Photonic Control of Terahertz Systems

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The use of Optical Control for millimeter wave systems has been extended recently to frequencies well over 100 GHz. New types of optical modulators, detectors and mixers can now be used to make novel systems for the first time operating at submillimeter wavelengths. In addition to the fabrication of the next generation of traveling wave polymer modulators and phototransistors, we have also developed novel approaches to high frequency testing. These involve both high frequency mixing and femtosecond pulse techniques. Applications of this technology to high frequency, electro-optic oscillators and integrated phase conjugation surfaces are now in their initial stages.

Submillimeter , Terahertz, modulators, phototransistors, phase conjugation

I. INTRODUCTION

NEW ADVANCES HAVE MADE IT POSSIBLE TO MAKE OPTICAL MODULATORS AND PHOTOTRANSISTORS THAT OPERATE AT FREQUENCIES ABOVE 100 GHZ. THESE NEW DEVICES ARE BEGINNING TO OPEN UP THE TERAHERTZ SPECTRAL REGION TO NOVEL FORMS OF OPTICALLY CONTROLLED SYSTEMS. IN ADDITION TO THE ACTUAL DEVICES, MAJOR ADVANCES HAVE BEEN DEMONSTRATED IN THE TESTING OF THESE HIGH FREQUENCY SYSTEMS. THIS HAD LED TO A NEW GENERATION OF APPLICATIONS.

II. MODULATORS

The advances in modulators that we are exploring have involved polymer structures using new types of chromophores. These devices are basically traveling wave structures in which the low dielectric constant of the polymer yields an excellent velocity match between the electric and the optical waves. In figure 1 we show an array of modulators formed on a mylar substrate.

These devices are connected with finline transitions so that they can be coupled to waveguide sources at millimeter wave frequencies. The flexible mylar substrate is low loss and is inserted directly into the guide as shown in figure 2. Using a laser heterodyne technique we are able to measure the frequency response of this system to extremely high frequencies. The actual setup used is shown in figure 3. A semiconductor laser is used in conjunction with a YAG at 1.3 μm to gain sufficient bandwidth.

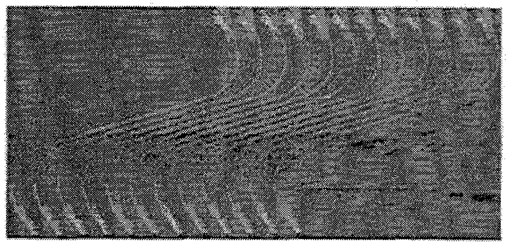

Fig 1. Photograph of the fabricated polymer modulator with integrated finline transitions at both ends of the traveling wave electrode

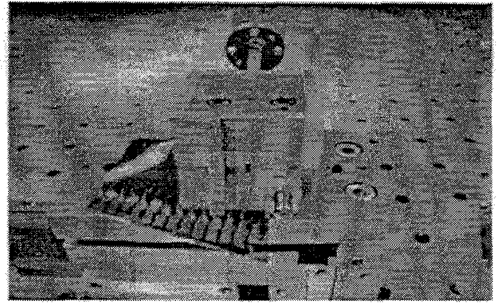

Fig 2. Photograph of the packaged W-band polymer modulator on the Mylar substrate. This shows one of the modulators in the array being fed through the rectangular waveguide

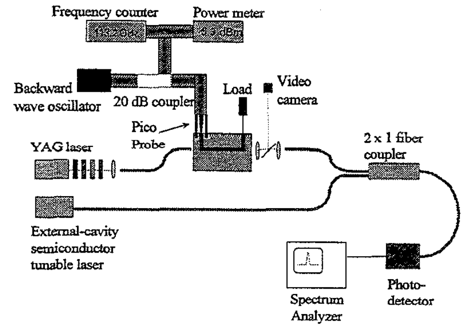

Fig 3. High Frequency Characterization setup

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Using these mixing techniques the response of the device was measured up to 113 GHz [1]. and did not show significant roll off as shown in figure 4.

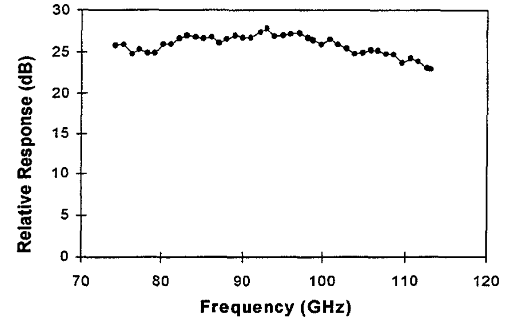
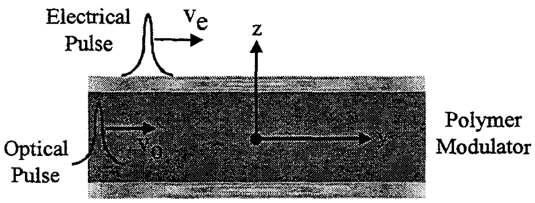


Fig 4. Frequency response of the polymer modulator from 74-113 GHz

This system is now undergoing tests using our Femtosecond pulse techniques such as shown in figure 5. In this system we use a high speed, low temperature GaAs two photon electrooptic switch. The basic system is shown in figure 6.



$$U(\tau)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A I_0\left(y-v_0(t-\tau)\right)\cdot E_e\left(y-v_e t\right)\cdot dt\,dy$$

Fig 5. Time domain characterization of polymer modulator - two pulse approach

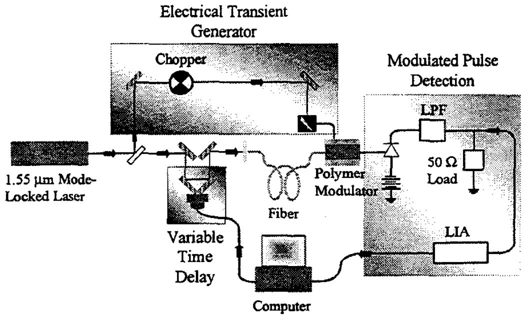


Fig 6. Schematic representation of polymer modulator characterization technique.

III PHOTOTRANSISTORS

In addition to work on traveling wave modulators we have also looked into high frequency phototransistors using HBT and HEMT structures [2]. One such device is shown in figure 7 uses an HBT device with a polyimide optical guide and a traveling wave configuration. This device can be very fast, and because of it's large volume, capable of handling substantial powers. The results at 60 GHz., shown in figure 8, demonstrates that it can be driven very hard before saturation.

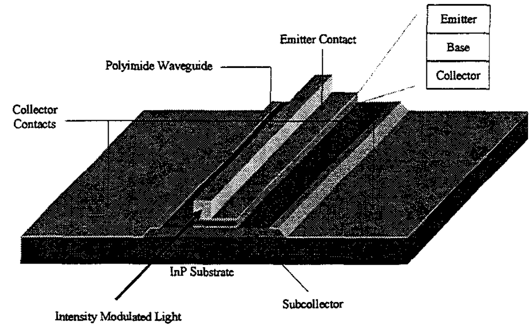


Fig 7. Schematic diagram of the TW-HPT. Polyimide waveguide is defined on top of the active region of an HPT. The HPT's electrodes are coplanar waveguide with a characteristic impedance of 50 Ω

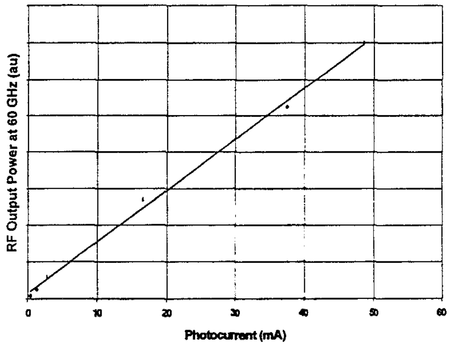


Fig 8. Optical power saturation at 60 GHz for 200 µm long TW-HPT

In another set of experiments we have used a new generation of InP based pseudomorphic HEMTs [3] with special G band probes to mix at 212 GHz. The basic set up for these measurements is shown in figure 9. The actually mixing results are in figure 10 and are being extended to yet higher frequencies with excellent signal to noise ratios.

IV. APPLICATIONS

There are many applications for this type of optically controlled high frequency systems. One of the most interesting concepts is the development of a Terahertz oscillator using photonic techniques. We have looked into one such approach using a system pioneered by JPL and shown in figure 11. This system is basically limited by the response of the modulator and the photodetector. In our initial measurements we worked up to 22 GHz to show proof of principle as indicated in figure 12. This work is now being future extended to W band.

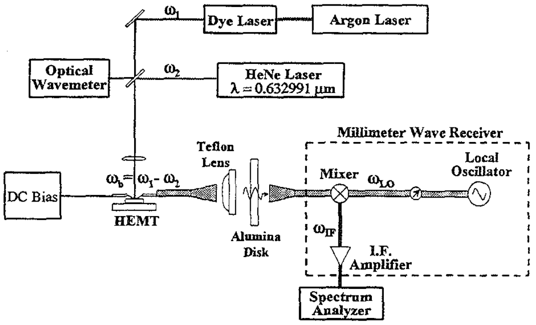


Fig 9. Setup for optical generation of millimeter waves

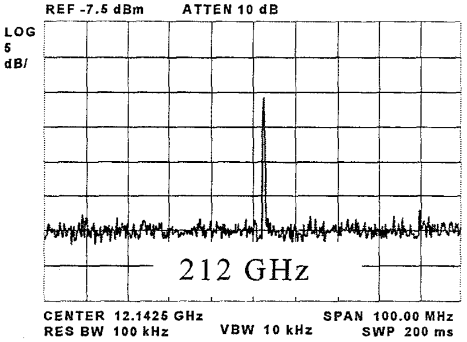


Fig 10. Spectrum analyzer trace of optically generated 212 GHz signal radiated into free space

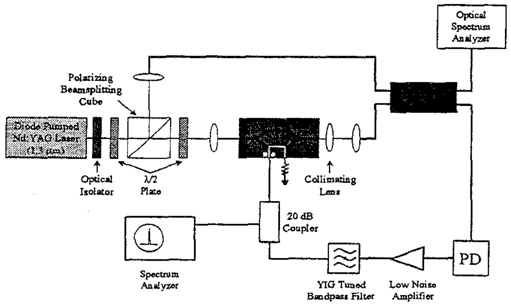


Fig 11. Experimental realization of 22 GHz photonic oscillator

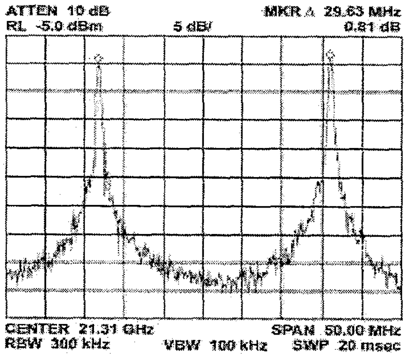
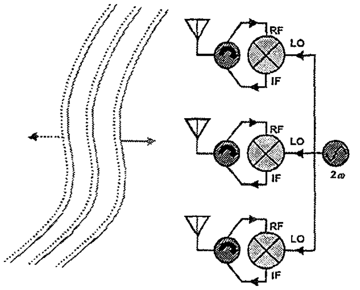


Fig12. Modes of a 22 GHz photonic oscillator

Finally, one of the novel applications at visible frequencies involves the use of nonlinear crystals for phase conjugation. This has been shown to be possible at millimeter wave frequencies using an electronic approach to conjugate the signal at specific antenna elements as shown in figure 13 [4].



$$e^{i(\omega t+\varphi_k)} \cdot e^{i2\omega t} \Rightarrow e^{i(2\omega t-\omega t-\varphi_k)} = e^{i(\omega t-\varphi_k)}$$

Fig 13. Electronic approach of phase conjugation at millimeter wave frequencies

By sampling at sufficiently dense intervals it is possible to conjugate an entire wavefront at submillimeter wavelengths. A prototype array is shown in figure 14 and actually simulates a nonlinear surface. The use of optical connections at these terahertz frequencies is the key enabling technology.

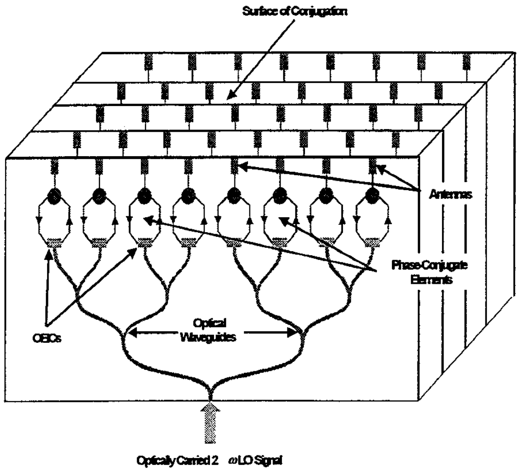


Fig 14. Prototype array for phase conjugation of an entire wavefront at submillimeter wavelengths.

V. CONCLUSION

We find that the technology involving lasers has made enormous advances over the last decade. By using this technology we are now capable of making entirely new forms of Terahertz systems. These will include sources and large arrays that are optically controlled. The use of photonics brings an entirely new capability to this area.

VI. REFERENCES

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