Workshop on Advanced Beam Instrumentation, 4/22-24/91,
Tsukuba, Japan, Vol. 1, pp. 141-144.



# A HIGH REPETITION RATE BEAM PROFILE MONITOR

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**Abstract:** A high repetition rate beam profile monitor is needed to measure the momentum distribution of each bunch in a 200 bunch train at the Brookhaven Accelerator Test Facility. We have designed a monitor using secondary emission from a microstrip delay line. The delay line converts position information into discrete time delays synchronous with the sampling rate of a fast transient digitizer. We present the results of initial electrical testing here.

## 1. Introduction

The Accelerator Test Facility at Brookhaven National Laboratory is a general purpose facility for accelerator and free electron laser research. It provides a 50 MeV electron beam synchronized with Nd:YAG and $CO_2$ laser pulses, with the quadrupled Nd:YAG radiation being used to generate the electron beam from a photocathode. In its free electron laser mode, the facility produces a train of 200 bunches separated by 12.25 ns. Each bunch may have a slightly different momentum distribution due to variations in the laser pulse duration or intensity, beam loading, or wake field effects.

We wish to measure the momentum distribution of each bunch through its transverse profile in a dispersive section of the beamline. Rather than use a "harp" monitor with parallel transient recorders sensing the voltage on each wire, we use secondary emission from a meandering conductor separated by dielectric from a ground plane. This conductor forms a microstrip delay line. The dimensions of the line are chosen so that the time delay between adjacent strips matches the sampling rate of a single transient digitizer. The use of a single digitizer keeps the cost of the monitor from being prohibitively high.

## 2. Construction

The conductor pattern of the prototype microstrip we have constructed is shown in Fig. 1. The lines represent gold conductor on a single-crystal sapphire ($Al_2O_3$) substrate. The groundplane underlying the pattern is also Au. Sapphire was chosen as the dielectric because of its high dielectric constant ($\epsilon/\epsilon_0$ = 9.3 to 11.5 depending on orientation) which allows shorter line lengths for a given delay, low electrical loss tangent (3.0 - $8.6\times10^{-5}$ at 10 GHz), and radiation hardness. The sapphire is in the form of a 500 $\mu$m thick wafer of the type used in the semiconductor industry. Gold was chosen as the conductor because of its high secondary emission coefficient, good electrical conductivity, and oxidation resistance. The conductor was applied in three steps. A thin Cr layer was vapor deposited onto the sapphire to provide a base with good adhesion, followed by a vapor deposited Au layer, followed by a 30 $\mu$m electroplated Au layer. The microstrip was then etched using a photoresist process.

The length of a half-period of the line was chosen to match its delay to the 742 ps sampling interval of a commercial transient digitizer[1]. The line comprises 14 such half-periods, so that

14 position "channels" are available. The 12.25 ns interval between bunches is approximately 16 samples, so that the monitor output from each bunch is temporally separate. The line width was chosen to make its impedance 50 Ω, matching the transient digitizer impedance. The unused end of the line is terminated in a matched load to prevent signal reflections.

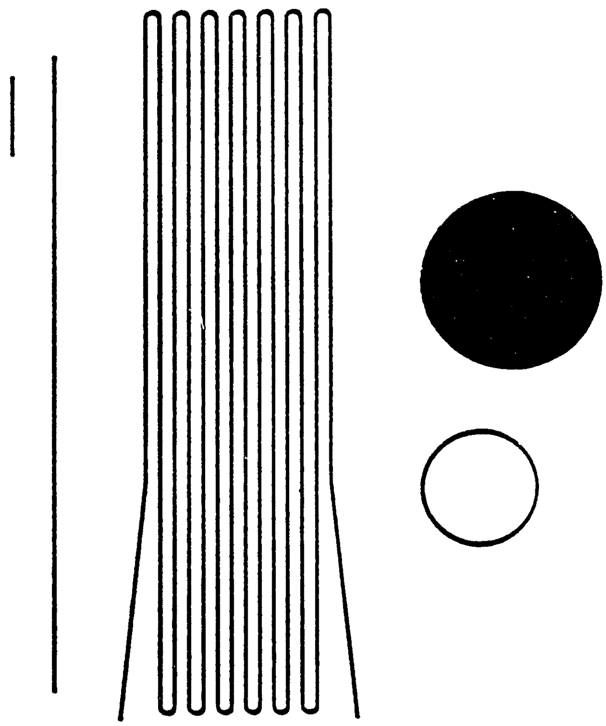

Fig. 1. Microstrip conductor pattern. The length of the vertical strips is 79 mm.

## 3. Radiation effects

Secondary emission has long been used as a means of monitoring current in electron linacs[2,3,4]. Previous investigators have found secondary emission coefficients of 3.5% [2] and 5.2% [4] from double-sided Al foils. Extrapolating to a single Au surface, we expect a secondary emission coefficient of 2 to 3%. Signal strengths, within the bandwidth of the transient digitizer, vary with the incident profile width, but will be of the order of 10 to 100 mV per nC bunch charge.

Radiation induced conductivity in sapphire has been measured by several authors[5,6,7]. Extrapolating from the results of van Lint *et al.*,[5] who find a conductivity of $10^{-5}$ $\Omega^{-1}$ $cm^{-1}$ for irradiation at 3. [illegible] rads/s with a 30 MeV electron beam, we find that the shunt resistance of a strip to ground will be approximately $10^4$ Ω for 200 bunches of 1 nC each. This shunt resistance should not measurably affect the performance of the monitor. It does, however, suggest another mode of operation in which the line is biased relative to the monitor, so that the radiation induced current through the dielectric becomes the signal.

The monitor will be locally heated by the beam. The instantaneous temperature rise from 200 bunches will be highest in the Au layers (210°C), and the average temperature in the monitor center, assuming edge cooling, will be 85°C above room temperature.

### 4. Electrical measurements

Preliminary electrical tests have been made of the prototype device. The propagation velocity in the line is accurately determined by measurement of the resonant frequencies in the ring resonator, shown at the right side of Fig. 1. The velocity is $1.15 \times 10^8$ m/s. Measurement of the capacitance of the disk on the right side of Fig. 1 gives the dielectric constant $\epsilon/\epsilon_0 = 11.2$. The capacitance per unit length of the line was measured to be $1.98 \times 10^{-10}$ F/m. Combining these values we find the line impedance to be 44 $\Omega$. The attenuation in the line has been measured using the ring resonator to be 0.07 dB/cm.

The impulse response of each line segment (strip) was measured by capacitively coupling a swept signal generator to a single line and observing the microstrip output with a network analyzer. This analyzer is equipped with software which calculates impulse response through Fourier analysis. The results are shown in Fig. 2 for strips 1, 5, 9, and 13. When the signal must propagate through greater line lengths, it becomes progressively smaller due to the line attenuation. Dispersion in the line is not apparent. Coupling between adjacent periods of the line is a problem and results in the dip following the signal.

The effect of attenuation and interperiod coupling will be somewhat improved in the next prototype monitor by adjustments of the line width, length, and spacing. Remaining small effects will be removed in numerical post-processing.

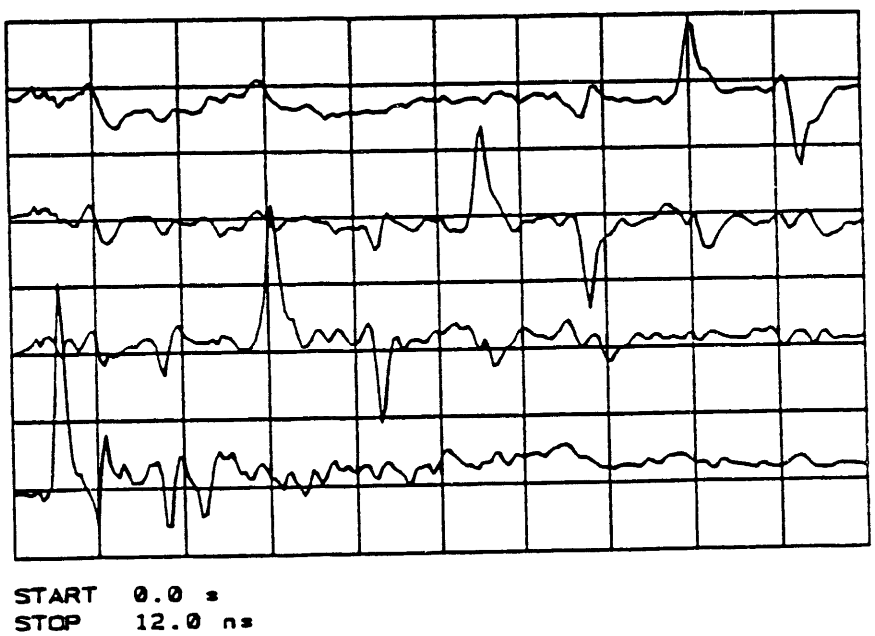


**Fig. 2.** Impulse response of the monitor to a capacitively coupled signal applied to strips (from bottom) 1,5,9, and 13. The vertical scale is arbitrary.

### 5. Conclusions

Electrical measurements of a high repetition rate profile monitor using a meandering microstrip show the principle to be useful, and also point out problems in interline coupling which we plan to solve in a second prototype. Radiation induced effects in such a device are believed to be understood, and tests in an electron beam are scheduled for the immediate future.

**Acknowledgements**

We would like to thank the members of the ATF collaboration and NSLS staff, especially I. Ben-Zvi and M. Woodle, for their contributions and suggestions. This work was supported by the U.S. Department of Energy.

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12/02/91