WIDEBAND, HIGH GAIN, DUAL DIODE GUNN AMPLIFIER CIRCUITS*

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Abstract

Design and performance of wide band, low noise, single stage 10 dB gain Gunn amplifiers in X, Ku and K-band are described. Novel dual diode circuits have been utilized to achieve nearly full band gain with two series connected cathode notch Gunn diodes. Average gains of 9.3 to 11.2 dB have been obtained over 90% of X and Ku-band and 75% of K-band. Noise figures are 15.5 to 18.9 dB.

Introduction

In recent years, single stage Gunn effect amplifiers with 6 to 8 dB gain have been built with waveguide bandwidths (40%) at frequencies ranging from 4 to 26 GHz [1-3]. These amplifiers utilize flat profile ohmic contact diodes. Higher stage gains of 8-10 dB have been reported over reduced bandwidths [4,5]. A comparatively low single stage gain of 6 dB average has been demonstrated from 7 to 10 GHz, employing a cathode notch device [6].

This paper describes the development of dual diode GaAs Gunn effect reflection amplifiers, utilizing two series connected cathode notch diodes.

The objective is to obtain 10 dB full band, low noise gain with a single stage, one circulator amplifier in the X, Ku and K-bands. These individually stable, 10 dB gain "blocks" are intended to be used in the design of high gain, long life, multistage, TWT replacement amplifiers. The dual diode approach minimizes the number of stages in the interest of small size and low cost.

Basic Electrical Design

Each of the amplifier modules consists of a dual diode microstrip amplifier circuit connected to a coaxial (stripline) ferrite circulator and a DC voltage regulator. In order to achieve low noise figures, four layer n-type GaAs Gunn devices with impurity profiles containing a doping notch at the cathode are used [7]. In general, cathode notch diodes have lower negative resistance, higher negative Q and therefore smaller gain-bandwidth products than flat doping profile devices. This is due to a large fraction of the active layer being biased high above threshold in a region of low negative mobility where favorable D/μ ratios can be obtained. In X-band, a series resonated notch diode in a 3 mm test circuit exhibits a negative Q of 5.9. Therefore, even in a three resonantor circuit, a maximum gain of 6 dB across full band can theoretically be obtained. A similar situation prevails in Ku and K-band, and for this reason, a dual diode circuit is used to achieve 10 dB gain across the band.

The dual diode circuit consists of four resonators which are arranged in the classical series-shunt configuration. The two series resonators are active and are formed by the series resonated Gunn diodes. The two shunt resonators are passive and are used for broadbanding (See Figure 1). An impedance transformer is used to obtain the desired gain level. Since no generalized synthesis technique exists for the design of a reflection amplifier containing two active devices, computer analysis and optimization is used for the determination of the susceptance slopes of the shunt resonators and the ratio of the impedance transformer.

X and Ku-Band Amplifiers

X-band. The photograph in Figure 2 shows the X-band configuration. The shunt diode is mounted at the end of a 0.025 inch thick alumina microstrip circuit. A bond wire acting as the resonating inductance is connected to the first of the two shunt resonators. These resonators are realized as half wave open circuited shunt stubs. The second (series) diode is bonded to a small 0.010 inch thick thermally conductive beryllia standoff, which is soldered directly to the copper carrier through a hole in the substrate. By properly connecting its bond wires, this diode is operated in series with the shunt diode from an RF standpoint, but thermally and DC in parallel with it. The capacitive reactance of the standoff is incorporated in the first shunt resonator. In X-band, the driving and load impedance is at the convenient 50 ohm level, so that no impedance transformer is needed. The bias voltage, which is common to the two diodes, is applied via a four-section bandstop filter. The DC return for the series diode is provided by a similar filter structure.

The small signal gain and noise figure performance of the X-band amplifier is summarized in Table I. The amplifier covers the 8.4 to 12.4 GHz frequency range with 11.2 dB average gain and $\pm$ 2.2 dB ripple. The noise figure (circulator losses included) ranges from 15.5 to 16.5 dB over most of the band and reaches a maximum of 18.2 dB at the bandedges. This characteristic of minimum noise figure near the bandcenter and maximum noise figure at the bandedges is caused by two compounding effects. The first is that the intrinsic noise measure of the diode is a parabolic function of the operating frequency which has its minimum near the bandcenter. The second effect is due to ohmic losses in the passive resonators. At the bandedges, the circuit reactance slope is large and with a fixed Q, the losses increase proportionally. These increased losses degrade the noise measure.

Ku-Band. The Ku-band configuration is basically the same as the X-band configuration with the exception that 0.010 inch thick beryllia is used as the microstrip dielectric. This has the advantages of higher cutoff frequency in the microstrip medium,

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Additionally, the series diode can be bonded directly to the top metallization pattern, where it is well heat sunk. In Ku-band, the second shunt resonator (See Figure 1) is not used in accordance with the computer analysis. Initial results in Ku-band were obtained with two flat profile diodes. This configuration gave a gain of 9 $\pm$ 2.0 dB from 11.0 to 17.2 GHz. A three-step transformer from 50 to 28.5 ohms is utilized to achieve a small signal gain of 9.3 $\pm$ 2.0 dB from 12.5 to 17.6 GHz with two lower gain, low noise diodes. The noise figures range from 16.9 to 18.3 dB over the band (See Table I).

At 1 dB compressed, the output powers of the X and Ku-band amplifiers are between +5 and +10 dBm. The DC power requirements of the Gunn diodes (without regulator) are 11 V, 0.42 A in X-band and 8 V, 0.80 A in Ku-band. Noise figures are obtained utilizing automated instrumentation in X and Ku-bands where low noise balanced mixers are available. The gain variations in the amplifier responses are mainly caused by reflections at the amplifier/circulator interfaces.

K-Band Amplifier

The electrical design of the K-band dual diode amplifier circuit differs significantly from the X and Ku-band units, and is an extension of previously published work dealing with the design of single diode coaxial and microstrip circuits in K-band [3]. As in the case of these single diode circuits, the reactive part of the impedance of the two series connected diodes is inductive over the entire operating frequency range. The first shunt resonator is not used. Therefore, in order to achieve wideband operation, the second shunt resonator is capacitively tuned to compensate for the inductive reactance of the diodes. This capacitively tuned shunt-like resonator consists of a cascade of two sections of transmission line, approximately half wavelength long at centerband and a short section of low impedance line. An impedance transformer from 50.0 to 62.5 ohms is incorporated in the matching network.

The microstrip layout is given in Figure 3, which shows the elements of the matching network and the bias input and DC return filter structures. The positions of the active devices in the circuit are also shown. The shunt diode is mounted on the copper carrier and connected to the capacitive tuning pad closest to the edge of the substrate (0.010 inch beryllia) with two 0.005x0.001 inch gold ribbons. The cathode of the series diode is bonded to the second tuning pad (the short section of low impedance line mentioned above). Two gold bonding ribbons are used to connect the top (anode) of the series diode to the common DC bias input. The diode is grounded via the DC return at the output of the circuit. From computer calculations, it was determined that an unpackaged series chip was required to assure stability. Laboratory verification substantiated the necessity from an unpackaged series diode and therefore, a chip was used in the final design.

Utilizing two cathode notch diodes, a gain of 9.5 $\pm$ 2.0 dB from 18.1 to 24.1 GHz is achieved with noise figures of 16.5 to 18.9 dB over the operating frequency range. The gain roll-off at the high frequency end is due to a slightly long active layer length. The 1 dB compression point is greater than +5 dBm at the output with a diode bias voltage of 5.4 V and 0.75 A current.

Mechanical Design

The mechanical designs of the X, Ku and K-band amplifier modules are nearly identical. In all three bands, the microstrip fabrication was performed utilizing standard photoetching techniques. The microstrip circuit is mounted at the bottom of a split-block constructed channel of width equal to that of the substrate. The channel width has been chosen such that no waveguide modes can propagate in the channel in the frequency range of interest. The volume of the packaged dual diode amplifier, excluding the connector, baseplate and circulator is very small, ranging from 0.31 cu inch in K-band to 0.41 cu inch in X and Ku-band. In all three bands the amplifier-circulator combination is mounted on a baseplate which is partially hollowed out for the DC regulator. The RF connectors are SMA type. A photograph of the completed K-band unit is shown in Figure 4. The size of the baseplate is 2.4x1.6 inch.

Conclusions

The feasibility of full band, low noise, GaAs Gunn effect amplification in small size, single circulator, 10 dB gain modules has been demonstrated from 8 to 26 GHz. Dual diode circuits have been utilized to achieve nearly full band 10 dB nominal gain with two series connected cathode notch diodes. These dual diode circuits have been realized in a thin film microwave integrated circuit format. Average gains of 9.3 to 11.2 dB have been obtained over $\sim$ 90% of X and Ku-band and $\sim$ 75% of K-band. Noise figures are 15.5 to 18.9 dB. The calculated minimum dynamic range is $\sim$ 57 dB in X-band and $\sim$ 54 dB in Ku and K-band. The 1 dB compression points occur at output powers of approximately +5 dBm minimum.

Overall full band noise figures of 14 dB appear feasible through improved control of GaAs epitaxial crystal growth and doping profile optimization. Maximum gain variations of $\pm$ 1 dB at the 20 dB gain level can be expected with advanced circuit techniques employing amplifier/circulator integration.

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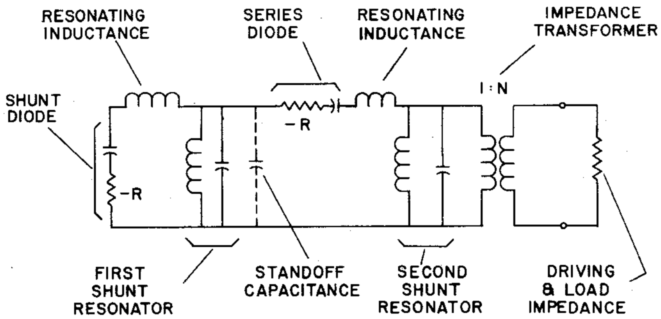

Figure 1 Equivalent Circuit of Idealized Dual Diode Gunn Amplifier

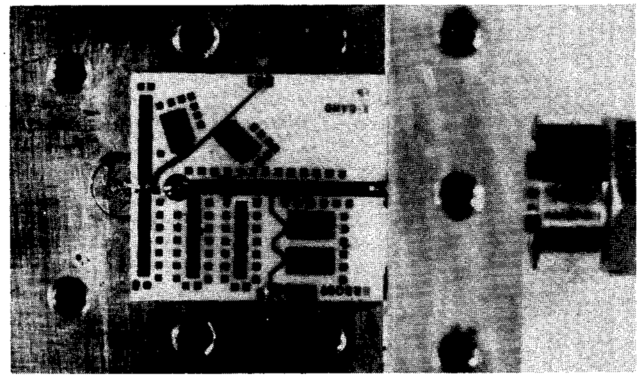

Figure 2 Photograph of X-Band Dual Diode Amplifier Circuit

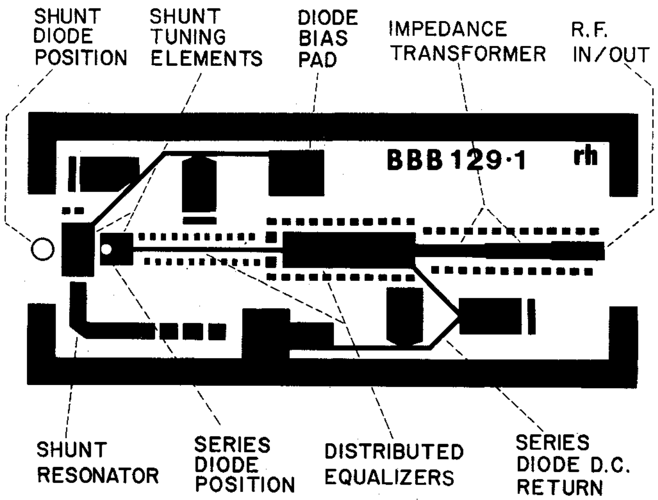

Figure 3 MIC-Layout of K-Band Dual Diode Amplifier

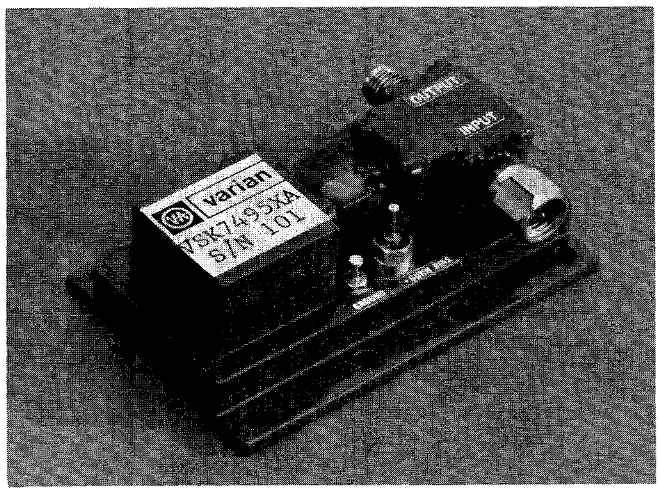

Figure 4 Photograph of Completed K-Band Amplifier Module

FREQUENCY BAND	FREQUENCY COVERAGE	AVERAGE SMALL SIGNAL GAIN	RIPPLE	NOISE FIGURE MIN	NOISE FIGURE MAX	NOMINAL OPERATING VOLTAGE	OPERATING CURRENT
	(GHz)	(dB)	(dB)	(dB)	(dB)	(V)	(A)
X	8.4 – 12.4	11.2	±2.2	15.5	18.2	+13	.41
Ku	12.5 – 17.6	9.3	±2.0	16.9	18.3	+11	.78
K	18.1 – 24.1	9.5	±2.0	16.5	18.9	+9	.75

Table I Performance Summary of X, Ku, and K-Band Amplifier Modules