COMPARISON OF INDIRECT OPTICAL INJECTION LOCKING TECHNIQUES OF MULTIPLE X-BAND OSCILLATORS

P. Wahi*, Z. Turski* , A.S. Daryoush+ and P.R. Herczfeld+

*LORAL-ATL, Lanham, MD 20706

+Dept. of Electrical and Computer Engineering, Drexel University, Philadelphia, PA 19104

ABSTRACT

Experimental results of indirect optical injection locking of two X-band oscillators are presented. Large signal modulation of the laser diode generates harmonics, which are employed to synchronize both oscillators over 110°C using an S-band master source. Both laser diode and FET oscillator nonlinearities can be exploited to achieve frequency multiplication and obtain subharmonic injection locking at X-band and above. The merits of these different methods are evaluated based on locking range and FM noise characteristics.

INTRODUCTION

Future tactical fighter planes are designed with greater electronic warfare capabilities and independence from electronically intelligent systems. For example, an instaneous frequency measurement (IFM) system is presently investigated, where the sensor listens for illumination at four quadrants of the plane in frequency bands of 2-18GHz and then engages in active/passive jamming. Such a system requires stability of local oscillators over 110°C (-45 to 65°C) to achieve IFM within 1MHz accuracy. Injection locked FET oscillators are selected as the stabilized local oscillator, which are synchronized to a common master source. The conventional coaxial cables, for distribution of the control synchronizing signals, are undesirable and fiberoptic distribution networks are considered as a viable alternative (1-2). The advantages of fiberoptic links are light weight, small size, low loss, immunity to interference (EMI, EMP).

The fiberoptic links are composed of a high-speed semiconductor laser, optical couplers and fiberoptic distribution networks, and high-speed photodetectors. However, the bandwidth of the state-of-the-art commercial electrooptic components (lasers and photodetectors) are limited to 10GHz and new schemes should be employed to extend the bandwidth of the synchronizing fiberoptic link. A possible approach to overcome this gap is to exploit the laser diode and FET oscillator nonlinearities to generate harmonics, thereby extending the effective synchronizing link's bandwidth. This paper reports on such a scheme to achieve synchronization of multiple X-band FET oscillators. Specifically, the results of indirect optical injection locking method (3) and a comparison between fiberoptic link nonlinearity and the FET are presented. By indirect optical injection locking we mean that the modulated optical signal is first demodulated by a high speed pin diode and then electrically injected to the FET oscillator versus direct illumination of the active region of the FET (4). The present work has two main objectives. First, to report on the simultaneous optical injection locking of two independent free-running X-band microwave oscillators using laser diode's nonlinearity. Second, to investigate and evaluate various methods of achieving sub-harmonic injection locking which extends the effective bandwidth of the optical link. In these experiments, both the laser diode and the FET oscillator nonlinearities are exploited to achieve frequency multiplication. More explicitly, the relationship between the master oscillator frequency, f_{master}, and the slave oscillator, f_{slave} , is expressed as

$$f_{slave} = m_{laser} * m_{fet} * f_{master} + \delta f \qquad (1)$$

where m_{laser} and m_{fet} are the frequency multiplication factors of the laser diode and the FET respectively and δf is the frequency detuning. These experiments demonstrate methods by which practical optical synchronization of oscillators can be extended to K-band and above. The performance of the sub-harmonic injection locked oscillator is compared in terms of locking range and FM noise for a matrix of different m_{laser} and m_{fet}.

INDIRECT OPTICAL INJECTION LOCKING

Experimental setup

The experimental arrangement is shown in Fig. 1, depicting two independent free-running slave oscillators, that are synchronized to a master oscillator via a fiber-optic link. For the optical source, a double burried hetero-junction (DBH) AlGaAs injection laser, with a short cavity, is used. The signal from the master oscillator is injected to the laser through a bias tee circuit, directly modulating the laser drive current, and hence the optical output. The laser output power is 7mW at 830nm with 3dB small signal bandwidth of 5 GHz for a driving current equal to 80% of the maximum output power level. The laser's output fiber is fused to a commercial 3dB optical coupler and the light from each arm is coupled to high speed GaAs pin photodetectors each with a responsivity of .45A/W at 840nm and 3dB bandwidth of 15GHz at 20V reverse bias voltage. The demodulated rf signals are amplified using 20dB gain broadband (8-18GHz) LNAs, and are electrically injected to the free-running oscillators.

The X-band free-running oscillators are designed and fabricated using low noise FETs (NEC71083). The oscillators are biased for 7 and 2dBm output power respectively. The external Q of the free running oscillators is determined by direct electrical injection locking and is found to be 60. The spectra of the free-running oscillators prior to indirect optical injection locking is shown in Fig. 2. The lack of synchronization and high FM noise is evident. The frequency drift of the free running oscillators over a temperature range of -45 to 65°C is measured

0149-645X/86/0000-0615$01.00 © 1986 IEEE

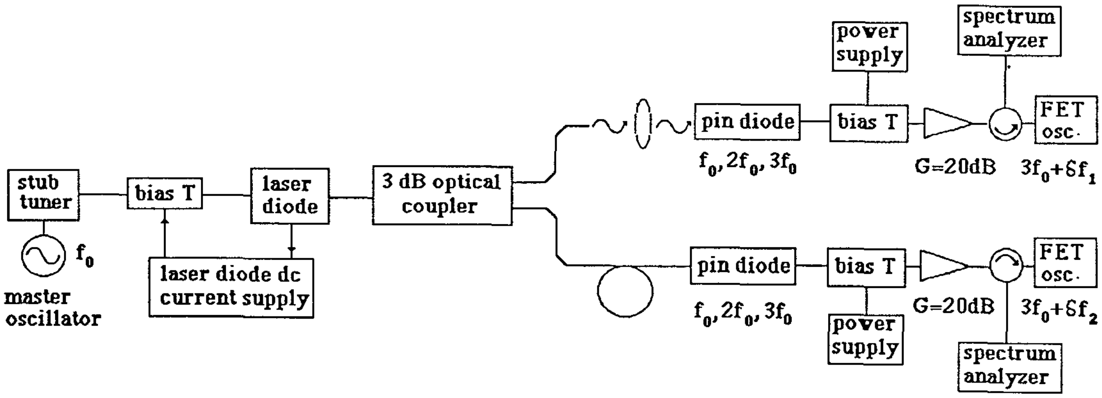


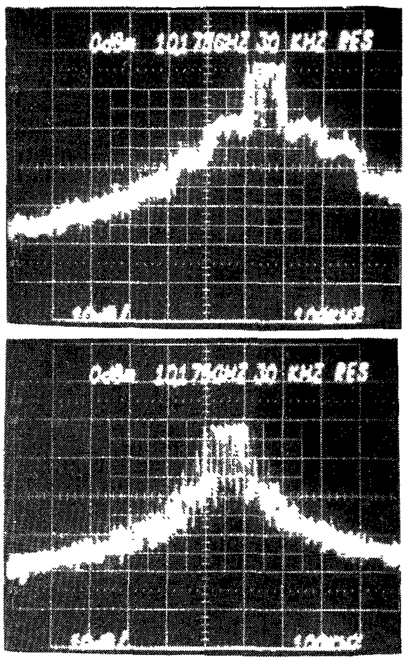
Fig. 1 Experimental setup for indirect optical injection locking of two X-band FET oscillators.

to be 20MHz. The goal of the optical injection locking is to maintain synchronization of the free-running oscillators over this temperature range, and to reduce their FM noise.

<u>Experimental results</u>

The laser diode is modulated at 3.393GHz by an 8dBm signal from a synthesized source. The fundamental signal, as well as higher harmonics are generated by the large signal operation of the laser diode(5) and are demodulated by the two high-speed photodetectors. In particular, the third harmonic signal (10.179GHz), is matched to the broadband LNA by a stub tuner and the amplified signal is electrically injected to the free-running oscillator. Both free running oscillators are simultaneously locked to the master source.

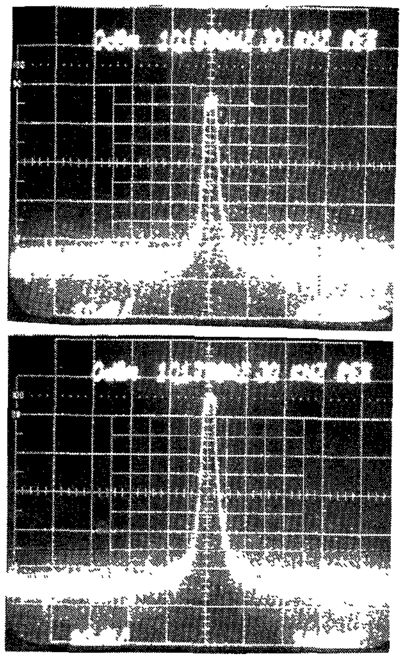
The injection locked spectrum of the free-running oscillators is shown in Fig. 3. It depicts synchronization of the two slave oscillators at 10.179GHz, the third harmonic of the master source, accompanied by a significant reduction in the FM noise. The injection locking process for the 2dBm oscillator is depicted in Fig. 4. A locking range in excess of 18MHz is achieved for both oscillators. The system FM noise degradation of the master oscillator signal due to the optical link and the broadband amplifier setup is measured to be 14dB, where 9dB is due to the third harmonic generation technique (20logN), 2dB is attributed to the fiberoptic link and 3dB is due to AM to PM conversion in the broadband LNA.



(a)

(b)

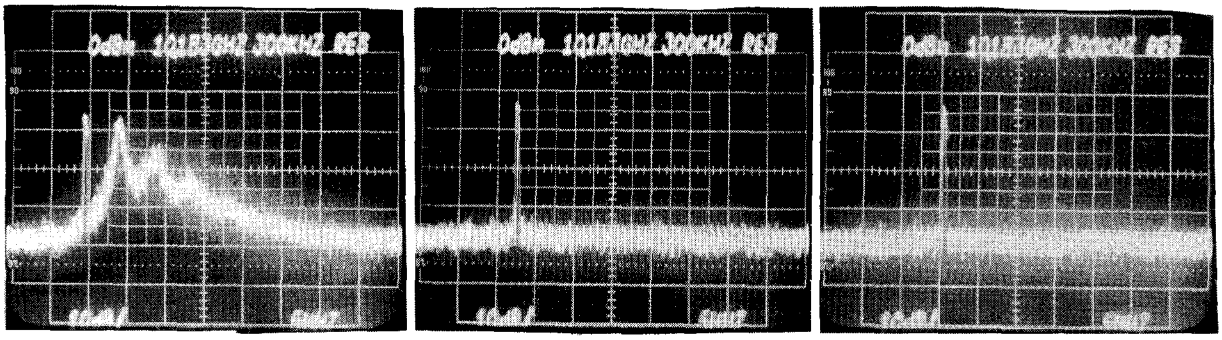
Fig. 2 Power spectra of two free-running FET oscillators; (a) oscillator #1, P_O=7dBm; (b) oscillator #2, P_O=2dBm. (Vertical scale is 10dB/div., and a 100KHz/div. in horizontal scale.)



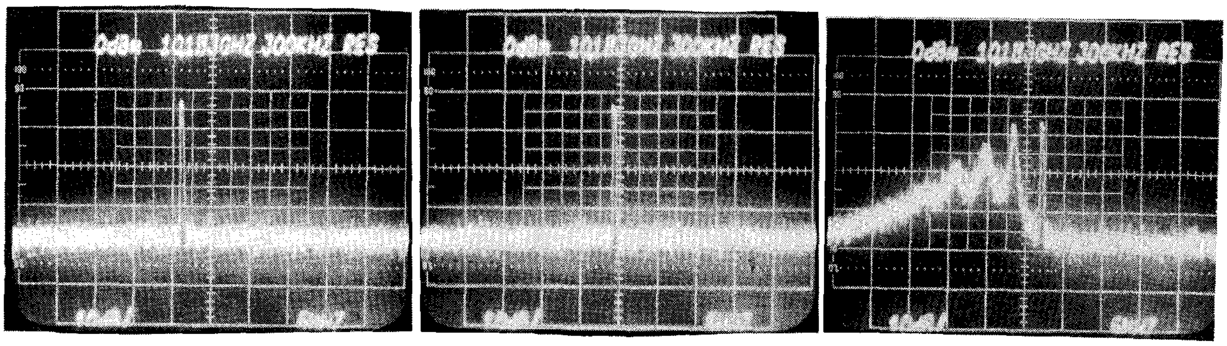
(a)

(b)

Fig. 3 Power spectra of the two X-band slave oscillators synchronized to the S-band master source; (a) oscillator #1, (b) oscillator #2. (Vertical scale is 10dB/div., and a 100KHz/div. in horizontal scale.)



(a) (b) (c)



(d) (e) (f)

Fig. 4 Master-slave pulling range of oscillator #2 for six 1MHz steps of the master source; (a) 3.390GHz (beginning of locking with sidebands); (b) 3.391GHz (locked); (c) 3.392GHz (locked); (d) 3.394GHz (locked); (e) 3.395GHz (locked); (f) 3.396GHz (end of locking with sidebands). (Horizontal scale 5MHz/div. and center frequency of 10.183GHz.)

COMPARISON OF LASER NONLINEARITY VS. FET

To examine the relative merits of the laser and the FET nonlinearity behavior and their applications in sub-harmonic optical injection locking, the laser is modulated by an 8dBm master source signal at approximate frequencies of f_{slave}, $f_{slave}/2$, $f_{slave}/3$ and $f_{slave}/4$. The demodulated optical signal at X-band is amplified using an 8-18GHz amplifier with 20dB gain, and is injected into the FET oscillator. In this set of experiments the laser nonlinearity is employed (m_{laser} = 1, 2, 3 and 4). The characteristics of the injection locked slave oscillator are listed in Table I. At the frequencies below the laser relaxation oscillation frequency (5GHz), the large signal operation of the semiconductor laser enhances the harmonic levels, which provides large locking range (32MHz). On the other hand, at the frequencies above the laser bandwidth, the large signal is attenuated and the harmonic levels are small, resulting in a reduced locking range (as low as 6MHz). In the second set of measurements the conditions remained the same except that the 8-18GHz amplifier is replaced by a 2-6GHz amplifier with 20dB gain. Therefore, the generated harmonics by the laser diode are filtered out and only the fundamental frequency is amplified, whence the harmonic generation by the FET (m_{fet} = 1, 2, 3 and 4) are employed in the injection locking process. The results of locking range, FM noise performance using the FET nonlinear contribution, are listed in Table II, where demonstrate that the laser nonlinearity provides a superior performance than the FET and hence should be further exploited.

Master osc. freq. (GHz)	m_{laser}	Locking range (MHz)	FM noise at 100KHz offset (dBc/Hz)	FM noise at 1KHz offset (dBc/Hz)
10.174	1	≈9	-78	-45
5.087	2	≈6	-75	-42
3.391	3	19	-72	-38
2.543	4	32	-70	-35

Table I Locking range and FM noise level of the indirect optically injection locked 10.174GHz FET oscillator with output power of 2dBm, using laser diode multiplication factor, m_{laser}.

Master osc. freq. (GHz)	m_{FET}	Locking range (MHz)	FM noise at 100KHz offset (dBc/Hz)	FM noise at 1KHz offset (dBc/Hz)
10.174	1	≈9	-78	-45
5.087	2	≈1	-74	-37
3.391	3	≈3	-72	-36
2.543	4	6	-71	-35

Table II Locking range and FM noise level of the indirect optically injection locked 10.174GHz FET oscillator with output power of 2dBm, using FET oscillator multiplication factor, m_{FET}.

DISCUSSION

The feasibility of the sub-harmonic indirect optical injection locking of the two X-band oscillators is demonstrated, using an S-band master source, where a locking range in excess of 18MHz is achieved. The advantages of the indirect over direct optical injection locking technique are the availability of commercial components, and higher available locking gain due to the effective light coupling into the pin diode and amplification of the control signal before injection locking.

The 14dB FM noise degradation of the master oscillator in the indirect optical injection locking system is related to the optical link and the broadband amplifier characteristics. The optical link noise degradation is dominated by the light scattering within the coherent length of the laser, which may be reduced by reducing the optical mismatch and use of optical isolators. A narrow band amplifier would reduce the amplifier's noise contribution by minimizing AM to PM conversion

Frequency multiplication by both the laser diode and the FET is also demonstrated. The large signal modulation of laser diodes increases the harmonics conten which are attenuated at the rates slower than 40dB/decade above the relaxation oscillation frequency (5). Therefore, large signal modulation of the lasers extend the effective bandwidth of the optical link. The experimental evaluation of nonlinear contributions of the laser diode and the FET oscillator, indicated that it is more desirable to utilize the multiplication by the laser than by the FET. Further optimization of the locking range, improvement in the system FM noise degradation, and a power budget calaculation is currently pursued.

ACKNOWLEDGEMENTS

This work is supported by the Commonwealth of Pennsylvania's Ben Franklin Partnership grant.

REFERENCES

(1) A.M. Levine, "Fober Optics for Radar and Data System," *Proc., SPIE Vol. 150,* Laser and Fiber Optics Communication, Bellingham, MA, 1978.

(2) J.R. Forest and A.A. Salles, "Optics Control Microwaves," *Microwave System News,* June 1981, pp. 112-122.

(3) A.S. Daryoush and P.R. Herczfeld, "Indirect optical injection locking of X-band oscillators," *Electron. Lett.*, 1986, **22**, pp. 133-134.

(4) A.A. Salles, "Optical control of MESFETs," *IEEE Trans.*, 1983 , **MTT-31**, pp. 812-820.

(5) A.S. Daryoush and P.R. Herczfeld, "Determination of nonlinearity in high-speed fiber optic links and its applications for indirect optical injection locking," submitted to *Electron. Lett.* (unpublished).