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TITLE: "A Microwave Interferometer to Measure Particle and Shock Velocities Simultaneously"

AUTHOR(S): Gabriel G. Luther, P-3
Lynn R. Veeser, P-15
Los Alamos National Laboratory
Barry Warthen
EG&G/EM

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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER

A MICROWAVE INTERFEROMETER TO MEASURE PARTICLE AND SHOCK VELOCITIES SIMULTANEOUSLY

Gabriel G. Luther, Lynn Veeser
Los Alamos National Laboratory

Barry Warthen
EG&G/EM

ABSTRACT

A microwave interferometric technique has been developed which measures the particle velocity, the shock velocity and gives information as to the index of refraction of the shocked material. The system has been tested at X-band from 40 to 300 kBAR. Experiments are underway to extend the frequency into the K-band and the pressure range to 600 kBAR. The apparatus will be described and data presented.

1. INTRODUCTION

A measurement of both the shock and particle velocity is sufficient to categorize the shock behavior of a material. The shock velocity is easy to measure by more or less standard techniques. Electrical or optical pins (1) at various locations, the times at which the shock is sensed and the distances between the pins give a good measure of this velocity. However, the particle velocity is more difficult to measure and the apparatus which measures it (axially symmetric magnetic [ASM] gauges for example)(2) perturbs the shock. Therefore, a near-by measurement of the shock velocity may or may not be an accurate representation, and a distant measurement of the shock may rely upon unverified assumptions about the shape of the shock front. The technique that we are developing has the advantage of measuring both velocities (shock and particle) in the same microwave cavity at the same time.

2. MICROWAVE INTERFEROMETER

Microwave interferometry is a mature technology and the interferometer that we are using is not particularly sophisticated. However, its simplicity and durability recommend it. An interferometer like this (Fig. 1) has survived eight or ten high explosive tests and four of them have performed well in underground tests in Nevada.

A Gunn diode (diodes with ranges of power 10 to 100 mW have been used) operating at 10.515 GHz supplies the microwave power. The 3-db coupler divides the microwaves into a detector signal and a local oscillator signal. The local oscillator power is directed to the mixer diodes. The electrical distance between the mixer diodes is adjusted so that the signals obtained are in quadrature. This feature is useful but not at all necessary. A single mixer diode would suffice. The circulator directs the signal reflected from the detector cavity to the arm containing the mixer diodes but in the other direction. In the mixer arm, therefore, we have two counter-propagating 10 GHz signals whose phase difference depends upon the change in the time delay in the detector cavity. This time delay consists of two parts: first, the time that would be required for the microwaves to traverse the distance to the reflecting surface and back in a vacuum and, second, the additional delay due to the index of refraction of the material in the cavity.

3. DETECTOR CAVITY

The detector cavity (Fig. 2) consists of a shorted section of wave guide embedded in a block of Teflon. The wave guide is constructed of a thin conducting material. We have used both ordinary household aluminum foil or copper foil plated onto the Teflon tongue inside the cavity. The Teflon tongue is tapered at its leading edge to avoid reflections. It should be emphasized that the shocked material, the Teflon in this case, lying both inside and outside of the microwave cavity, is essentially a homogeneous solid and, therefore, the shock is not perturbed by the very thin walls of the cavity. The shorted end of the cavity, in these preliminary tests, is a 3/8 in. aluminum plate. This aluminum plate may be replaced with conducting foil (the shorted end of the cavity) and a dielectric material or conducting material may be extended in this direction also.

It should be noted that Teflon is not the only candidate for the material in the cavity. Teflon was chosen primarily because of its low dielectric loss at the frequency of interest and its density was appropriate; however, another advantage is that the fluorine in the Teflon tends to quench ionization. Other suitable candidates might be aluminum oxide, silica, lithium fluoride, etc.

At the shock front, as the shock runs up the cavity from the shorted end (the dotted line in Fig. 2), there is an abrupt change in the index of refraction due to the higher density of the material behind the shock front. The reflection from this dielectric discontinuity can be as high as several percent:

$$\left(\frac{N1 - N2}{N1 + N2}\right)^2$$

where N1 and N2 are the indices of refraction in front of and behind the shock front.

The wavelength associated with a 2π change as detected by the mixer diodes is 1.1 cm (measured). That is, the phase change difference ($\delta\phi$) between the detector signal and the local oscillator signal at the mixer diodes is $\delta\phi = 2\pi X/X_0$ where X is the distance the shock travels in the cavity and $X_0 = 1.1$ cm. At the same time, the microwaves which pass through the shock front (not reflected by it) are reflected from the moving shorted end of the wave guide. This short, a conducting metallic surface, is moving at particle velocity. The wavelength associated with this motion is, however, more complicated. In the approximation that the dielectric constant is proportional to the density of the material,(3) the wavelength of the particle velocity motion will be equal to the wavelength in vacuum since the same quantity of material is inside the cavity. For a WR-90 waveguide (the dimensions of the Teflon inner tongue are 0.4 inches by 0.9 inches), this wavelength is 1.8 cm for the same 2π phase shift at the mixer diodes. The particle velocity always being slower and its wavelength always being longer allows the signals associated with the shock and the particle velocity to be separated. The relative amplitudes of these two signals is a function of the relative reflectivity of the dielectric discontinuity and the short at the end of the microwave cavity; hence, their ratio is a measure of the density at the shock front. These three measurements are not linearly independent and, consequently, form an internal check. In order to have an independent measure of the shock velocity, fiberoptic pins (microballoons) were embedded in the Teflon block outside the cavity.

4. RESULTS

The apparatus on the first trial consisted of a high explosive lens, four inches of 9501 high explosive, 3/8 inch aluminum and then the Teflon detector cavity. The calculated pressure at the aluminum-Teflon interface was 280 kbar. The signals from the mixer diodes were recorded on LeCroy digitizers. One of the quadrature signals from the first attempt is shown in Fig. 3. The frequency of the signal associated with the shock velocity (the high frequency component) combined with its 1.1 cm wavelength yields a velocity decreasing with time from about 4.0 km/sec down to 2.7 km/sec, the variation being due to the decay of the shock. The particle velocity as derived from Fig. 1 goes from 2.3 to 1.1 km/sec (Fig. 4). These velocities are in good agreement with the published values(4) for the shock and particle velocities at these pressures and also agree quite well with the shock velocity as deduced from the fiberoptic pins.

To test the low pressure response of the system, we have used water as a damper separating the high explosive from the microwave cavity. Four inches of water was calculated to reduce the pressure to 40 kBARs. The resultant signal-to-noise ratio was almost as good as at 300 kBARs and, again, the measured velocity agreed quite well with the preshot calculations.(5)

5. CONCLUSION

A technique for the simultaneous measurement of shock and particle velocities and the density behind the shock front has been developed. The technique allows an unperturbed measurement of these values in the same cavity. A higher resolution apparatus (operating a K-band, 25 gHz) is being built. Higher pressure tests, up to 600 kBARs, are ongoing.

ACKNOWLEDGEMENTS

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5. Joe Fritz and Stanley P. Marsh, Private communications.

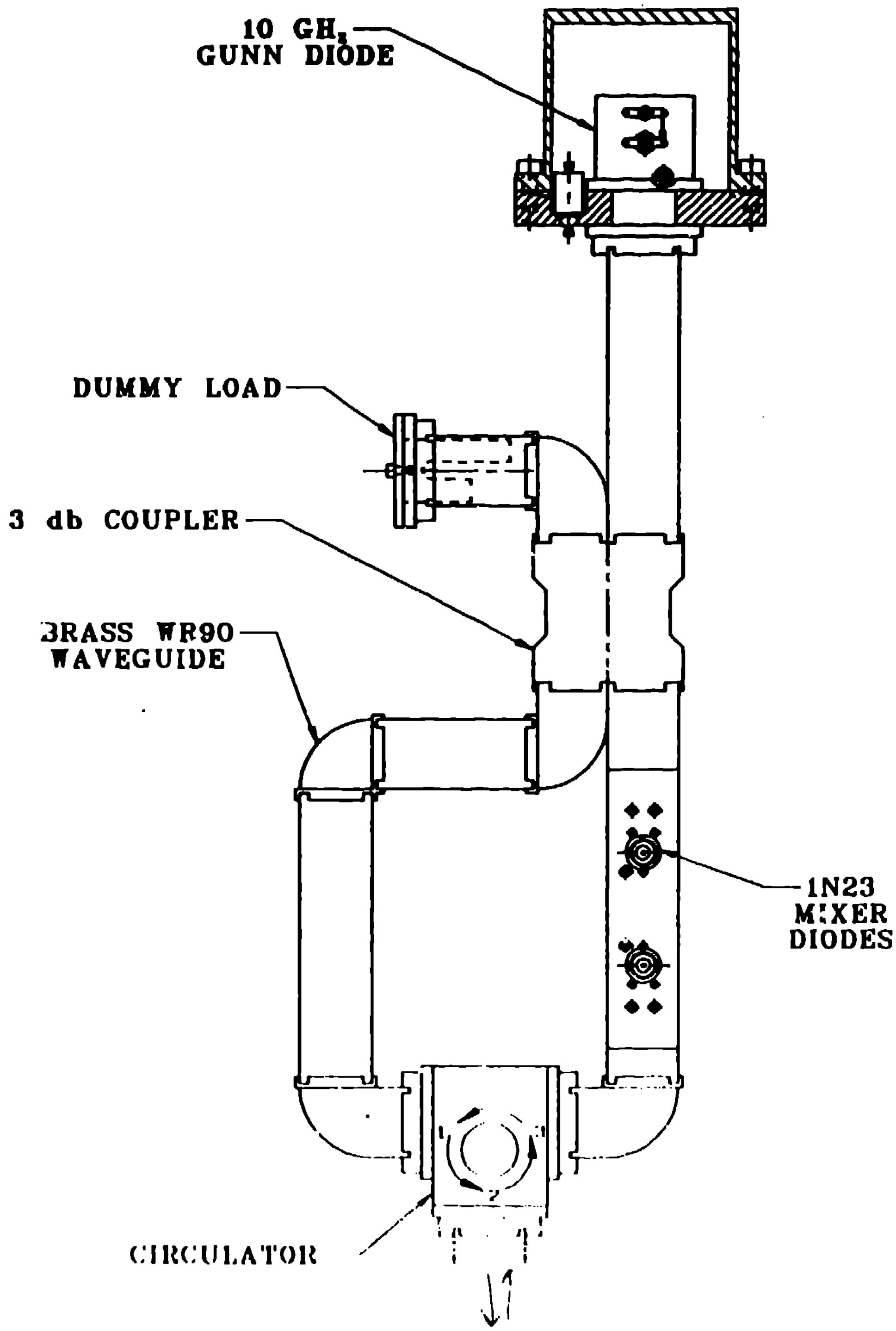

Fig 2 – Microwave
Inter. Computer

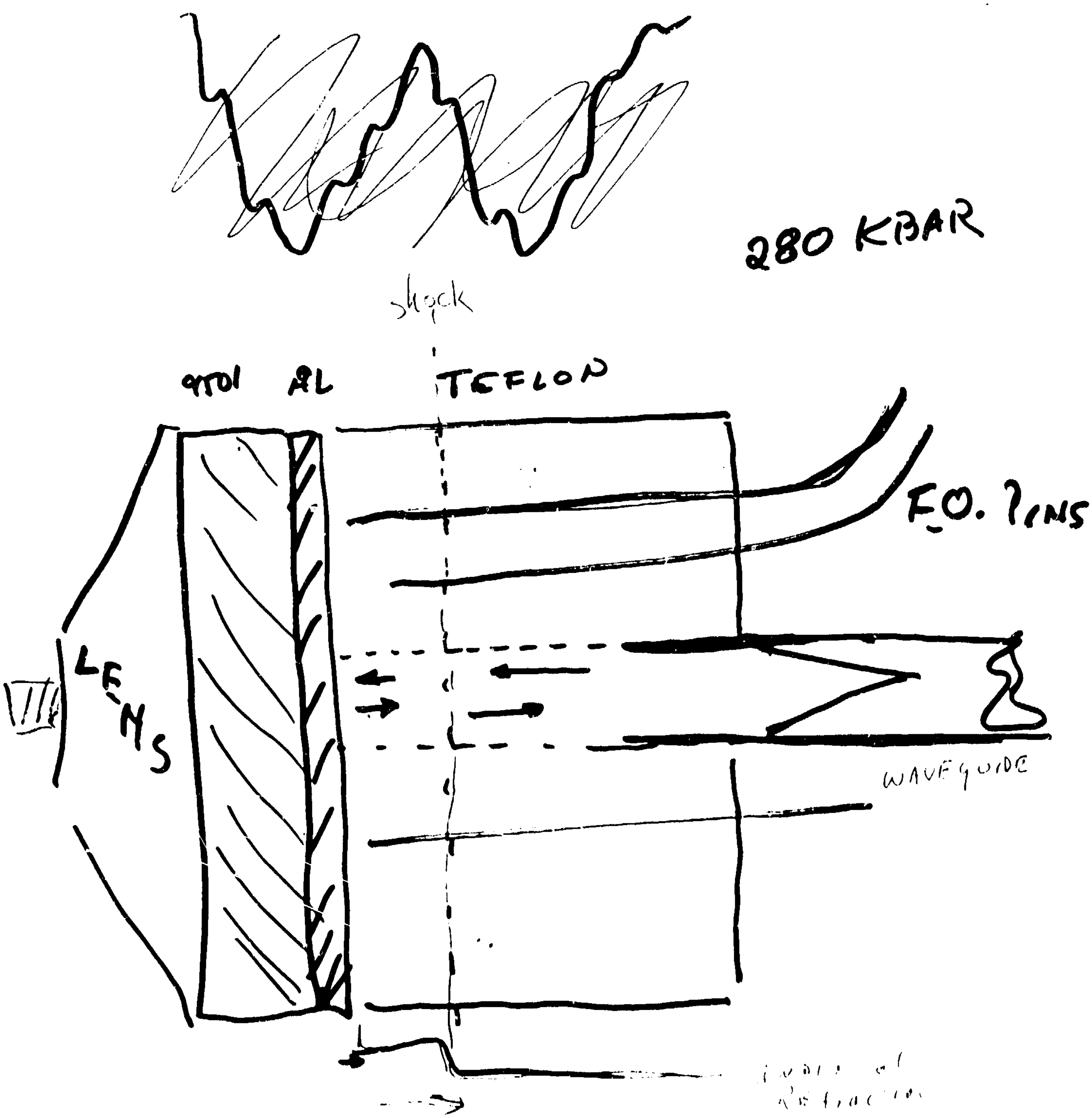

Fig 2. the Detector

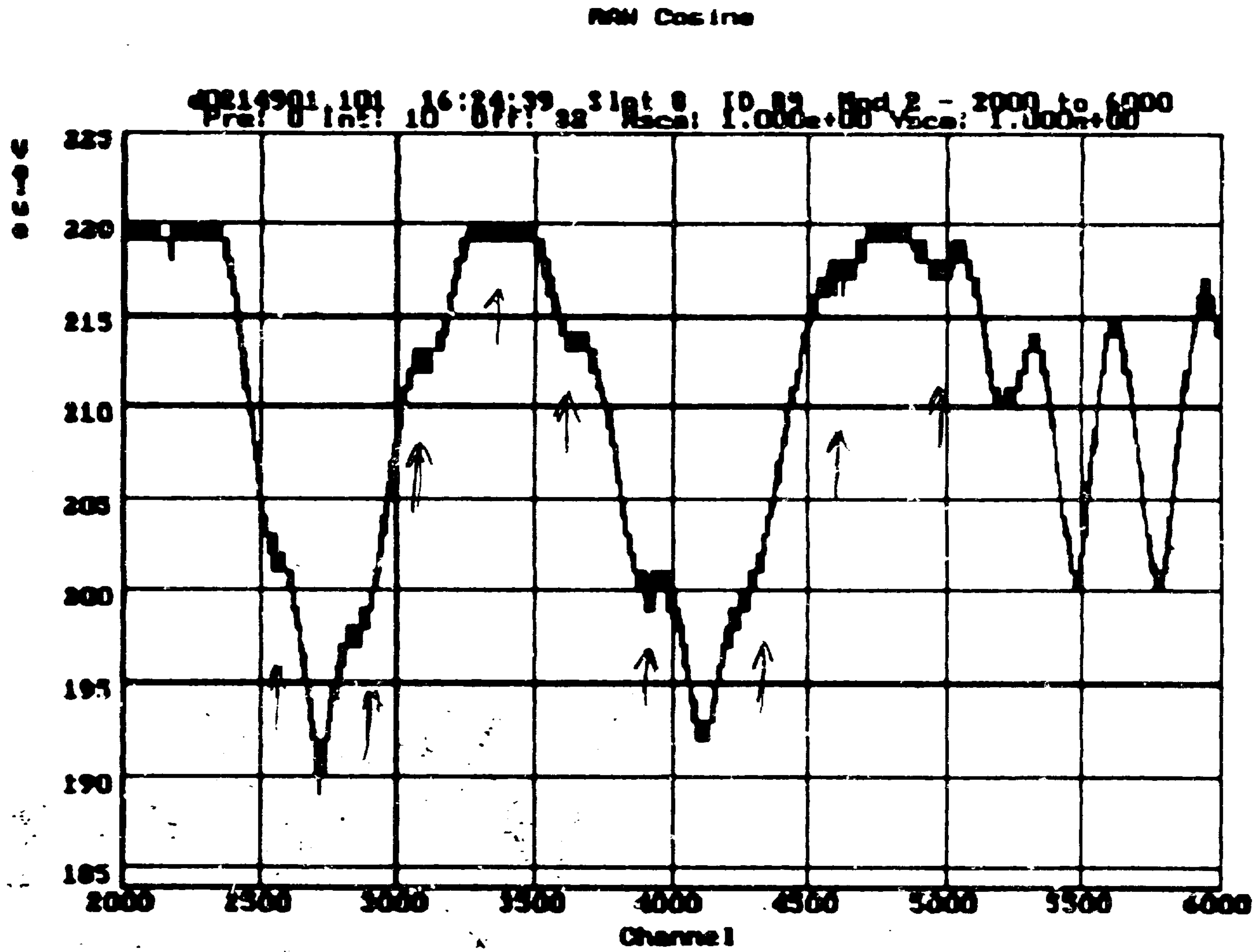

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Fig 3 RAW DATA [illegible]

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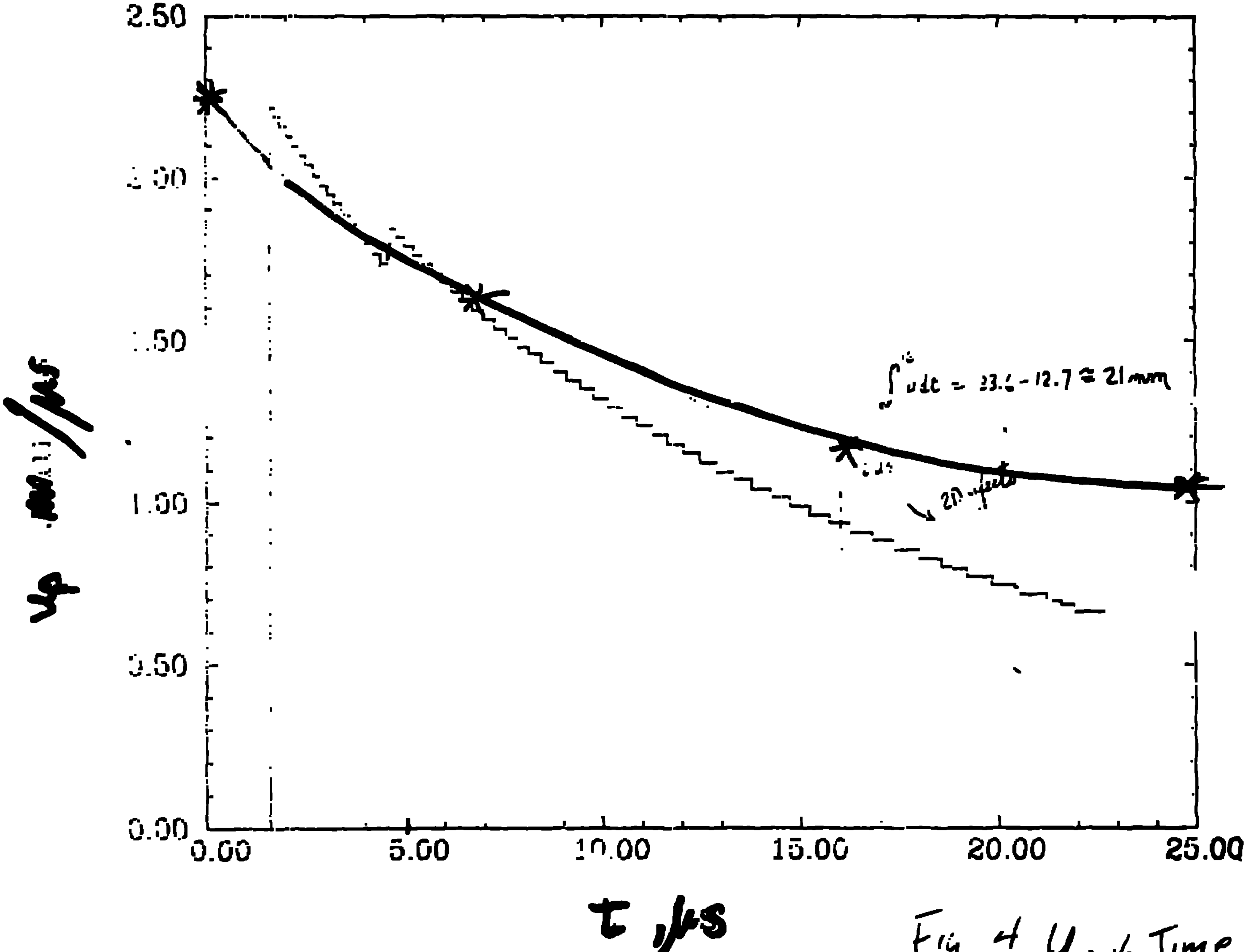

Fig 4 u_p vs Time