OPTICAL TECHNOLOGY FOR MICROWAVE APPLICATIONS

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ABSTRACT

Phased array radar, communication, telemetry, and electronic warfare systems frequently require the transmission and processing of gigahertz bandwidth signals. In airborne and space applications, where low weight and immunity from electromagnetic interference are desirable, low loss optical fibers with bandwidth distance products as great as 100 GHz·km are an ideal vehicle for the transmission of these broadband microwave signals.

The use of an optical signal to control solid-state microwave devices has attracted the attention of many researchers recently. It is a promising method of providing high-speed control of microwave signals at relatively high power levels. In addition, it offers the advantages of perfect isolation between the microwave circuits and the input control signals, resistance to electromagnetic interferences, and savings in space and weight through replacing microwave cables and waveguides by optical fibers.

There are two approaches to accomplishing optical control: illuminate the passive elements in the microwave circuit or illuminate the active elements. Examples of the first approach are the opto-electronic switching of microwaves in silicon and GaAs to generate short bursts of microwave signals with complicated waveforms and the optically controlled millimeterwave phase shifters and antennas. Examples of the second approach are the reduction of the turn-on phase jitter of TRAPATT oscillators, the optical switching of GaAs IMPATT oscillators, the optical injection locking of microwave oscillators, and the microwave mixing in FET amplifiers.

Depending on the applications, the optical signal used can be either low level dc light, high peak power short pulses, or microwave modulated light transmitted through a fiber optic link. A typical microwave fiber optic link has three basic elements: a transmitter that converts the input broadband microwave signal to a modulated optical signal, a fiber transmission line to carry the optical signal, and a receiver to demodulate the optical signal and provide the broadband microwave output.

Semiconductor lasers with their small size, ease of operation, high efficiency, and integration possibility have emerged as the most desirable optical sources. These lasers can be modulated either by an external modulator or by direct current modulation. External modulation has the advantage that the laser retains cw operation and therefore that its output spectrum does not vary with time and the modulation speed is not limited by the frequency response of the laser. Direct modulation, on the other hand, is quite simple and requires much lower drive power. It is the most commonly used approach today.

In the past few years there has been remarkable progress towards the development of high speed optical devices. Semiconductor lasers have been demonstrated with room temperature direct current modulation bandwidths of approaching 20 GHz and traveling wave $LiNbO_3$ modulators have been demonstrated with modulation bandwidths as high as 17 GHz. High speed, high sensitivity GaAs and InGaAs photodetectors have also been demonstrated with bandwidths in excess of 20 GHz. Therefore it appears that a wideband fiber optic link with bandwidth in excess of 10 GHz can be realized.

One example of the potential use of microwave optical links is in a phased array antenna. In such a system several remotely located microwave sources are required to be phase coherent. A method that has been conceived uses microwave fiber optic links for distributing phase information to each remote microwave source. In this system, an optical "clocking signal" is generated at a central location by a stable microwave oscillator which drives an optical transmitter. The optical clocking signal is distributed to remote sources by a fiber optic manifold.

Several techniques can be used to control the phase synchronism of the microwave sources. The optical signal can be detected, demodulated and amplified to serve as the microwave source. This technique is suitable for wide bandwidth signals. Alternatively, for narrow band signals, the microwave sources could be oscillators that

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are phase locked by direct optical injection. The microwave oscillators in such a system would be semiconductor devices such as IMPATT diodes or FETs. When the light is guided into the active region of these devices (the p-n junction of an IMPATT, or the gate depletion region of a FET) the microwave modulation signal is demodulated and coupled into the oscillator circuit. The fiber optic distribution manifold is compatible with integrated optic switches, which may be used to form programmable phase shifters. The inclusion of programmable phase shifters would permit the use of a single master clocking oscillator for the optical transmitter, while allowing the phase of each remote source to be independently set by the integrated optical phase shifters.

Fiber optic links can also serve as microwave delay lines because the fiber transmission line has an approximate delay of 5 μm/Km and losses as low as 0.5 dB/km, with accurate delay times ranging from a nanosecond to tens of microseconds. In the microwave frequency range fiber optic delay lines open up new capabilities unattainable with acoustic delay lines. The wide bandwidth of optical fibers implies that the demodulated transmission response can be flat over microwave bandwidths, while the loss of an acoustic delay line has a frequency squared dependence that requires large amounts of equalization to be designed into the transmitter or receiver to obtain a flat bandpass. Because a fiber transmission line may be tapped along its length using fiber couplers, a microwave optical link may be configured as a tapped delay line. Fiber optic taps may be constructed by fusing fibers together or by using integrated optic couplers. In addition, the taps may be programmable if electro-optic directional coupler switches are used. The tapped delay line may be transformed into a transversal filter if all the tap outputs are fed into a single detector. Transversal filters have applications in adaptive array radars.

The application of microwave fiber optic links to signal processing opens up significant new opportunities in radar and electronic warfare systems. New capabilities will be available to the system designer to simplify current system concepts and to create new signal processing techniques.