Optical Injection Locking of BARITT Oscillators

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Abstract—Optical injection locking of BARITT oscillators is investigated. Preliminary experimental results are presented for the first time. A simple first-order locking theory gives reasonable agreement with measurements.

In modern high-performance radar systems, it is advantageous to use many low-power transmitters in an electronically steerable phase-array configuration. All these low-power transmitters have to oscillate with the same frequency and a given phase relation using locking signals distributed to the individual oscillators. This may be achieved by optical injection locking if electrooptotic microwave semiconductor devices—e.g., IMPATTs—are used. These optical locking signals can then be distributed by optical fibers with the advantage of low loss, negligible dispersion, and low weight as compared with conventional microwave transmission lines.

Forrest and Seeds [1] have shown that optical injection locking of IMPATT oscillators should be possible. A large-signal theory of an IMPATT diode under the influence of intensity modulated light has been developed and a locking bandwidth of about 0.5 percent at X-band has been predicted but experimental results are still lacking. Optical injection locking of bipolar transistor oscillators at 1.8 GHz has been realized by Yen and Barnoski [2]. Recently, Sallas and Forrest [3] have demonstrated optical injection locking of GaAs MESFET oscillators at 2.35 GHz. With an optical power of about 1 mW, a locking bandwidth of 0.2 percent has been achieved.

In the following, the optical locking behavior of UHF-MSM-BARITT oscillators is investigated. To determine the locking bandwidth, the simple lumped model of BARITT oscillators as shown in Fig. 1 with the small-signal admittance $Y_p$ of the BARITT device, the load admittance $Y_L$, and the ac locking current source $I_{ph}$ is used. The hole- or electron-locking current $I_{ph}$ is generated by illuminating one of the Schottky contacts with intensity modulated laser light (see inset in Fig. 2). Using the Adler criterion [4], one obtains a linear dependence of $\Delta \omega$ on $I_{ph}$ according to

$$\Delta \omega = \frac{\omega_e |I_{ph}|}{Q_L \left( R G_L P_{HF} \right)^{1/2}}$$

where $\omega_e$ is the oscillator frequency, $Q_L$ the loaded $Q$ factor of the oscillator, $G_L$ the load admittance, and $P_{HF}$ the microwave output power of the oscillator. Assuming optical generation of carriers within surface layers only, it is easy to show that the photocurrent is approximately given by [5]

$$|I_{ph}| = \frac{q \eta \rho \lambda}{h_c} \left[ \sin^2(\omega_p \tau) + \left( \frac{\cos(\omega_p \tau) - 1}{\omega_p \tau} \right)^2 \right]^{1/2}$$

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There is reasonable agreement between measurement and theory. In the higher microwave range, it is recommended to use light modulated by a subharmonic of the oscillator frequency as the optical injection signal because, at present, it might be difficult to modulate laser light using high microwave frequencies.

REFERENCES


where \( \omega_m \) denotes the modulation frequency of the optical signal, \( \tau \) the transit time of the optically injected holes or electrons, respectively, \( P \) the total sideband power of the modulated optical signal, \( \lambda \) the vacuum wavelength of the light, and \( \eta \) a correction factor taking into account the quantum efficiency and the losses due to reflection at and absorption in the metallic contact. If neither the velocity of holes nor the velocity of electrons is saturated within the BARITT device, the transit time \( \tau_e \) of electrons is shorter than the transit time \( \tau_h \) of holes, hence the locking bandwidth in case of optical electron injection should be larger than in case of optical hole injection.

In the locking characteristics of Fig. 2, experimental and theoretical results are compared for optical hole and electron injection. As can be seen, the measured locking bandwidth increases linearly with optical power, and the locking bandwidth in case of electron injection is much larger than in the case of hole injection, as predicted by theory. Intensity modulated laser light \( (\lambda = 633 \text{ nm}) \) was used as the optical locking signal. The loaded \( Q \) factor was measured with conventional electronic injection locking. The theoretical characteristics were calculated using the measured oscillator and circuit parameters, the numerically calculated small-signal admittance \( Y_0 \), and the transit times \( \tau_e \) and \( \tau_h \).

As a result, the simple theory offers reasonable correlation as compared with the experimental results. However, the measured locking bandwidths are approximately 50 percent larger than the calculated bandwidths. This may be traced back to the fact that the simple theory does not allow for an optical modulation of the device admittance \( Y_0 \) and its influence upon the locking characteristics. The locking bandwidth of about 0.6 percent as obtained with BARITT oscillators is similar to the bandwidths predicted for IMPATT oscillators [1] and for transistor oscillators [2], [3]. Experimentally, it has been shown that optical injection locking of BARITT oscillators is possible. A locking bandwidth of 0.6 percent is obtained which may be viewed as a useful value.