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J.D. BROESCH, W.A. PEEBLES,[†] P. PRYBYL,[†] and R.T. SNIDER

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[†]IR&T

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J.D Broesch,[1] W.A Peebles,[2] P. Prybyl,[2] and R.T. Snider[1]

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608
[2]IR&T, 326 25th Street, Santa Monica, California 90402

ABSTRACT

CO_2 pumped FIR (Far Infrared) lasers have a number of valuable uses in the diagnostics arena of fusion research. To maintain lasing, the tuning of the two lasers must be tightly coupled. This coupling presents interesting control problems. A number of analog approaches have been employed to implement tightly coupled tuning control. Such implementations, however, suffer from a lack of flexibility. A new digital controller has been developed that greatly increases the range of control strategies that may be implemented. Of further interest is the controller's capability to provide 96dB of dynamic range when driving -200V piezoelectric transducers. This paper will discuss the algorithms and hardware used in this controller. Lessons learned from the development effort will presented.

I. BACKGROUND

FIR lasers are particularly well suited for fusion plasma diagnostics. They can be utilized for electron density (interferometry), magnetic field (polarimetry) and turbulence (scattering) measurements in a wide range of devices. FIR lasers provide a high power source, negligible beam diffraction due to plasma inhomogeneity, and have sufficiently large phase shifts for the Faraday rotation angle in polarimetry to be detected. Of particular interest are optically pumped methanol lasers, which can produce high output power at a wavelength (118 μ) typically of interest for diagnostic purposes. Figure 1 shows a typical laser interferometer diagnostic configuration.

While conceptually simple, the arraignment shown in Fig. 1 presents several practical problems. Of interest for this discussion is the need to independently tune each of the lasers to obtain heterodyne phase detection. Both the CO_2 pumping laser and the FIR laser are tuned to provide optimum output power. Since each laser is operating independently, the control algorithm must simultaneously optimize two independent variables. In this case the independent variables are the voltage applied to piezoelectric tuning elements located on each laser. The dependent variable is the power of the lasers as measured at the detector.

Notice that the arrangement shown in Fig. 1 makes use of a beam splitter to pass 50% of the beam power through the plasma. The other half or the laser beam is routed around the plasma for the interferometric reference. This naturally limits the maximum power and also only allows homodyne detection of the phase delay, resulting in reduced diagnostic capabilities of the laser interferometer. A logical refinement and the goal of the effort described here is to use two FIR lasers pumped by a single CO_2 laser. Such an arrangement is shown in Fig. 2.

The dual FIR configuration was the overall goal of this project. The initial work on the interferometer was done by the IR&T members of the team using the configuration shown in Fig. 1. An analog controller was used. The controller modulated the CO_2 and FIR lasers at two separate frequencies. The inter-modulation product was then detected and its RMS value measured. Based on the measured amplitude, the DC components of the modulation waveforms were adjusted to provide optimum FIR output power. The loop time constants and gains were determined experimentally. The resulting controller was simple, and robust, and performed well at keeping the lasers locked. Obtaining the initial lock, on the other hand, required manually tuning the lasers and then switching in the analog controller. This manual operation necessitated a skilled operator. Additionally, since there are several

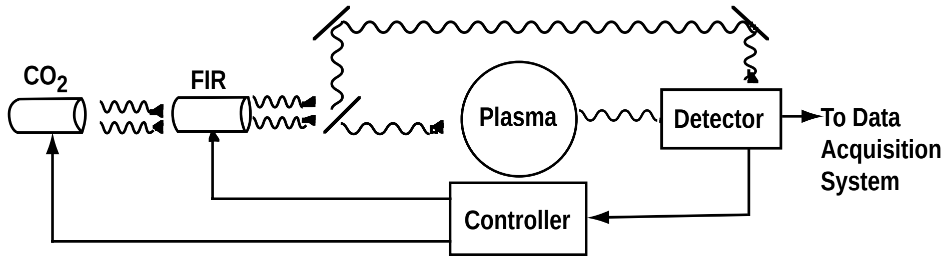

Fig. 1. Basic CO_2 pumped FIR laser diagnostic.

cavity modes at which lasing can occur, it was only possible to insure that the lasers were lasing – not that an optimal mode had been obtained.

II. A Digital Controller

Three key requirements drove the need to develop a digital controller. The first, as mentioned above, was the desire for the controller to automatically scan the entire control space to find the best lasing mode. The second requirement was the desire to add the second FIR laser. This led to the third requirement that the controller be capable of quickly and easily implementing different control algorithms.

The first step in designing the controller was to determine the dynamic range required. Modulation voltages used by the analog controller were often on the order of less than 1 V. The DC range varied from 0 V to 90 V, or in some configurations, –200 V to 0 V. To meet both the requirements to accurately position the DC potential over these large DC ranges and still be able to generate control signal on the orders of tens of millivolts required 16 bit resolution. To keep the input and output characteristics symmetrical, both the input and the output resolutions were specified for 16 bits.

The 16 bit I/O architecture drove the choice of a processor. Both a Digital Signal Processor (DSP) and conventional microcontroller architectures were considered. While either would have met the requirements, it was decided that the greater flexibility and easier programming of a microcontroller was worth trading against the higher performance of a DSP. To insure adequate computational performance, however, a microcontroller was desired that supported some classical DSP features such as hardware multiply and Multiply and Accumulate (MAC). This led to the selection of the XC68HC812A4 from Motorola.[1] This processor is still in the pre-release phase. However, we found it to be sufficiently stable and well enough documented for our purposes.

The final design decision was the specification of the high voltage amplifiers required to convert the 0 V to 5 V output of the DACs to the 0 V to 90 V (or –200 V to 0 V) output. This circuit is based on the OP41A high voltage operational amplifier manufactured by Apex.[2] The –3dB bandwidth of the amplifiers is approximately 10 KHz. Figure 3 is a block diagram of the basic controller configuration.

The controller was built using a commercial off the shelf development board[2] containing the processor, RAM, and EEPROM. The high voltage amplifiers were built using the PA41A from Apex Microtechnology. The programmable amplifiers, ADCs, and DACs were placed on a custom printed wiring board designed for this project.

FIR Controller Functionality. When power is applied to the unit, only the low voltage power supplies (+5 V, ±12 V) are energized. The microcontroller is automatically reset and begins an initialization sequence of the hardware and software. The output DACs are first set to zero output. Next, the high voltage power supplies (+100 V, and in some configurations, –300 V) are turned

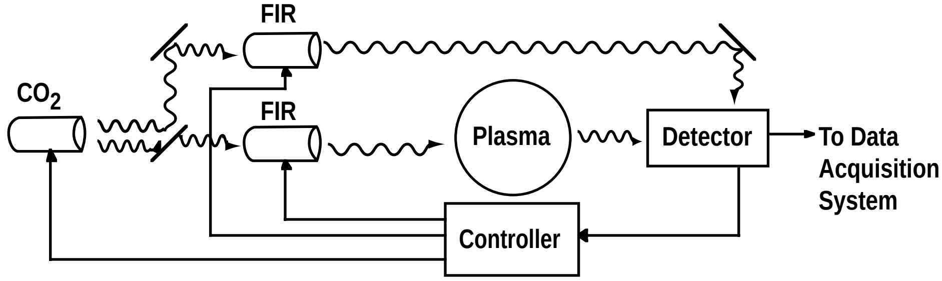

Fig. 2. Dual FIR configuration.

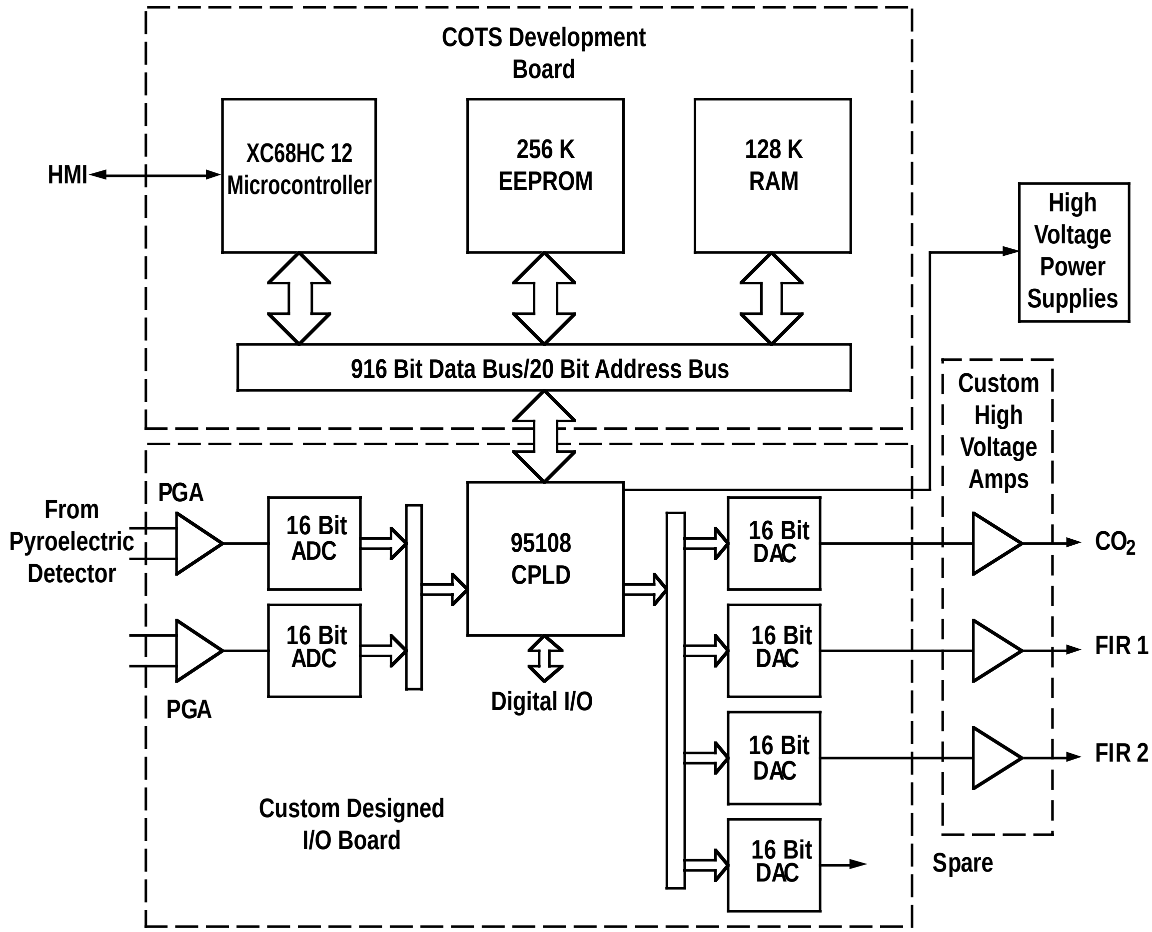

Fig. 3. Major Components of the controller.

on. At this point, the microcontroller begins looking for commands from the control computer. In all modes, the microcontroller monitors the status of the AC power. If power is lost for any reason, the analog outputs are reset to 0 V and the high voltage power supplies are turned off.

The controller may be operated in either automatic or manual modes. In both modes, the power values read from the laser power monitoring are displayed on the control computer's display. In manual mode, a set of slider controls are displayed on the control computer's display. Adjusting these sliders sets the output voltage to the lasers.

In automatic mode the controller performs two basic operations: 1) a lock scan, and 2) modulated feedback.

Lock Scan. The purpose of the lock scan sequence is to identify the point where the lasers are producing maximum power. The basic operation is to first apply ramp voltages to each laser. First, the CO_2 laser is stepped by some ΔV. Next, a ramp voltage is applied to the first FIR laser. The maximum value is recorded, and the process repeats:

$$V(x,y) = \sum_{m=L1}^{H1} \sum_{m=L2}^{H2} M \Delta V \ln \Delta V2 \qquad (1)$$

where V(x,y) is the control voltage applied to the lasers, $\Delta V1$ is the CO_2 step voltage, $\Delta V2$ is the FIR step voltage, and L and H define the lower and upper range of the scan respectively.

The initial start point for the lasers is simply:

$$SP = \max [V(x,y)]] \qquad (2)$$

The starting point is reached by first resetting the outputs to zero volts, then ramping the voltages to SP. The purpose of resetting the voltage to zero is to minimize hysteresis effects in the piezoelectric control element of the laser.

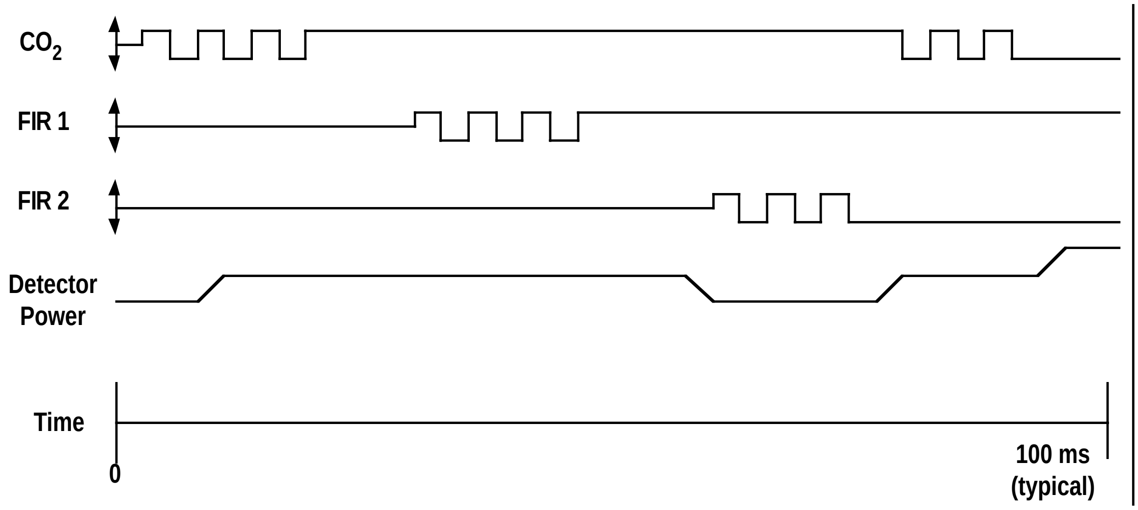

Fig. 4. Typical stimulus response cycle.

Modulation Lock:. The modulation lock may be entered either automatically from the scan state or manually from the manual state. In either case, the operation of the modulation lock state is the same. First, the CO_2 laser is stepped by some small voltage ΔV up. The resulting power change is noted. Next, the voltage is stepped down 2 ΔV and the voltage change is again noted. This process is repeated *n* times. The results are then used to adjust the set point of the laser. Next, the control voltage is left idle for some period. This allows the effects of the modulation to die out in the system. Next the process is applied to the FIR lasers. The waveforms for this operation are shown in Fig. 4. Note that the delay times between bursts, as well as the number of and size of the bursts, are user programmable by modifying constants in the control program.

III. RESULTS

The digital controller was demonstrated to perform as well as the analog controller in maintaining lock in the CO_2/single FIR laser configuration. Additionally, the automatic scanning and laser acquisition function were implemented. This eliminated the need for a skilled operator to be present to operate the interferometer.All three lasers were locked successfully, however a full evaluation of the configuration remains to be done.

Several control strategies were tested. These ranged from simple step/response strategies to the burst mode modulation algorithm presented here. While we found the modulation strategy to perform best, this result was in part based on the nature of the detector electronics. The detector electronics outputs are AC coupled, introducing a high pass filter. This made it difficult to fully evaluate the merits of a simple step response control loop.

The relatively long quiescent periods allowed by the digital controller provide an overall quieter system that should lead to improved performance of the interferometer. The flexibility and precision of the digital controller clearly make it the optimum choice for these types of systems.

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