A COOLED MIC PARAMETRIC UPCONVERTER

G. V. Kopcsay, R. A. Lange, E. W. Sard, and J. J. Taub
AIL, a division of Cutler-Hammer
Melville, New York 11746

Abstract

A parametric upconverter, suitable for cryogenic cooling in a low-noise receiver system, has been developed using microstrip circuit techniques. The prototype upconverter provides 2.4 to 3.0 dB of gain for input signals from 1.35 to 1.73 GHz with an output in the 4.6 to 4.98 GHz band. Less than 26 mW of pump power at 3.25 GHz is required for its operation. The cooled noise temperature of the upconverter is less than 7 K.

Introduction

The excellent noise performance of a positive resistance upconverter allows this device to be used in front of an existing low-noise receiver[1]. The resulting cascaded configuration extends the frequency coverage of the receiving system with a relatively minor increase in complexity and cost.

This paper describes the design and development of a parametric upconverter which has an input frequency range of 1.35 to 1.73 GHz and produces an output in the 4.6 to 4.98 GHz band. These operating frequency bands were required for a radio astronomy application. The upconverter is cooled to 18 K for use in a multiple frequency, low-noise front end, with a cryogenically cooled parametric amplifier as the second stage. Microwave integrated circuit (MIC) techniques were employed to produce an upconverter package having minimum size, weight, and cooling time.

Since the pump frequency of 3.25 GHz is approximately twice the input frequency, negative resistance effects, due to difference frequency generation, must be prevented from deteriorating the performance of the upconverter. Consequently, a balanced diode configuration was used to cancel difference frequency currents in the input circuit.

Block Diagram

The block diagram of a balanced upconverter, suitable for MIC realization is shown in Figure 1. The input signal is coupled into the parallel varactors via inductance L_1. Inductance L_2 is chosen to resonate the varactor capacitance at the center of the sum band. The combination of L_1 and L_2 resonate the varactor capacitance at the center of the signal band. Varactor bias is injected through a choke, and the dc and signal frequency paths are completed through a short-circuited bypass line which is chosen to be a quarter-wavelength long at the sum frequency.

The varactors are pumped in series by coupling the unbalanced line pump input to a 3-dB hybrid which has a 180-degree phase difference between its output arms. Each pump line contains a network to couple the 3.25 GHz pump signal into the diodes while presenting an open circuit to each varactor in the signal, difference, and sum frequency bands.

The sum frequency output is phased such that coupling each line to a second hybrid will result in addition of the signals at the hybrid's output. Band-pass filters in each sum line provide rejection over the signal, difference, and pump frequency bands. Additional rejection at the pump frequency and its harmonics is provided by a band-reject filter located at the sum hybrid output.

Theoretical Analysis

Using as a basis the block diagram, which was described in the previous section, a computer program was written to model the performance of the upconverter. The computer model includes the effects of diode parameters, signal circuit tuning, sum circuit tuning, pump circuit loading, and difference frequency termination on the gain and noise temperature of the upconverter.

A three-port model of the pumped varactor, derived by an extension of the two-port analysis given by Matthaei[2] was used in the program.

The computer analysis aided in determining the required varactor parameters and in optimizing the characteristics of other circuit elements. Figure 2 is a plot of gain and noise temperature (assuming a physical temperature of 18 K) versus input frequency for the prototype upconverter configuration. This predicted performance takes into account diode loss as well as circuit loss in the other elements of the upconverter.

Prototype Upconverter

Figure 3 is a photograph of the prototype upconverter. The basic upconverter circuit was constructed on a single 2 by 4 inch alumina substrate with photo-etched copper conductors forming microstrip transmission lines as well as lumped element capacitors and inductors. Chip varactor diodes were mounted on the upconverter substrate. The pump and output hybrids are rat race rings[3]. Two-pole coupled resonator band-pass filters[4] are included at the sum frequency output. The pump coupling networks are a series cascade of a tuning inductance, quarter-wavelength impedance transformer, and single pole band-pass filter. Dc bias is injected through a flag choke and the input line is dc-blocked by a ceramic chip capacitor.

The upconverter substrate is mounted in an aluminum housing with additional pump reject filtering included at its output. The pump reject filter is a two-stub design formed on a 1 by 1 inch substrate and mounted in a separate compartment of the same housing.

The measured performance of the prototype upconverter is summarized in Table 1. This data was taken at normal room temperature. The upconverter has been cooled to 20 K with no apparent performance degradation. Preliminary measurements indicate that the upconverter, when cooled, contributes less than 7 K to the system noise temperature.

Table 1.

Measured Performance of Prototype Upconverter

	Gain	Tuning Limits (GHz)
	2.4 dB	1.35 to 1.73 (instantaneous bandwidth, 140 MHz)
	3.0 dB	1.46 to 1.54
Pump Power		26 mW (maximum) at 3.25 GHz
Lower Sideband Isolation		
	Input Port	22 dB below input level
	Sum Output Port	35 dB below input level
	Pump Port	48 dB below input level

Conclusions

A parametric upconverter, with an L-band input and a C-band output, has been developed to meet the requirements for use in the cryogenically cooled, low-noise front end of a multiple frequency radio astronomy receiving system. Utilization of microwave integrated circuit techniques resulted in a final package with a volume of 6.5 in ^{3} and weighing less than 7 ounces.

In addition, computerized analysis and design techniques have successfully been employed in optimizing the parameters of the circuit and in predicting the performance of the final upconverter.

Extention of this MIC upconverter technology to other frequency bands should be relatively straightforward.

Acknowledgement

The work described herein was supported by the National Radio Astronomy Observatory as a part of the Very Large Array project. The authors wish to thank D. L. Thacker of NRAO for his technical guidance and for performing the cyrogenic testing.

They also wish to thank J. Whelehan of AIL for many helpful discussions and suggestions. They are also grateful to A. F. Anderson, R. Gibbs, and L. P. Hernandez for assistance in fabricating and assembling the circuits.

References

1. E. Sard, B. Peyton, and S. Okwit, "A Positive Resistance Upconverter for Ultra-Low-Noise Amplification," IEEE Transactions on Microwave Theory and Techniques, December 1966.

2. G. L. Matthaei, "A Study of the Optimum Design of Wideband Parametric Amplifiers and Up-Converters," IRE Transactions on Microwave Theory and Techniques, January 1961.

3. J. Reed and G. J. Wheeler, "A Method of Analysis of Symmetrical Four-Port Networks," IRE Transactions on Microwave Theory and Techniques, October 1956.

4. S. B. Cohn, "Direct Coupled-Resonator Filters," Proceedings of the IRE, February 1957.

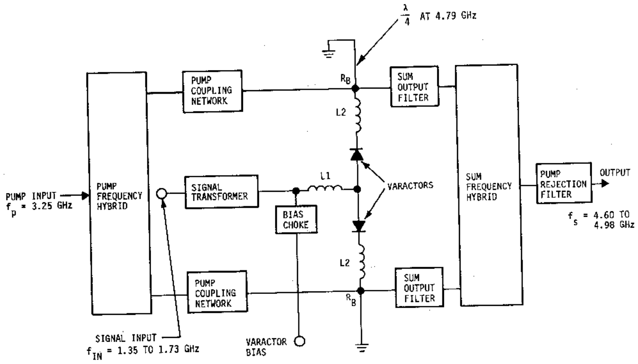

Fig. 1. Block diagram of balanced parametric upconverter

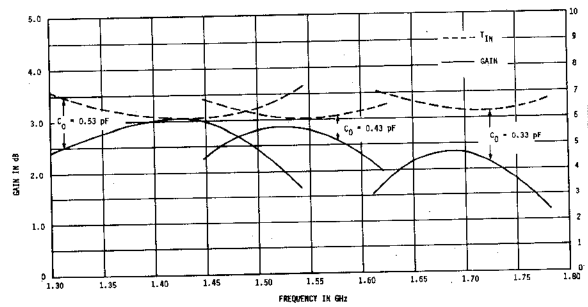

Fig. 2. Theoretical gain and noise performance of MIC

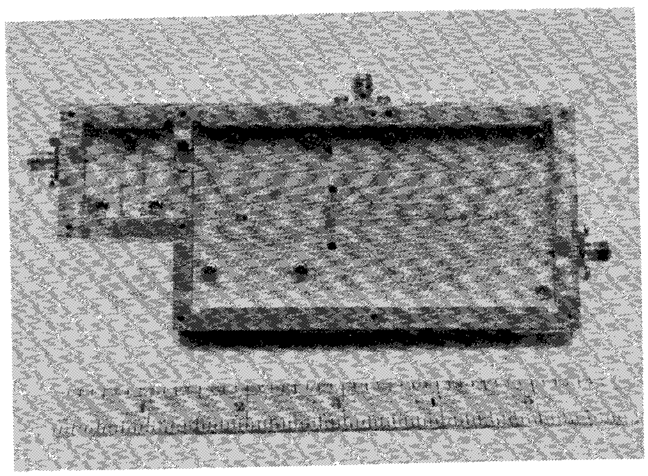

Fig. 3. MIC balanced upconverter