UCRL-JC-124862
PREPRINT

Temporal Multiplexing for Economical Measurement of Power Versus Time on NIF

S. Thomas, B. Boyd
D. T. Davis, B. Hall

This paper was prepared for submittal to the
2nd Annual International Conference on
Solid-State Lasers for Application to ICF
Paris, France
October 22-25, 1996

October 22, 1996

Lawrence Livermore National Laboratory

Temporal multiplexing for economical measurement of power versus time on NIF

Stan Thomas, Bob Boyd, Don T. Davis and Bob Hall

Lawrence Livermore National Laboratory
Box 808, L-495, Livermore, CA. 94551

ABSTRACT

We have designed an economical device to measure the power time history in the National Ignition Facility's (NIF) 192 beam laser. The heart of the system is a commercial, high-speed, four-channel digitizer with a 15,000 point record length. Samples of several beams are taken with fiberoptic pickoffs, separated in time with appropriate fiberoptic delays and presented to high-speed vacuum photodiodes, which convert the samples to electrical signals for the digitizer. Amplitude and time multiplexing are used to cover the required dynamic range and to record 12 samples on the digitizer, making the cost per sample competitive with alternative approaches. Forty-eight digitizers can record the required three samples from each of the 192 beams. An additional similar but lower bandwidth system is used to record the backreflected light from the main laser amplifiers and elsewhere. The recording electronics are discussed in detail.

Keywords: NIF laser power diagnostic transient digitizer backreflection

2. BACKGROUND

The system design of the National Ignition Facility's (NIF) 192 beam laser incorporates a requirement to measure the power balance of all beams to insure that it is within tolerance. In order to do this, the time history of the complex-shaped, 22 ns-long, power pulse must be measured on each beam line. The results are used to correct the input to each beam line to achieve the desired balance.

3. SYSTEM DESCRIPTION

The measurements are to be accurate to within two percent (averaged over any two-ns interval) covering a dynamic range of 5000:1 and with a rise-time capability of 250 ps or less. Additionally, back-reflected light from several of the optical components in each beam line path between the preamplifier stages and the target chamber will be measured to insure that damage thresholds in the preamplifier sections will not be exceeded. This large number of measurements (768) will be recorded using commercial, high-speed digitizers with long record lengths and a variety of optical delays.

3.1 Power sampling

Figure 1 shows the beam paths and sampling points. The preamplifier (PAM) output at 1.053 µm (1ω) is injected into the transport spatial filter (TSF). The PAM output is sampled by the input sensor, which passes a sample to the power sensor by a fiberoptic bundle. The injected beam is next passed through the main amplifier, a four-pass amplifier, back through the main amplifier and then returned to the TSF where a second sample, still at 1.053 µm, is taken. The sample is guided to the output sensor by an air path and then to the power sensor by a fiberoptic bundle. The time delay between the first and second sample, the time-of-flight through the main and four-pass amplifiers, is about 900 ns.

The beam continues to the target chamber where it is converted to 351 nm (3ω) light by a KD*P crystal array in the final optics assembly (FOA). A reflection from the crystal output surface is guided back through the optics to the TSF where a third sample is taken and guided to the power sensor, first by an air path (to the output sensor) and then by a fiberoptic-cable bundle. The 351 nm sample arrives at the power sensor about 1.4 µs after the sample from the preamplifier.

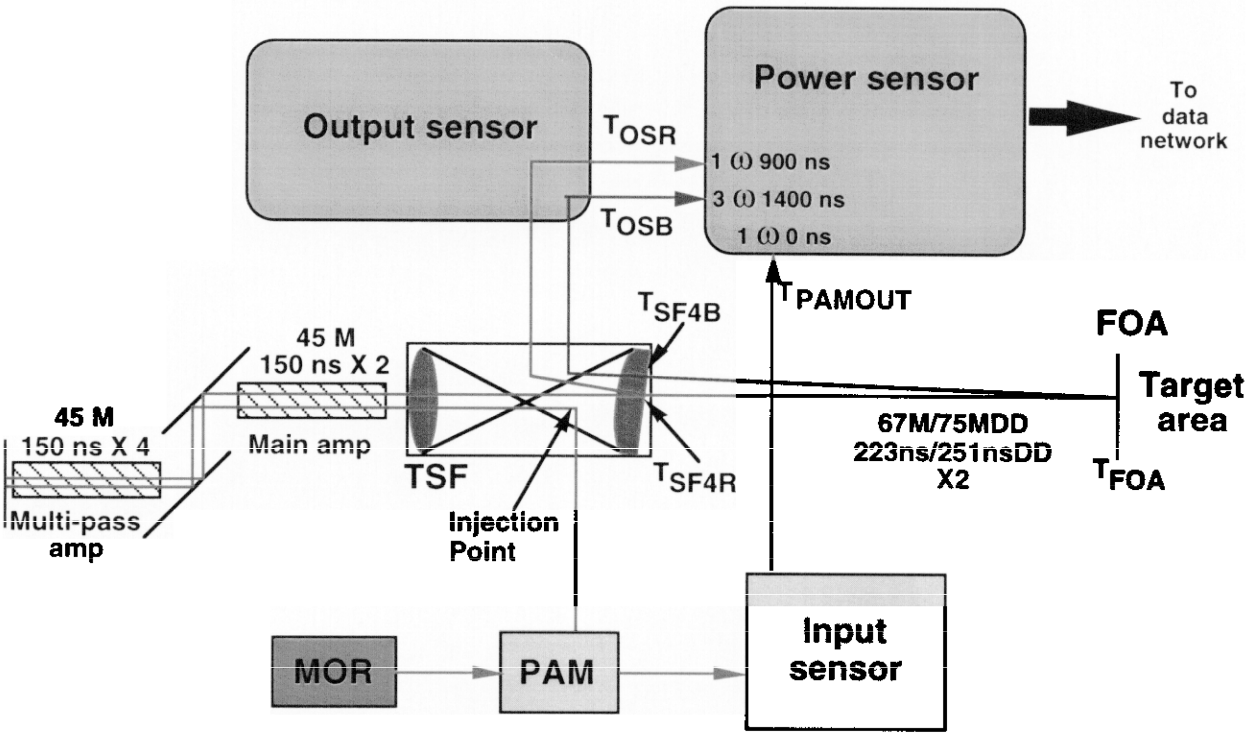
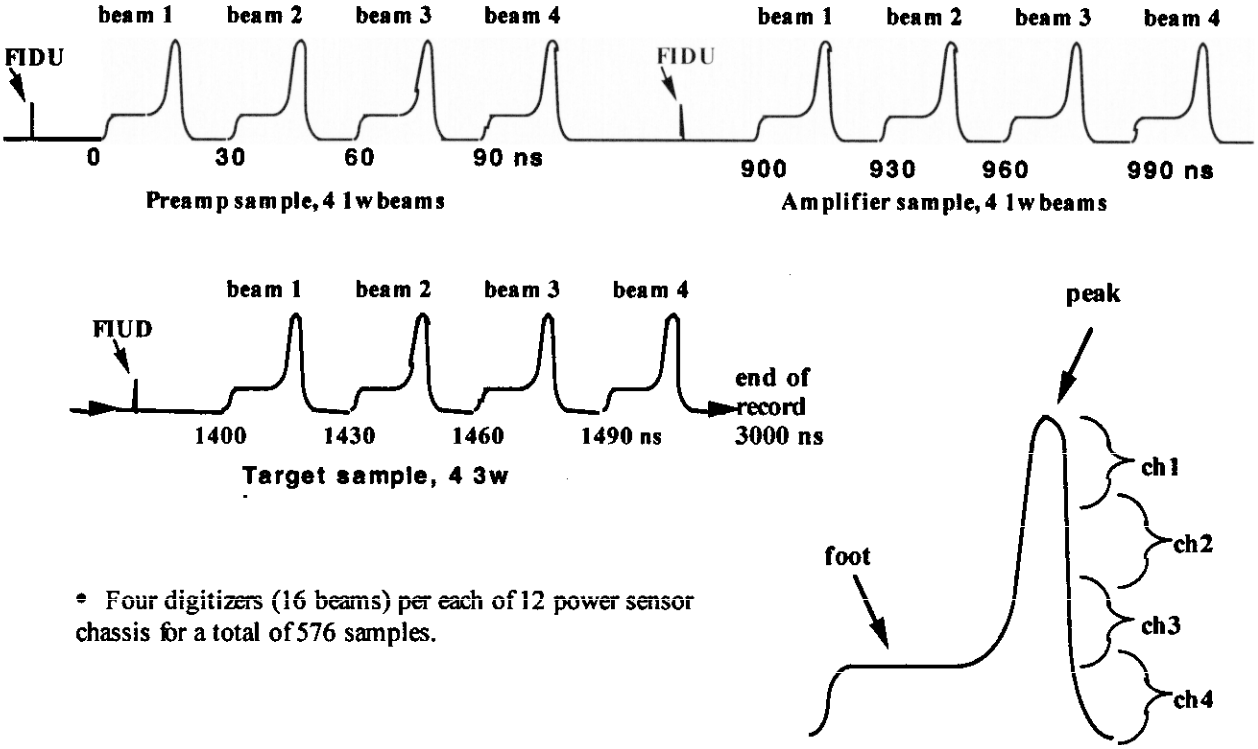


Figure 1. Power sampling

- **Samples taken by summation of all four channels of one digitizer.**



- Four digitizers (16 beams) per each of 12 power sensor chassis for a total of 576 samples.

Figure 2. Temporal multiplexing of power samples

3.2 Temporal Multiplexing

Figure 2 shows that the result of the above sample collection scheme is three power samples from one beam line (beam 1), separated in time by 900 ns and 500 ns, respectively. Similar samples from three more beam lines (beams 2, 3 and 4) are combined with the first by delaying each of these by an additional 30, 60 and 90 ns, respectively. (Since the stability of the digitizer (100 ppm) meets our timing requirement accuracy of 100 ps only for a few hundred nanoseconds, a fiducial time mark (FIDU) is added through an electrical input to channel 1 at the beginning of each group of four samples. This mark is generated from the timing generator, which controls timing for the entire laser system and is extremely accurate and stable. Along with appropriate calibration of other system parameters such as exact fiber path lengths, the FIDU allows determination of the degree of synchronization of all 192 beams, an important factor in overall laser performance.) The beam samples are then collected by a fast photodiode and converted to an electrical input for the digitizer, as shown in Figure 3. In this way, four beams are sampled at three points, for a total of 12 samples per digitizer card. For the 576 power measurements, 48 digitizer systems are required. Additional units are required for the backreflection measurement.

3.3 Photodiode

The Hamamatsu, 60-ps rise time photodiode we use has an S-1 spectral response photocathode. Since we use the same detector system to take measurements at 1ω and 3ω, it is clear that our only choice is the S-1 photocathode, which requires about 4 KW at 1ω and 122 W at 3ω in order to provide the required 20 Volts to the 2:1 transformer at the peak power of the pulse.

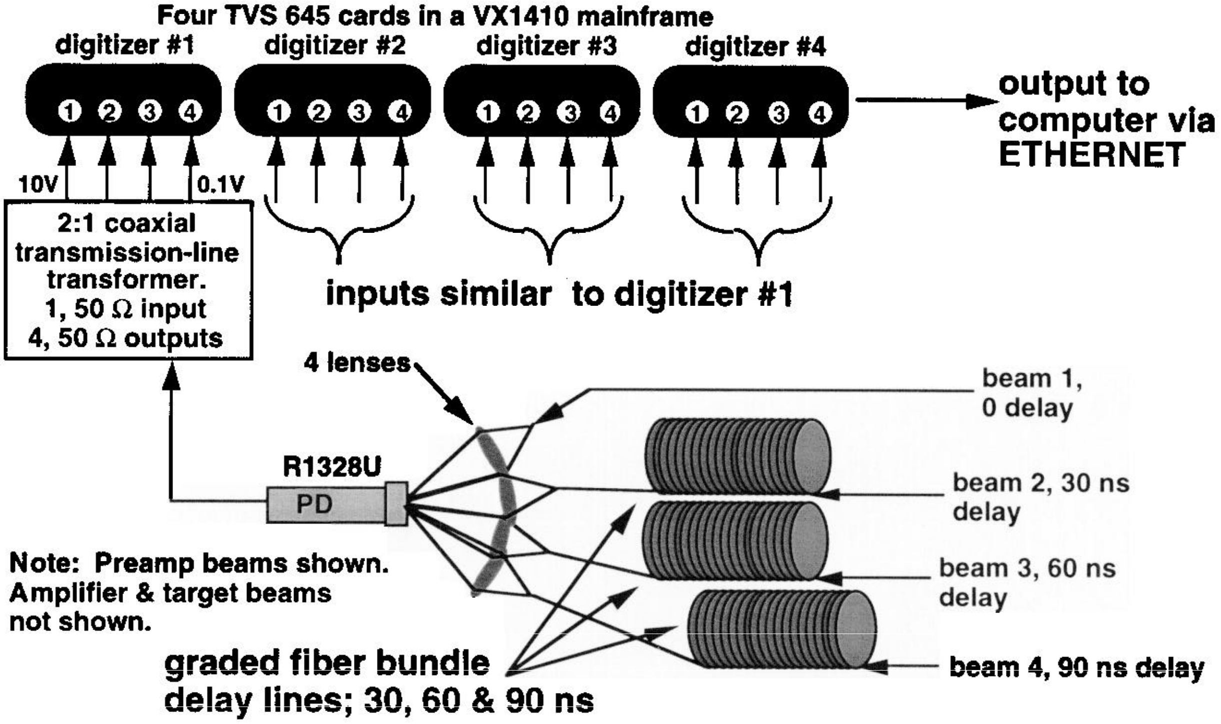


Figure 3. Power measurement

3.4 Digitizer

The digitizer is VXI Bus compatible, the sample rate is 5 GS/s (5•E9 samples/second), and it has a bandwidth of 1 GHz. In order to realize the 1 GHz bandwidth (350 ps rise time), each of the four input channels must have its full scale sensitivity set between 100 mV and 10 V. The digitizer has only an eight bit converter with 6.3 bits effective resolution, but it has four identical channels per chassis. Even though the 2% accuracy point of the digitizer is exceeded for signals less than 63% of full scale, the accuracy requirement is for the average over any 2 ns time interval, which permits averaging to be used to increase the individual digitizer's effective dynamic range. The four channels are used in parallel, with each channel set to a different full-scale sensitivity in order to cover the required dynamic range by amplitude multiplexing the input signal, as shown in the lower right portion of Figure 2. Signal processing will be used to reconstruct the full dynamic range of the signal.

The digitizer is mounted in a supporting VXI mainframe with power supply. There is room for a control card (local computer), a communications card and a total of five digitizer cards, four of which will be the Tektronix TVS 645 and the fifth, a slower TVS 641 for the backreflection measurement. Including labor, the fiber bundles and the electronics, the projected cost is about $6200 per measurement. Fiber bundles are required to reduce speckle modulation, which would be excessive if a single fiber were used. The fiber bundles are a major labor expense because optical delays of all 20 fibers must be within 50 ps of each other in order not to affect the overall system rise time significantly. This requires a tedious procedure of measuring and trimming each of the large number of fibers using an optical time-domain-reflectometer and then bundling and adding connectors and a protective shield.

Preliminary evaluation of the digitizer gives indications that the device meets or exceeds all of the manufacturer's specifications that we checked. Of concern was crosstalk among channels, which was specified at 30:1 (3 V on one channel would produce less than 0.1 V on the other channels). During testing, we saw no crosstalk signal on three of the channels at 5 mV sensitivity when the fourth channel was driven with a 6-V, fast-rise pulse. Other tests also produced encouraging results.

Comment: Although the specified risetime requirement is not met by the system described, and computer processing will have to be used with some compromise in performance on dynamic range, it is likely that improvements in commercial digitizers will be realized in time for implementation on NIF. An increase in bandwidth to 1.5 GHz would allow us to achieve our rise-time requirement. Although commercial manufacturers refuse to speculate on future improvements, one manufacturer now has a 10 GS/s digitizer, and there are commercial RF amplifiers available with bandwidths of several Ghz.

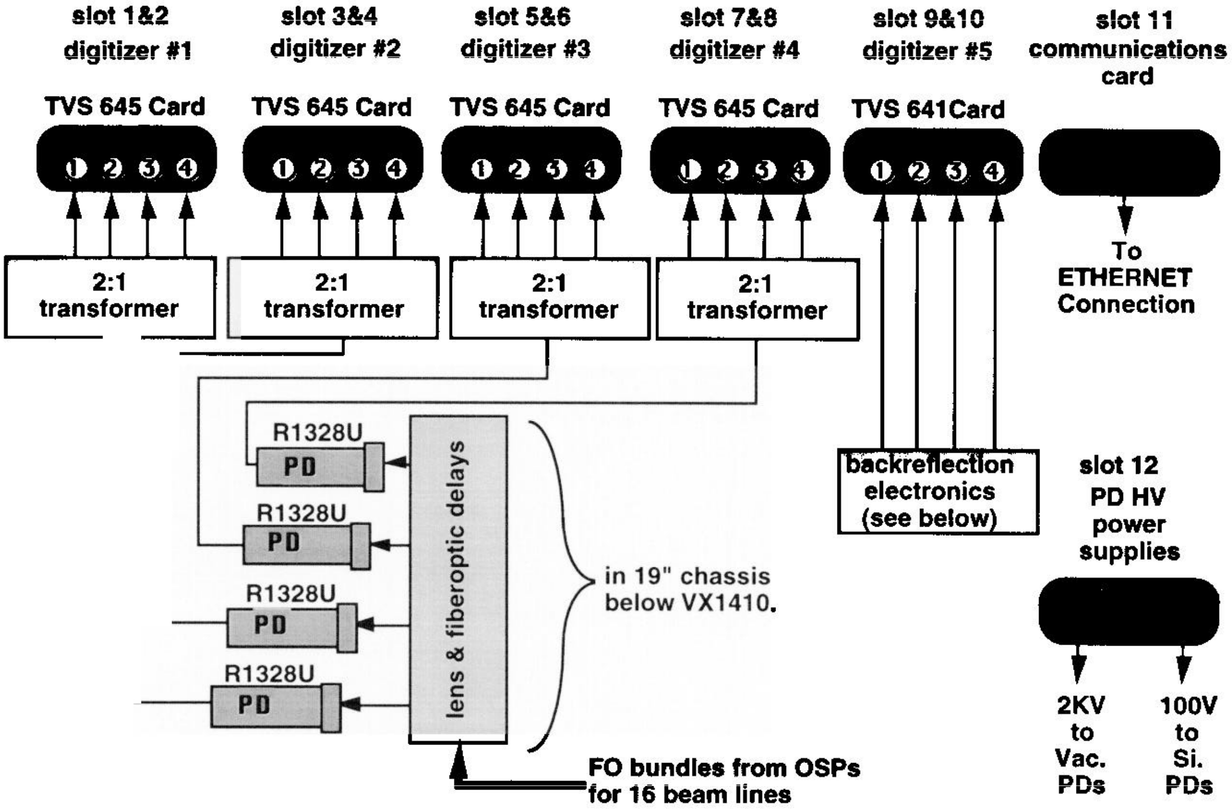


Figure 4. Power/backreflection sensor in a VX1410 mainframe

3.5 Mainframe chassis

Figure 4 shows the block diagram for one complete system to measure three samples each of 16 beam lines, as well as their backreflections. All of the electronic components are mounted within the Tektronix VX1410 mainframe. The lenses, fiberoptic delays and photodiodes (PD) are enclosed within two chassis below. The 50 Ω photodiode outputs are fed to two-to-one, coaxial-line, high-speed transformers with four identical 50 Ω outputs, which drive each of the four inputs of one digitizer. Each digitizer occupies two of the 13 slots. The fifth digitizer is a TVS641, a slower unit, for the backreflection measurements. The communications card and a high voltage (HV) power supply for the photodiodes occupy slots 11 and 12. Not shown is the control card in slot 0.

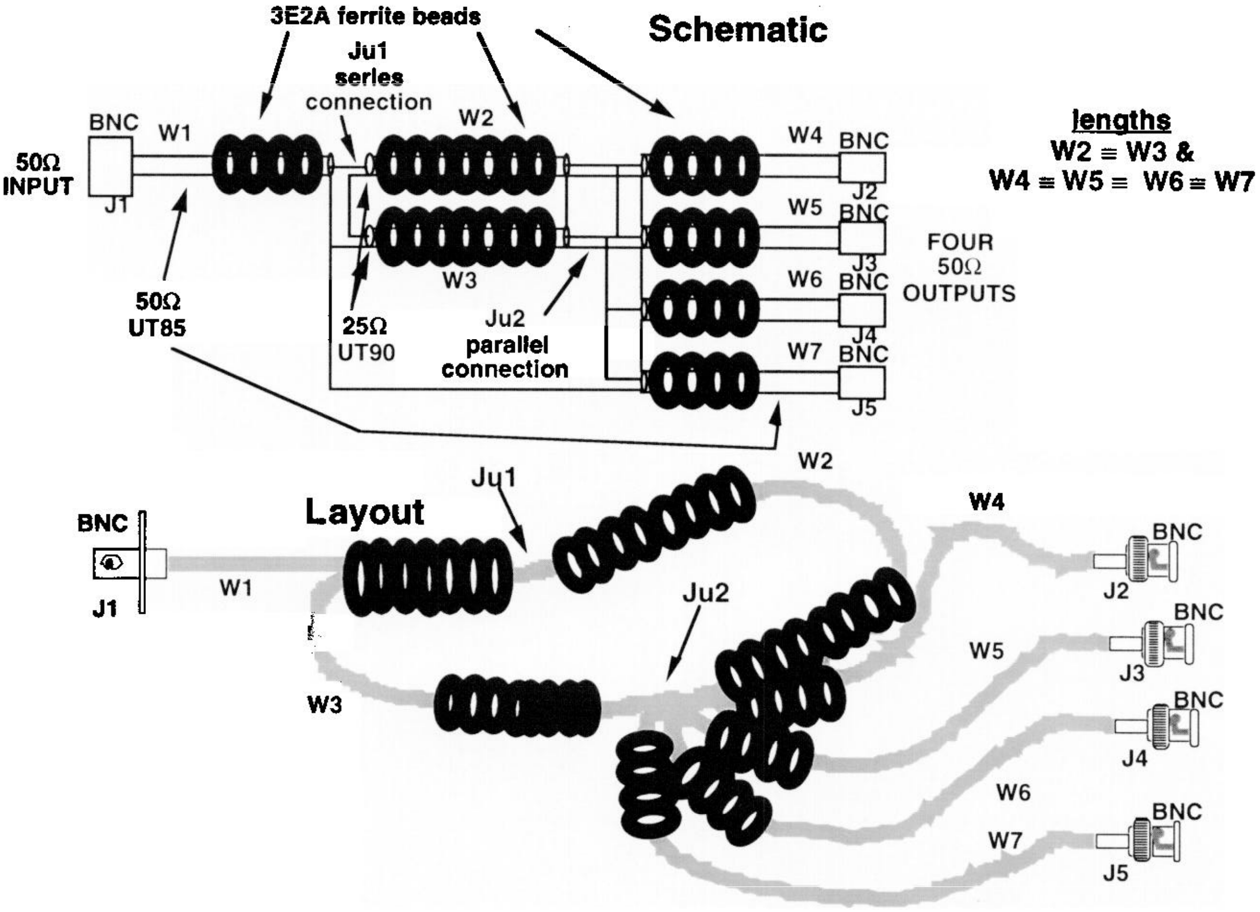


Figure 5. 2:1 coaxial-line transformer

3.6 Transformer

The two-to-one transformer is shown in Figure 5. Semi-rigid, copper-jacketed coaxial cable with polytetrafluoroethylenl dielectric is used for its high frequency characteristics and stability. W1 is a 50 Ω cable. W2 and W3 are identical lengths of 25 Ω cable and are connected in series at their input (Ju1) to match W1 and in parallel at their output junction (Ju2) in order to provide a 12.5 Ω impedance. W4 to W7 are identical lengths of 50 Ω cables connected in parallel at the output junction (Ju2), providing a match to the 12.5 Ω impedance of W2 and W3 at this point. The cable from the photodiode is connected to J1, and J2 through J5 are connected to the four input channels of the digitizer. 3E2A ferrite beads placed near the junction points provide a high common mode impedance, preventing losses to the surrounding air and extending the low frequency characteristics of the transformer. Rise time can be in the order of 50 ps if proper care is taken to make the lead connections as short as possible at the junctions and to keep the beads close to the junctions. The output voltage is half of the input; the four outputs are identical since the output cables are all tied to the same point (Ju2) at one end.

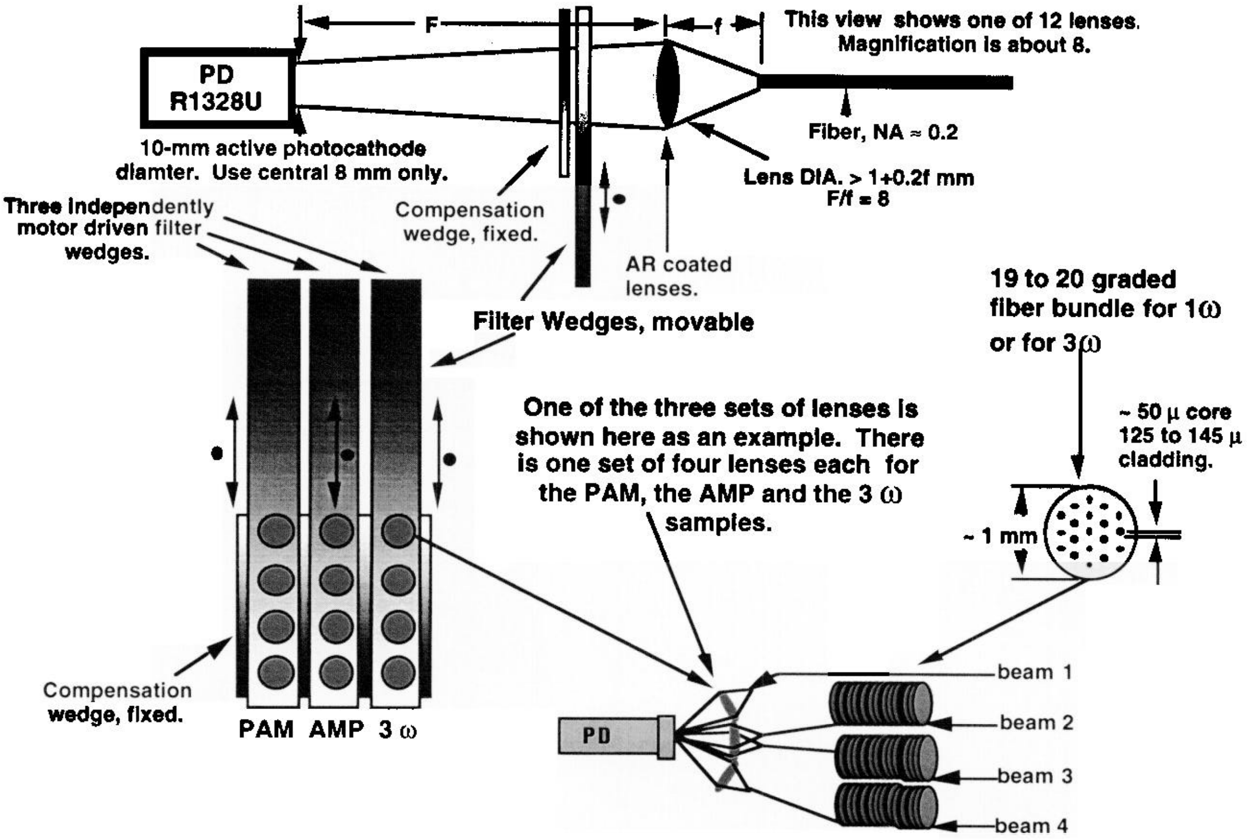


Figure 6. Lens and filter system

3.7 Lens and Filter

The amplitudes of the beams from the four preamps (PAM) being sampled will be adjusted in the respective input sensors with fixed filters to produce equal intensity outputs from the fiberoptics when they are sent to the lens and filter system in the power sensor, as shown in figure 6. The same holds true for the four amplifier (AMP) and the four 3ω samples from the output sensors. However, the intensity ratios of the PAM, AMP and 3ω samples vary with overall laser power, which can be different for different laser shots. Therefore, independent control over the groups of samples must be achieved. This is accomplished by use of three independently stepper-motor-driven attenuator wedges. The wedges have greater attenuation at one edge than the other, requiring a fixed wedge to be used for compensation. An anti-reflection (AR) coated lens is used to image the outputs of each fiber bundle onto the photodiode. The figure shows only one of the three sets of lenses needed to image the 12 samples onto the PD.

3.8 Issues

If reflections occur within the beam line and become mixed in time with any of the desired signals, data could be affected or obliterated. This effect will be investigated on Beamlet, our working, one-beam NIF prototype laser. There are other questions concerning the operating characteristics of the digitizers which will have to be answered by prototype evaluation, which is underway.

We have contracted with a foreign vendor to supply us with fiberoptics for use at 3ω. The expected attenuation is high, but acceptable for our application, as are the other important parameters. The contract has just started and there is the possibility that it may be unsuccessful in accomplishing the design goals. Alternatives will undoubtedly be more expensive.

3.9 Backreflection

Slots 9 and 10 (see figure 4) of the mainframe are used for the TVS641 digitizer for the backreflection measurement. Backreflection refers to any light that is reflected backwards down the beam path. It is of concern because the optics compress the size of the beam in the back direction while amplifiers add more energy. This can increase the fluence above the damage threshold for optics in the PAM. The TVS 641 has a digitizing rate of 1 GS/s and an analog bandwidth of 250 Mhz, which are adequate for this application. Single 100-μm fibers instead of bundles and silicon diodes with their lower bandwidth can be used here, both of which reduce costs. Since the damage threshold is a constant, a lower dynamic range configuration using only one digitizer channel can be used. Attenuation of the sample for each beam line can be fixed at the pickoff point, which is located at the main laser backreflection beam dump. Four backreflection samples are combined using appropriate fiber delays, sent to one diode and used as the input to one of the digitizer's four channels. In this fashion, backreflection from 16 beams can be recorded from one digitizer.

4. CONCLUSION

An economical method of simultaneously measuring and recording 768 time-resolved power samples from the NIF laser has been described. The main constituents are commercially available items.

5. ACKNOWLEDGEMENT

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551