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INDIRECT SUB-HARMONIC OPTICAL INJECTION LOCKING OF A MILLIMETER WAVE IMPATT OSCILLATOR

A.S. Daryoush[+], P.R. Herczfeld[+], A. Rosen[*], A.K. Sharma[*], and V.M. Contarino[**]

[+]Dept. of Electrical and Computer Eng., Drexel Univ., Philadelphia, PA. 19104
[*]RCA, David Sarnoff Res. Lab., Princeton, N.J. 08540
[**]Naval Air Development Center, Warminster, PA. 18974

ABSTRACT

This paper presents results of indirect optical injection locking of a free-running 38GHz (Ka-band) IMPATT oscillator over the locking range of 2 to 132MHz, depending on the injected power level (amplifier gain). In this experiment, The nonlinearity of the both laser diode and the IMPATT, are exploited to achieve twelfth sub-harmonic injection locking. Methods by which optical links may be extended into 60 and 90GHz are demonstrated.

INTRODUCTION

Future airborne tactical and surveillance phased array radar systems with as many as 10^4-10^5 solid state transmit/receive (T/R) modules are designed for high resolution target detection and accuracy. To achieve a coherent target detection, the T/R modules are synchronized to a master oscillator using injection locking techniques. However, distribution of control synchronizing signals to each element, using the conventional coaxial feed networks are undesirable due to their high loss, large size and weight. On the other hand, recent advancements in MMIC fabrication processing facilitates low cost integration of optoelectronic components with T/R modules, and hence distribution of control signals using light weight fiberoptic links is an attractive alternative (1-2). Future trends in microwave and millimeter wave requires fiberoptic links at frequencies of 20, 40, 60, 90GHz. However, the laser diode's bandwidth, at room temperature, is presently limited to microwave frequencies (10GHz), and it is not anticipated that optoelectronic devices with bandwidths in excess of 30GHz, would be available in a near future. Therefore, alternative techniques must be explored to extend the bandwidth of the fiberoptic links to the millimeter wave frequencies. A possible approach to overcome this gap is to exploit the inherent nonlinearities of semiconductor laser diode and millimeter wave local oscillators, such as IMPATT and Gunn diodes, to generate harmonics, thereby extending the effective synchronizing link bandwidth. This paper reports on such a scheme to stabilize a millimeter wave IMPATT oscillator. Specifically, this paper presents results of indirect optical injection locking of a free-running 38 GHz (Ka-band) IMPATT oscillator over the locking range of 2MHz to 132MHz depending on the injected power level (amplifier gain). Indirect optical injection locking (3) means that the rf modulated optical signal is first demodulated by a high-speed pin diode, amplified and then electrically injected to the IMPATT oscillator as opposed to direct illumination of the active device (4). In this experiment the nonlinearity of both the laser diode (5) and the IMPATT diode is exploited to achieve a combined twelfth sub-harmonic locking.

EXPERIMENTAL PROCEDURE

Experimental setup

The experimental arrangement is shown in Fig. 1, depicting the free-running slave oscillator which is synchronized to a master oscillator via a fiber-optic link. For the optical source, a double burried hetero-junction (DBH) AlGaAs injection laser, manufactured by ORTEL Corp., is used. The laser drive current and hence the optical output is directly modulated by a 3.235GHz (f_o) signal from the master oscillator. The laser diode has a 3dB small signal bandwidth of 5 GHz for a driving current level corresponding to 80% of its maximum output power. The laser output is coupled to a multi-mode fiber, with a 70% coupling effeciency. The laser diode's output is fused to a 3dB optical coupler, which splits the optical signal into two optical links. One arm of the optical link is connected to a receiver and the other arm is not used at the present. On the optical receiver end, the light is collimated using a .25 pitch selfoc lens, and then focused on a high-speed photodetector using a short focal length laser diode focusing lens. The pin photodetector is a GaAs pin diode from Ortel Corp., which has a responsivity of .45A/W at 840nm with 3dB bandwidth of 15GHz at 20V reverse bias voltage. The fourth harmonic signal, $4f_o$, is generated by the laser diode under large signal operation, and is amplified using two cascaded ac coupled broadband (8-18GHz) amplifiers from Narda. The electrical signal could be tapped off after either the first or the second amplifier providing for gains of 22dB and 45dB respectively. The synchronizing control signal is then electrically injected via a bias-tee to the free-running Ka-band IMPATT oscillator circuit. The power spectrum of the IMPATT oscillator is observed on a spectrum analyzer.

IMPATT Oscillator design and fabrication

The IMPATT diode is fabricated from high resistivity Si using techniques that include controlled ion implantation, SIMS doping profile measurements, wafer thinning techniques and localized laser annealing, which have been reported earlier (6). The Ka-band free-running oscillator is designed and fabricated using planar millimeter wave circuits compatible with monolithic and hybrid techniques. The microstrip oscillator circuit utilized in this experiment is shown in Fig. 2. The oscillator circuit consists of the IMPATT diode, a bias network and an impedance matching network. To minimize low frequency instabilities, a bias network using a low pass prototype Cauer filter is implemented. It consists of four open-circuit stubs separated by three quarter-wavelength transmission line sections, it provides for higher cutoff

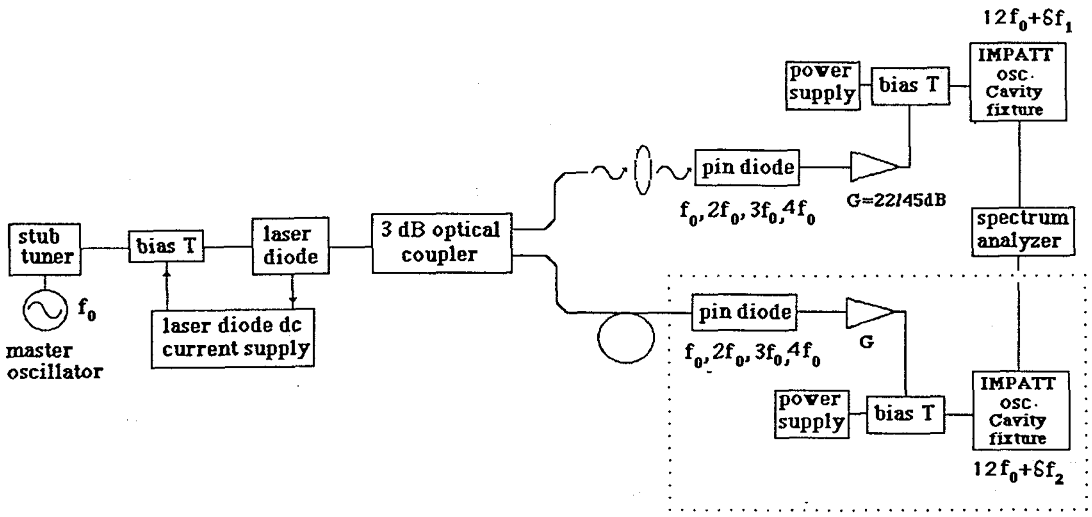

Fig. 1 Experimental setup for indirect optical injection locking of two millimeterwave IMPATT oscillators. The dotted enclosed section is not presently used.

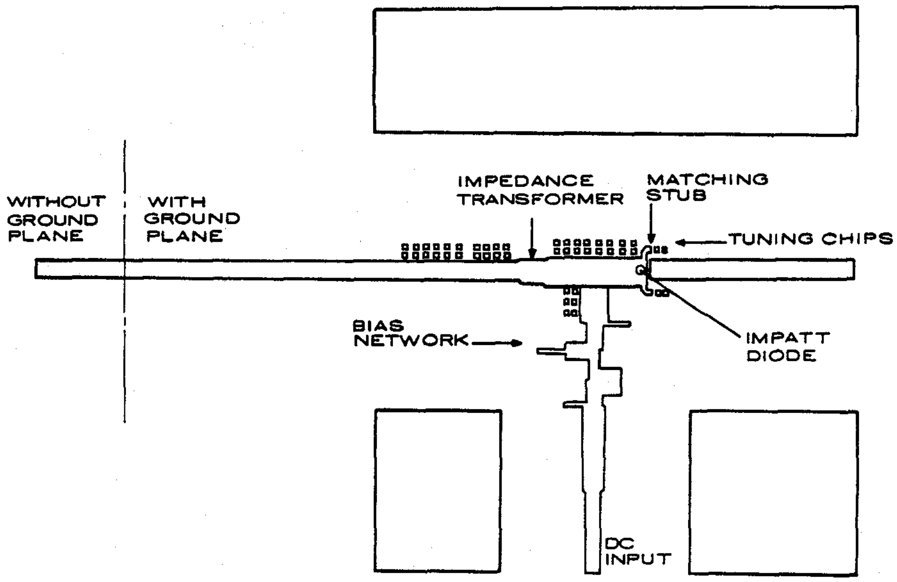

Fig. 2 Microstrip oscillator conductor pattern on front of the substrate.

frequency and adequate attenuation in the stop band (23GHz). The IMPATT diode is matched to 50 ohm using two parallel open circuited stubs and a quarter wave transformer. In order to isolate dc bias from the rf circuit, a microstrip dc block is employed using the symmetric coupled lines.

The microstrip oscillator can be used in various applications. For example, it may be used as a unit cell that feeds an array of series fed microstrip patch antennas in the transmit module. However, for the purposes of the present investigation, it is necessary to place the circuit in a waveguide below cutoff to prevent propagation of unwanted waveguide modes. The waveguide enclosure does not require critical tolerances and can be produced at a very low cost. The microstrip to waveguide transitions are required to enable measurements of the microstrip oscillator performance. The microstrip electric probe transition is used for ease of coupling. It consists of the microstrip line on the substrate, which is inserted in the E-plane of a rectangular Q-band waveguide. A maximum electric field at the location of the electric probe is attained by the use of a tunable short. This transition is capable of providing broadband performance with low VSWR and low insertion loss. The IMPATT oscillator output power is dependent on the driving current and is measured to be as high as 23mW with a 4% rf conversion efficiency.

EXPERIMENTAL RESULTS

The laser diode is intensity modulated at 3.235GHz by an 8dBm signal from a synthesized source. Under large signal operation of the laser diode, harmonics are generated, which are demodulated by the pin photodetector. In particular, the fourth harmonic signal ($4f_0$=12.940GHz), is detected at -55dBm and is amplified by the LNA . The amplified signal is electrically injected to the free-running IMPATT oscillator which is biased for couple milli-watts output power. Injection locking is observed at three times the frequency of the injected electrical signal, or at 3*12.940GHz=38.820GHz. With respect to the master oscillator, the injection locking process takes place at the twelfth harmonic, i.e. $4*3*f_0$=12*3.235GHz=38.820GHz. The sub-harmonic electrical injection locking using 9.705GHz signal ($3f_0$) from the master source, has indicated that the generated fourth harmonic by the IMPATT oscillator, does not contribute to the injection locking process. Hence, the forcing function is dominated by the 12.940GHz control signal rather than 9.705GHz, for the IMPATT oscillator under study in the sub-harmonic injection locking experiments.

The power spectra of the free-running and injection locked IMPATT oscillator are shown in Fig. 3. It depicts a significant improvement in the oscillator stability and FM noise level. The single sideband FM noise of the free-running IMPATT oscillator at 100KHz offset carrier is measured to be -50dBc/Hz, which reduces to -55dBc/Hz at 5KHz offset carrier for the injection locked case. The locking range capability of the injection locked oscillator is also investigated. A locking range in excess of 2MHz is achieved with an amplifier gain of 22dB, and with a gain of 45dB the locking range is increased to 132MHz. The injection locking process is depicted in Fig. 4.

DISCUSSION

The feasibility of the sub-harmonic indirect optical injection locking of a millimeter wave oscillator, using an S-band master source has been demonstrated and a locking range of up to 132MHz is achieved. It should be further pointed out that in the present experiment only half of the available modulated optical power is utilized, therefore the potential exist for the simultaneous synchronization of two or more independent oscillators. The nonlinearities of the semiconductor injection laser and the IMPATT diode are exploited to use a combined twelfth harmonic locking. With the availability of the larger bandwidth electrooptic components, indirect optical injection locking in the important frequency ranges of 60 and 90GHz becomes a distinct possibility.

The FM noise degradation of the indirect optical injection locked oscillator 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 improving the fiberoptic link efficiency and use of optical isolators. The amplifier noise contribution may be minimized by employing a narrow band amplifier to reduce AM to PM conversion.

The advantages of the indirect over direct optical injection locking technique are higher coupling efficiency of the modulated power to the pin diode than the active region of the IMPATT diode, and amplification of the control signal before injection locking. Further optimization of the system FM noise performance, efficiency and theoretical power budget analysis of the IMPATT synchronizing link, are presently being investigated.

ACKNOWLEDGEMENTS

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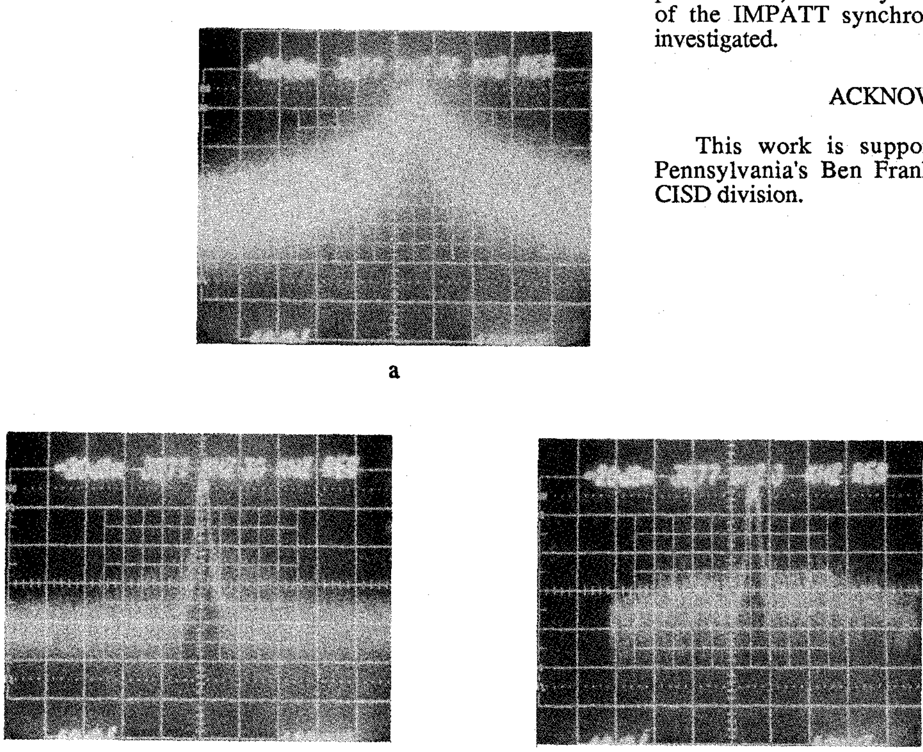
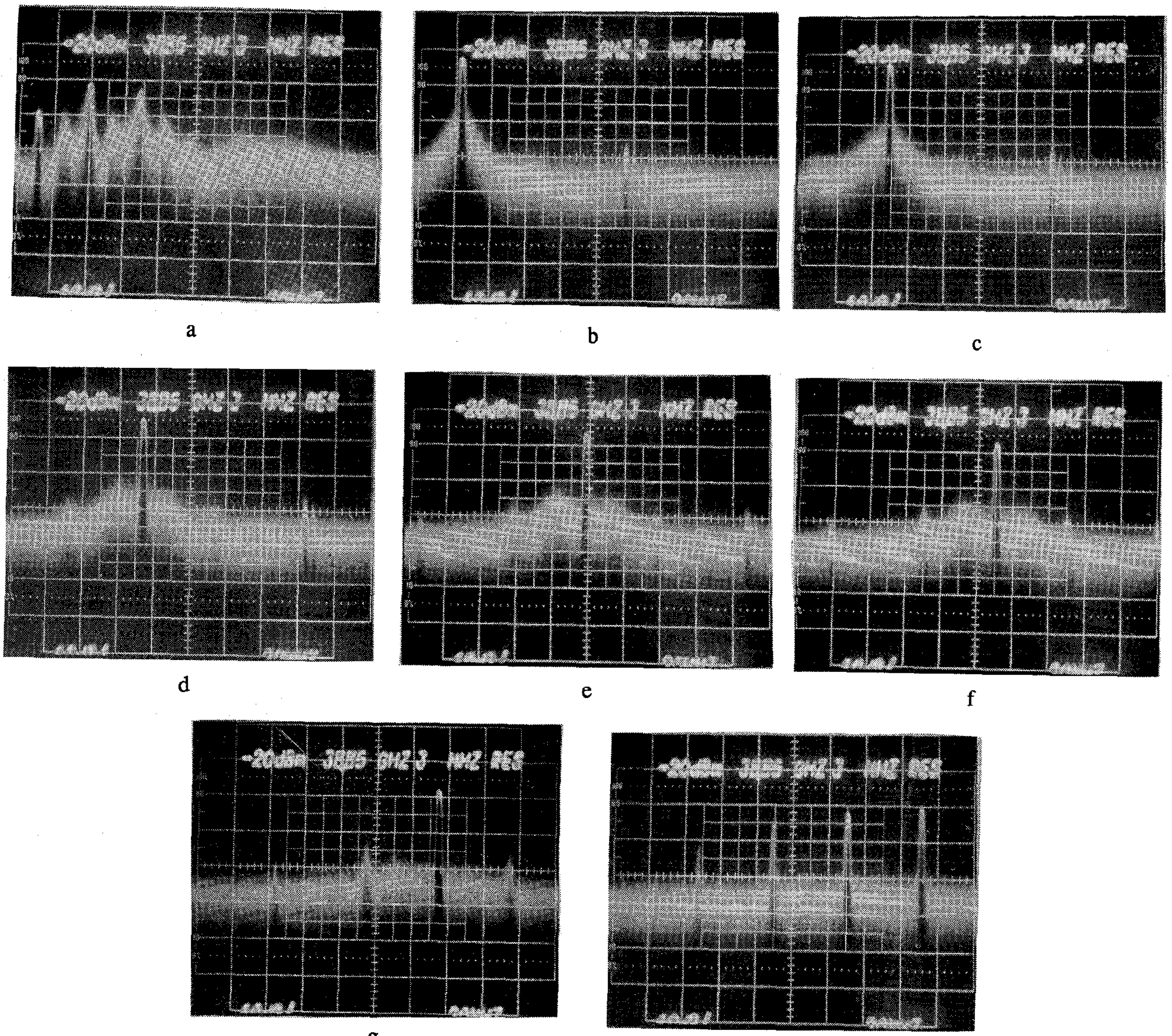


a

b

c

Fig. 3 Spectrum of the IMPATT oscillator before and after indirect optical injection locking by an S-band master source at 3.327GHz (Vertical scale is 10dB/div); (a) free-running at 38.77GHz (horizontal scale 100KHz/div), (b) Injection locked (horizontal scale 100KHz/div), (c) Injection locked (horizontal scale 10KHz/div)



a b c d e f g h

Fig. 4 Master-slave pulling range of IMPATT oscillator for eleven 1MHz steps of master source; (a) 3.225GHz (beginning of locking with sidebands), (b) 3.226GHz (locked), (c) 3.228GHz (locked), (d) 3.230GHz (locked), (e) 3.232GHz (locked), (f) 3.233GHz (locked), (g) 3.235 (locked), (h) 3.236 (end of locking with sidebands). (Horizontal scale20MHz/div and center frequency of 38.78GHz.)

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