AN OPTICAL LINK FOR W-BAND TRANSMIT/RECEIVE APPLICATIONS
(Invited Paper)

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Abstract

This paper describes the design, fabrication, and evaluation of a low noise optical link for W-band transmit/receive applications. The optical link is at Ku-band with an input power of 5 mW, compatible with the direct frequency coherent synthesizer, followed with low-cost MMIC x6 for W-band output of 70 mW and x3 for the W-band x2 subharmonic mixer with an output power of 32 mW. A diode pumped YAG laser at 1319 nm is modulated with a Mach-Zehnder modulator at Ku band and detected with PIN diode photodetector. The measured Ku band phase noise floor of -145 dBc/Hz was obtained with a projected W-band phase noise of -129.4 dBc/Hz.

Introduction

The use of lightweight fiber optic links with low loss has the advantage of immunity from electromagnetic interference. The fiber optic link can also provide true time delay for phased array applications. Millimeter waves are now being used for signal distribution for wide and local area networks. They are also a solution for applications where space is limited and narrow beamwidth and high antenna gain are required.

This paper reports on an application for optical distribution for W-band systems with an optical link to provide a transmitter signal as well as a local oscillator signal for W-band transmit/receive (transceiver) applications [1]. The architecture and overall design of the optical link is considered first. Next the design and measurement of individual link elements are shown followed by measurements of the system and conclusions.

Optical Link Architecture

The optical link is configured to be compatible with the direct frequency coherent synthesizer when the transmitter signal and receiver local oscillator signal are derived from a common reference signal. The reference signal is multiplied, mixed, divided, and filtered to generate the desired signal. The system can change frequencies rapidly since no phased lock loops with voltage controlled oscillators are used. The stable local oscillator (STALO) output frequency is Ku-band for the transmitter and local oscillator frequencies. The optical link is configured at this Ku-band frequency, and low cost MMIC frequency multipliers at the output of the optical link obtain the required millimeter wave transmit and local oscillator signals.

The output W-band frequency is obtained by multiplying the Ku-band STALO frequency by 6. The subharmonic x2 mixer is advantageous for millimeter wave signals, since a lower local oscillator frequency can be used with only a 1 to 2 dB increase in conversion loss over a direct mixer [2]. This link is designed for such a system, when the STALO local oscillator signal is multiplied by 3 (not 6) for a Q-band output signal.

Figure 1 illustrates the optical link block diagram. An externally modulated laser system was chosen for the potentially lower noise capability compared to a direct modulated system. A diode-pumped, solid-state, non-planar YAG ring laser manufactured by Lightwave Electronics with 8-mW power at 1319 nm was used. This system reduced the relative intensity noise (RIN) to about -135 dBc to 1-MHz offset frequency. The noise then falls off to within 2 dB of the shot noise limit for offset frequencies greater than 20 MHz. Since the offset frequency is Ku-band, this noise should be insignificant. This laser was coupled to a polarization maintaining fiber with a net output power of 5.2 mW.

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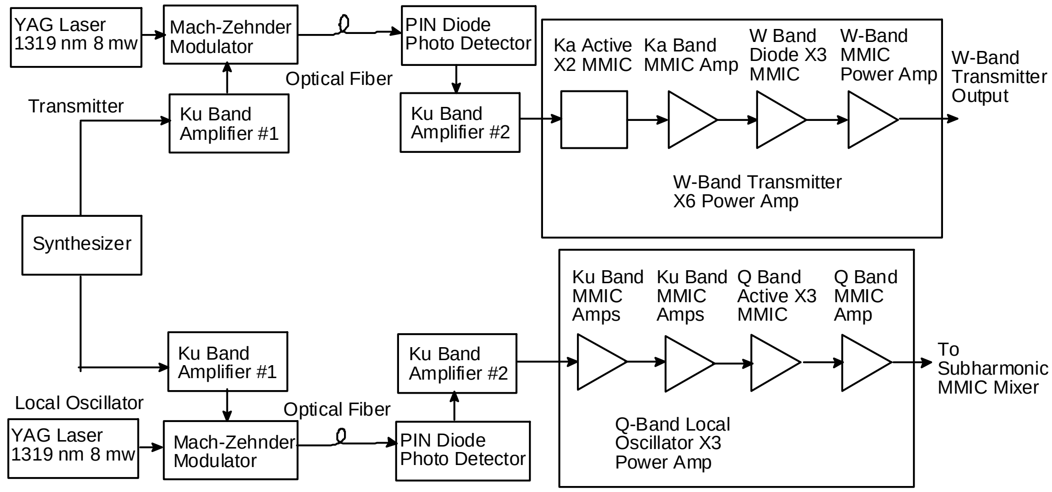

Figure 1. W-Band Optical Link

The laser was coupled to a Mach-Zehnder modulator manufactured by United Technologies with a half wave modulator voltage (Vπ) of 13.5 volts, an optical loss of 3.74 dB, and a modulation loss of 3 dB. A PIN diode photo-detector was employed manufactured by Ortel. This detector was terminated internally with an ac coupled 50-ohm resistor for matching. The measured responsivity was 0.45 A/W at 15-16 GHz. The total optical connector losses were 1 dB and the measured optical power delivered to the detector was 0.84 mW.

The output power of the synthesizer is in the mW range (5 mW), so an amplifier is required (Amplifier #1) to raise the STALO signal so that the input signal to the modulator is much larger. The output signal-to-noise out of the PIN diode detector determines the dynamic range (signal-to-noise) of the system. Too large a signal will result in an increase of loss and poor operation for systems with multiple carriers, while too small a signal will result in poor signal-to-noise performance. The maximum input signal to the modulator is limited to 27 dBm.

The output of the PIN diode detector is followed by a low noise amplifier MMIC (Amplifier #2) with a noise figure of 2 dB and 27 dB of gain used to set the thermal noise level of the system. Finally a MMIC x6 W-band transmitter amplifier consisting of four MMICs in cascade, namely an active x*2* PHEMT multiplier, a Ka band 0.25 W PHEMT amplifier, a diode tripler, followed by a PHEMT amplifier configured for 70 mW output to a waveguide for measurement. The all MMIC Q-band x3 power amplifier to drive the W-band subharmonic mixer contains four MMICs, specifically, two amplifiers, an active PHEMT tripler, and a PHEMT amplifier for Q-band with 32-mW output power.

Frequency Multipliers

Figure 2 illustrates a photograph of the MMIC x6 multiplier. The first element is a Ku to Ka-band active PHEMT frequency doubler. This was designed to take advantage of the high second harmonic current that exists when the PHEMT is biased at pinchoff. A short circuit at the output is provided at the fundamental input frequency and the ac load line was optimized for maximum second harmonic power. The input was matched for gain. As part of the multiplier, an input buffer amplifier was designed to saturate, so that over a significant power range, the output power vs input power remained fairly constant. The normal frequency doubler response is very nonlinear.

The next stage is a 0.25-W, 0.25-micron gate length PHEMT MMIC amplifier to drive the MMIC diode x3 multiplier. The multiplier chip that was developed for a higher output power [3] of 0.09 W was modified by rebiasing the tripler at 0 V instead of 30 V and eliminating half of the diodes in parallel. These modifications reduced the power to the correct level and kept the idler frequency correct with good input and output match. The final MMIC stage is a W-band amplifier using 0.1-micron PHEMTs at 80-mW output power [4]. A microstrip to waveguide transition is incorporated into the unit for measurement of the output.

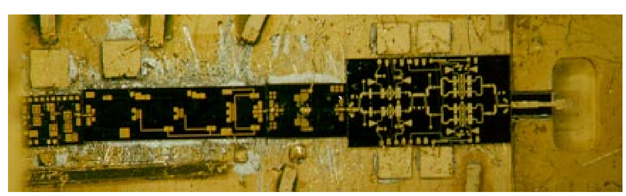

Figure 2. MMIC x6 Multiplier

Figure 3 illustrates the power output vs input with a 70-mW output power. An input level of -4 dBm is suggested to prevent overdriving the output power amplifier and to

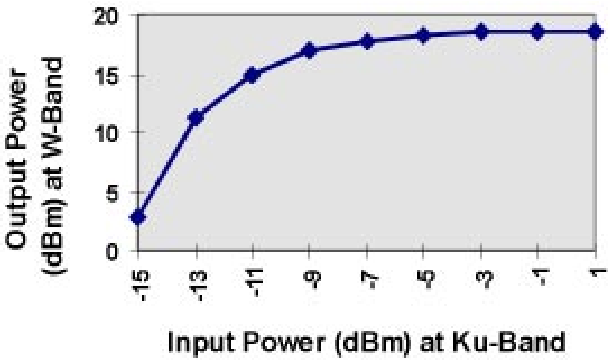

Figure 3. MMIC x6 W-Band Power Amplifier

maintain fairly constant output power over temperature and for varying input power levels for the x6 W-band power amplifier. Also, operating at this point will reduce AM noise due to limiting.

The MMIC x3 power multiplier to drive the subharmonic mixer as seen in Figure 4 consists of two MMIC Ka-band amplifier stages cascaded with an active x3 multiplier followed by a Q-band amplifier. The input MMICs are commercially available HP HMMC-5618 chips while the output chips were developed for this program. The x3 active multiplier chip is biased near pinchoff and uses the third harmonic current of the Class B amplifier. The output has short circuit terminations at the first and second harmonic while the third harmonic is optimally terminated

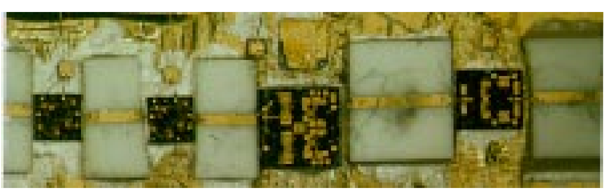

Figure 4. MMIC Active Q-Band x3 Power Amplifier

for output power. A Ka-band input amplifier is included at the front of the chip, and the output is a balanced stage to reduce even harmonics. The measured output fundamental was 40 dB below the third harmonic output with the second harmonic down 25 dB. The output Q-band MMIC amplifier chip is a 0.25-micron gate PHEMT to boost the signal to 32 mW.

Figure 5 illustrates the measured output power vs input power for this x3 Q-Band power amplifier with 32 mW of

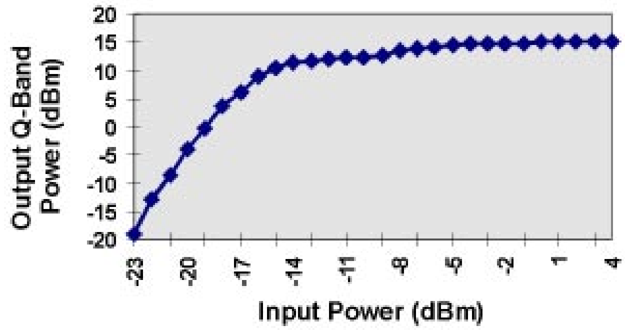

Figure 5. Output Power vs. Input Power Q-Band Active x3 MMIC Amplifier

output power. This observed limiting characteristic was designed to reduce AM noise, and make the system less sensitive to power variations. The operating point of -3 dBm is suggested to provide good output power and reduce any AM noise.

Experimental Measurements

The first measurement evaluated the insertion loss of the optical link vs. RF input power. Figure 6 illustrates the measured loss vs input power. To perform this measurement, amplifiers were used both before and after the optical link and the loss measurements did not include any amplification. The amplifiers were linear throughout the signal level range, so gain compression was determined entirely by the optical link. The small signal loss is 49.4 dB and the loss for the maximum input signal level of 27 dBm is 50.2 dB-some 0.8 dB higher than the small signal loss. Operating at 23.5- dBm input power with 0.2-dB increase of loss over linear was desired to maximize the signal-to-noise out of the system. The signals in question are not multiple signals where third order products are important. For that later situation, the input power drive would be reduced. The loss could be reduced by 7.5 dB if the detector diode was driven to its rated input power of 2 mW instead of the measured value of 0.84 mW with the use of a higher laser power.

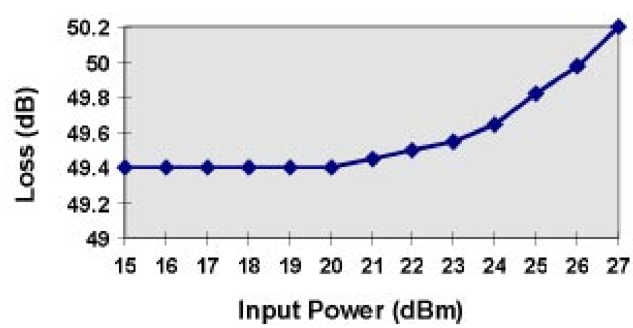

Figure 6. Optical Link Loss vs. Input Power

This measured loss is 0.4 dB lower than the theoretical loss [5] shown by the following expression:

$$G = 10\ \log\left(\frac{i^2_{input}\ \ a^2 r^2 \pi^2 z_{input} z_{load}}{4V_\pi{}^2}\right)$$

where:

- i_{input} = laser power (W)
- a = attenuation of elements from laser to detector (power ratio)
- r = responsivity of photo detector (W/A)
- z_{input} = impedance of modulator (Ohms)
- z_{load} = impedance of load (Ohms)
- V_π = modulator half wave voltage (V)

The phase noise of the optical line was determined using a low noise source consisting of an 80-MHz crystal oscillator output cascaded with three x2 multipliers with an output at 640 MHz followed with a step recovery diode multiplier. A filter was fabricated to pick the 24th harmonic of 640 MHz for Ku-band output. A phase bridge was used to measure the phase noise. Figure 7 illustrates the measured phase noise at Ku band. The noise floor is -145 dBm/Hz and the measured signal level at the PIN diode optical detector is -26.2 dBm. The noise floor is then -171.2 dBm. The calculated noise floor is - 170.2 dBm Hz taking both thermal noise and shot noise into account. One can observe the 1/f noise present 100 Hz to 100 kHz, due to the GaAs PHEMT amplifiers and source.

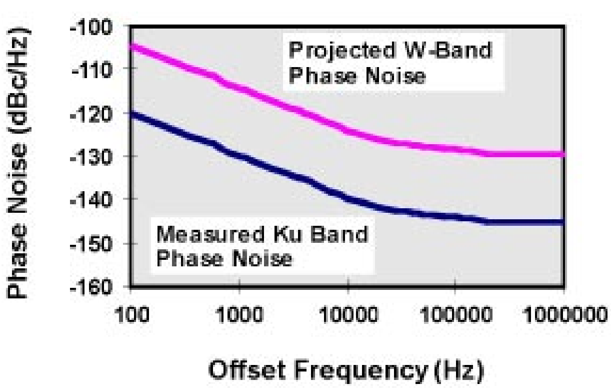

Figure 7. Measured Ku-Band Phase noise and Projected W-Band Phase Noise

The AM noise will be attenuated due to the limiting in the amplifiers. The phase noise at W-band will increase 20 log(6) = 15.6 dB over the Ku-band phase noise due to the multipliers.

The complete system was measured with 70-mW output at W-band and 32 mW at Q-band for 5-mW input power at Ku-band.

Conclusions

An optical link was designed, fabricated, and tested with low phase noise characteristics. The all MMIC x3 and x6 low cost multipliers provide power for W-band operation.

Acknowledgments

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