An X-Band LSA Amplifier

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Abstract—**Linear reflection gain has been observed from a GaAs diode oscillating in the LSA mode with gain occurring at a frequency not harmonically related to the fundamental oscillation frequency. The characteristics of the amplifier are presented together with measurements of the circuit load as seen by the device. The mechanism of operation is also discussed.**

I. Introduction

THE INVESTIGATIONS described in this paper arose from the observation of simultaneous oscillations at two unrelated frequencies produced by an LSA relaxation oscillator in which the normal large-amplitude oscillation characteristic of the LSA mode was present together with a second low-amplitude oscillation at a higher frequency.

Preliminary investigations have been successfully carried out in which the higher frequency (thought nonessential for space-charge control) was suppressed and the circuit then used as a negative-resistance amplifier at the frequency of the suppressed component of oscillation. The circuit consists of a thick iris in X-band waveguide [Fig. 1(a)] similar to that used by Jeppesen and Jeppsson [1] and gains of between 14 and 26 dB have been observed at a frequency of $\simeq$9.5 GHz with the oscillator continuing to oscillate at its original frequency of 4.15 GHz. No detailed noise measurements have been made in the circuit so far.

II. Microwave Circuit

The 5-Ω diode chip (supplied by Cayuga Associates Inc.) has an active length of 10^{-4} m with a free-carrier density of 1.6×10^{21} m^{-3}, and for handling convenience the diodes are encapsulated in S4 varactor packages. To obviate heat-sinking problems the devices are pulsed using pulse lengths of between 50 and 350 ns at a duty cycle of about 0.001 percent.

The complete circuit is seen in Fig. 1(b). Coupling into the iris from the waveguide is provided by the double-step $\lambda/4$ transformer. The variable impedance probe and X-band short circuit provide oscillator tuning and also input coupling for the injected signal. The filter in arm 3 of Fig. 1(b) is incorporated to separate the main oscillation output from the reflected incident signal when they differ in frequency.

A Operation as an Oscillator

The oscillator operating in the LSA relation mode as discussed by Jeppesen and Jeppsson [1] is identified from the device length, compared to the frequency of operation, circuit considerations, and the characteristic relation between the oscillation period and the bias voltage. Stable operation can be obtained over the frequency range 3.5–5.0 GHz by appropriate bias-voltage tuning.

Fields at the fundamental are confined to the vicinity of the iris and this presents an inductive impedance to the diode. Higher harmonics propagate into the waveguide producing some 4–8 W of pulsed power, predominantly second harmonic, with a corresponding efficiency of between 2 and 4 percent.

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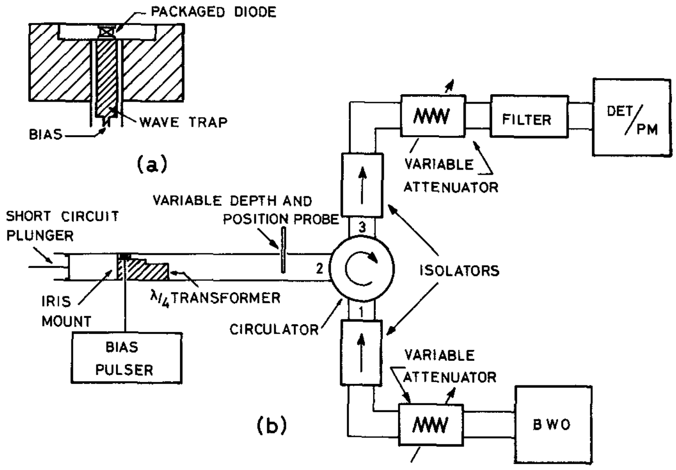

Fig. 1. (a) X-band iris. (b) Complete waveguide circuit.

B. Operation as a Reflection Amplifier

With the oscillator operating stably at 4.15 GHz the frequency components propagating in the waveguide were found to be predominantly second harmonic, a little third harmonic, and an additional output at 9.476 GHz. The waveguide tuning elements were adjusted to tune out harmonic components above second and minimize the 9.476-GHz oscillation. The filter was set to attenuate all frequency components up to and including the second harmonic.

Reflection-gain conditions were found to exist at 9.476 GHz, the frequency of the suppressed oscillation. Fig. 2(a) shows the gain as a function of input power with the bias optimized for stable operation with a maximum input level of 30 mW, which is the maximum available with present equipment. The gain is reasonably constant at almost 15 dB. Fig. 2(b) shows the gain versus power for several incident power ranges optimized by the bias for stable operation at each power range. It is seen that at the low input power levels, corresponding to slightly higher bias voltage, a gain of at least 26 dB can be achieved. The bandwidth over which the circuit provides reflection gain is approximately 25 MHz to the 3-dB point on either side of the center frequency of 9.476 GHz. There is no indication that either the second-harmonic or the fundamental power levels change when the device operates simultaneously as an oscillator–amplifier. However, it is evident that the bias voltage increases slightly as a result of the applied signal.

III. Diode Load Admittance Analysis

A method due to Griffin [2] was used to determine the load presented to the diode at the fundamental, second-harmonic, and gain frequencies. The diode is removed and replaced by a coaxial adaptor consisting of a modified omni

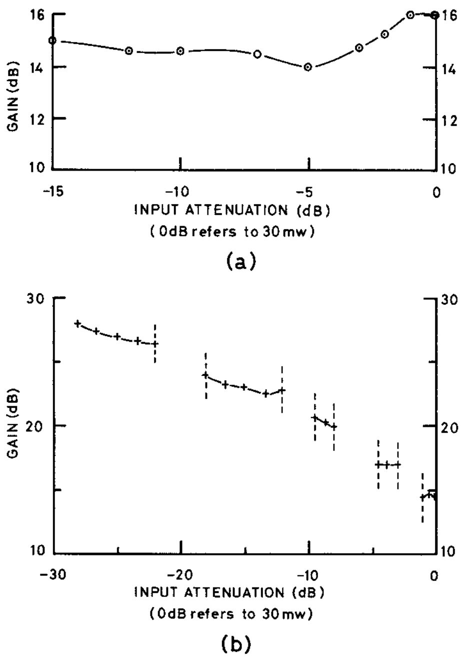

Fig. 2. (a) Gain versus input with bias optimized for stable operation at 30-mW input. (b) Gain versus input power with bias optimized for several ranges of input power.

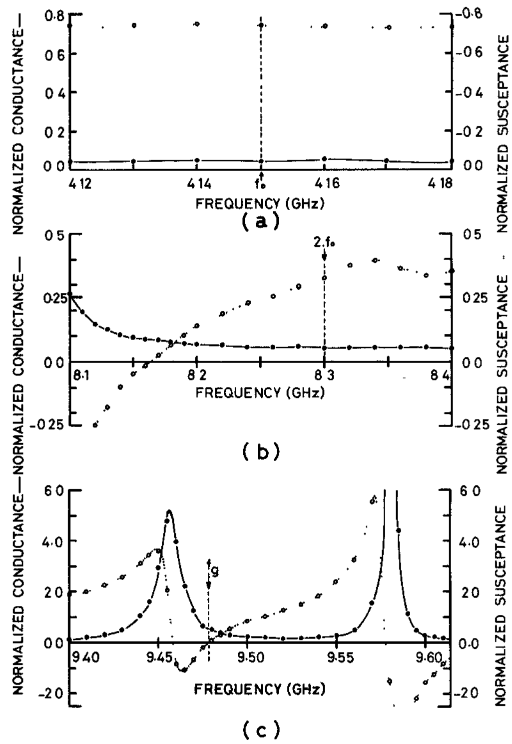

Fig. 3. Circuit admittance seen from the diode versus frequency normalized to 0.02 mho. (a) Fundamental frequency. (b) Second-harmonic frequency. (c) Gain frequency.

spectra miniature (OSM) socket. The adaptor forms the termination of a 50-Ω line and the resultant terminal admittance measured using a coaxial slotted line is related directly to the admittance seen by the diode. To determine the transformation between the measured admittance and the true load admittance, the adaptor can be calibrated by using it with known admittance radial cavities. However, since the dimensions of the adaptor are small compared with the wavelength, a 1:1 transformation was assumed between the measured and required admittances. The measured admittances were then transformed through the package using the Owens [3] equivalent circuit for the S4 encapsulation and allowance made for the self-capacitance of the diode. The subsequent admittance is thus the admittance presented directly across the diode negative conductance. The results of this admittance are shown as a function of frequency in Fig. 3(a)–(c).

At the fundamental frequency of 4.15 GHz the results confirm that the admittance across the negative conductance is inductive and agrees very closely with the calculated effective inductance of the iris. Since there is no coupling to the output at the fundamental frequency the very small but nonzero conductance must indicate some loss in the iris or bias circuit.

At the second-harmonic frequency the measured circuit admittance referred through the package is still inductive, but when the diode capacitance is allowed for, the susceptance across the diode negative conductance is capacitive, as indicated in Fig. 3(b).

Fig. 3(c), showing the admittance around the gain frequency, is complex in form but may be explained in fairly simple terms. In auxiliary experiments, in which the short-circuit plunger was replaced by a matched load, it was clear that the series resonance at 9.46 GHz is a series resonance in the iris–probe cavity. Similarly, the series resonance at 9.58 GHz is formed by the iris–short-circuit section. The parallel resonance at 9.476 GHz is the coupled resonance formed by the two aforementioned series resonances and this is precisely the frequency at which the gain occurs. It is seen that the loading on the diode is only 20 times the diode cold resistance and it is this very heavy loading that has suppressed the original oscillation at 9.476 GHz.

Measurements made in waveguide arm 2 [Fig. 1(b)] of the input reflection coefficient of the amplifier circuit, with the diode not biased, show that it is only around 9.476 GHz that the input signal is reasonably well matched into the diode circuit. $|\rho|$ increases to $1/\sqrt{5}$ at 25 MHz on either side of $|\rho| \simeq 0$.

IV. Discussion of Operation

The extremely narrow bandwidth of operation is consistent with the narrow frequency range over which the circuit is matched to the input signal. The frequency at which gain occurs is determined by the longitudinal position of the probe. However, when the probe was moved longitudinally this also changed the second-harmonic conditions and led to unstable operation. Consequently, the tuning range was restricted to ± 20 MHz.

Parametric effects were considered as possibly being responsible for the observed gain. It is interesting that the lower sideband frequencies (9.476–4.15) GHz and (9.476–8.3) GHz have recently been detected by a loop coupling into the iris but no evidence of any circuit resonances has been found at these frequencies.

As mentioned previously, the original oscillator delivered some power at about 9.476 GHz even with no input signal. Clearly, the circuit is able to oscillate with a large field swing at 4.15 GHz and simultaneously at 9.476 GHz with a much smaller amplitude. Asynchronous oscillations of this type have been reported by several authors. Schaffner [4] states that asynchronous oscillations are not self-starting, and Reich [5] concludes that asynchronous oscillations, in general, are not stable. However, Hoffins and Ishii [6] have reported simultaneous asynchronous self-oscillations in waveguide-mounted tunnel-diode oscillators, and they attribute the operation to the frequency-dependent load similar to that in these experiments. When the circuit was to be used as an amplifier the self-oscillation at 9.476 GHz was virtually suppressed by suitable circuit tuning to increase the load conductance to the large value 0.01 mho already quoted. The circuit can then be used as a negative-resistance reflection amplifier at the appropriate frequency. In practice there still remained a little self-oscillation, of peak value less than 3 mW, occurring at the beginning and end of the bias pulse, but this is very small compared with the output amplified signals.

V. Conclusions

It has been shown that an LSA oscillator can oscillate at two apparently unrelated frequencies, the output at the lower frequency being dominant. The smaller output can be suppressed by overloading with a suitably large conductance and the circuit can then be used as a negative-resistance amplifier at the appropriate frequency. The operation is very narrow band, but with the somewhat limited input powers used to date the gain is constant. Similar results have been obtained from two waveguide circuits with different diodes. Work is continuing in order to develop a modified circuit which it is hoped will produce broader bandwidth operation.

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