A 3-6 GHZ LIGHTWAVE/MICROWAVE TRANSCEIVER MODULE FOR MICROWAVE FIBER-OPTIC COMMUNICATIONS

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ABSTRACT

A novel 3-6 GHz lightwave/microwave transceiver module has been demonstrated which combines an advanced lightwave component packaging technology with MMIC module technology. The module is compact and low profile, measuring 0.1x1.0x0.9 in., and exhibits greater than 16 dB RF-to-RF gain. This transceiver module marks the first significant step in the integration of fiber-optic interfaces into microwave subsystems.

INTRODUCTION

Optical fibers possess inherent features that make them very attractive as media for microwave signal distribution: small size, flexibility, very low attenuation loss (0.2 dB/km), extremely wide bandwidth (>100 GHz•km), and immunity to EMI interference. However, to realize the advantages of fiber-optic media, efficient microwave-to-optical transceiver circuits and packaging techniques for optical transducers must be developed. Recently, high-gain microwave fiber-optic links[1,2] have been demonstrated using high efficiency collecting optics and reactively-matched circuits. Nevertheless, an efficient, low-profile packaging approach to combine optical transducers and microwave integrated circuits is still needed to implement these new lightwave/microwave transducer modules. Existing laser and detector packages are inadequate because of excessive circuit parasitics, and the optics required to interface with fibers also are typically inefficient and bulky. These limitations have prevented widespread application of microwave fiber-optic signal distribution in many microwave systems.

This paper reports a novel packaging approach for reducing the size and weight while maximizing the efficiency of optical submodules in a manner that permits their insertion as part of the overall MMIC module. The demonstration vehicle for this approach is a 3-6 GHz lightwave/microwave transceiver module incorporating optical transmit and receive submodules with low-noise and driver amplifier MMICs. The optical submodules measure 0.02x0.15x0.75 in. (transmit) and 0.02x0.07x0.15 in. (receive) with optical coupling efficiency of 35% and 80%, respectively, from the laser and detector to single-mode fibers. The estimated microwave gain of the passively matched transceiver was -11 dB without the MMIC amplifiers, and +16 dB for the overall module. Thus, small, efficient lightwave-to-microwave interface circuits can be built and integrated as part of any MMIC module.

APPROACH

Our approach for an efficient 3-6 GHz lightwave/microwave transceiver module entailed two separate activities: first, optical transmit and receive submodule design and, secondly, microwave circuit design and module integration.

Optical Transmit and Receive Submodules

The transmit and receive optical submodules were realized using AT&T's silicon optical bench technology[3]. The silicon optical bench technology utilizes lithography and anisotropic etching of silicon to produce mechanical structures to assist in the assembly and alignment of optical components such as lasers, detectors, lenses, isolators, and fibers. This technology provides a low-cost, optically efficient, low-profile optical platform suitable for integration with MMIC modules. The transmit module consisted of a DFB laser, a ball lens, a YIG crystal isolator, a GRIN lens, and a single-mode fiber. The DFB laser provided a high-gain, low-noise optical source in the 3-6 GHz range, which is far from the natural relaxation oscillation frequency of 14 GHz, when used in conjunction with a 30 dB optical isolator. The overall collecting efficiency from the laser to single-mode fiber was estimated at 40% with a 4:1 magnification of the laser beam. The receive module consisted of a p-i-n photodetector, a turning mirror, and a fiber, with fiber-to-detector coupling efficiency better than 80% . Both these modules contained grounded via-holes, and their layouts permitted minimal bondwire lengths to the laser and detector to minimize microwave parasitics.

Microwave Circuit Design and Module Integration

To obtain optimal gain for the fiber-optic link, a reactive matching approach[1,2] was used to achieve a 20 dB improvement over broadband resistive matching. The laser and detector were characterized using a standard through and delay technique, and SuperCompact™ device modeling was used to extract the relevant device models. To obtain optimal gain over the 3-6 GHz band, a distributed element approach was used for the transmit submodule and a lumped-element approach was used for the receiver module. The approach was to achieve maximum gain at 6 GHz with mostly reactive matching circuits, while introducing resistive components at the lower frequencies to flatten the gain curve and improve the VSWR of the input and output. To compensate for the overall RF loss from the transmit-to-fiber-to-receive chain and to reduce the overall noise figure of the module, a low noise amplifier MMIC was used to drive the transmit submodule. A driver amplifier MMIC followed the receive module to provide additional gain needed to compensate for the optical insertion losses of optical time-delay elements, optical dividers, etc., that may be used with the transceiver module.

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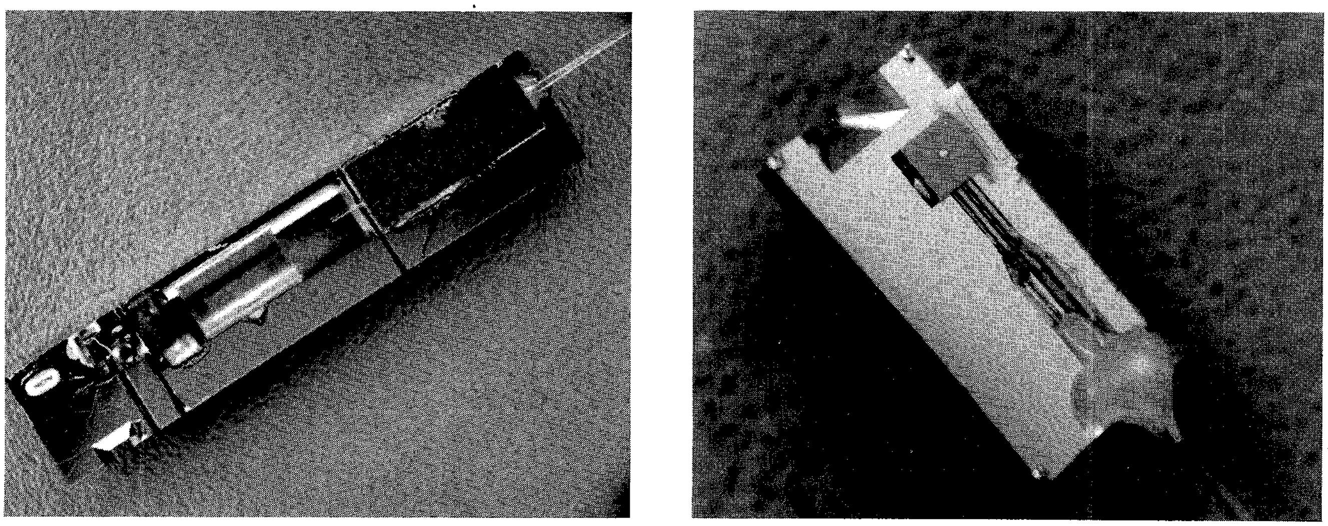
RESULTS

Figure 1 shows the fabricated transmit and receive optical submodules. Measured optical coupling loss from the laser through the ball lens, isolator, GRIN lens, and fiber is 35%, resulting in overall quantum efficiency of 0.09 W/A. Similarly, the coupling efficiency measured from single-mode fiber to the p-i-n detector was 80%, resulting in the overall quantum efficiency of 0.75 A/W.

The transmit and receive submodules were completely characterized in a special test fixture and the device parameters extracted. Matching circuits were then designed and optimized using the SuperCompact™ CAD tool. Figure 2 shows the circuit model of the transmit-to-receive F/O link, with the measured device parameters and the expected performance. Simulated input and output return losses in excess of -8 dB and overall insertion loss of -11 dB is expected over the 3-6 GHz band.

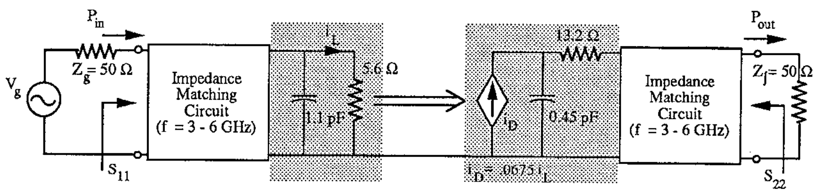
The overall layout of the transceiver module is shown in Figure 3. The optical submodules, matching circuits, LNA, and driver amplifier were laid out on a brass carrier with a common alumina substrate, which measured 0.1x1.0x0.9 in. Based on the simulated performance of -11 dB for the optical link and measured performance for the LNA and driver amplifier of +12 dB and +15 dB respectively, an overall gain of +16 dB is expected for the 3-6 GHz transceiver module.



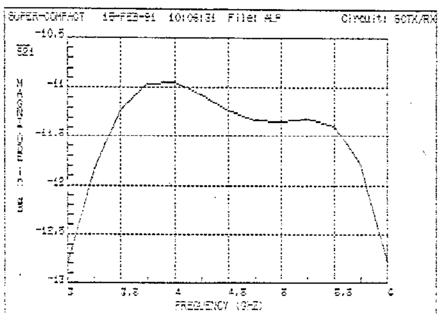
(a) Optical transmit submodule (0.02x0.15x0.75 in.) consisting of DFB laser with back-facet monitor photodetector, ball lens, YIG crystal isolator, GRIN lens, and single-mode fiber pigtail.

(b) Optical receive submodule (0.01x0.07x0.15 in.) showing backface-illuminated detector and single-mode fiber pigtail.

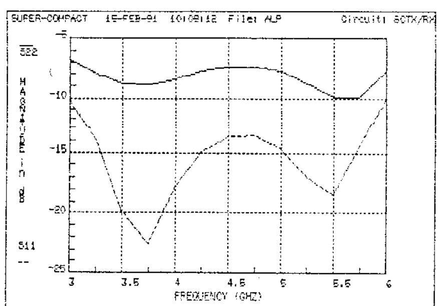
Figure 1. Fabricated T/R Optical Submodules



(a) Equivalent circuit model of transmit-to-receive F/O link



(b) Predicted RF-to-RF insertion loss



(c) Predicted input and output return losses

Figure 2. Circuit Model and Predicted Performance for Transmit-to-Receive Fiber-Optic Link

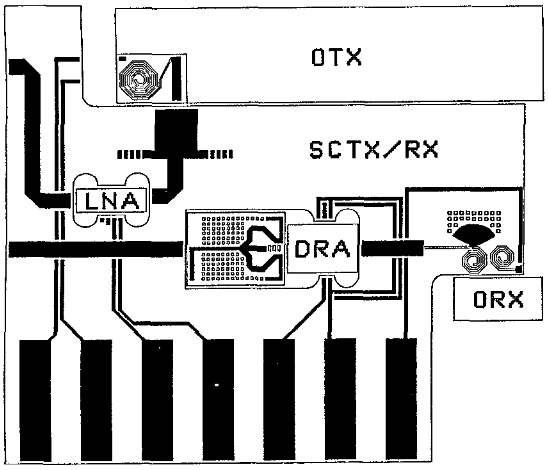


Figure 3. Layout of 3-6 GHz Lightwave/Microwave Transceiver Module

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