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SHOCK ANALYSIS USING THE MULTI POINT VELOCIMETER (VISAR)

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Abstract

The velocity of short duration high-amplitude shock waves and high-speed motion created by sources such as explosives, high energy plasmas and other rapid-acceleration devices are difficult to measure due to their fast reaction times. One measurement tool frequently used is VISAR (Velocity Interferometer System for Any Reflector). VISAR is an optical-based system that utilizes Doppler interferometry techniques to measure the complete time-history of the motion of a surface. This technique is gaining worldwide acceptance as the tool of choice for measurement of shock phenomena. However, one limitation of the single point VISAR is that it measures only one point on a surface. The new Multi Point VISAR remedies the single point VISAR's limitation by using multiple fiber optics and sensors to send and receive information. Upcoming programs that need analysis of large diameter flyers prompted the concept and design of a single cavity-multiple fiber optic Multi Point VISAR (MPV). Preliminary designs and the testing of a single cavity prototype in 1996 supported the theory of compact fiber optic bundle systems for development into the Multi Point VISAR. The new MPV was used to evaluate the performance of two components; a piezo-driven plane wave generating isolator, and a slim-loop ferroelectric (SFE)-type fireset.

Acknowledgments

Our thanks go to Lloyd L. Bonzon and Jim Asay who provided the financial and development support, and to William Brigham for assisting in the fabrication of the Multi Point VISAR. Also our thanks go to Vincent Loyola and George Clark for providing funding and technical assistance for the isolator and fireset devices.

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The velocity of short duration high-amplitude shock waves and high-speed motion created by sources such as explosives, high energy plasmas and other rapid-acceleration devices are difficult to measure due to their fast reaction times. One measurement tool frequently used is VISAR (Velocity Interferometer System for Any Reflector). VISAR is an optical-based system that utilizes Doppler interferometry techniques to measure the complete time-history of the motion of a surface. Laser light is focused to a point onto a target of interest and the reflected light is collected, routed through an unequal leg interferometer, and converted to electronic information. This information is then analyzed for the amount of Doppler shift during a given time. This technique is gaining worldwide acceptance as the tool of choice for measurement of shock phenomena. However, one limitation of VISAR is that it can only measure the velocity at one point on a surface. If the shock amplitude and planarity of a device is non-uniform, the single point measurement limitations (and resultant data) of VISAR will not accurately represent the overall performance of the test unit. Secondly, if there is a need to measure the shock simultaneity and amplitude generated from multiple devices, single point VISAR is incapable of accomplishing these requirements.

Measuring multiple points on a surface with several VISARs is possible but the equipment cost, complexity, and physical size of such an instrument package is formidable. The new Multi Point VISAR remedies most of these problems by using multiple fiber optics to send and receive Doppler information from a target. The receiving fiber optics are bundled together and the light is routed through one interferometer cavity. The fiber optic bundle is separated back into single fiber optic images where the Doppler information is individually analyzed. Multi Point VISAR allows the user to measure multiple events, and then temporally correlate the shock arrival time as well as shock amplitude history. This information is critical in evaluating shock planarity, amplitude, and simultaneity for a variety of devices, especially components with large diameter shock fronts. This information is also valuable for modeling the component's performance.

VISAR Background, Theory of Operation

The predecessors of the modern VISAR are the Wide Angle Michelson Interferometer (WAMI) and the Lockheed Laser Velocimeter.[1] The WAMI, first described in 1941, was a modified Michelson interferometer that allowed a diffuse target to be used as a reflecting source, instead of the traditional mirrored surface required with displacement interferometers. This new interferometer also used an etalon to temporally lengthen the path of one leg of the interferometer, while keeping the apparent image paths equal. The difference between these paths is defined by the equation:

$$x=h(1-1/n) \tag{1}$$

where h is the length of the etalon in one leg of the interferometer, and n is the index of refraction of the etalon. This path difference (equation 1) makes Doppler shifted light possible. The longer the path length, the larger the Doppler shift for a given velocity, which provides greater sensitivity when measuring slower events. The Lockheed Laser Velocimeter used the same techniques as the WAMI and is acknowledged as the first linear velocity interferometer to be used for shock physics. Barker and Hollenbach used the previous developments of the Lockheed Laser Velocimeter to build a laser interferometer for shock physics at Sandia National Laboratories.[2] That system was improved upon, and uses the acronym "VISAR" (Velocity Interferometer System for Any Reflector). Subsequent developments and improvements to VISAR were the advent of the Push/Pull VISAR, developed by Hemsing, where the previously unused optical information of the interferometer was added to the primary signal, causing a twofold increase in signal and a reduction in optical noise[3]. A later development that had significant impacts on the ease and portability of VISAR was the Fixed Cavity VISAR.[4] This innovation greatly simplified the use of the system while providing an extremely stable interferometer that allows the user to trigger recording equipment off of the first motion of the event. This capability is valuable for devices where the function time is not known, therefore eliminating the use of pre-triggering recording equipment at the proper time during the event.

The primary components of a typical VISAR are a single frequency laser, a modified unequal leg Michelson interferometer cavity, high-speed photomultiplier tubes and a recording device such as a digitizing oscilloscope **(Figure. 1)**. The laser used for this experiment is a single frequency; frequency doubled Nd:YVO (Neodymium-doped Yittrium Vanadate Oxide crystal) operating at 5 Watts, continuous wave (cw) and a wavelength of 532 nanometers.

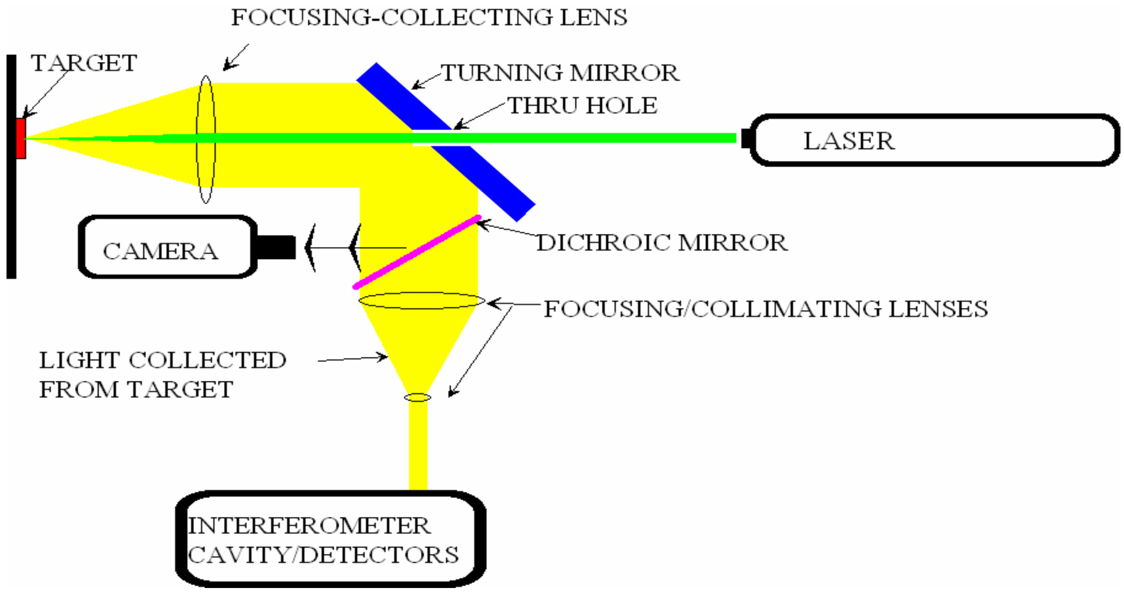

Figure 1. *Typical open beam- non-fiber optic coupled VISAR experiment diagram.*

The VISAR cavity is a modified, unequal leg Michelson interferometer that can be used singly, or in the dual delay leg configuration[5]. The components in the Fixed Cavity VISAR are cemented together to significantly reduce the need for alignment, and greatly increases optical stability **(Figure 2)**. The light from the output fiber optic is connected to the sensor, collimated, and then sent through the cavity. The beam splitting coating reflects one beam through the glass "delay bar" and the other beam through air and a 1/8-wave retarder. The beams are recombined to form two sets of interference patterns, which have simultaneous intensities 180 degrees out of phase with each other. The interfered light is routed to optical detectors that convert the optical information to electronic signals. Half of the light is electronically inverted and added to the normal phase light which doubles the signal intensity and cancels out most of the self light that may be generated during an experiment. A bandpass filter placed in front of the return beam further filters the laser light to keep the signal-to-noise ratio high and to exclude light generated from explosive, or other reactions[6].

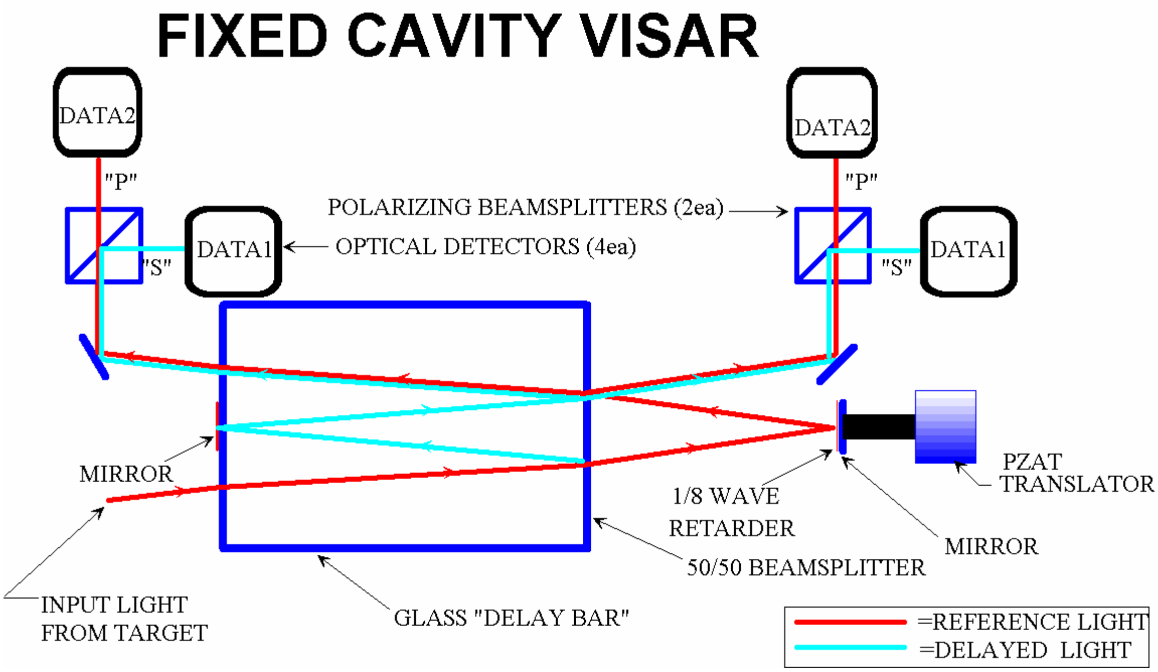

Figure 2. *Drawing of Fixed Cavity interferometer. "DATA X" are optical detectors. The PZAT Translator simulates the return signal, and provides fine adjustments of the interferometer (Glue bonds and optical support glass are not shown).*

Using VISAR to measure the results of a shock driven into, or through, a surface can be accomplished in two ways. The simplest method is a "free surface velocity" measurement. Laser light is directed onto a bare target and the reflected light is collected in a fiber optic that is routed to the interferometer cavity. When the surface is driven into motion, the Doppler shifted light from that surface is recorded yielding a direct correlation of **free surface velocity** with respect to the Doppler shifted light. A second method commonly used to measure shock pressure is to prepare a transparent "window" material with a reflective coating on one side. This window is attached to the sample with the reflective coating side adhered to the sample using a very thin adhesive layer. As the shock travels through the sample and into the window, a **particle velocity** is generated causing a Doppler shift in the laser light that is analyzed by VISAR diagnostics. If the shock Hugoniot is known for the window and sample materials, the shock pressure of the sample can be derived from the particle velocity (**Figure 3**).

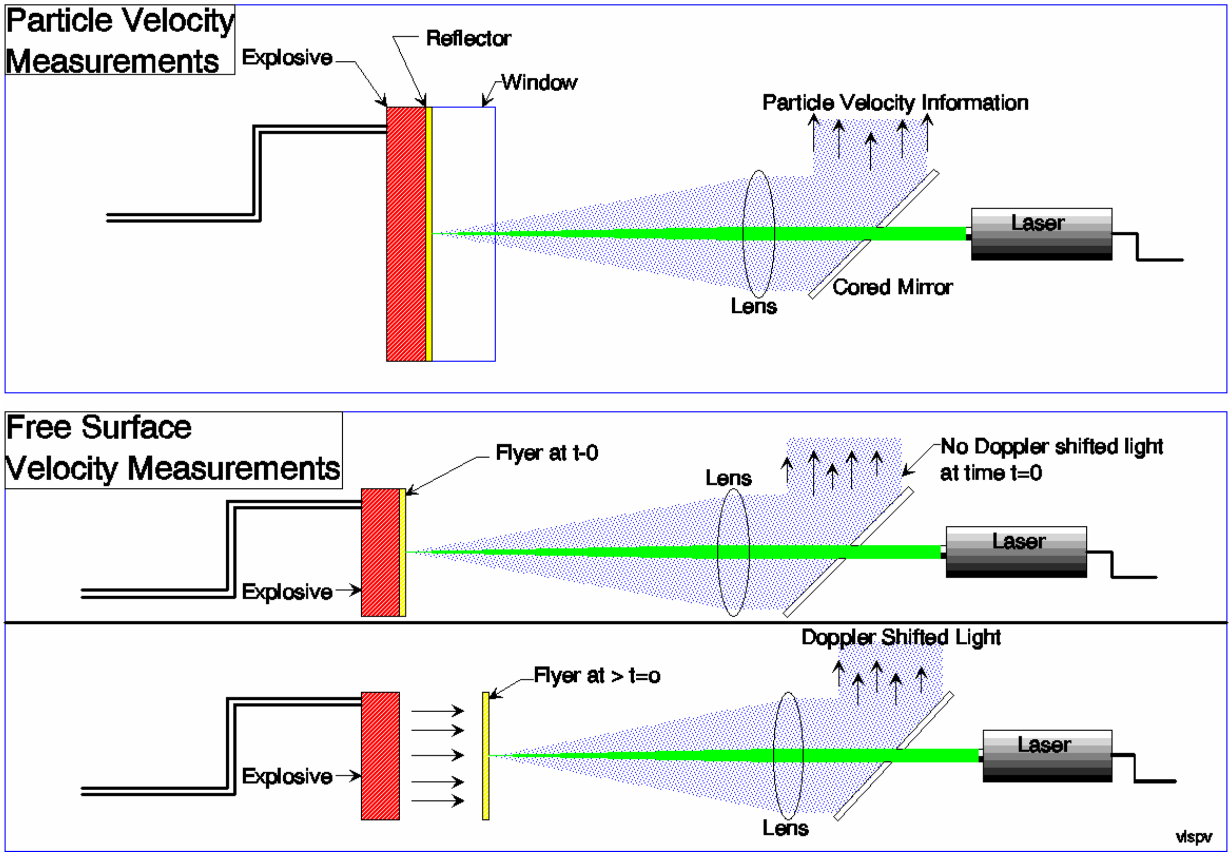

Figure 3. *Drawing of particle velocity vs. free surface measurements.*

In an equal leg interferometer system, the Doppler shifted arrival time would be equal resulting in no change in the interference pattern generated by laser light recombination. VISAR, however, has unequal length optical path distances in the interferometer cavity, resulting in different Doppler shift arrival times at the beam recombination point**.** This path length difference is defined by:

$$\Delta \, length = (h(1-1/n))\cos a \qquad (2)$$

Where h is the delay leg length, n is the index of refraction in the delay etalon, and $\cos a$ is the correction factor for the angular path of the beam traveling through the cavity. Using the relationship from equation (2), the delay time τ is:

$$\tau = 2h/c = \frac{2h(1-1/n)}{c} \qquad (3)$$

Where c is the speed of light in a vacuum.
Using these relationships, the fringe count $F(t)$ relates to target velocity $u(t-\tau/2)$ as:

$$u(t-t/2)=\frac{\lambda F(t)}{2\tau(1+\Delta\nu/\nu)}\cdot\frac{1}{1+\delta} \quad (4)$$

In which λ is the wavelength of the laser light, $\Delta\nu/\nu$ is an index of refraction correction factor for the window, if used, δ is a correction factor with respect to wavelength for dispersion in the etalon (delay bar) material. Equation (3) is manipulated to obtain the ***velocity-per-fringe*** (VPF) constant for an interferometer, which is:

$$VPF=\frac{\lambda}{2\tau(1+\Delta\upsilon/\nu)}\cdot\frac{1}{1+\delta} \quad (5)$$

Data reduction software converts the sinusoidal traces to a polar plot, then to velocity as a function of time plot as in **Figure 4**.

Data Reduction

When characterizing the output performance of the plane wave generator and explosively driven fireset, polymethylmethacrylate (PMMA) was chosen as the window material for both experiments. PMMA provides particle velocity measurements at high pressures (>200 kBar), and the epoxy glue used for bonding the window to the sample has similar shock properties compared to PMMA[7]. Having similar shock properties reduces the requirements for ultra-thin bond areas. The shock Hugoniot of PMMA is the relationship between the shock and particle velocities of the material and is expressed as:

$$U_s = C_o + SU_p \quad (6)$$

Where U_s is the shock velocity in mm/μs, C_o is the initial bulk sound velocity in mm/μs, S is a dimensionless empirical parameter, and U_p is the particle velocity in mm/μs
For example, PMMA in equation 5 has the form:

$$U_s = 2.49 + 1.69U_p \quad (7)$$

The measured particle velocity can be plotted as a function of shock velocity. By knowing the values of shock velocity, particle velocity, and density, the compressive pressure can be calculated using conservation of momentum:

$$\mathrm{P} - \mathrm{P_o} = U_s U_p \rho_o \quad (8)$$

Where P is the final pressure in Gpa, P_o is the initial pressure, and ρ_o is the initial density in g/cc (in this case = 1.184).
During shock loading, the stress at any time in the event can now be calculated. It is important to note that equation 7 should not be used in unloading because the relationship between U_s and U_p differs from that of equation 6 and complete unloading is not currently documented in PMMA at this time.

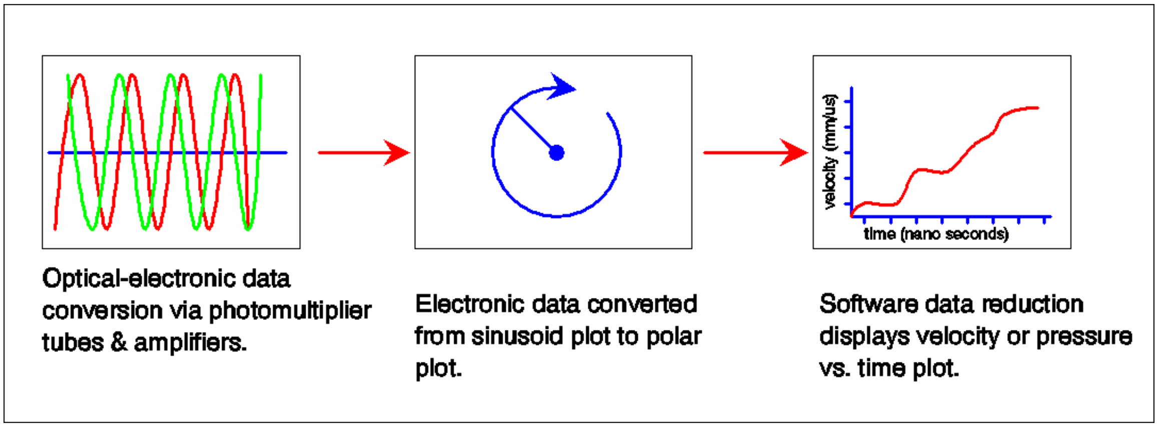

Figure 4. *Simplified data reduction sequence.*

Multi Point VISAR Design Criteria

Having the ability to measure multiple zones of a surface, or surfaces, under shock loading makes modeling the device easier and more accurate. Previous methods for obtaining shock measurements from different areas of a device's surface were limited to either using several VISAR cavities, or measuring a different point on several similar units with the assumption that they performed identically. The Multi Point VISAR was designed to meet several criteria, including accuracy, simplicity of use, efficient laser light transmission, portability, fiber optic coupling, and minimal cost. Since the system can accurately measure several individual points of a target's surface simultaneously and can temporally correlate each measurement point, the accuracy is greatly enhanced over previous methods. Data reduction is performed identically to a single point VISAR, with the additional data of temporal correlation of each measurement point to one another. The light gathering efficiency of the system is high, due to the use of the latest generation of low aberration, variable index-of-refraction optics. Using these optics with proper imaging design and fiber optic coupling, allows the measurement of multiple points using only a single laser with moderate output power. MPV is a portable system due to the compact design and stability of the fixed cavity interferometer. Additionally, by using frequency doubled Nd:YVO lasers that operate on standard 120 Volt power with internal closed loop cooling, the entire system is portable and power efficient **Figure 5**. This laser is small and efficient compared to the two-meter long argon-ion lasers used on single point VISARs which use 208 or 440 Volt three phase power and refrigerator-sized chillers for cooling. These lasers prevented any easy portability of a VISAR system to the field, or other laboratories. The Multi Point VISAR is a modular system that can be moved as a unit, or quickly disassembled to its individual component boxes.

Figure 5. *Five Watt, single frequency-frequency doubled Nd:YVO laser, attenuator, and Pockels Cell modulator with fiber optic coupling (For reference, holes on optical table are 1" apart).*

The entire system is operated on 120 Volt AC single-phase current which allows its use in virtually any area with either hardwired outlets, or portable generator-produced outputs.

Optical Design

Considerations for system design and development of the Multi Point VISAR are: mechanical stability, fiber-to-fiber coupling stability and efficiency, minimal aberrations, ease of fine adjustment, and accurate temporal correlation between measurement points. The interferometer cavity is made from adhesive bonded glass and Invar, which have low thermal coefficients of expansion, making the system very stable over an extended period of time **Figure 6**. Optical alignment components consist of five x-y-z translation stages specifically made for fiber optics, and are used for fine adjustment for sending and receiving laser light originating from the target area. Polarizing beam splitters and turning mirrors are integrally mounted to minimize area consumption and maximize rigidity of the mounting system. The entire optical array is mounted on an internally vibration dampened optical breadboard that stabilizes the Multi Point VISAR which minimizes the need for adjustment.

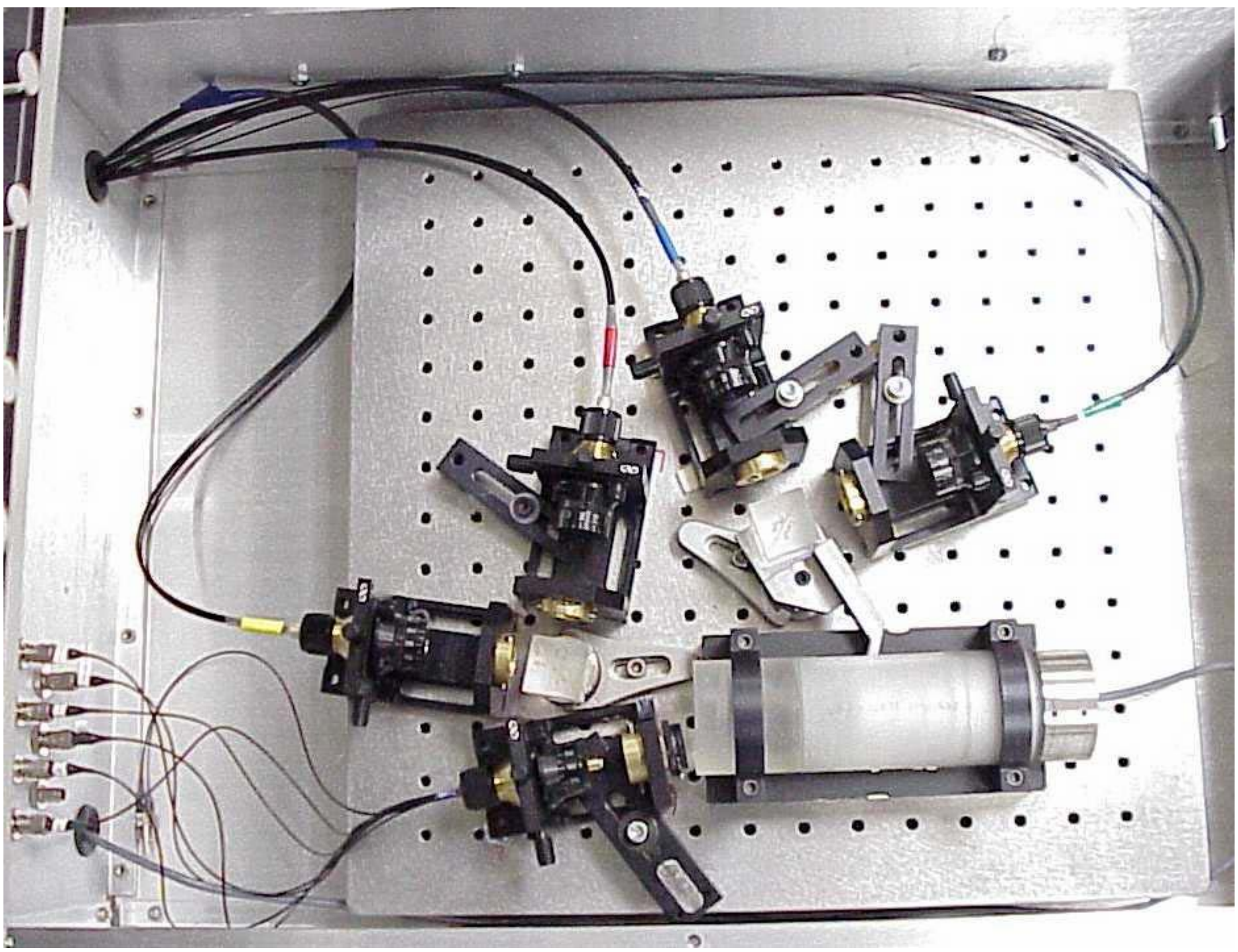

Figure 6. *Overhead view of the Multi Point VISAR. Input channels are on the left of the chassis box. The optical breadboard is 16" square and the holes are one inch apart (for reference).*

The safest, and most versatile method for sending discrete optical information using the Multi Point VISAR is with fiber optic bundles. At first glance, one might infer that the diverging light emitted from a fiber optic would interfere with the light from the adjoining fibers in the bundle, resulting in a scrambled optical signal. This is prevented by using multimode fiber optics, which prevents interference from adjoining fibers. It is easier to understand the concept of imaging fiber bundles by noting that a camera images millions of points of light reflecting from a flower, for instance, then relays and focuses that image on the camera film. The role of the optics in the MPV is to image an extended source (the emitting fiber bundle) through the cavity, then relay that image to the receive fiber optic bundles. It is imperative to pay particular attention to minimization of aberrations and image magnification ratios. The laser light is focused into fiber optic beam splitter(s), which are coupled to send/receive fiber probes that send light to the target(s), and then collect the reflected light in one or more fiber optics (**Figure 7**).

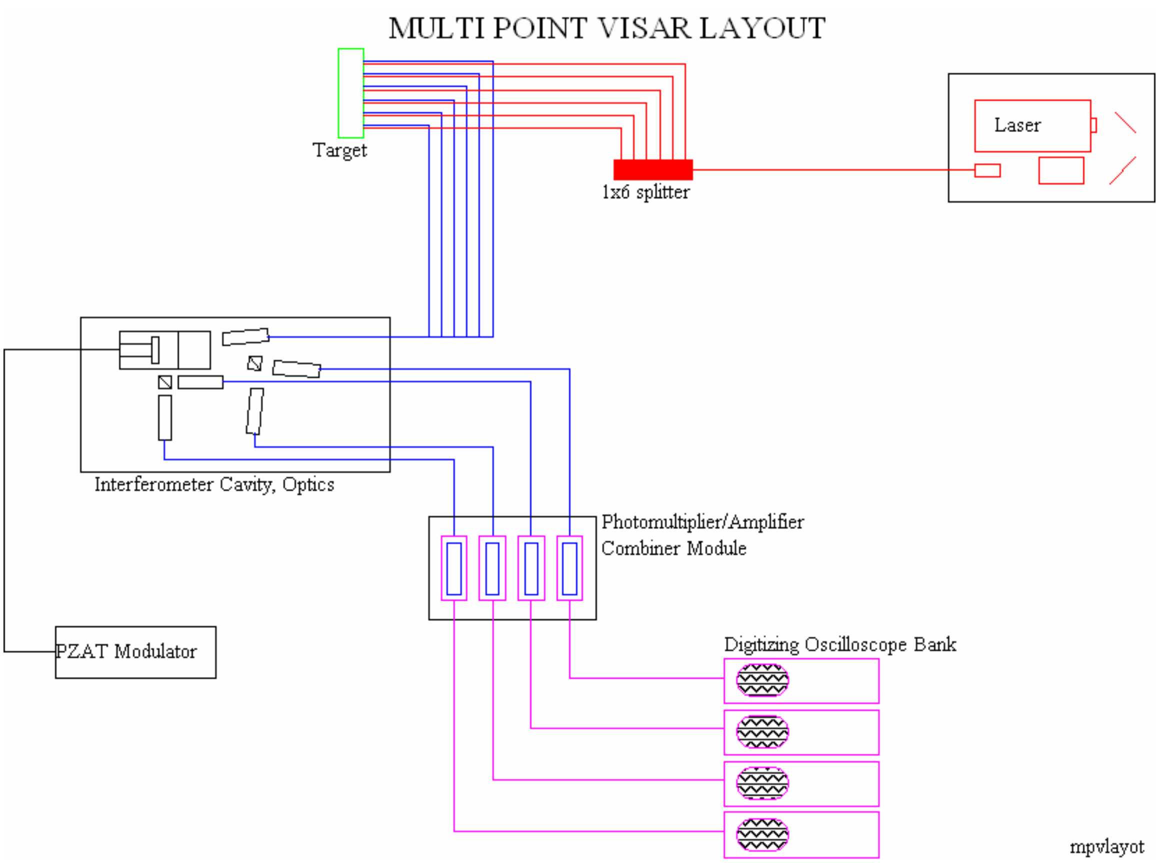

Figure 7. *Multi Point VISAR diagram depicting a six-channel system. Additional fixed cavity modules for dual leg system are not shown in this drawing.*

The Multi Point VISAR uses basically the same interferometer cavity as the single point fixed cavity system (**Figure. 8)**. The only modifications are the increased diameters of the reflective mirror on the delay bar, the combination mirror/waveplate assembly, and the turning mirror access slot. These modifications are needed to reflect and transmit the multiple beams, which emit light to form a larger image as it propagates through the optics. In this particular system, magnification, M, is 2/1. The reason for the magnification requirement is that the relatively large diameter of the "send" fiber bundle is an extended source (as opposed to a point source), resulting in an image divergence through the interferometer cavity that is more than three times greater than that of a single fiber in the bundle. The larger image diameter causes the beams to diverge as they propagate through the optical system, resulting in a larger image spot at the "receive" fiber optic bundles. If the send and receive fiber optics were built to be the same diameter and numerical aperture, and were used with a 1/1 magnification, the result will be an overfilled image with larger spherical aberrations, causing the outer six fiber optics in the bundles to exceed their numerical apertures. This results in significant light loss and "cross talk" between individual fibers that can potentially corrupt the data.

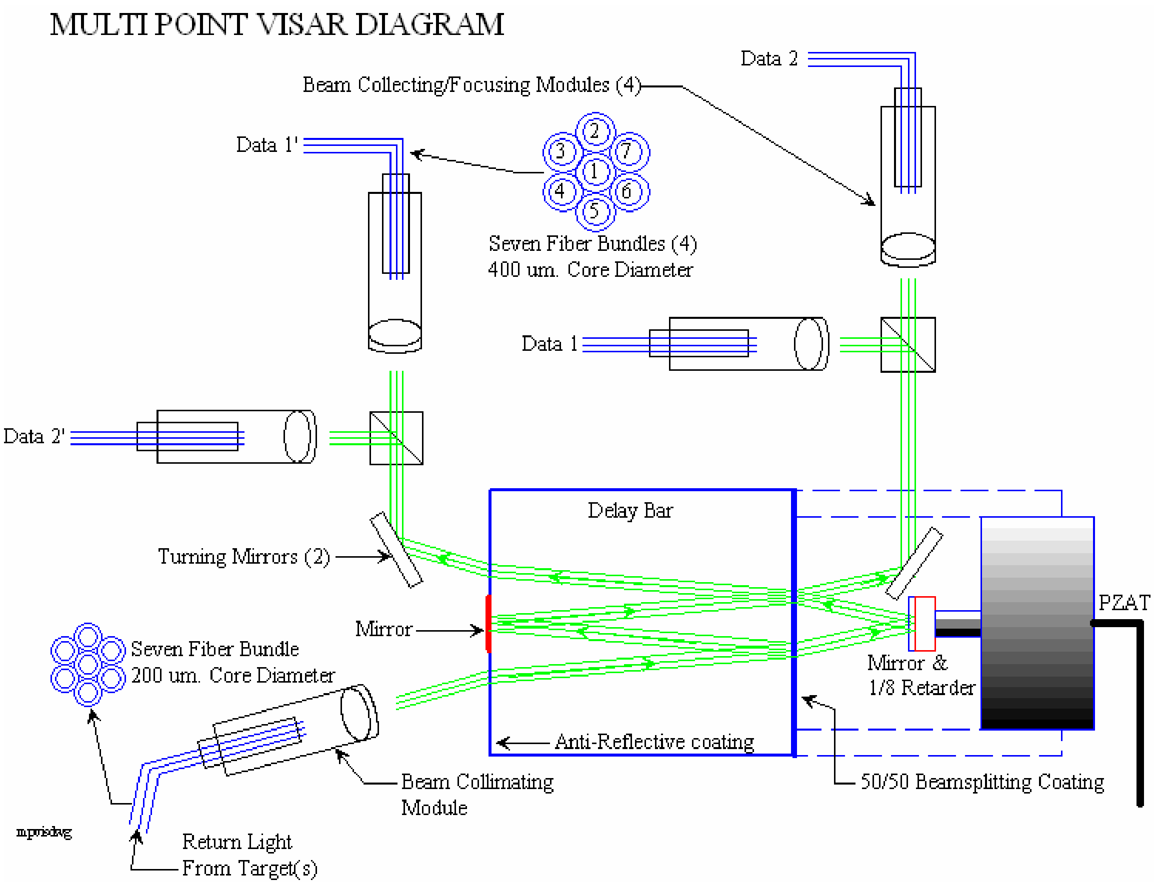

Figure 8. *Layout of the Multi Point VISAR optical components and optical beam paths.*

Optical to Electronic Conversion

Traditional single point VISARs have four individual photomultiplier tube (PMT) detectors that convert the laser light to an electronic signal. These units are driven by individual high voltage power supplies that are varied to balance the gain of the detectors. The Multi Point VISAR uses high bandwidth-high gain 4 dynode photomultiplier tubes that currently have a 360-picosecond rise time (rise time is defined as the time it takes for the input signal to change from 10% to 90% of maximum amplitude). The information is transferred from the photomultiplier tubes to 1.3 GigaHertz bandwidth summing-inverting amplifiers. Data 1' and Data 2' channels are a replication of the Data 1,2 channels but are out of phase 180 degrees with respect to optical signal amplitude. The summing-inverting amplifiers take two input pairs (Data 1,1' and Data 2,2') and add them together, then amplifies the resultant signal by a factor of 10. This process doubles the resultant signal, and cancels most of the non-laser light, which may be generated by explosives, or other photon-producing reactions.

The shear number and weight of individual photomultiplier tube assemblies (28 per Multi Point VISAR), each requiring amplitude balancing, prompted the development of a compact PMT module with provisions for balancing amplitudes on each unit (**Figure 9**). Since each point in the MPV requires four photomultiplier assemblies, a four-"pod" unit was designed and developed to simplify the system, as well as reduce the bulk and weight of the Multi Point VISAR.

Since the laser light is coupled to the PMTs using fiber optics that produce a naturally divergent beam, a different method of intensity balancing is used. These four-pods incorporate iris attenuators that optically adjust the amount of light entering the photomultiplier tube. This allows the user to optically, not electronically balance the gains of individual PMTs.

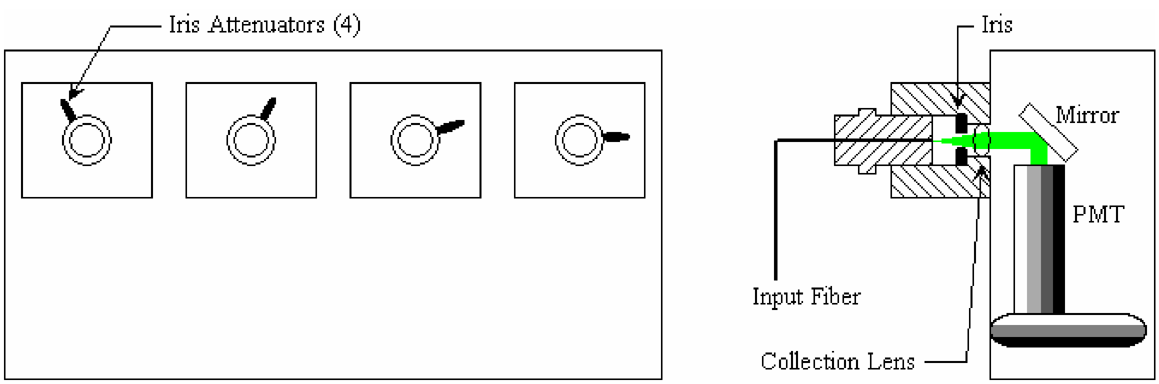

Figure 9. *Four-pod photomultiplier device showing input fiber & beam path to PMT(s). Dimensions for the device are 6" wide by 4.25"tall by 2.5" deep*

Since the PMTs now only need a single set voltage, a single power supply with coaxial splitters is the only requirement, which further reduces the cost, bulk, and weight of a system that would normally require 28 separate adjustable power supplies **(Figure 10)**. This innovation allows much more compact instrumentation arrangements, and provides easier PMT amplitude adjustments. Additionally, using a set voltage that is optimized for the PMT's dynamic range maximizes the linear response of the photomultiplier tube. Optimal linear response provides a more accurate optical-to-electrical signal conversion, which makes VISAR data more accurate.

Figure 10. *Front view of the four-pod photomultiplier tube systems. Shown are 32 separate channels with fiber optics originating at the interferometer cavity.*

Temporal Calibration & Accuracy

Knowing the overall system accuracy (velocity-per-fringe constant), as well as temporal correlations between each channel is paramount in validating the accuracy of the Multi Point VISAR. Before attempting to quantify accuracy and maximum velocity measurement capability of a particular VISAR, the fill time void must be known. The fill time void is the temporal lag in the two (reference & delay) beams recombining to form interference fringes. This fill time is equal to the delay time τ, which is:

$$\tau = 2h/c = \frac{2h(1-1/n)}{c} \qquad \text{(from equation 3)}$$

This fill time void is important in designing the appropriate system because some or most of the data in a fast event may be lost. Accuracy of a VISAR system, in general, is +/- 2% but this number may grow if the system is not optimized for the measurement event. It is desirable to minimize fill time and maximize the amount of fringes measured with a system without compromising the system bandwidth.

Multi Point VISAR also provides temporal correlations between individual measurement points. Since there are several components in a VISAR system that contribute temporal changes, the entire system must be calibrated to ensure the best accuracy. One method that affords simplicity and calibration accuracy is the attachment of a bundle of fiber optics containing a central fiber optic that sends out laser light, surrounded by six receive fibers **(Figure 11)**. This bundle is precisely fabricated to tightly surround the central fiber optic. This minimizes cosine errors due to the angular displacement of the central fiber to the six receive fibers. The reflecting surface is diffused to provide a uniform Lambertian light distribution to minimize cosine errors in the receive fiber optics.

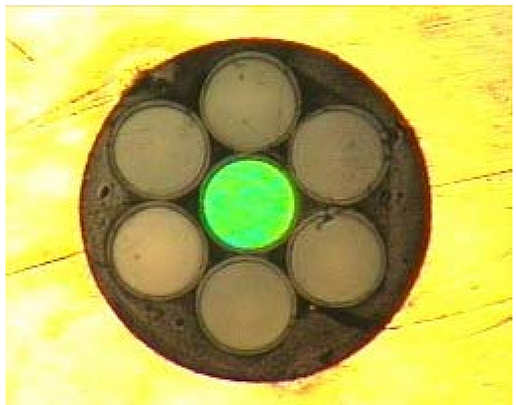

Figure 11. *Microphotograph illustrating the central illumination ("send") fiber surrounded by the "receive" fibers. Each fiber optic is 200 um diameter.*

The outgoing light is sent to a reflective surface that has a detonator, or Detasheet, which produces a planar shock. The return (Doppler shifted) light is intercepted by the receive fibers where their light is routed to the VISAR **(Figure 12)**. Since the reflected light is originating from a single pseudo-point source, the Doppler shift should occur at the same time for all the receive fiber optics. **Figure 13** displays a calibration shot using this technique. Each of the VISAR channels is recorded on similar equipment.

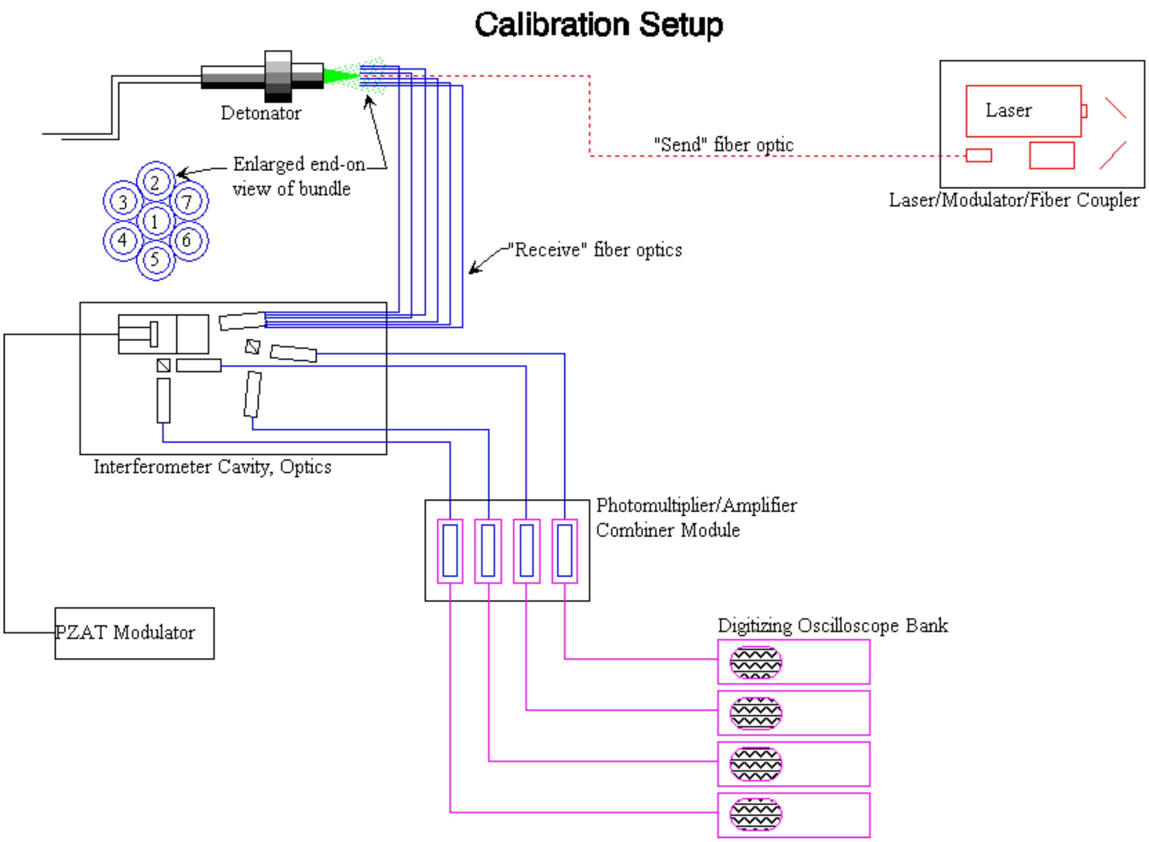

Figure 12. *Calibration technique for temporal correlation of each data channel Fiber 1 is the "send" and two through seven are the "receive" fibers. (The seventh channel, not shown, is calibrated against the six "receive" channels shown in this drawing).*

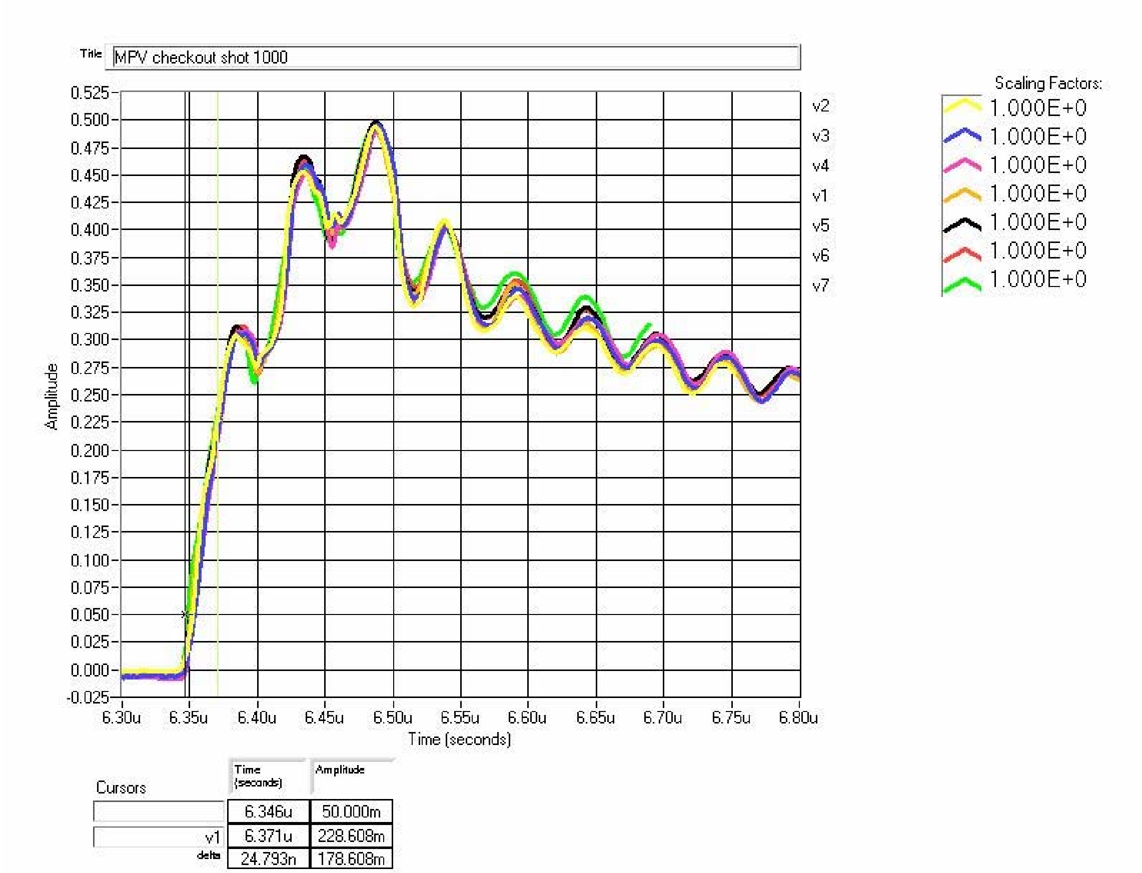

Figure 13. *Calibration test for verifying temporal simultaneity between channels.*

Not shown is the original calibration shot that displayed an eight nanosecond temporal error due to a mismatched electronic cable length. This was corrected to produce the calibration simultaneity as was shown in **figure 12**. This technique is a powerful tool in determining the ultimate bandwidth of the system. Determining the bandwidth is accomplished by calibrating a system as shown above. Once temporal simultaneity is achieved, one of the fiber optic cables is replaced with a slightly shorter length of the same type of fiber, and then tested. When there is a measurable temporal difference, that value is the system limit for discerning shock arrival time. A typical fiber optic with a Numerical Aperture (NA) of .2 will have a throughput transmission time determined by the material, NA, dispersion, and to a small extent, the core diameter.

There are a number of phenomena that contribute to the bandwidth limitations. Ultimately, these phenomena affect temporal accuracy and bandwidth of the VISAR. Although dispersion effects such as Rayleigh and stimulated Brillouin scattering contribute to temporal discrepancies, intermodal, or group delay has the largest effect on Doppler-shift resolution. Detailed discussion pertaining to ultimate bandwidth of a VISAR system is beyond the scope of this report, however, the following points are valid for maximizing the bandwidth of a system:

- Shorter fiber optics
- (Typically) smaller core fiber optics
- Low fiber optic Numerical Aperture (NA)

- Mode mix incoming light into the fiber optic(s) as soon as possible
- Maximize the system velocity-per-fringe constant value (optimize data resolution)

It is important to note that Doppler interferometry (VISAR) bandwidth is (typically) significantly higher than digital bandwidth as advertised by fiber optic manufacturers.

Isolator Evaluation*

The following examples of data collection illustrate the value of simultaneously measuring an event with multiple data channels of the Multi Point VISAR. The isolator delivers a planar shock wave to a piezoelectric-type material, which delivers high voltage to other devices **(Figure 14)**. The planarity and pressure profiles are critical to proper system function. These devices were from systems that were decades old, therefore quantities of devices for evaluation were severely limited. Attempting to measure planarity using a single point VISAR is only possible by measuring one point, then initiating another device while measuring another point at a different location, hoping that all of the devices are functioning identically. The Multi Point VISAR is able to measure up to seven points simultaneously, which also increases the amount of total data available by a factor of seven (**Figure 15)**.

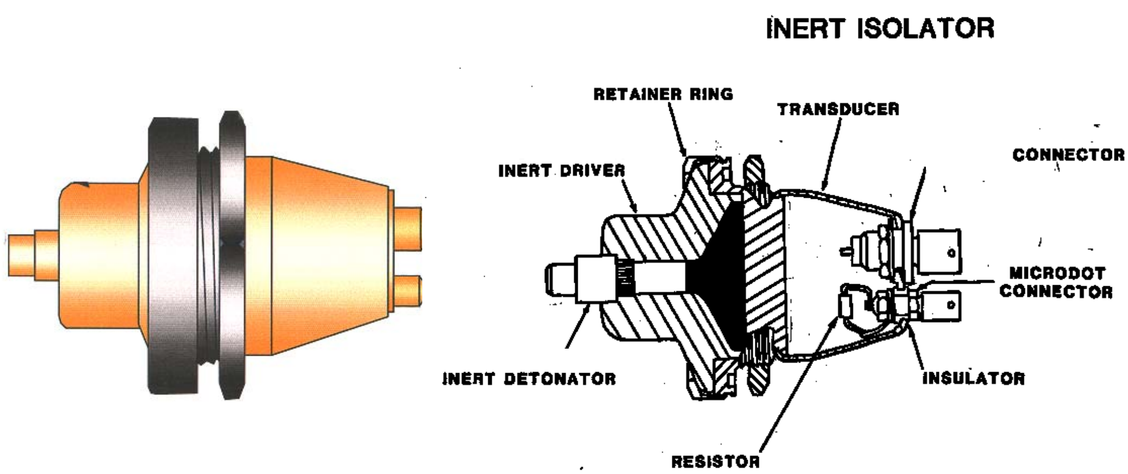

Figure 14. *Drawing of isolator component. Detonation wave travels from left to right.*

The isolator (plane wave generator) has a detonator that initiates an explosive column that transfers a shock wave into a brass material. This material is bonded to a chromoly steel plate, which is attached to a piezoelectric material. This piezoelectric component requires a planar shock wave to operate correctly. Until this component's performance was evaluated with Multi Point VISAR, there was minimal shock planarity or pressure measurements to validate the operation of the device. The method of measurement for this device is to use a technique where the particle velocity is measured at an interface between the component's output and a transparent PMMA window as described in the first section of this paper.

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* Note: Detailed discussion of data for the isolator and fireset are not addressed in this paper. In this context, these devices only serve to illustrate the data obtainable from Multi Point VISAR. More detailed data on these two devices are in a forthcoming SAND report.

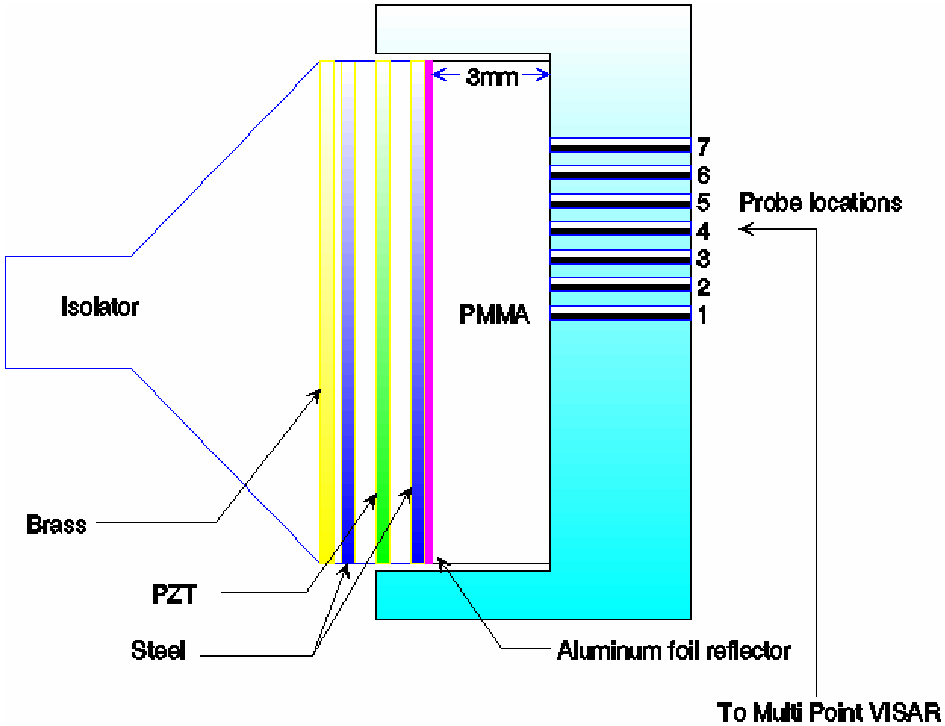

Figure 15. *Probe placements on isolator. Probe placement spirals radially from center to minimize optical signal mixing.*

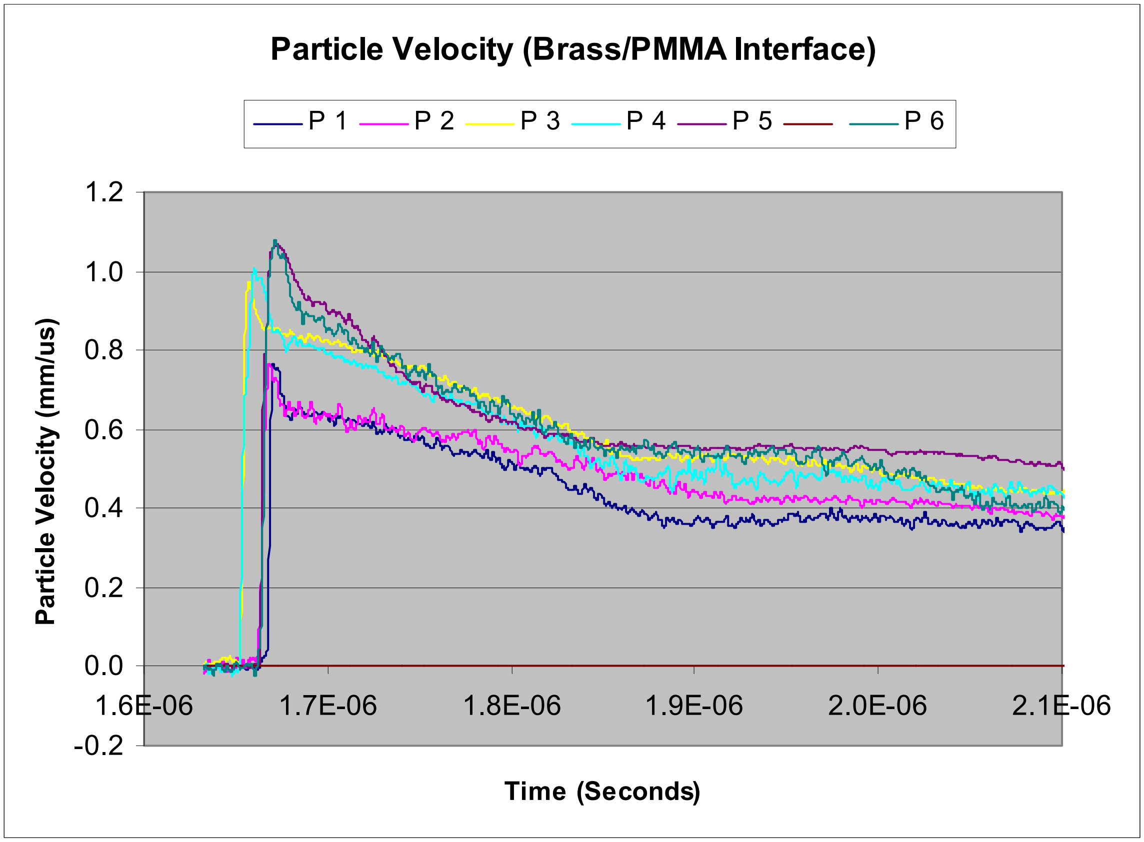

Figure 16. *Typical data illustrating particle velocity (pressure equivalent) versus time for the brass/polymethylmethacrylate interface. Graph also displays shock planarity of that surface.*

Table 1. *Summary of preceding particle velocity plot. Probes 1-6 originates in center of device and radiates outward.*

Probe Callout V	Probe Location (Inches)	Break Away (Sec.)	Peak Speed (mm/us)
P 1	0.00	1.667E-06	0.7638
P 2	0.28	1.662E-06	0.7643
P 3	0.30	1.653E-06	0.9730
P 4	0.35	1.652E-06	1.0078
P 5	0.40	1.663E-06	1.0661
P 6		1.663E-06	1.0807

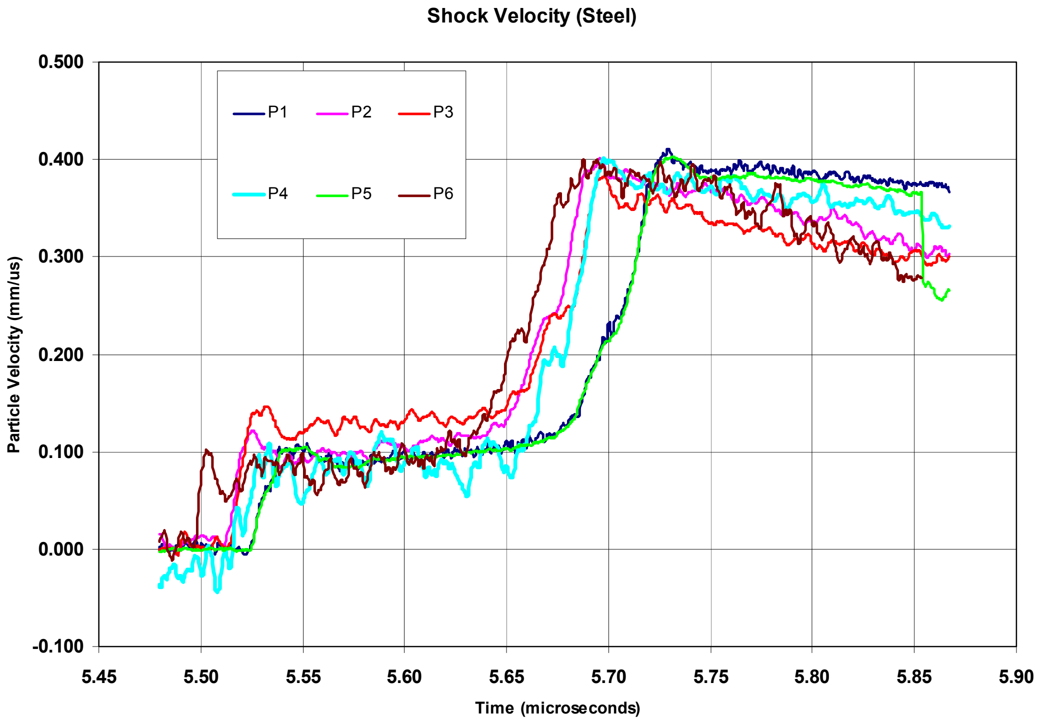

Figure 17. *Particle velocity of isolator shock front at the steel/polymethylmethacrylate (PMMA) interface (Note the elastic wave precursor at the 5.52-5.65 time interval). The corresponding peak pressure is approximately 32 kBar with wavefront simultaneity of +/- 20 nanoseconds.*

Piezo Fireset Performance Evaluation

This fireset is a device that uses multiple explosive pellets that produce simultaneous shock "points", creating a pseudo-planar shock wavefront that is driven into a piezo-type (SFE) material **(Figure 18).** This piezo material then delivers a high voltage output that initiates the isolator shown in the previous pages. The fireset's design includes multiple channels filled with explosives that initiate the pellets that create the plane wave. The shock simultaneity measurement of this device using a high speed-framing camera was previously attempted. The camera imaged the pellet output to discern if the light generated by the explosive pellets occurred at the same time. The results had limited success, and there was no shock pressure associated with the data. Multi Point VISAR was used on this device to characterize its output performance using a PMMA window for both shock arrival time and pressure.

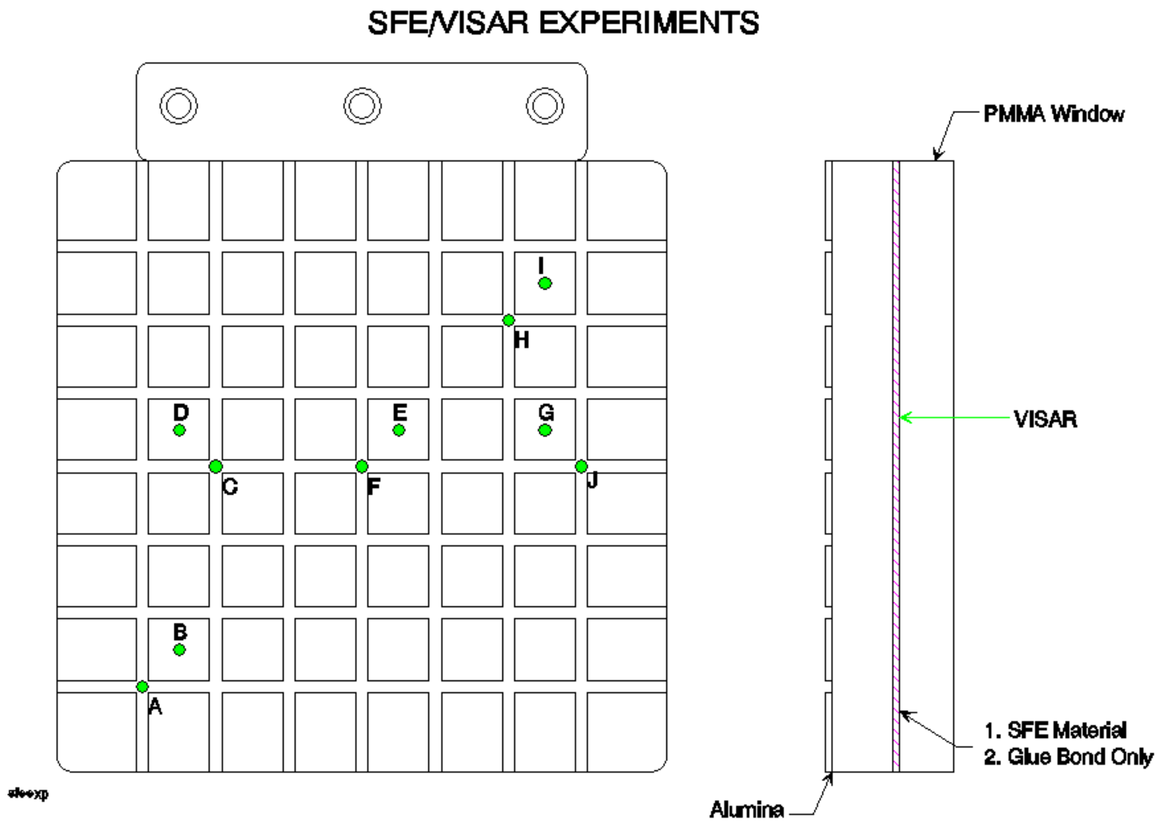

Figure 18. *Probe sampling diagram showing areas of measurement with Multi Point VISAR*

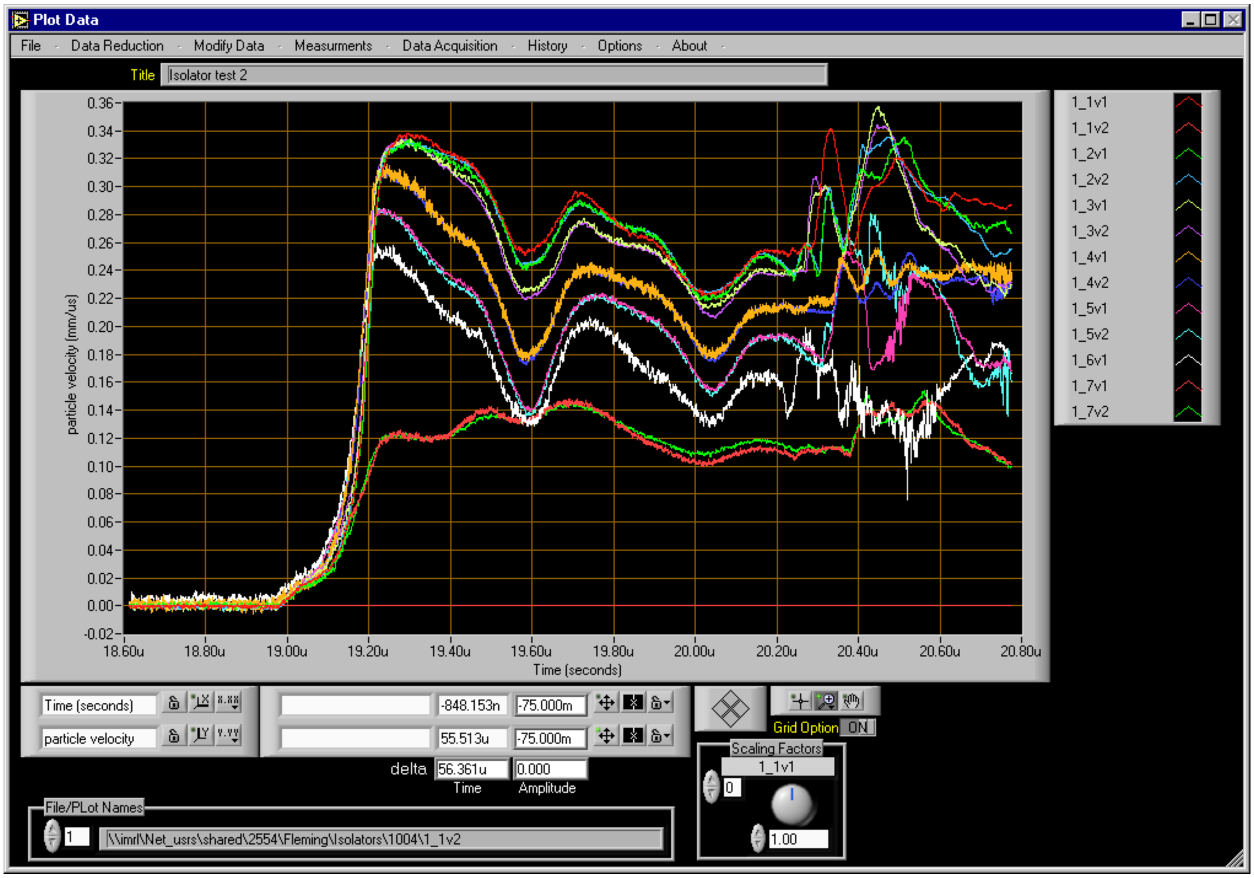

Figure 19. *Explosive fireset performance measurement using Multi Point VISAR (Data reduction for this test uses new VisPlot package). Note the detailed simultaneity and pressure (particle velocity) measurements of the entire time history of the detonation. Peak pressure ranges from 12 to 33 kBar in the compression phase of the shock.*

Conclusions

Multi Point VISAR is the next evolution in a system that has had a substantial contribution to the area of shock physics. With the advent of stable optical components, and high optical output/low input power lasers, the system is capable of being field-portable. Currently, the temporal resolution of the system for measuring multiple areas of a shock or flyer plate is better than 4 nanoseconds. This equates to the ability of measuring shock non-planarities of less than .001" in steel. The accuracy and ability to measure multiple points has also greatly aided in creating models of component performance that were previously unobtainable without the Multi Point VISAR data. The next generation of Multi Point VISAR is underway, with a capability of nineteen separate measurement points.

References

1. Barker, L. M., Hollenbach, R. E., "Laser Interferometer for Measuring High Velocities of Any Reflecting Surface." *Journal of Applied Physics, Volume 43, Number 11, November 1972.*
2. Barker, L. M., Hollenbach, R. E., "Interferometric Measurement of Shock-Induced Internal Particle Velocity and Spatial Variations of Particle Velocity".
3. Hemsing, W. F., "Push Pull VISAR Modification", *Review of Scientific Instruments, Volume 50, 1979.*
4. Crump, O. B., Stanton, P. L., Sweatt, W. C., "Fixed Cavity VISAR", Sandia Report, *SAND92-0162.*
5. Crump, O.B., Stanton, P.L., "The Velocity Interferometer System for Any Reflector." Mod B, Push-Pull With Double-Delay Leg and Dual VISAR Modes." *Sandia Report SAND87-1974.*
6. Fleming, K. J., Crump, O.B., "Portable, Solid State, Fiber Optic-Coupled Doppler Interferometer System for Detonation and Shock Diagnostics". *Tenth International Detonation Symposium, July 1993.*
7. Barker, L. M., Hollenbach, R. E., "Shock-Wave Studies of PMMA, Fused Silica, and Sapphire." *Journal of Applied Physics, Volume 41, Number 10, September 1970.*