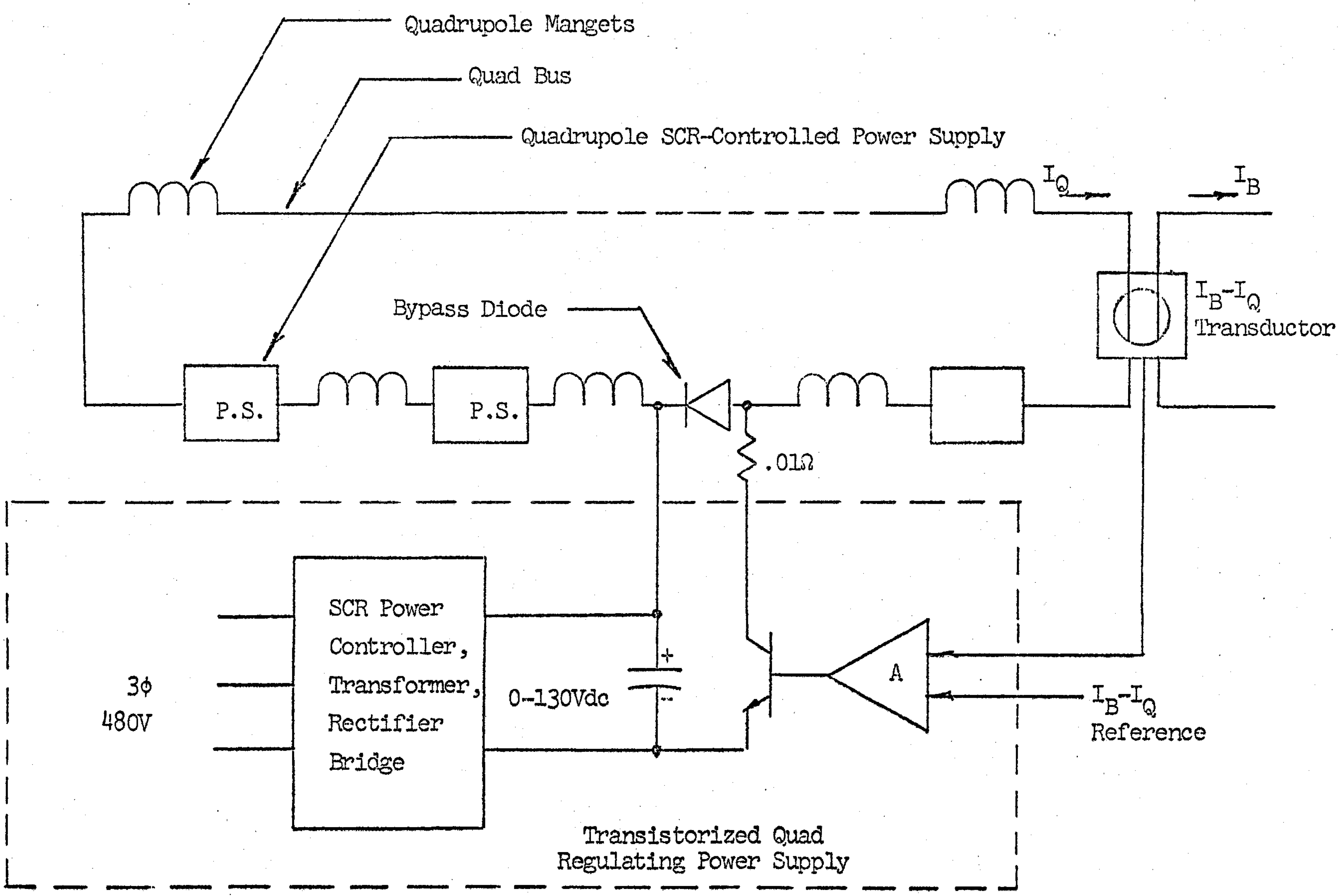

FIGURE 1 - Generalized Schematic of Transistorized Quad Regulating Power Supply

A bypass diode across the supply is reversed-biased, preventing any bus current from flowing through the diode. As acceleration of the beam begins, other quad supplies begin to phase-on to provide additional voltage and an SCR-controlled power supply takes over the regulation of the quad bus for the remainder of the Main Ring cycle. While other supplies are coming on, the transistorized supply is programmed to remain in its operating region and provide current filtering up to a quad bus current of 300A (past beam transition). Above 300A, the power source for the transistorized regulator, automatically phases off, allowing bus current from the other quad power supplies to bypass the transistorized supply, for the remainder of the cycle, through a large (6000A rms) diode. Thus, the transistorized supply provides regulation and filtering during the critical injection and transistion times of the Main Ring cycle.

In practice, the transistorized supplies control the quad current by regulating the difference seen between the current in a bend magnet bus and a quad magnet bus as shown in Figure 1. (The bend current is programmed and regulated separately.) The amount of difference which is required is set by the bend minus quad reference signal to the accuracy allowed by the finite gain of the amplifier. Power for the supply is derived from the Main Ring pulsed power system which is stepped down from 13.8 kV to 480V and then passed through a 3-phase, 6-SCR controller and step-down transformer. The transformer output is full-wave rectified to provide a maximum output voltage of 130Vdc. The typical peak current which the power supply passes is 300A.

Since the output of the transistorized regulator is connected to a high power Main Ring bus, proper voltage isolation of the supply is essential. The main power isolation is provided by a conventional 30kVA distribution transformer which is hi-potted to 5kV before use in the system. Auxiliary power to the circuits operating at the main bus potential is supplied by a 40kV isolation transformer. The analog control signal up to the equipment on the bus is transmitted by means of a 20' light pipe to eliminate any possible high voltage breakdown to the low-level electronics. The current transductors which provide the current feedback signals have a minimum of 33kV of isolation from the Main Ring bus. Under normal conditions, the maximum peak voltage-to-ground is less than 2kV.

Successful operation of the transistorized power supply is dependent on the ability to transfer the Main Ring bus current from the power supply to the bypass diode at a preset current level, or at least to limit the amount of current through the power supply to about 300A.

As long as the transistorized supply puts out voltage and reverse-biases, the bypass diode, all of the Main Ring ramp current, which can rise to 5000A, attempts to pass through the power supply. Excessive current through the supply could destroy the semiconductors and damage the associated buswork. Several levels of protection for the power supply are used. First, a quad bus current signal is used to phase-off the 6-SCR ac power controller when the quad bus current reaches 300A, allowing the bypass diode to become forward-biased. Second, if the power supply current reaches 350A, an internal current monitor quickly sends a trip signal to open the contractor supplying 480V power to the unit. Third, if the first two levels of protection do not work, a slower acting ac current limit circuit in the 6-SCR controller takes over when the ac current to the supply becomes excessive and limits the ac current so that the maximum dc current passed by the supply is about 275A. The remainder of the dc bus current is passed by the bypass diode. Fourth, if the lower levels of protection have failed, allowing the bus current to rise to about 450A. an overcurrent relay pulls-in, causing a Main Ring permit trip resulting in the shutdown of all the quad power supplies. Finally, a 0.01Ω is placed in series with the transistorized supply output at the Main Ring bus to limit the bus current which could flow down the power supply cables in the event a short circuit occurred at the power supply output. The voltage across the resistor due to bus current would forward bias the bypass diode, limiting the current through the shorted leads to a maximum of about 100A.

A more detailed description of the operation of the power supply circuitry is presented in Reference 1.

OPERATING RESULTS

Quad Bus Characteristics: To allow testing of the power supplies with a simulated load, the frequency characteristic of the Main Ring quad bus was measured. The response curve, along with the test set-up, is presented in Figure 2. Also shown in Figure 2 is a quad bus equivalent circuit derived from the test data. Subsequent construction and use of the equivalent circuit has shown the equivalent circuit to be an

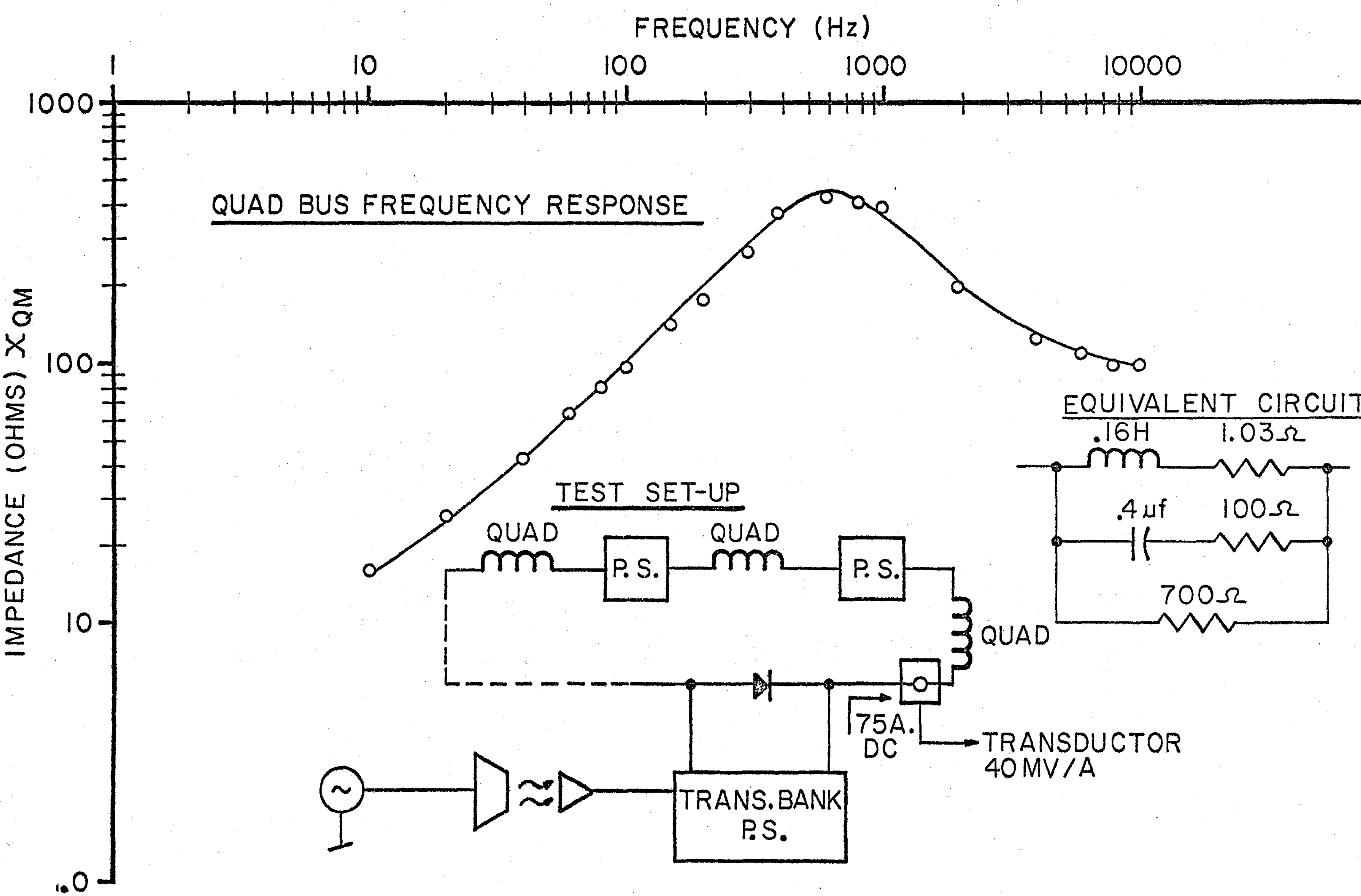

Figure 2. Quad Bus Frequency Response.

accurate model for the distributed impedance Main Ring quad bus.

Tune Improvements: With the transistorized quad regulating supplies, substantial improvements from injection through transition have been realized in the Main Accelerator's tune fluctuations over use of the conventional Main Ring SCR-controlled regulating power supplies. During injection, the typical quad bus ripple is about 10mA peak-to-peak at a power supply output level of about 90A. The resultant tune fluctuations are small as can be readily seen on a tune plot during injection of the Main Accelerator. Figure 3 shows the tune fluctuations for the conventional SCR-controlled power supplies, and Figure 4 shows the improved tune fluctuations obtained when the transistorized power supplies are used.

After injection, a conventional SCR-controlled Main Ring power supply takes over as the primary regulating supply for the Main Ring quad bus. During the ramp through transistion, a B-Q program is sent to the transistorized supply which keeps the supply in its operating region. The transistorized power supply then acts as a low frequency active filter to reduce the current ripple up to about 360Hz which is generated by other power supplies in the quad bus. The transistorized supply continues to filter the quad current until the ramp current reaches the maximum level the supply can safely handle, at which time it automatically turns off, allowing the ramp current to bypass the supply. As a result, tune fluctuations caused by current ripple through the transistion region are also improved. The smaller tune variations during the initial critical part of the Main Ring ramp effectively make the Main Ring have

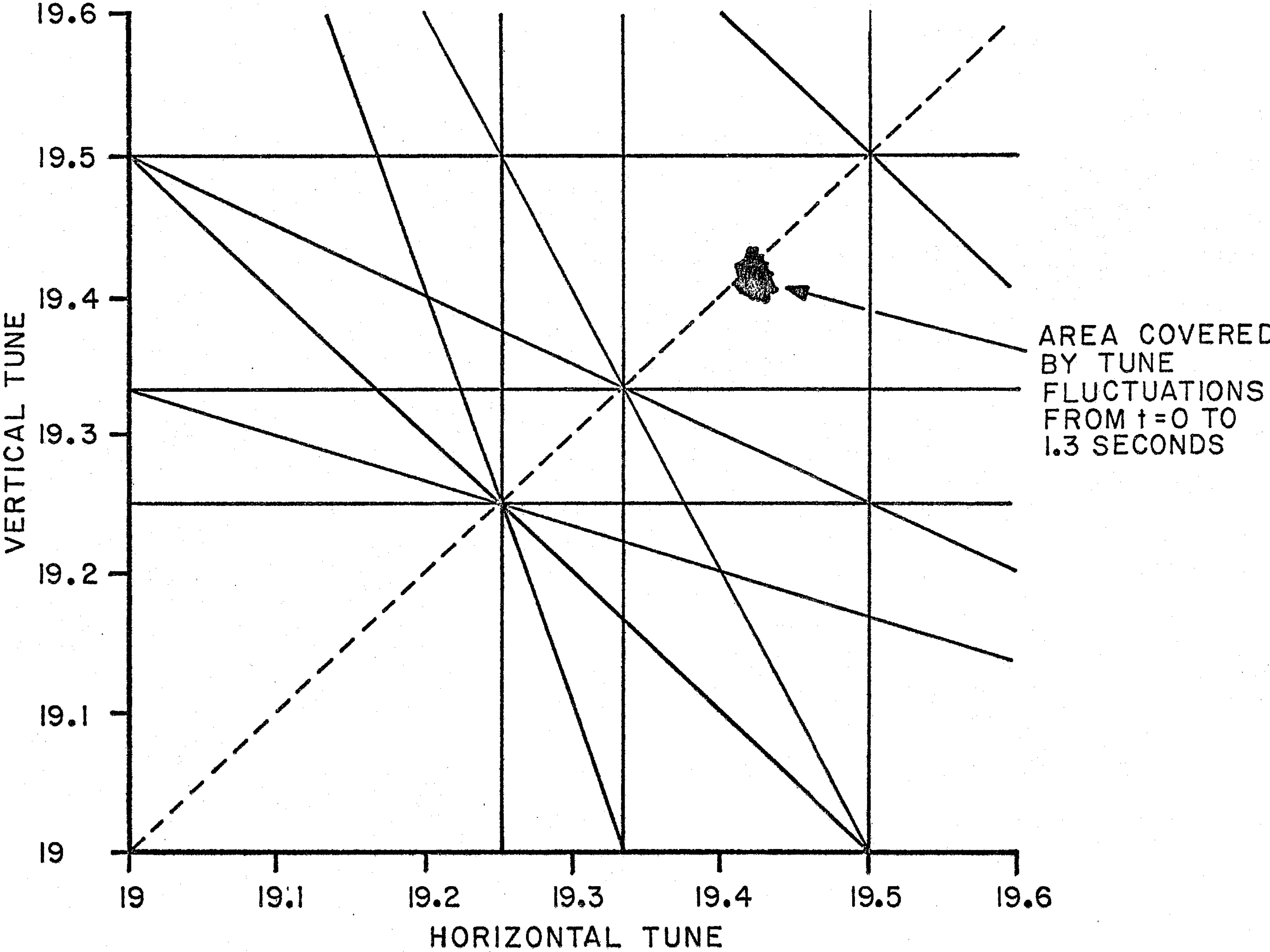

Figure 3. Tune Fluctuations With SCR-Controlled Power Supplies

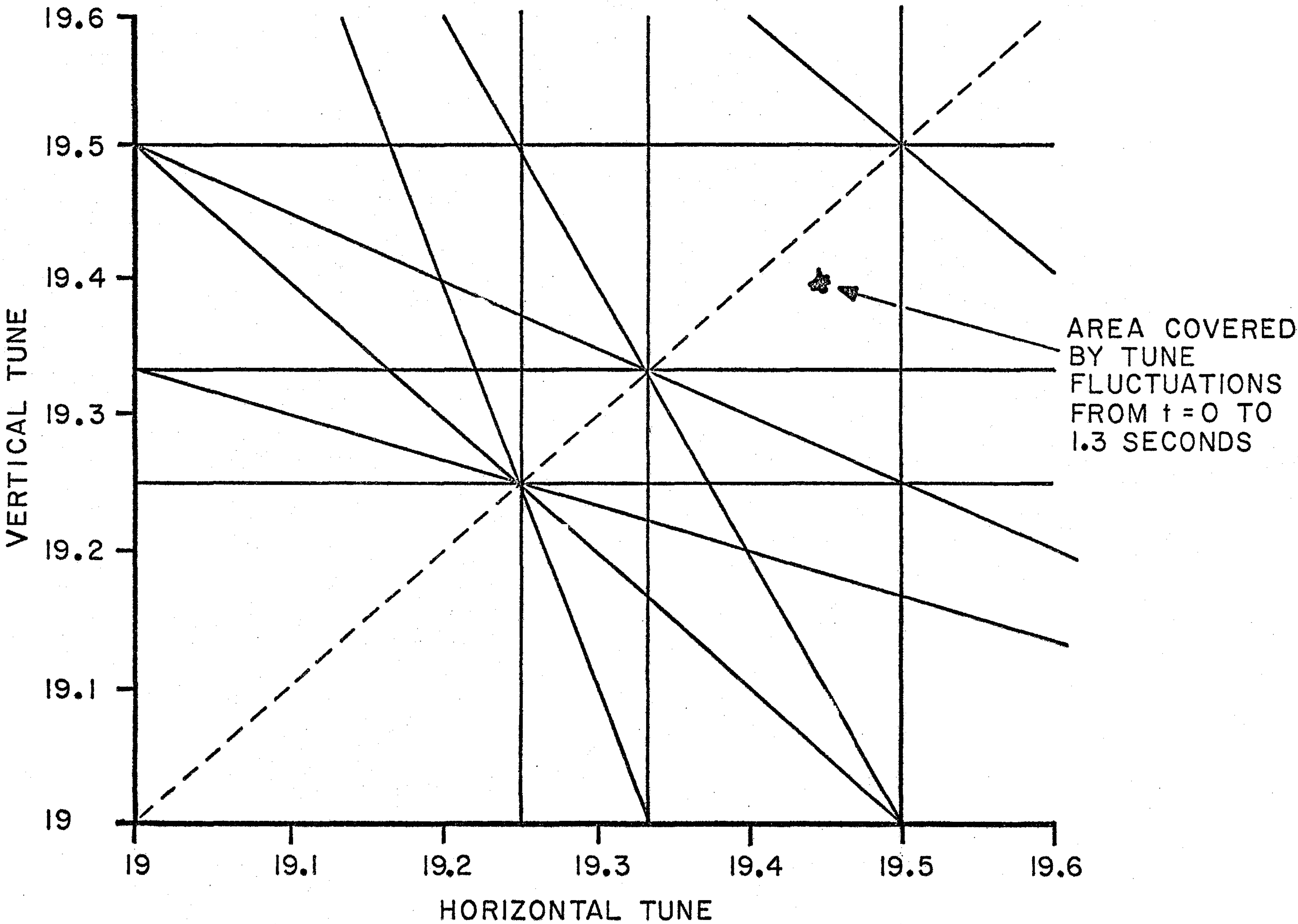

Figure 4. Tune Fluctuations With Transistorized Power Supplies.

a larger beam aperture. Thus, the machine can be tuned more easily and higher beam intensities are possible in the Main Ring without necessarily higher beam losses.

The transistorized power supplies were installed last year and became operational in July, 1975. Since that date, they have been in continuous use, and have proved to be very reliable.

REFERENCES

1. "Main Accelerator Quadrupole Transistorized Regulators for Improved Tune Stability", Internal Report, 20 pages, R. J. Yarema, July 16, 1975.