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A key goal of our research is to demonstrate all-optical metholds for generation, processing, and transmultiplexing (data format conversion) of ultrafast lightwave signals. Recently our effort has focused on incorporating pixellated optoelectronic modulator arrays into femtosecond pulse shaping systems. This work could lead to pulse shaping systems generating (or processing) data signals and packets which can be reprogrammed at rates in the nanosecond regime. This would fill an important need in both TDM packet networks and bit-parallel WDM linds. The research also aims at experimental tests of an ultrashort pulse code-division, multiple-access (CDMA) optical communications system and of the devices needed to implement such a system.

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Femtosecond Laser System for Research on High-Speed Optical Transmultiplexing and Coding

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I. Acquired equipment

We acquired the following equipment using funds from this contract:

Item	Quantity	Vendor	Description	Cost
1	1	Hewlett Packard	3 Gb/s bit error rate test	$79,877 ($65,342 from this contact)
2	1	Hewlett Packard	50-GHz oscilloscope	$13,925
3	2	Hewlett Packard	Triple output power supply	$1592
4	2	Hewlett Packard	Digital multimeter	$1592
5	1	Environmental Optical Sensors, Inc.	External cavity diode laser	$14,725 ($11,325 from this contract)
6	1	Mellwood Laboratories	high-speed visible photodiode	$950
7	1	PenStock	40 GHz bias tee	$1157
8	1	ILX Lightwave	diode laser controller electronics	$8531
9	1	Laser Diode Inc.	Diode laser	$918
10	1	Newport Corp.	Power meter	$1786
11	1	George Mason University	CMOS-SEED device foundry	$7500 ($2000 from this contract)
12	1	Technical Manufacturing Corp.	Optical table	$11,920
13	1	Spectra Physics	5-watt diode-pumped, frequency-doubled solid-state laser	$55,800 ($48,800 from this contract)
14	1	National Instruments	digital-to-analog converter card	$1077

There are some differences between the list of equipment purchased and the equipment list in the proposal. The most significant differences are as follows:

a) The 50-GHz oscilloscope (item 2 above) was purchased at a steep discount for roughly $30,000 below the budgeted amount.

b) A logic analyzer system, budgeted in the proposal at $42,500, was purchased using other funds.

c) A spatial light modulator and the associated control electronics, budgeted in the proposal at $10,700, were purchased using other funds.

These savings were applied to purchase other needed equipment, as follows:

d) Instead of the budgeted 1.4 Gb/s bit error rate test (budgeted at $43,700), we had the opportunity to purchase a 3 Gb/s bit error rate test set (item 1 above) at the significantly discounted price of $79,900. We made this purchase using $65,300 from the current contract, with the remaining funds coming from other sources. The higher rate error rate test set will extend our capabilities to handle high speed optical communications systems.

e) We purchased a diode-pumped frequency-doubled solid-state laser (item 13 above) and an optical table (item 12 above) to be used in setting up a new femtosecond laser system.

f) We submitted a design for a custom CMOS-SEED smart pixel array (item 11 above) to the Bell Labs-Lucent foundry service through George Mason University. This smart pixel array will be used to demonstrate ultrafast optical pulse manipulation and transmultiplexing systems based on space-time processing concepts.

II. Research projects summary

Equipment purchased under this contract has been used by approximately fourteen researchers (one post-doc, ten graduate students, three undergraduates) for several research activities, summarized briefly below.

II.A. Ultrafast optical transmultiplexing using space-time processing

A key goal of our research is to demonstrate all-optical methods for generation, processing, and transmultiplexing (data format conversion) of ultrafast lightwave signals. Recently our effort has focused on incorporating pixellated optoelectronic modulator arrays into femtosecond pulse shaping systems. This work could lead to pulse shaping systems generating (or processing) data signals and packets which can be reprogrammed at rates in the nanosecond regime. This would fill an important need in both TDM packet networks and bit-parallel WDM links. Additional, this may result in additional processing power in optical pulse shaping systems through the use of smart pixel device arrays.

Two examples of our work using equipment from this contract are as follows:

- We have constructed and demonstrated a femtosecond pulse shaping apparatus where the generated waveform is a directly scaled version of a spatial masking pattern. This is in contrast to the usual pulse shaping geometry where the output waveform is determined by the Fourier transform of the spatial masking pattern. Our current configuration is preferred for applications involving generation of reprogrammable pulse packets for use in TDM optical communications, because each pulse can be associated with an individual element on a high-speed optoelectronic modulator array.

- We have performed static tests of a GaAs-MQW/Si-CMOS ("CMOS-SEED") smart pixel array fabricated through a Bell Labs-Lucent foundry process. This array will soon be tested in the new pulse shaper noted above. Additionally, we have designed a second generation smart pixel array (item 11 in equipment list) which is now being fabricated.

II.B. Ultrashort pulse code-division multiple-access (CDMA) optical communications

Our research aims at experimental tests of an ultrashort pulse code-division, multiple-access (CDMA) optical communications system and of the devices needed to implement such a system. We have obtained several key results during the period of this contracted, listed below:

- Demonstration of nearly dispersion free propagation of 250-500 fs pulses over a 2.5-km fiber link using a combination of standard single mode fiber and dispersion compensating fiber. Completely distortion-free propagation of 500 fs pulses over 2.5 km link using a femtosecond pulse shaper to compensate residual cubic phase.

- Construction of fiber-pigtailed programmable femtosecond pulse shapers (encoders and decoders in the CDMA system) with fiber to fiber insertion loss as low as 5.3 dB. For the first time we have demonstrated femtosecond spectral phase encoding and decoding using two separate pulse shapers connected by a length of fiber.

- Conducted experiments on ultrafast optical thresholders based on nonlinear frequency shift effects in optical fibers. Our thresholder provides a contrast as high as 36 dB between uncoded femtosecond pulses and equally energetic but less intense coded picosecond noise bursts. Thresholders are needed for suppression of multiple-access interference from a large number of users in a CDMA system.

II.C. Femtosecond optical manipulation of terahertz (THz) radiation

We are engaged in a program to investigate the use of shaped pulses to manipulate THz radiation emitted by biased photoconductor samples as well as via optical rectification from second order nonlinear optical materials. Previously we demonstrated several interesting forms of THz waveform control from photoconductive samples, e.g., tunable narrowband THz radiation in the 750 GHz-1.2 THz frequency range. We have also shown that the use of femtosecond pulse trains allows a considerable enhancement of the peak THz power spectral density through avoidance of saturation effects. During the period of the current contract, we compared THz waveforms measured by using photoconductive dipole antennas and by using electro-optic sampling. These measurements elucidate the role of the frequency-dependent antenna response in waveform measurements using photoconductive receivers.

II.D. Laser speckle for characterization of and imaging within optically scattering media

We are investigating a new technique for characterization of and imaging within dense optically scattering media based on observation of laser speckle statistics at the output of the medium. The key concept is that the modulation depth of the laser speckle depends on the variance in the photon travel times through the medium relative to the laser coherence time. Therefore, the speckle statistics are sensitive to inhomogenities within the scattering medium. During the period of this contract, we have performed preliminary experiments demonstrating the use of a narrow-linewidth but tunable laser diode to synthesize light with a variable and controllable optical bandwidth (and hence a controllable coherence time). This technique for coherence time synthesis should enhance the practicality of our speckle imaging approach.