A MONOLITHIC K_A-BAND SUB-HARMONICALLY PUMPED FREQUENCY CONVERTER +

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ABSTRACT

A GaAs monolithic Sub-harmonically Pumped (SHP) Ka-band frequency converter has been developed. The complete frequency converter Monolithic Millimeter-wave Integrated Circuit (MMIC), having six microwave ports, consists of an SP2T RF switch, LO buffer amplifier, anti-parallel diode mixer, 3-stage IF amplifier, and SP3T IF switch. To minimize circuit cost, the converter was fabricated with conventional MMIC material and processing. The frequency converter exhibited a conversion gain of 8 dB and a single sideband noise figure of 20 dB. This Integrated Circuit (IC) is the first demonstrated monolithic Ka-band SHP frequency converter and has a higher level of integration than previous MMIC SHP mixers. [1]

SHP K_A-BAND FREQUENCY CONVERTER

Introduction

The frequency converter MMIC was developed in conjunction with a Ka-band Low Noise Amplifier (LNA) MMIC, which are integrated together in a Ka-band frequency converter module. The frequency converter module and its MMIC components were designed to operate across medium RF, LO, and IF bandwidths so that the MMIC converter can replace narrowband hybrid converters in multiple systems, operating at different frequencies. To attain these bandwidths and minimize MMIC size and cost, frequency converter noise figure was sacrificed. The gain of the separate LNA is high enough to permit this.

The frequency converter MMIC downconverts Ka-band RF signals (30-36 GHz) to a C-band IF (3.5-6.0 GHz), using a Ku-band LO (13-15 GHz) such that $f_{IF} = f_{RF} - 2f_{LO}$. SHP mixers are desirable because they use lower frequency LO sources, which are more reliable, less expensive, and increase port-to-port isolation. Unlike a single diode, the anti-parallel diode pair used in the SHP mixer suppresses even order mixing products.[2] Thus the fundamental mixing product, $f_{RF} - f_{LO}$, is quenched eliminating an additional loss mechanism and interference source. An ideal SHP mixer, and its diodes' I-V curve are shown in Figure 1a and 1b. Frequency conversion in the mixer primarily results from the diode pairs' non-linear resistance represented by its I-V characteristics. Since the anti-parallel diode pair I-V curve is an odd function,

$$I(V) = \sum_{n=0}^{\infty} a_{2n+1} V^{2n+1}$$

only odd order mixing products are generated at the diode pairs' terminals.

Circuit Design

The frequency converter MMIC consists of a Ka-band RF SP2T switch, single stage Ku-band LO buffer amplifier, anti-parallel diode mixer, 3-stage C-band IF amplifier, and C-band SP3T IF switch (Figure 2). This IC has six microwave ports.

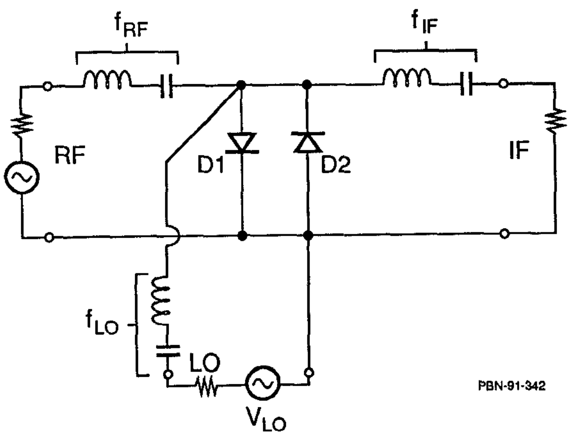

Figure 1a. Ideal Anti-parallel Diode Pair SHP Mixer [after Maas (ref. 3)].

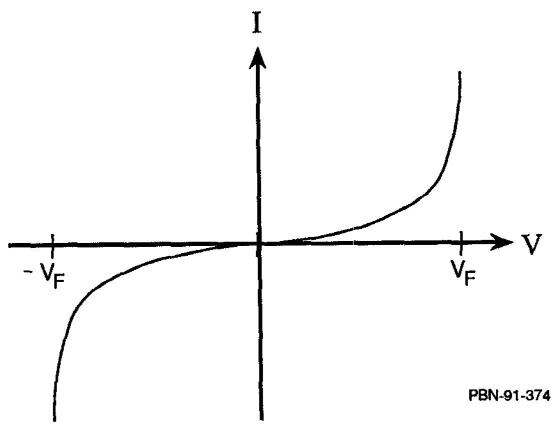

Figure 1b. Anti-parallel Diode Pair I-V Curve.

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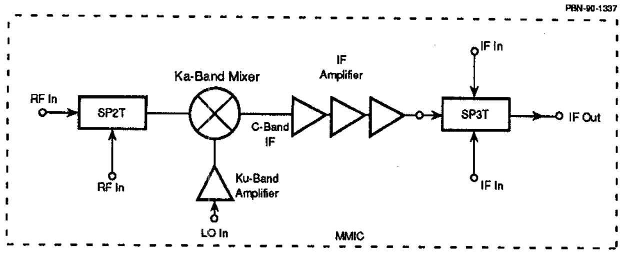

Figure 2. Ka-band SHP Frequency Converter Block Diagram.

The MMIC was designed with a combination of harmonic balance and linear Computer-aided Design (CAD) simulators.[3] A single ended anti-parallel diode pair mixer topology was chosen to eliminate the balanced mixer hybrid, reducing area and thus cost, but at the expense of circuit complexity. An individual Schottky diode periphery of 30 microns was chosen as a compromise between large RF bandwidth, favored by small periphery diodes, and low mixer conversion loss, favored by large periphery diodes.

The ideal circuit shown in Figure 1a is difficult to realize at millimeter-waves, particularly across more than narrow bandwidths. To obtain medium bandwidth performance, the mixer RF and IF terminals are connected to one diode pair node and the LO terminal is connected to the other node (Figure 3). At each terminal, an appropriate termination in three different frequency ranges must be provided.

Most challenging is the RF terminal filter which must present an optimum termination to the diodes in the RF band, high impedance in the IF band to reduce loading effects on the IF circuitry, and low impedance in the LO band enabling a LO signal return path through the diodes. This multiband frequency termination at the diode RF terminal was accomplished with a lumped element high pass filter with a series transmission line (Figure 4a). This structure is a compact and broader bandwidth alternative to much larger transmission line filters, reducing circuit area and cost, and increasing circuit bandwidth. Conversion efficiency is sacrificed with this topology though because the RF filter IF termination impedance is in parallel with and on the order of the IF load impedance (Figures 3 and 4b). Thus significant IF power is dissipated in the RF filter and not in the IF load.

The Ka- and C-band switches employ a distributed topology. The Ka-band switch uses transmission line transformers rather than series MESFETs, to isolate off state arms and reduce switch insertion loss. Lower converter noise figure is thus achieved. Alternatively, the C-band switch uses series MESFETs to isolate off state arms to improve port-to-port isolation.[4]

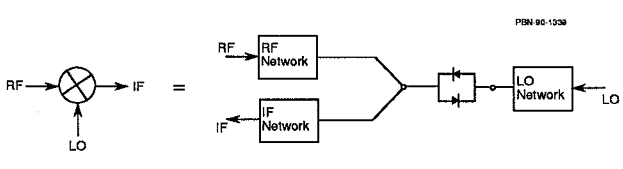

Figure 3. Ka-band SHP Mixer.

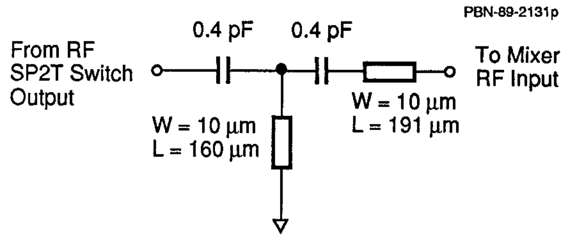

Figure 4a. RF Filter.

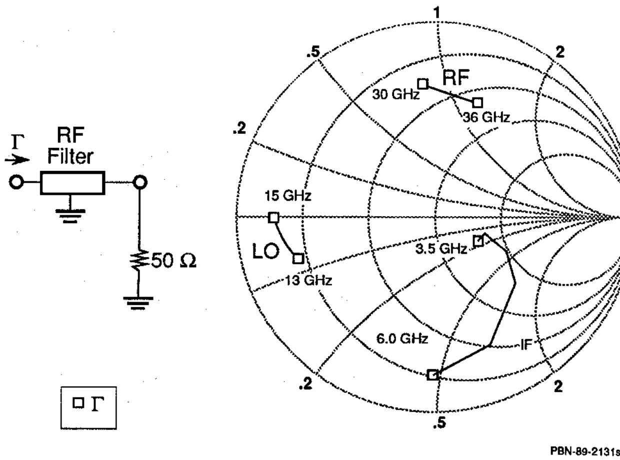

Figure 4b. RF Filter Impedance at Mixer RF Input Terminal.

The LO buffer amplifier provides up to 4 dB of gain in the Ku-band. The amplifier appropriately terminates the mixer LO terminal to enhance pumping efficiency. A resistor is placed in series with the gate of the amplifier's 300 micron MESFET to stabilize that device. The output of the amplifier includes a short circuited half-wave Ka-band shunt stub to provide the return path for the RF signal. The LO amplifier is biased at one half of the MESFET I_{dss}.

The three stage IF amplifier utilizes a feedback topology to obtain a 50% bandwidth and has a 22 dB gain and 8 dB noise figure. Each of the three feedback cells uses a 300 micron MESFET. The amplifier appropriately terminates the mixer IF terminal to enhance the IC's conversion gain. The input matching network of the IF amplifier includes a Ka-band quarter wave length transmission line followed by a radial stub which provides a low impedance in Ka-band. This network provides a high impedance in Ka-band at the input of the IF amplifier to reduce the loading effects of the IF circuitry on the RF circuitry. The IF amplifier is biased at the MESFET I_{dss}.

Fabrication

The frequency converter was fabricated at Raytheon's GaAs foundry, the Monolithic Microwave Center, on 2×10^{17} cm^{-3} ion implanted GaAs material (Figure 5). The IC dimensions are 235 by 116 by 4 $mils^3$. The diodes and MESFETs were processed concurrently with 0.5 micron length gates. Standard GaAs MMIC material and processing were used to minimize IC cost. The diodes have ideality factors of 1.2, zero bias junction capacitances of 1.28 pF/mm, and parasitic series resistances of

1.0 ohm*mm. The resulting diode cutoff frequency is 124 GHz, only four times larger than the RF, contributing to converter gain and noise figure degradation.[5] The MESFETs demonstrated saturation currents of 340 mA/mm, pinchoff voltages of -4.0 V, breakdown voltages of 13.5 V, and zero bias dc transconductances of 95 mS/mm.

Measured Performance

The frequency converter MMIC provides up to 8 dB conversion gain in its IF band, while requiring only -2 dBm LO pumping power (Figure 6 and 7). The converter exhibits a 15% RF bandwidth with a minimum of 27 dB RF to LO isolation and 50 dB RF to IF isolation (Figure 8). The converter also demonstrated a minimum of 50 dB LO to IF isolation, 7 dB LO to RF isolation, 20 dB noise figure, and 13 dBm third order intercept point in its operating bands (Figures 9 and 10).

Even order product suppression is demonstrated by second order intermodulation product measurements. Two RF signals, separated by a frequency in the IF band (e.g. 31 and 35 GHz), directly mix and create an undesired second order product, IM2, at the IF, such that $f_{IM2} = f_{RF1} - f_{RF2}$. The second order intercept of the frequency converter is greater than 37 dBm across the IF band (Table 1).

Table 1

Ka-band SHP Frequency Converter Second Order Intercept Point

IM2 Frequency (GHz)	IP2 (dBm)
4.0	47.4
5.0	37.8
5.5	49.3

Summary

The first Ka-band SHP frequency converter MMIC, using standard material and processing, has been successfully demonstrated. This highly integrated frequency converter IC exhibits excellent conversion gain and requires little LO pumping power.

Although the converter noise figure and LO to RF isolation are large and small, respectively, these parameters are not critical for module performance. The frequency converter

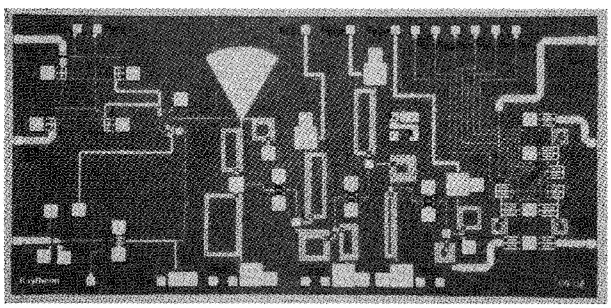

Figure 5. Photograph of a Ka-band SHP Frequency Converter MMIC.

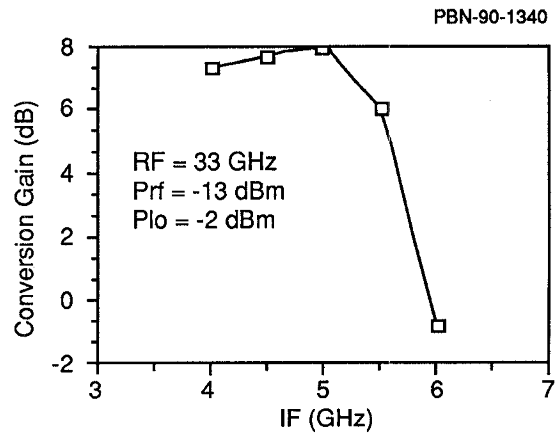

Figure 6. Ka-band SHP Frequency Converter Swept IF Conversion Gain.

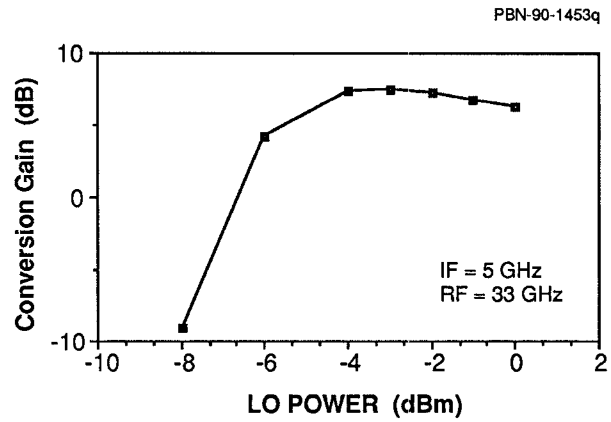

Figure 7. Ka-band SHP Frequency Converter Conversion Gain with Swept LO Power.

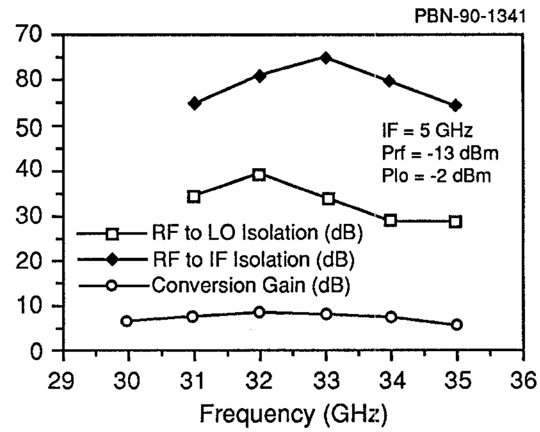

Figure 8. Ka-band SHP Frequency Converter Swept RF Conversion Gain and Isolations.

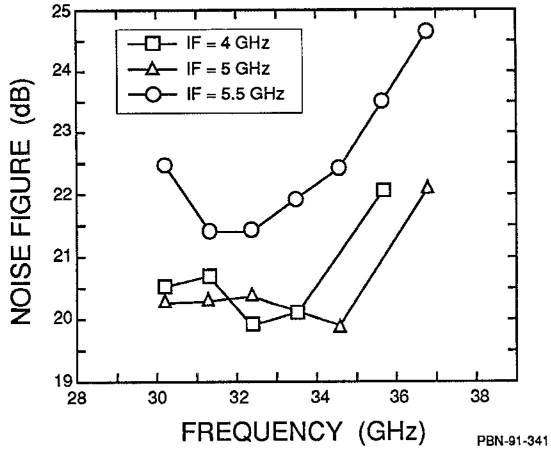

Figure 9. Ka-band SHP Frequency Converter Noise Figure.

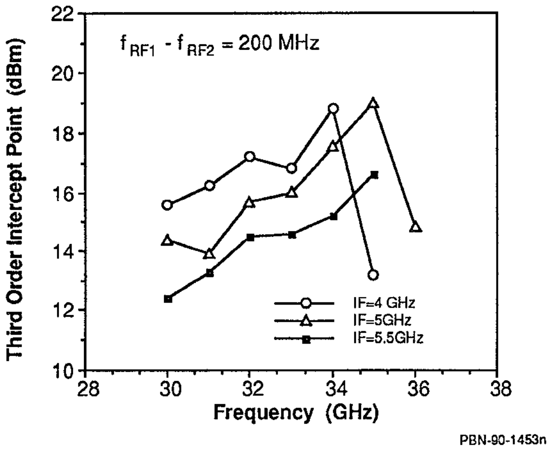

Figure 10. Ka-band SHP Frequency Converter Third Order Intercept Point.

module's noise figure is established by the noise figure of the preceding LNA. LO to RF isolation is not important since the LO signal level is low and the LO band is far removed from the RF band. Also the LO and other spurious signals, such as the image, are suppressed at the module RF ports by system filtering.

ACKNOWLEDGEMENT

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