HIGH POWER V-BAND DOUBLE DRIFT IMPATT AMPLIFIER

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ABSTRACT

A 490 mW circulator-coupled IMPATT reflection amplifier with 6.9 dB gain at 59.25 GHz and 1.9 GHz bandwidth for 1 dB rolloff has been developed using double-drift IMPATT diodes on diamond in a novel circuit designed to minimize subharmonic instabilities.

Introduction

Although the potential for efficient millimeter wave power generation using double-drift silicon IMPATT diodes has been demonstrated in the oscillator mode,[1,2,3] little work has been reported on the operation of these devices as stable reflection amplifiers in the millimeter frequency range. Single drift IMPATT amplifiers have been developed for operation in the 60 GHz range with a reported output power of slightly greater than 300 mW.[4] Based on the inherent superior power generation capability of double-drift devices, at least double the output power can be anticipated for double-drift amplifiers in the same frequency range.

The object of this paper is to discuss the problems encountered and the results achieved in the development of a small-signal stable double-drift IMPATT amplifier for operation in the 60 GHz range. Multi-epitaxially grown silicon double-drift IMPATT devices with a symmetrical flat doping profile having a breakdown voltage at low current of 21 volts were used. The diodes were thermo-compression bonded to a diamond heat sink and assembled in a miniature quartz ring package which is capable of being hermetically sealed. As oscillators, the diodes were typically capable of 700 - 800 mW output power and 6% conversion efficiency in the 60 - 65 GHz range. The basic circuit configuration used for the amplifier was a reduced height rectangular waveguide with a coupling post that extends through the waveguide into a short coaxial section which is terminated by the diode. A special coaxial bias circuit was developed to help stabilize the amplifier. With this circuit, a circulator-coupled amplifier has been constructed with 490 mW output and 6.9 dB gain at 59.25 GHz; the 1 dB bandwidth was 1.9 GHz.

Circuit Design Considerations

A major part of the overall design problem for development of a small-signal stable IMPATT reflection amplifier is the elimination of instabilities. The first priority is to design a package and circuit configuration which will prevent spontaneous oscillation from occurring while also providing the desired small-signal gain characteristic. Since the IMPATT diode possesses a very wideband negative resistance characteristic, eliminating oscillations completely is difficult, particularly at millimeter frequencies. If a circuit resonance exists near the desired amplifier frequency band, spontaneous oscillation is very likely to occur. Therefore the IMPATT package was designed to remove the package shunt resonance as far as possible from the desired amplifier passband. To increase the resistive loading outside the amplifier passband, a relatively narrowband bias line filter choke with a lossy termination behind it was used in the amplifier design. A sketch of the first design is shown in Figure 1. The

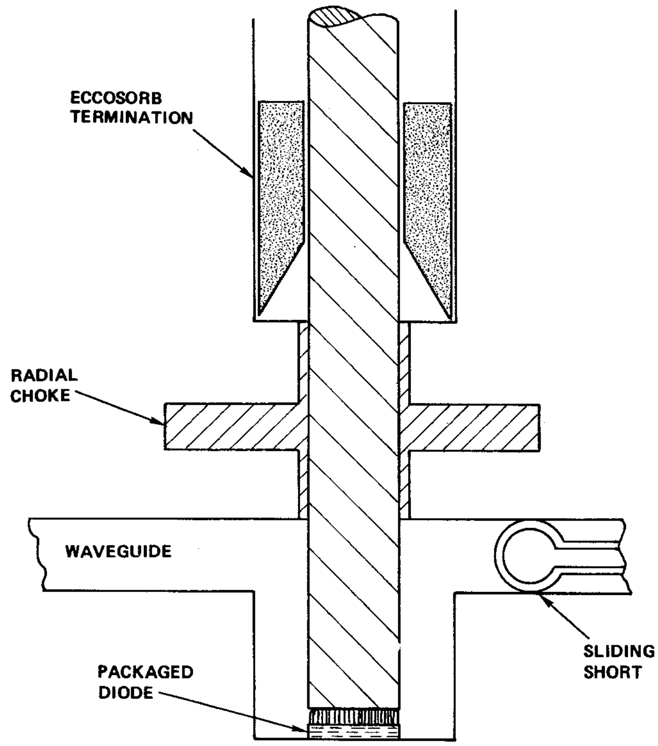

Figure 1 Amplifier Circuit with Radial Bias Line Choke.

Eccosorb termination provides some loading through the bias line for frequencies outside the stop band of the radial choke.

Since the package shunt resonance frequency is far above the desired amplifier passband, the impedance transformation from the device chip to the package terminals has a very small influence on the series equivalent negative resistance. A large transformation is required to properly match the package level negative resistance to the waveguide load for the desired reflection gain. Referring to Figure 1, the short coaxial section between the diode and the waveguide coupling region is designed to provide the required transformation. The waveguide tuning short is still required to provide the necessary fine tuning to achieve small-signal stability with the desired gain. The short position is approximately a quarter wavelength away from the coupling post at the fundamental frequency of operation. With the short in this position, the circuit impedance at the coaxial entry to the waveguide is relatively high allowing a transformation to a

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low load impedance at the diode package using a coaxial transformer with a moderate value characteristic impedance.

It also has been found that careful short positioning is necessary to suppress oscillation at frequencies above the amplifier passband which can easily occur due to the package shunt resonance. At the package shunt resonance, the diode chip negative resistance is transformed to a much higher value at the package terminals. This occurs because the package acts as a narrowband impedance inverter. With the short positioned properly, a counteracting circuit resonance occurs which properly loads the packaged IMPATT to prevent oscillation. This requirement on short tuning limits the amount of adjustment in gain and center frequency tuning which can be accomplished.

Although small-signal stability and gain at the desired frequency can be achieved using the configuration of Figure 1, large-signal instabilities can occur which will limit the power capability of the amplifier. A large-signal instability can result from a low frequency rf induced negative resistance which results from rectification in the IMPATT diode.[5] This type of instability results in low frequency oscillations or very noisy behavior generally accompanied by relaxation-type oscillations. Another large-signal instability, which is more troublesome at millimeter frequencies, results from the parametrically-induced negative resistance due to pumping of the nonlinear avalanche inductance of the IMPATT device.[6] The effect, if not suppressed, results in early power saturation and noisy operation when the amplifier is driven to the threshold for instability.

The low frequency instability problem can generally be solved in a straight forward manner by properly loading through the bias circuit. A high impedance load is required in the low frequency range to prevent instability. A high impedance must be maintained up to the upper cutoff frequency beyond which the induced negative resistance vanishes. By designing the rf choke to have a very low capacitance and providing a high impedance load outside the choke, a sufficiently high impedance can be maintained to several GHz. This stabilizing circuit is adequate for properly designed diodes in rf circuits which provide proper rf matching. The stability problems associated with parametric effects are much more troublesome in millimeter IMPATT amplifiers because the induced negative resistance also occurs in the millimeter frequency range, most predominantly near half the fundamental or "pump" frequency. A small inductive load impedance is usually desired to prevent instability in this subharmonic range. This loading must be provided without distrubing the fundamental matching.

Experimental Results

Although small-signal stability can be achieved with the circuit configuration of Figure 1, the dynamic characteristics of the amplifiers generally exhibit peculiar behavior. An example of this behavior is illustrated in Figure 2. The power output is plotted as a function of power input for an amplifier being driven at 62 GHz. Up to a drive level of 10 mW, the amplifier behaves in the expected manner with a smooth dynamic curve. Beyond this drive level, abrupt changes are seen in power output as a function of power input. The origin of this behavior has been determined to be a power robbing large-signal instability occurring near half the fundamental frequency of amplification. The presence of this instability is not apparent from measurements at the waveguide output because the frequencies involved are below cutoff. The instability was detected by probing the bias line with a spectrum analyzer. The radial line choke passes frequencies

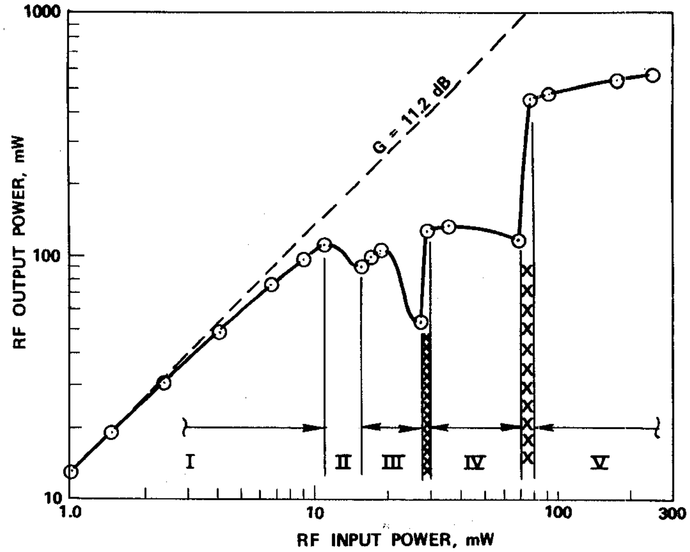

Figure 2 Dynamic Characteristic of a High Power Double-Drift IMPATT Amplifier at 62 GHz Constructed in the Circuit of Figure 1.

through the subharmonic frequency range fairly well. The lossy termination behind it attenuates the signal greatly, but oscillations could still be detected.

The five regions into which the dynamic curve of Figure 2 is divided correspond to changes in the spectral output seen in the bias line. In region I, the device behaves in the classical manner for a negative resistance amplifier. No spurious output or subharmonic signals are observed, and the gain saturates smoothly as the power increases. In region II, the power saturates abruptly and a subharmonic signal at exactly half the drive frequency can be observed in the bias line. The amplitude of the 31 GHz signal increases with increasing RF drive level at the expense of 62 GHz RF output. In region III, bias line signals at 26 and 36 GHz also appear accompanied by 5 and 10 GHz mixing products. The exact frequencies of the parametric signals are a function of drive level, but the sum of the two frequencies is always equal to the drive frequency of 62 GHz. In region IV, the noise level increases dramatically and no coherent signal is discernible. In region V the noise level drops and only the 31 GHz signal is observed. The power level of this subharmonic signal is 10 dB larger than for regions II and III.

Using frequency scaling, impedance measurements have been made on a model of the amplifier circuit to better understand the cause of the instability. The circuit impedance presented to the diode package terminals in the equivalent frequency range 20 to 110 GHz was measured. Two resonances occur in the subharmonic range; one near 26 GHz and another near 36 GHz. At these points the impedance is very large so the parallel equivalent admittance is small which will allow subharmonic oscillations to build up. In general, the parametric oscillation is more likely to occur near the half frequency of the fundamental (pump frequency) which is 62 GHz. The oscillations tend to built up where the circuit resistance is high and the circuit reactance is changing rapidly. It is interesting to note that the observed parametric signals leaked through the bias line were either at 31 GHz or at 26 and 36 GHz.

The origin of the 26 GHz circuit resonance has been traced to the resonance which occurs at waveguide cutoff. The second resonance at 36 GHz was traced to the radial line choke in the bias line. The resonance associated with the waveguide cutoff is a fundamental characteristic of any waveguide circuit and is difficult to remove. The most desirable approach would be to provide a shunt element near the diode to short out the resonance. Attempts at doing this have not as yet been successful. Another approach is to provide a series tuning element in the bias line which can be adjusted to achieve at least conditional stability (device and circuit reactances do not cancel for any potentially unstable frequency). A circuit for doing this is shown in Figure 3. The radial choke is replaced by a quarter wavelength long dielectric spacer which helps to prevent rf leakage at the fundamental but passes the subharmonic. A lossy mismatch is tuned to suppress the subharmonic instability. Using this circuit, amplifiers with a well behaved dynamic characteristic over a broad bandwidth up to power levels above 600 mW have been constructed when mounted on a broadband directional coupler. A circulator-coupled amplifier with the bandpass characteristics shown in Figure 4 has been developed using this circuit. The amplifier is stable up to a drive level of 100 mW. Beyond this level, power robbing instabilities occur at some frequencies as indicated by the dotted curve. At 58.5 GHz, the dynamic characteristic remains smooth up to a power level of 576 mW with a 5.8 dB gain.

Conclusion

As a result of the work reported here, the state-of-art power level achieved in the 60 GHz range by a small-signal stable circulator-coupled reflection amplifier has been doubled. This performance was achieved by using double-drift silicon IMPATTs mounted on diamond in a circuit which minimizes the occurance of large-signal instability. Although these results represent a significant advancement in IMPATT amplifier power capability in this frequency range, realization of the full potential of the device is still prevented by the onset of subharmonic instabilities. Further work, aimed at properly loading the IMPATT closer to the chip, will be required before the full power capability of the device is realized in a stable amplifier.

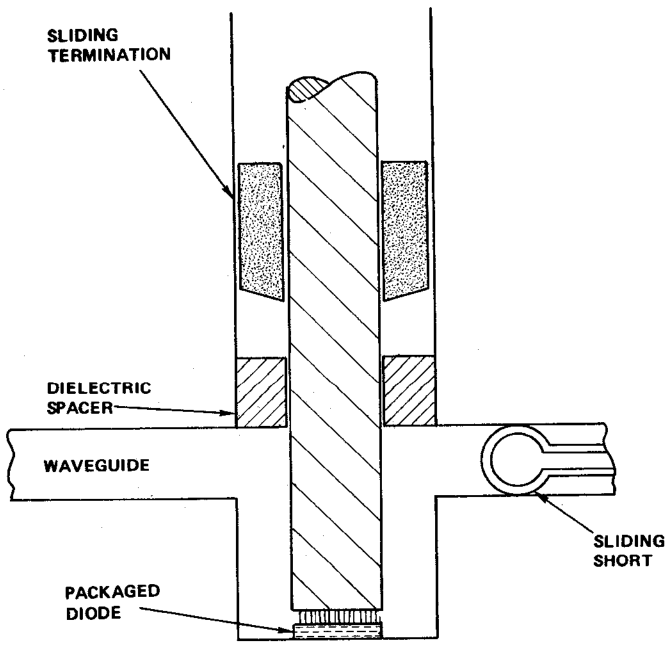

Figure 3 Amplifier Circuit with Tunable Bias Line Termination Behind Dielectric Spacer.

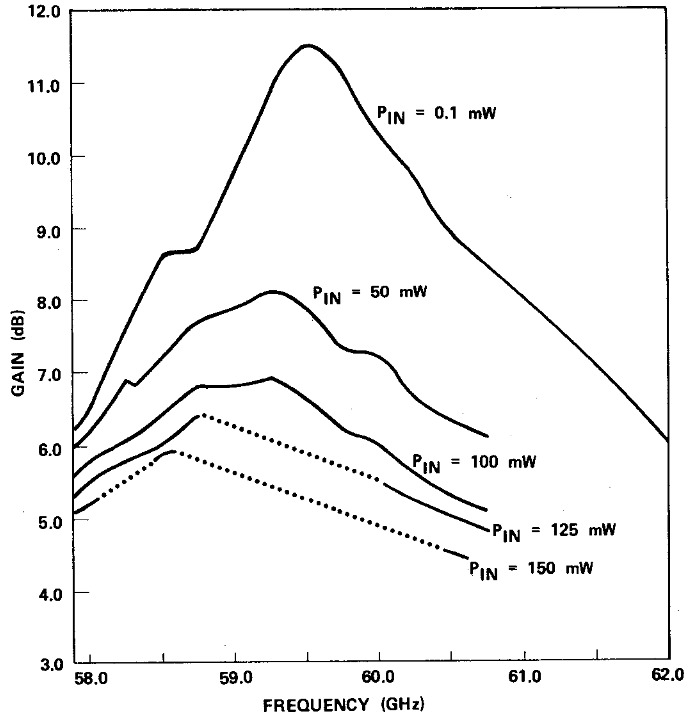

Figure 4 Small and Large Signal Bandpass Characteristics for Circulator Coupled Amplifier Constructed in Circuit of Figure 3. The dc Bias Requirements are 475 mA Current at 27.95 volts. The measured diode thermal Resistance is 18.6°C/W.

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