MMIC Based SOM in Optically Fed Phased Array Antennas for Ka-band Communication Satellites

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ABSTRACT

Experimental results are presented for an optically fed MMIC based self-oscillating mixer (SOM) at 19GHz. A frequency reference, used to subharmonically synchronize the 19GHz VCO, and FM data signals are optically distributed to generate RF signals for Ka-band communication satellites.

INTRODUCTION

Future communication satellites are designed to operate at frequencies of Ka-band using active phased array antennas. The challenge of distributing Ka-band signals to the active transmit/receive (T/R) modules of a phased array could be overcome by a fiberoptic distribution link. In a proposed optically fed phased array antenna architecture, the satellite communication system performs up-conversion of the IF signals at the active phased array antennas in the transmit mode of operation. Similarly, down-conversion of the RF signals to IF is also performed in the antenna mounted electronics in the receive mode of operation. This architecture is different from the conventional systems where the frequency translation occurs at the processor level. However, this architecture provides a lot of advantages in the performance of the optical distribution networks. This approach is labeled as T/R level data mixing as opposed to the conventional method of the CPU level data mixing. Using the T/R level data mixing technique a much higher dynamic range is obtained over the conventional CPU level data mixing method[1]; however, this approach requires having a local oscillator at each antenna element. Furthermore in the active phased array antennas, coherent communication system is only achieved when the frequency translation is realized by the phase coherent local oscillators [2]. The stabilization of local oscillators (LO) in distributed systems is ensured by providing a reference signal from a synthesizer to the remotely located active T/R modules.

DESIGN APPROACH

Performance comparison of the T/R- and CPU-level data mixing architectures have been reported for an optically fed 2x4 MMIC phased array antennas at C-band [1]. The conceptual realization of a T/R level data mixing system architecture for the transmit mode of operation at Ka-band is shown in Fig. 1. In this design, the frequency reference and data signals are distributed to the transmitter modules. The frequency reference stabilizes the LO of the self-oscillating mixer (SOM). The data signal is also inputted to the SOM, which in turn mixes with the stabilized LO to generate an RF signal. The RF signal is power conditioned by the MMIC TX prior to radiation by the antenna. In our experiments an LO signal of 19 GHz and data signals of 1.5-3.0 GHz are employed to generate a 16.0-17.5 GHz. A similar approach is envisioned for the receive mode using an LO of 26 GHz to down-convert 27.5-29.0 GHz RF signals to IF signal of 1.5-3.0GHz.

The mixing operation is realized in SOM using the nonlinearity of the oscillator portion (i.e., a saturated amplifier). A MMIC oscillator circuit is designed similar to the block diagram reported earlier [3]; this new design is composed of the input buffer amplifier, 6-port Active Com/Div, and a voltage controlled oscillator (VCO). The 19 GHz VCO is constructed using the 14-24 GHz amplifier with an external feedback path including a varactor loaded delay line. The addition of this varactor diode is suitable for both frequency locking and phase locking using the concept of ILPLL [4]. Another important novelty of this design is the input buffer amplifier of 0.3-5 GHz,

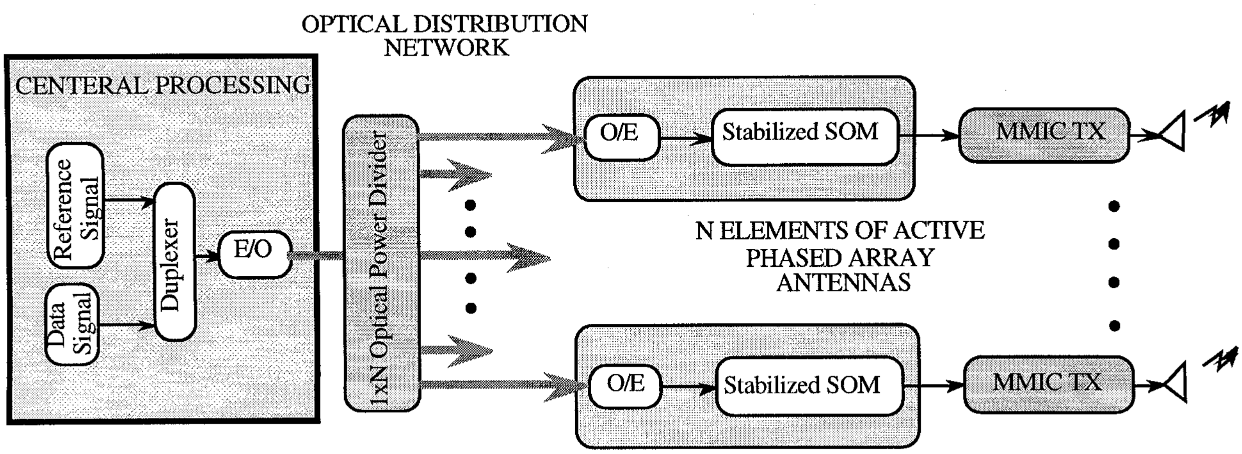

Fig. 1 conceptual representation of optical distribution of a frequency reference and data signals to N elements of a Ka-band phased array antennas. The reference signal is used to synchronize the local oscillators in the SOM. Data signal is mixed with the stabilized SOM to generate an RF signal. (E/O and O/E are optical transmitter and receiver modules. MMIC TX represents a MMIC based transmitter module.)

which amplifies any frequency reference that corresponds to the nth subharmonic ($n \geq 4$) of the 19GHz VCO. The amplification of the injected reference signal by ≈22dB results in a very large subharmonic injection locking range, as was reported earlier[5]. In addition, the amplifier is used to amplify the IF signal of 1.5 - 3.0 GHz, prior to mixing with the stabilized local oscillator ≈19 GHz.

This paper presents results of: 1) dynamic range performance of directly and externally modulated fiberoptic links for distribution of Ka-band communication satellites; 2) realization of MMIC SOM at 19GHz; 3) performance of the MMIC SOM at fundamental and 4th subharmonic injection locking; 4) mixing characteristics of this SOM to generate RF signals; and 5) discusses its impact on Ka-band communication satellites.

EXPERIMENTAL RESULTS

First, the experimental results of fiberoptic distribution of frequency reference to synchronize the VCO are being reported. Both directly and externally modulated fiberoptic links are realized for transmission of the frequency reference and data signals. A DFB laser diode from Ortel combined with a traveling wave external modulator from Sumitomo is used as the optical transmitter (E/O) in the external modulation experiment. Whereas in direct modulation experiments, the DFB laser is employed as E/O. Moreover, a high-speed waveguide photodiode from NTT Electronics Technology is used as the optical receiver (O/E). Spurious free dynamic range (SFDR) of $90dB.Hz^{2/3}$ (cf. Fig. 2) and $86dB.Hz^{2/3}$ are measured at 2.5GHz for the non optimized externally and the directly modulated links respectively. These results are at least 20dB better than the CPU-level data mixing performance at Ka-band.

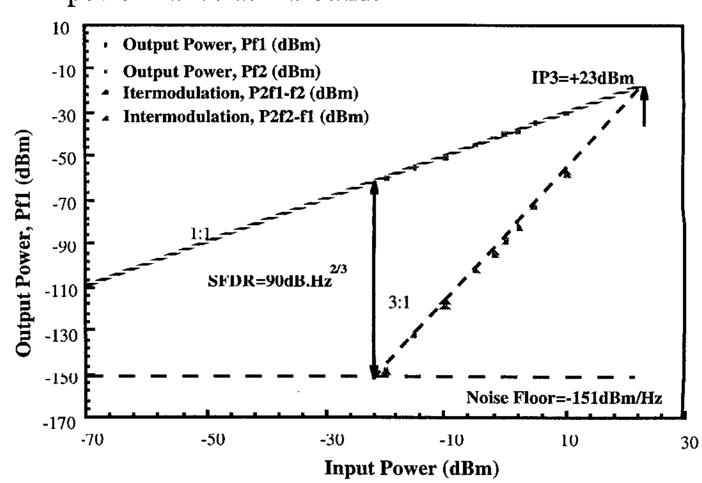

Fig. 2. SFDR of an externally modulated FO link using a DFB laser as the optical source.

The MMIC SOM circuit is laid out and fabricated using 0.2 μm HEMT *foundry service*. A varactor diode is implemented by single ending a T-gate HEMT as a Schottky diode for the VCO operation of the SOM. The VCO's measured output power is +4dBm. Fig. 3 shows dependence of the output power and oscillation frequency of the MMIC VCO on the varactor diode's bias. A tuning sensitivity of ≈720 MHz/V is measured at the varactor diode reverse bias of 0.2 v. Output power variation is less than ±1dB over the tuning range of 600MHz. Hence, the following experiments are performed at the varactor diode's reverse biased voltage of 0.2V.

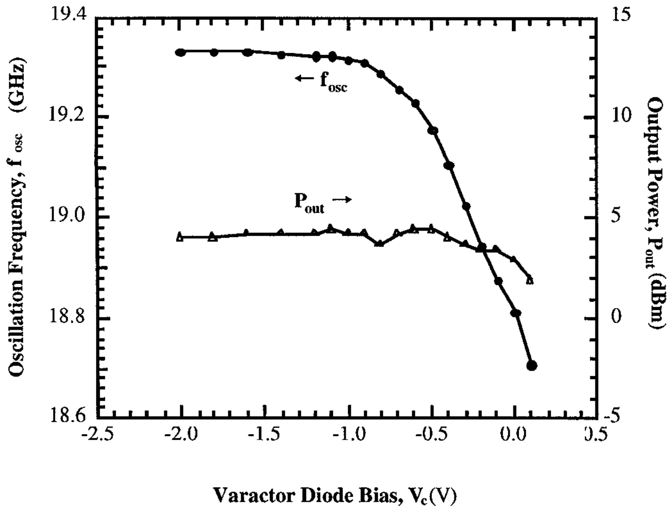

Fig. 3. Frequency tuning and output power variation characteristics of the MMIC VCO versus the varactor diode bias voltage.

Both locking range and the SSB phase noise of the VCO under fundamental and sub-harmonic injection locking are studied. Impact of externally modulated fiberoptic link on the phase noise degradation is more severe than the directly modulated fiberoptic links. In particular, when the external modulator is operated in the nonlinear operating points, away from the phase quadrature point. An AM/PM conversion difference as high as 8dB is measured between the quadrature and the in-phase operating bias points. Nonetheless, the overall phase noise degradation of the frequency reference has been negligible, when the fiberoptic links are operated in the linear operation points. Considering the measured locking range versus the locking gain, the external quality factor of ≈10 is measured. Comparison of the fundamental and subharmonic injection locking range is shown in Fig. 4, where a significant improvement is observed for the 4th subharmonic injection locking range. This improvement in locking range is due to the ≈22dB gain of the buffer amplifier. The SSB phase noise of the injection locked oscillator closely tracks the frequency reference characteristics at the center of locking range. However, a 2-4 dB degradation in the close-in to carrier phase noise is experienced at the free running oscillation frequencies close to the two edges of the locking band. The performance results matches with the previously reported results [4]. Next, an IF signal is distributed through the fiberoptic link to the MMIC SOM. Up-conversion of the 2.5 GHz IF signal to the RF signal is observed in the SOM. A conversion loss of ≈10 dB is measured at 2.5 GHz, as shown in Fig. 5. The SFDR of the SOM is influenced by the third order intercept point of the buffer amplifier. This parameter is strongly dependent on the input power for the frequency reference. The measured SFDR for 4th subharmonic injection locking is 102dB.Hz$^{2/3}$.

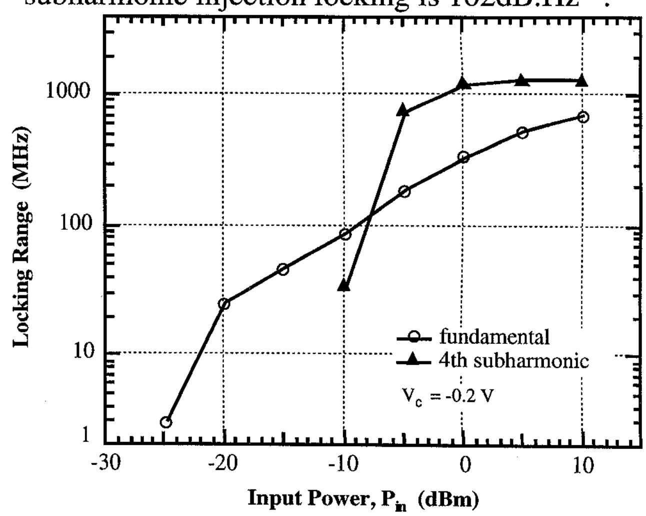

Fig. 4. Comparison of fundamental and 4th subharmonic injection locking range as a function of the injected power. The varactor diode is biased at V_c = -0.2 v.

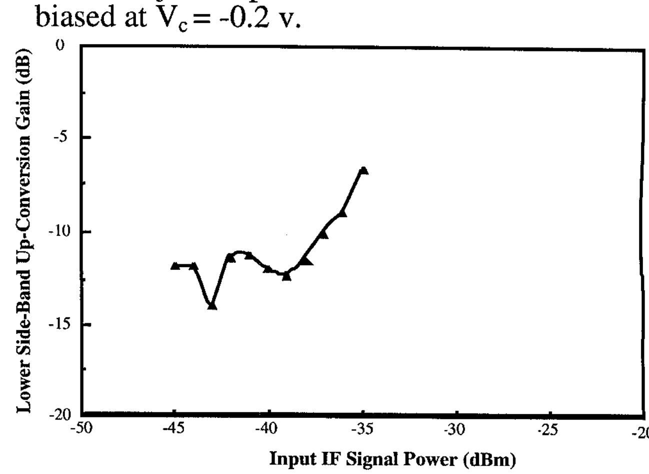

Fig. 5. Conversion gain of SOM at P_{in}=-20dBm, f_{in}= 18.86GHz, and IF signal of 2.5GHz.

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To demonstrate viability of data transmission using this architecture, an FM data signal at sub-carrier frequency of 2.5GHz is transmitted through the fiberoptic link; the received data signal is inputted to the buffer amplifier input port along with the 4.75GHz reference signal, employed for stabilization of the VCO. FM spectra of the IF (at the output of the externally modulated fiberoptic feed) and RF signal (at the output of the SOM) are shown in Fig. 6. The overall SFDR performance of this architecture, from the CPU, using directly modulated FO link, to the modulated output from the SOM, is 86dB.Hz$^{2/3}$. On the other hand, an additional 14dB of amplification is required after O/E to overcome excess loss of external modulator and maintain SFDR of 90dB.Hz$^{2/3}$.

CONCLUSIONS

This paper has presented experimental results of optical distribution of Ka-band communication satellite traffic. The fiber architecture is based on the T/R level data mixing approach. Experimental results of the MMIC based SOM are indicative of 4th subharmonic injection locking and up-conversion of the IF signals. Performance of the commercially available directly and externally modulated fiber optic feed are the limiting factor in generating a 16.0-17.5GHz RF signal.

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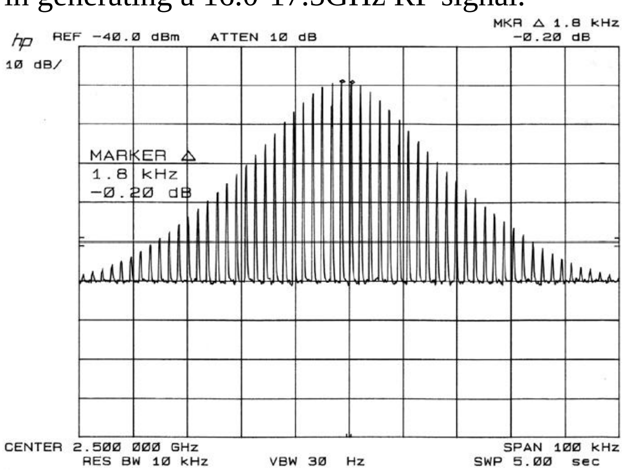
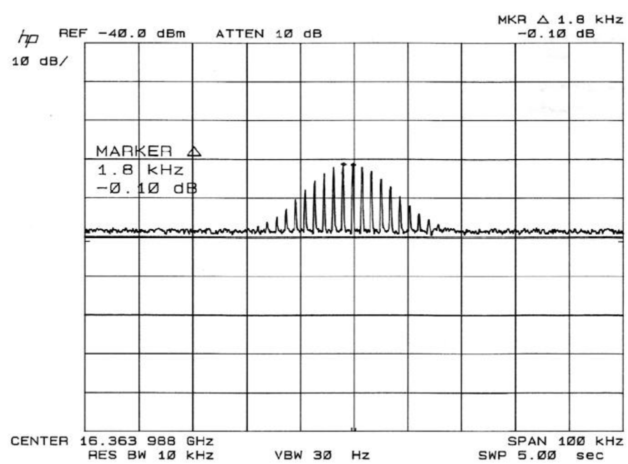


(a)



(b)

Fig. 6. Up-conversion of an FM information at 2.5GHz by the stabilized MMIC SOM, a) IF at 2.5GHz after distribution by the fiberoptic feed, b) RF at the frequency of ≈16.4GHz at the SOM output. (Modulation frequency of IF signal is 4kHz at a sweep rate of 10msec. The spectrum analyzer plots are generated at a sweep rate of 5 sec, resolution bandwidth of 10kHz, video bandwidth of 30Hz, and span of 100kHz. Center frequency for "a" is 2.500GHz and for "b" is 16.384GHz. Note that the noise floor of the spectrum analyzer masks the FM side-bands for the received power levels below -90dBm.)

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