LOW-NOISE THIN-FILM DOWNCONVERTERS FOR MILLIMETER SYSTEMS APPLICATIONS

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ABSTRACT

Millimeter wave downconverters intended for systems applications have been developed using thin film planar technology. The downconverters, operating with subharmonic-pumping, have achieved a total receiver noise figure as low as 5.7 dB SSB over an RF Bandwidth in excess of 20%. The converters are fixed-tuned, requiring no adjustments, and utilize improved planar Schottky barrier diodes which exhibit up to 3.5 THz zero bias cutoff frequencies. Although subharmonically pumped, the downconverters exhibit performance which in many respects is superior to conventional balanced mixers, and may provide a useful solution to cost effective systems requirements at millimeter wavelengths.

INTRODUCTION

A series of millimeter wave downconverters have been designed which are capable of low noise applications between 18 and 140 GHz. The converters, developed using low frequency model structures, have scaled to the 30-40 GHz frequency range, and more recently to the 80-100 GHz band. Although similar to previous circuits described by Schneider [1], these downconverters have been developed for broad bandwidth signal processing applications where mass-production is an important criteria. The following general guidelines were used in development of the designs:

1. The thin-film stripline medium is as thick as possible, while still allowing proper circuit operation. This facilitates mass production of the devices.

2. The downconverters will have no adjustable shorts or tuning plungers. All circuit matching elements will be photolithographically reproduced as part of the thin-film conductor pattern.

3. The downconverter would have a wide instantaneous bandwidth. The noise figure would be comparable to the best whiskered contact Schottky diode mixers. Additionally, IF frequencies between 100MHz and 10GHz should be accommodated with only small design variations.

4. The local oscillator drive requirement at the subharmonic frequency should not exceed +10dBm under optimum conditions.

5. The converter should be capable of being mass produced in large quantities for systems applications at a relatively low cost.

These goals were best met using a suspended substrate medium and a newly developed planar Schottky diode capable of considerably enhanced performance over previously available commercial diodes. Extensive use of computer design and low frequency models were used to optimize the approach to the embedding network and the full waveguide band waveguide to stripline transitions used in the design.

CIRCUIT DESCRIPTION

The suspended substrate circuit used in the converter is typically 50% thicker than substrates previously reported in the literature. As a result, the substrate channel used in the construction is relatively smaller, but provides a more reliable configuration for mass production. In order to assure wide-bandwidth performance, a waveguide to stripline transition was designed using computer aided analysis. This transition provides a full waveguide band coupling between the suspended stripline and the dominant mode waveguide used for the signal or local oscillator ports. No adjustable shorts or tuning plungers are used in this design. This transition supplies the input signal to the subharmonic diode pair which is placed in series with the millimeter-wave stripline.

One side of the diode pair is tied to a virtual circuit ground at the RF, LO, and simultaneously at the IF Frequency used in the converter. A bandstop filter, which separates the broadband LO input transition for the IF output is similar to a filter described by Schneider [2], but achieves a wide 30% stopbandwidth at the -60dB level. A photograph of two 30-40 GHz mixer substrates in Figure 1, illustrate the principle advantages of the device. Because of the frequency independence of the three ports, the RF, IF and LOSC embedding impedances are independently optimized with remarkable ease over broad operating bandwidths. This is primarily due to the wide RF to LO frequency separation occuring in a subharmonic downconverter. The thin-film circuit patterns are deposited and then electroplated on fused quartz using standard techniques.

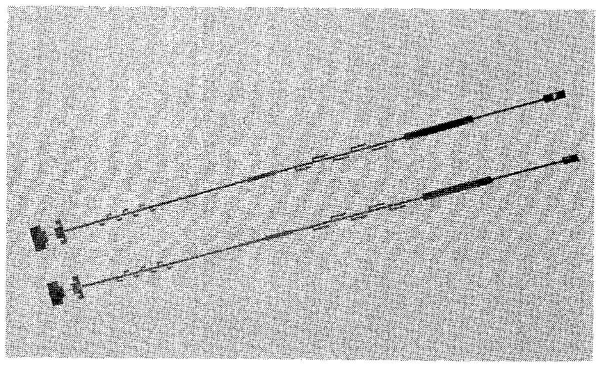

Figure 1 30-40 GHz suspended substrates the diodes are mounted on the left end of the substrate next to the multi-frequency circuit ground used to terminate all 3 ports of the embedding network. In this design a non-synchronous IF transformer at the opposite end of the substrate is used to match the 1-2 GHz IF output to better than 1.4:1 over the entire octave.

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In parallel with the development of the circuit for this downconverter, a new planar GaAs Schottky barrier diode was developed. The characteristics of these diodes varied in various experimental manufacturing runs from best results where a typical series resistance of 2.8 ohms, a total zero bias capacitance of 0.015pf and a breakdown voltage of 4.5 volts were observed. In the worst case, 0.045pFd and 2.2 ohms were observed in some of the diodes. Special consideration was given to reducing the overall device capacitance to a level comparable to the best whiskered diodes.

The actual zero bias junction capacitance in the best units measured is estimated to be less than 0.008pFd, with the overlay capacitance in this improved design adding the remainder of the observed total capacitance.

In Figure 2 we show a typical Alpha DMK6605A X Band Beam lead diode along side a planar millimeter wave diode for purposes of size comparison. As is evident the construction and overall size of the millimeter-wave diode is a sharp departure from previous planar diode technology.

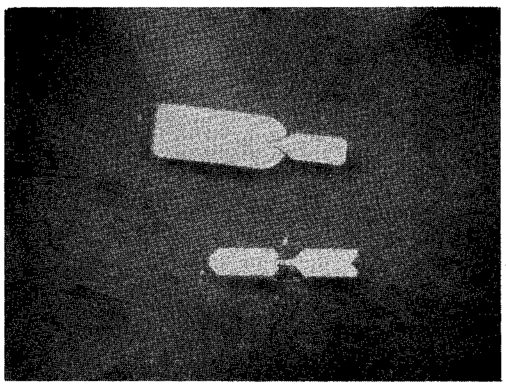

Figure 2 Alpha DMK6605A standard Beam Lead Diode photographed alongside experimental millimeter-wave planar device.

PERFORMANCE

In Figure 3, we illustrate the measured single sideband noise figure for two particular test models of the mixer. More than fifty mixer substrates, testing various design approaches and different test runs of the planar Schottky barrier diodes, were evaluated. Using the lowest capacitance diodes (C_t = 0.015-0.020pFd) in a broadband design, total receiver noise figure of 6dB SSB was obtained. This includes the 1.8dB contribution from the 1.5GHz IF amplifier.

In these experiments, the noise ratio, defined from the relation:

$$NR = 1 - F_{IF} + F_{SSB}/L_c$$

was measured to be the low value of NR = 0.6.

The typical conversion loss measured using isolated calibrated thermistor power meters at the RF and IF Frequencies was 5.2dB when converting to a 1.5GHz IF Frequency. It is felt that the low noise ratio measured here was primarily indicative of nearly perfect resistive mixing with only small parasitic parametric effects. This is probably a reasonable explanation, since the diodes used in these experiments had an extremely small capacitance swing, and in addition were designed to blend-in to the transmission medium. This was accomplished through the use of conical transformation elements which feed the diode junction. As a consequence, the series parasitic inductance in our design is virtually eliminated. In some experiments the conversion loss was seen to approach 3.9dB, but the noise ratio increased so as to keep the measured SSB Noise Figure fairly constant. These effects are still under investigation at this time.

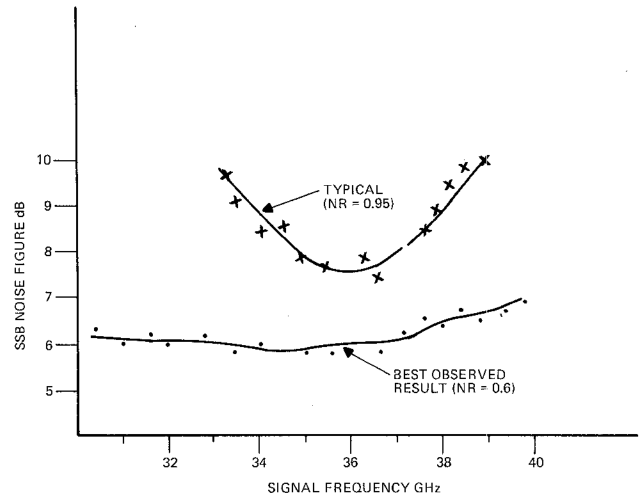

Figure 3 SSB Noise Figure including a 1.8dB IF noise contribution. The lower curve was obtained using diodes with ~0.02pFd total capacitance while the upper curve for a design still under development uses diodes with 0.035pFd total zero bias capacitance. Both mixers are double sideband mixers with no image enhancement or adjustable tuning plungers

Using diodes of somewhat lower cutoff frequency (C_t = 0.035pf Rs=2.9 ohms) we optimized our circuit for a 4 GHz RF band centered around 36 GHz. The preliminary results, as of the date of this writing, show a 7.5dB SSB noise figure in the band center including the IF Contribution. It is felt that further optimization will again result in a noise figure comparable to those results obtained with the lower C_t diodes cited above. Most optimization involves achievement of a broadband matching structure that exhibits the low noise ratio achieved in the earlier design while using a somewhat lower cutoff diode pair.

FURTHER PERFORMANCE DATA

The conversion loss and noise figure can be sustained over an octave IF bandwidth in this design, and both a 1-2 GHz and 4-8 GHz IF circuit have been evaluated. Spurious mixing products were at least 50dB below the IF output level over the entire IF passband. In particular, the "4x2" product, where the second harmonic of the RF signal mixes with the fourth harmonic of the subharmonic pump was measured. As can be seen from the data in Figure 4, the intercept point for the "4x2" product was +23dBm with a +6dBm local oscillator drive. The 1dB conversion compression point occurs at -2dBm in these 35 GHz measurements. Typically, 4 to 6mW of subharmonic LO drive are required for optimum noise figure using the planar diode and structure we have described.

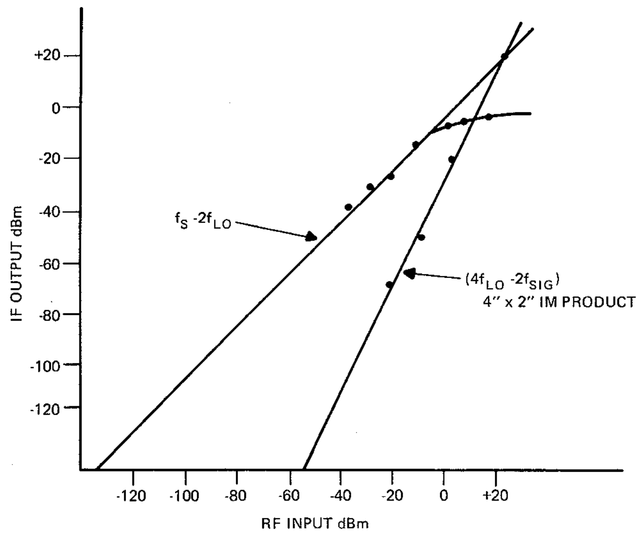

Figure 4 Fundamental and spurious mixing products obtained at 35 GHz with 1.5 GHz IF frequency. +6dB LO drive was used in these measurements.

Excellent pump to signal port isolation is achieved in this design, with the measured output at the signal port at the second harmonic of the pump frequency being 38 to 43 dB below the input power at the pump port. The LO to IF port isolation is greater than 60 dB for all LO frequencies. A photograph of the mixer laboratory prototype appears in Figure 5. It is made of aluminum in a split block construction which is easily mass produced.

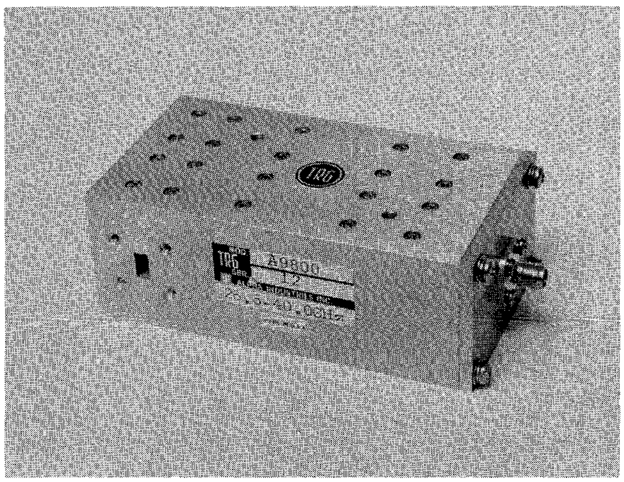

Figure 5 Ka Band Mixer Prototype. A split block construction in Aluminum is used in this design.

SYSTEMS CONSIDERATIONS

This type of mixer represents one approach to the achievement of low noise mass producible mixers for millimeter wave systems applications. Use of planar diodes makes this mixer uniquely suitable in severe shock and vibration environments. Additionally, elimination of the labor intensive step of whiskering the diode should lead to a reasonable cost effective solution for a system involving large quantities at a reasonable cost per piece. Since many different types of filters can be incorporated onto the suspended substrate, image enhanced, image reject, and true single sideband mixers with high IF frequencies can be accommodated with relative ease. Additionally, the use of a subharmonic local oscillator is particularly advantageous at the higher frequencies where it is more costly to obtain a low noise or phase locked oscillator source.

CONCLUSION

Subharmonically pumped mixers, using high quality GaAs planar Schottky diodes in suspended substrate media, are superior in performance to all other MIC mixer types, and are comparable or better (especially at high IF frequencies) to waveguide converters. The use of the low-loss suspended substrate media and a carefully designed diode embedding network can provide low-noise performance in a simple, reliable and broadband device.

These downconverters, when used in millimeter-wave systems applications will provide a large increase in state-of-the-art reliability over all other technologies currently employed. Image enhanced versions of this mixer with noise figures even lower than those obtained in this investigation will provide ultra-low noise wideband capability comparable to that obtained with some of the most sensitive cooled mixers presently in operation, but without the added complication of cooling.

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