MILLIMETER WAVE UP/DOWN CONVERTER TECHNOLOGY FOR SPACEBORNE APPLICATIONS

M. Piloni, F. Montauti, S. Crema

Siemens Telecomunicazioni S.p.A.
20060 Cassina de' Pecchi, Milan, Italy

ABSTRACT

This paper deals with the design of V band up/down converters for spaceborne communication systems. On the analysis of interesting results obtained on BB models, it demonstrates that, at present, the above design approaches represent the most reliable and performant circuits to operate as up/down converter above 60 GHz.

INTRODUCTION

Satellite communications are moving to high frequencies as the low frequency range becomes saturated, and V band (around 60 GHz) has been considered for commercial use in particular for Inter-satellite link (ISL) and Inter-orbital link (IOL) applications. The work described in this paper, does concern the design of a 60/12 GHz down converter and of the corresponding 12/64 parametric up converter intended to be used in the above mentioned communication systems.

UP-CONVERTER DESCRIPTION

The up-converter described in this section was implemented using a varactor diode in single ended configuration and it works on the base of parametric mixers theory; this equipment being used as an upper sideband up-converter produces conversion gain.
To go further into details, the up-converter should be used in the transmit section of a MMW satellite payload in order to drive with sufficient output power a 20 W V band TWTA.
Fig. 1 shows a photo of the implemented mixer.
Actually the cavity consists of a radial structure having the same height of the varactor package in order to minimize parasitic reactances.
In this mixer the IF input was implemented in waveguide (WG) configuration; anyway a coaxial port could be adopted too.
The IF signal is fed to the varactor through a coaxial line so arranged to provide tuning means at signal frequency.
LO signal coupling is obtained with a WG filter which prevents the RF signal to propagate along the LO matching sections.

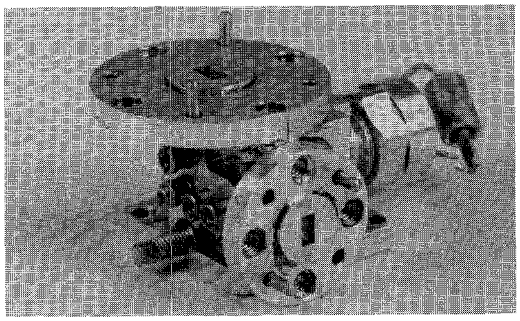

Fig. 1 - 12/64 GHz Up Converter

The RF output port is loaded on a WG filter operating at cut off (about 75 GHz) in order to attenuate LO and image signal (> 80 dB); the tuning of the RF port is accomplished by means of spring stubs placed on the top of the waveguide. The bias voltage is fed to the varactor through a choke system providing proper rejection at all frequencies involved.
The varactor used for this design is a GaAs Schottky barrier diode providing 1000 GHz cut off frequency, low series resistance (1.3 Ω) and high breakdown voltage (12 V).
An electrical equivalent circuit of the up-converter is shown in Fig. 2.

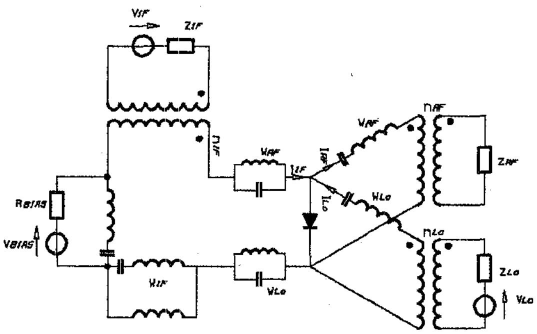

Fig. 2

Parametric Up Converter Equivalent Circuit

S

CH3141-9/92/0000-0691$01.00 © 1992 IEEE

UP-CONVERTER TEST RESULTS

Theoretical performances of the mixer at issue can be easily derived from the well known Manley Rowe equations; moreover theoretical results fit rather well with experimental ones.
The main performances of the varactor up-converter are summarized in the following table:

- Input Power:	-15 dBm, +10 dBm
- Signal Bandwidth:	500 MHz
- IF Centre Frequency:	12.27 GHz
- RF Centre Frequency:	63.75 GHz
- Conversion Gain:	2 dB
- Po_{1db}:	≥ 10 dBm
- LO Power Level:	18 dBm (at 51.48 GHz)
- DC Power Consumption:	negligible

Fig. 3 shows Po vs Pin curves according to different LO power levels whereas Fig. 4 shows Po_{1dB} vs LO power.
It can be noticed that Po_{1dB} ranges from 8.5 dBm (Plo = 16 dBm) to 12 dBm (Plo = 20 dBm).

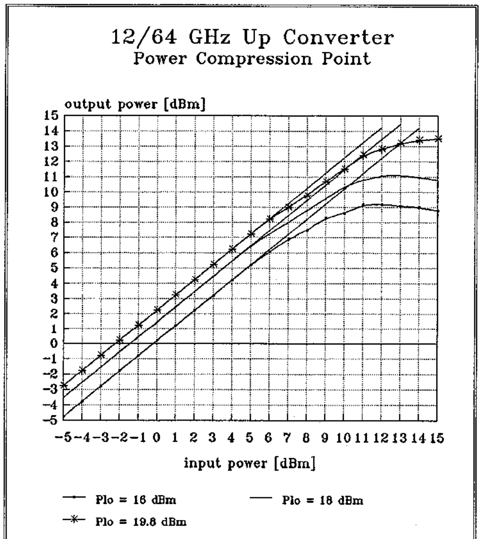

Fig. 3

Because the varactor diode is not LO saturated, Po_{1dB} characteristic is linear vs LO power levels; however LO driving levels should not exceed 21-22 dBm, otherwise varactor diode would operate in the proximity of breakdown region.

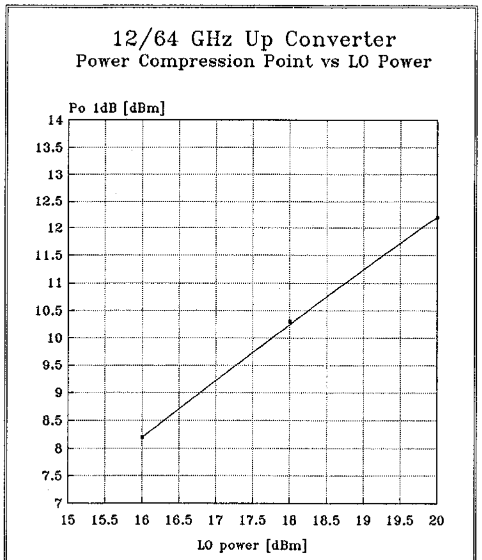

Fig. 4

The up-converter was tested over a temperature range from -20° C to +60° C showing a gain stability (in 500 MHz bandwidth) better than 0.5 dBpp.
Because the mixer works in Upper Side Band Up converter, noise figure is very low and then difficult to measure with a good accuracy. According to theory explained in ref. [1] and taking into consideration the electrical parameters of the used varactors, a noise temperature lower than 13°K was computed.

DOWN CONVERTER DESCRIPTION

With regard to low noise mixer design, the best structure in this sense is the cross-bar configuration (using resistive diodes) which allows a clear separation of the various LO sideband harmonics, which can thus be duly recovered (image enhancement).
During the breadboarding activity, high cut-off frequency (≥ 1500 GHz) diodes have been tested in cavities tuned at 60 GHz (IF = 12 GHz).
A simplified representation of the implemented down converters is shown in Fig. 5 whereas a B.B. cavity is shown in Fig. 6.
It consists of a waveguide cavity containing a thin fused silica substrate (alumina substrate could be used too) with a pair of beam lead Schottky barrier diodes mounted thereon (Fig. 7). The image frequency is terminated by properly positioning (by means of spacers) an image rejection filter at the input. The LO signal is capacitively coupled to the diodes from the back of the mixer cavity.
To match the mixer input impedance to the standard waveguide, the diodes (which are in parallel at the mixer output) are connected directly to the IF output.

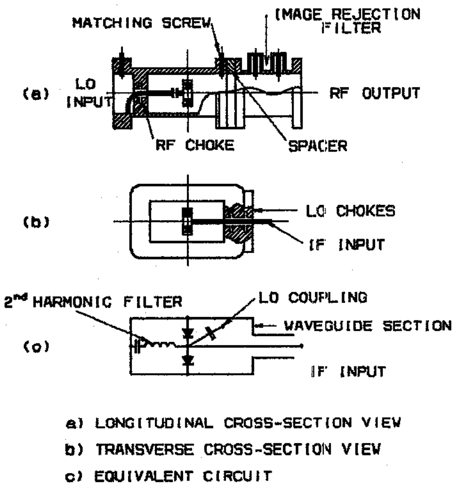

Fig. 5 - Mixer Schematical Drawing

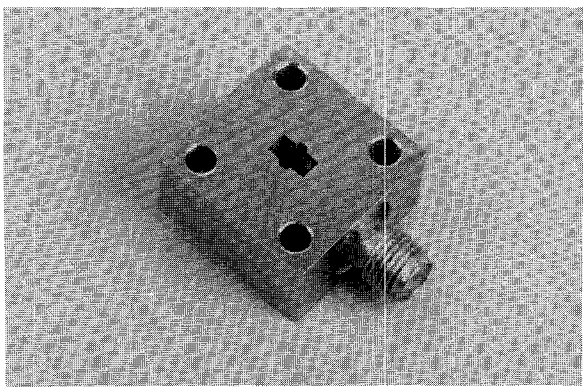

Fig. 6 - 60/12 GHz Down Converter

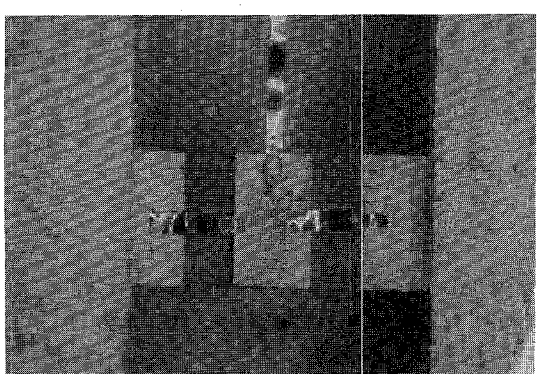

Fig. 7 - Beam Lead Diodes Support

DOWN CONVERTER TEST RESULTS

The fundamental sensitivity parameter of the mixer is the overall noise figure given by:

$$NF = CL \cdot (NF_{if} + TNR - 1)$$

where the diodes related parameters are conversion loss CL and noise temperature ratio TNR whereas NF_{if} is the contribution of IF stage. It has been found experimentally that TNR depends on the relationship between current and voltage on the diode junction and assumes a value very close to unity for intermediate frequency higher than 1 MHz [2]. The measured overall noise figure, driving the mixer with an LO power of 12 dBm at 48 GHz, was 6.2 dB with an IF contribution of 2 dB over the frequency band 12-12.5 GHz; therefore, being the thermal noise ratio negligible for the previous consideration, the relevant mixer noise figure results 4.2 dB (Fig.8). It is worth remarking that for these mixers GaAs diodes with a declared conversion loss of 5 dB at 30 GHz were used, that is 1-2 dB worse than the obtained performance.

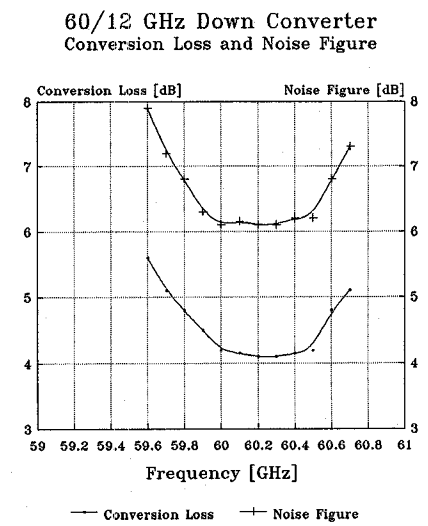

Fig. 8

This is due to the fact that diode manufacturers do not take into account mix product recovery during the electrical characterization of the diodes.

Supposing this mixer to be followed by a post amplifier (working up to 12 GHz) providing an NF value of 1.2 dB (a performance easily obtainable with standard HEMT devices) and with the input port noise matched on the mixer IF port, a 60 GHz receiver performing an overall noise figure of 5.4 dB can be realized.

The above performance is rather close to the ones obtainable with a low noise pre amplifier employing R&D Lab. HEMT devices, at present not yet commercially available, and in any case characterized by the important disadvantage of requiring a remarkable DC power consumption (400 mW).

CONCLUSION

Test results obtained on MMW up/down converter mixers showed to be competitive with the ones achievable with alternative solutions.
Concerning the parametric up converter the most remarkable advantage is the high output power, provided with a better efficiency than the one achievable with a resistive mixer followed by a FET or Gunn diode post amplifier.
On the other hand, the low conversion loss provided by the MMW down converter makes it attractive in view of its high reliability and of the possibility to be easily integrated with a really performing pre amplifier when it will be available for space use.

The parametric up converter study has been done for the European Space Agency under FIAR Contract.

The down converter study has been done under European Space Agency contract.

AKCNOWLEDGMENTS

The authors would like to thank Mr. D'Ambrosio for his helpful technical suggestion and Mr. Castelli for the development of the parametric cavity.

REFERENCES

[1] G.B. Stracca: "Amplificatori parametrici "Alta Frequenza Vol. XXX N° 2 - Febbraio 1961.

[2] M. J. Sisson: "The Development of Millimeter Wave Mixer Diodes", The Radio and Electronic Engineer, Vol. 52, N°11/12, pp. 534-542, November/December 1982.

[3] G.B. Stracca: "On frequency converters using non-linear resistors", Alta Frequenza N. 5 Vol. XXXVIII - 1969.

[4] G.B. Stracca, F. Aspesi, T. D'Arcangelo: "Low Noise microwave down converter with optimum at idle frequencies", IEEE Transactions on Microwave Theory and Techniques N. 8, August 1973.

[5] L. Mania, G. Savina, G.B. Stracca: "Conversion loss in microwave balanced mixers with junction diodes", Alta Frequenza Vol. XLV N. 10 - 1976.

[6] S. Maas: "Microwave Mixers" Artech House 1986.