MILLIMETRE-WAVE DOWNCONVERTER USING MONOLITHIC TECHNOLOGY FOR HIGH VOLUME APPLICATION

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ABSTRACT

Ten receiver downconverters have been produced, tested and deployed for TV distribution at 29GHz. GaAs monolithic technology has been chosen in order to make the imminent production version an affordable product. Conversion gains and noise figures are 30 to 38dB and 12 to 16dB, respectively. DRO stability is +/-2MHz over -20°C to +40°C.

INTRODUCTION

The British Government has recently suggested a possible shift to millimetre-waves for local distribution of multi-channel TV, MVDS. This is encouraging for the future of the BTRL mm-wave TV delivery system known colloquially as M^3VDS (Millimetre-wave Multichannel Multipoint Video Distribution Service) [1]. The economics of consumer products require a home receiving set-up to cost around $350, comparable with satellite receiving systems. Only about $200 can be allowed for the mm-wave antenna/downconverter. We believe this is an application *requiring* the low costs that monolithic microwave and millimetre-wave ICs (MMIC/MMWICs) are capable of providing, assuming a high volume production run. Furthermore, considering that at mm-wave frequencies parasitics become more significant and assembly tolerances become tighter, we believe that this is an application *requiring* monolithic technology if it is to be manufacturable with a reasonable yield,

Ten 29GHz to 1GHz receiver downconverters have been developed for a demonstration of M^3VDS, with the main objective of demonstrating the economics and feasibility of monolithic technology for this and other applications. These have been installed in a small town in Eastern England.

The customers' apparatus consists of an antenna/downconverter unit mounted outdoors, a coaxial downlead carrying the IF signal, and an indoor IF/demodulator unit. The system has been designed to minimise the total cost of a receiving installation. The channel spacing, modulation format and 1st IF are common to that presently used by Direct Broadcast by Satellite (DBS) so the low-cost DBS indoor units, already in mass-production, can be used. Therefore, the long-term feasibility of this system depends critically on the cost of the antenna/downconverter.

GENERAL DESCRIPTION OF DOWNCONVERTER

The following performance was sought from the downconverter.

Noise Figure:	as low as possible, target 12dB
Conversion gain:	>30dB
Operating band:	28.43 - 29.08 GHz
Image rejection	>35dB
LO frequency	27.61 GHz
LO frequency stability:	+/-3 MHz (+/-5ppm/°C)
Temp range	-12 to +32°C still air ambient
IF output	950 - 1750 MHz
1dB compression point	>-30dBm referred to the input

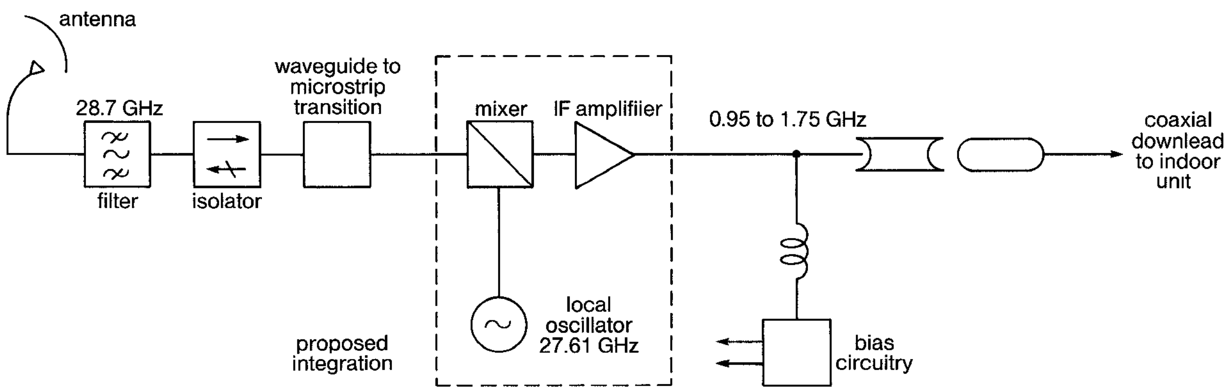

Figure 1. Block schematic of downconverter

The downconverter is shown schematically in Figure 1. The microwave components are contained in a small integrated unit mounted underneath the antenna. An E-plane bandpass filter is used for out-of-band rejection of signals and noise. A waveguide E-plane isocirculator provides an image termination for the mixer and supresses LO radiation. The areas targetted for monolithic integration are shown within the dotted box in Figure 1. Presently, the mixer is a MMWIC and the IF amplifier is a cascaded pair of MMICs. The local oscillator is a dielectric resonator oscillator (DRO) initially incorporating a discrete FET in a hybrid circuit but a MMWIC design is under development. The active circuits are fabricated on a drop-in microstrip assembly which incorporates a probe-type transition to waveguide. +20V DC power is fed via the coaxial IF lead from the indoor receiver unit.

ANTENNA

The antenna is a 155mm diameter, offset-fed parabolic dish. Measured gains are 30 to 31dBi, and the corresponding half power beamwidth is 5^{o}. The reflector is manufactured using a metal forming technique. Low cost is achieved now in small batches, and will fall further in mass production.

FILTER AND ISOCIRCULATOR

The E-plane filter and E-plane waveguide isocirculator are integrated into the downconverter housing : these parts were designed and constructed by GEC Research Ltd. The filter and isolator together exhibit a typical insertion loss of 0.7dB in the passband, with 30dB rejection at the LO frequency and greater than 50dB at the image frequency. Over the operating band, both the return loss at the antenna port, and the isolation, exceeds 20dB.

MIXER MMWIC

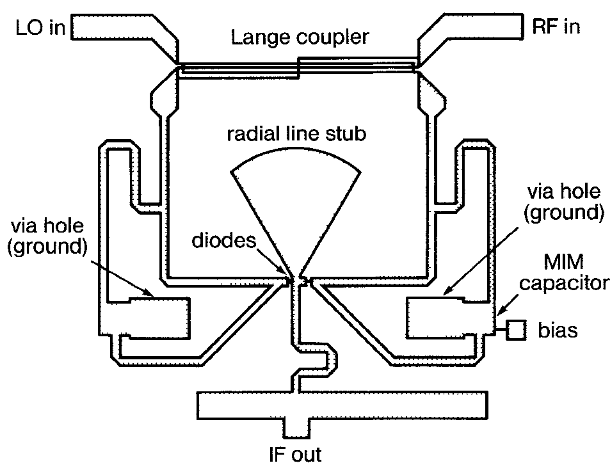

Figure 2. Layout of mixer

A diagram of the mixer chip, is shown in Figure 2. This 2mm x 2mm chip was fabricated at BTRL. Two through-substrate via holes are used to provide an RF ground for the matching circuit (via an MIM capacitor for one diode) and an IF ground. Selective-area ion implantation is used to define the active areas of the diodes. This ensures compatibility with the MESFET process ready for the integration of local oscillator and amplifier on to the same chip.

The design procedure was considerably aided by the use of mixer analysis software. The microstrip circuit embedding the diodes is analysed by the linear analysis program TOUCHSTONE™, and the impedances at the various mixing frequencies loaded into a mixer analysis program. This program is based on that given by Maas [2], but extensively modified. The large-signal analysis uses the multiple reflection algorithm. The small-signal analysis has been augmented to automatically transform the balanced circuit into the equivalent single-diode configuration, and the mismatch at the IF port is now taken into account. These and other alterations have resulted in the close correspondence between the predicted and measured conversion loss as shown in Figure 3. Across the band of interest the measured conversion loss and noise figure are approximately 7dB and 8dB, respectively.

The CAD procedure allowed the microstrip matching circuits to be optimised, and also predicted that a forward DC bias on the diodes would reduce the LO power requirement. This has indeed turned out to be the case in practice as shown in Figure 4. With 1.1V bias applied, the noise figure falls by only 0.5dB, as the LO power is reduced from 10dBm to 3dBm. This was an important requirement for compatibility with low-cost stable local oscillators of the type to be described here.

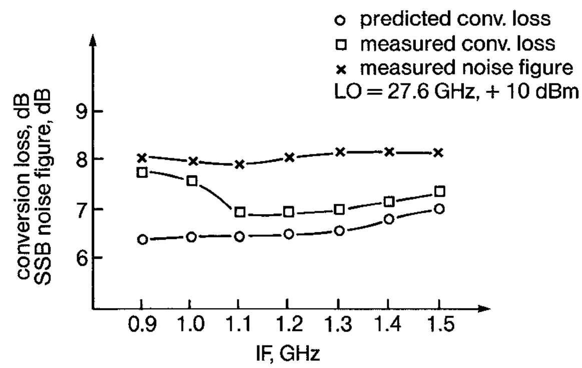

Figure 3. Measured and predicted mixer performance (zero bias)

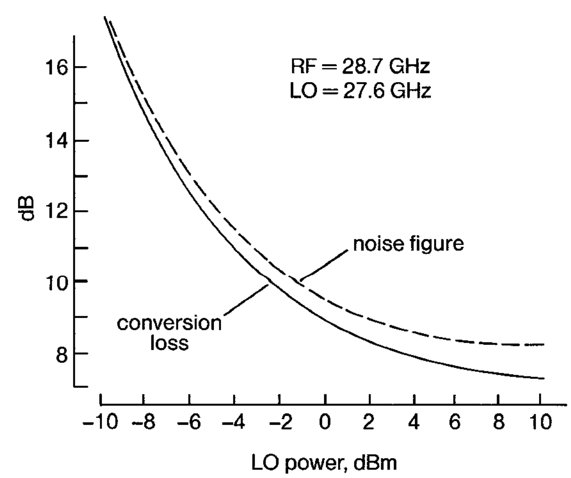

Figure 4. Mixer performance with 1.1V bias

IF AMPLIFIER MMIC

This 1 - 2 GHz MMIC was designed and the GDS-II mask layout tapes created at BTRL : fabrication was carried out by the Triquint GaAs foundry. The chip is 1.5mm x 0.9mm and is shown in Figure 5. The amplifier circuit consists of two stages incorporating 0.5micron MESFETs, with feedback applied to the first. The IF amplifier performance, measured on-wafer and shown in Figure 6, closely matches the simulations, with a gain of 22dB per chip and 3dB noise figure. Two chips are used to give the required gain of at least 40dB. For both the mixer and IF amplifier the yield of working chips is high at over 80%.

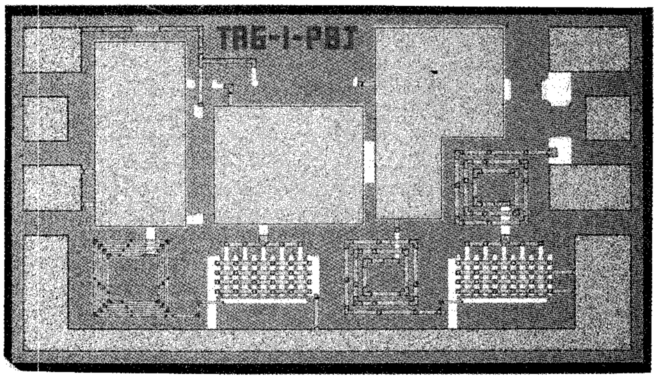

Figure 5. IF amplifier chip

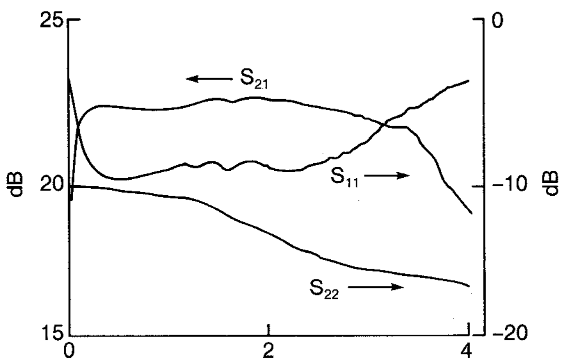

Figure 6. Typical amplifier performance

LOCAL OSCILLATOR MIC

The circuit diagram is shown in Figure 7. This is a series feedback reflection oscillator using a dielectric resonator for frequency stabilisation. This MIC design uses an NE673 0.3um chip MESFET in a microstrip thin film circuit on an alumina substrate, and is suitable for monolithic integration. A CAD procedure was followed in order to assist the design [3]. Output powers in the range +3 to +5dBm are obtained (adequate to drive our mixer), and the phase noise at 10kHz from carrier is -75dBc/Hz. The frequency drift with temperature, observed at IF with a 28.61GHz RF input signal, is plotted in Figure 8. The drift is less than +/-2MHz from -20°C to +40°C.

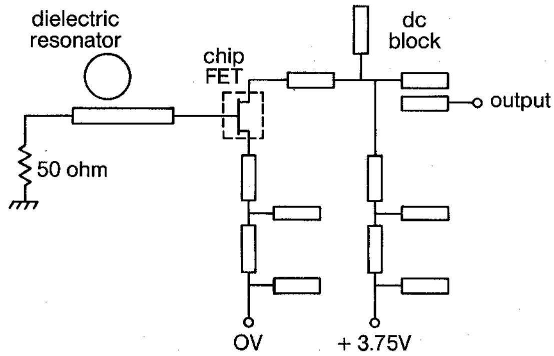

Figure 7. Circuit diagram of hybrid local oscillator

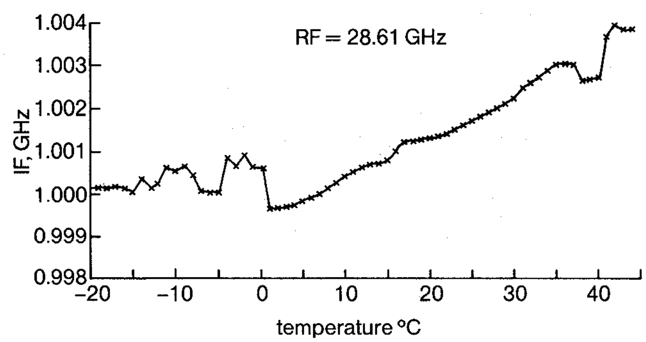

Figure 8. Frequency stability

CONSTRUCTION OF THE DOWNCONVERTER

The first stage in the assembly procedure is to affix the waveguide-to-microstrip transition, mixer, IF amplifier chips, and local oscillator substrate to a carrier to form the drop-in MMIC assembly, shown in position in Figure 9.

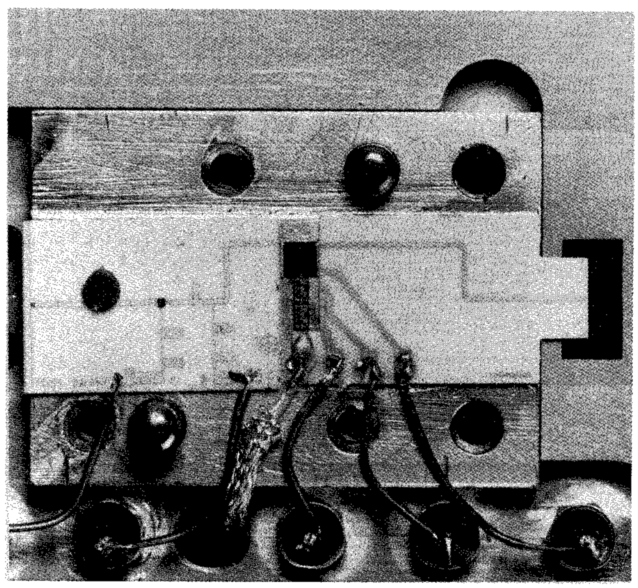

Figure 9. MMIC assembly

The assembled downconverter is pictured in Figure 10. The size, 107mm x 78mm x 45mm, is dictated by the filter and isocirculator integrated within. At the top of the photograph is the bias circuit including a DC/IF splitter formed using capacitors, transmission lines and a spiral inductor, and regulators for the MMIC bias supplies. For small size this is implemented using surface-mount technology. Nearside is the MMIC assembly.

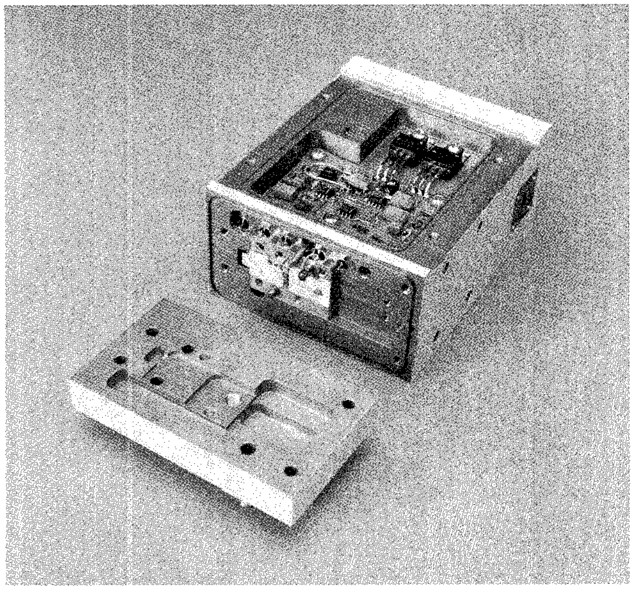

Figure 10. Downconverter housing showing MMIC assembly and bias circuits

PERFORMANCE OF THE DOWNCONVERTER

Ten downconverters have been assembled and tested and their performance is shown in Figure 11. Conversion gains are in the range 30 to 38dB, and noise figures are in the range 12 to 16dB. It is believed that the variations in noise figure and gain from unit to unit are due to chip performance variations and placement repeatability on the probe transition. The higher than expected average value of noise figure is thought to be an electrical interface problem between the waveguide components and the mixer and is being remedied in the next version.

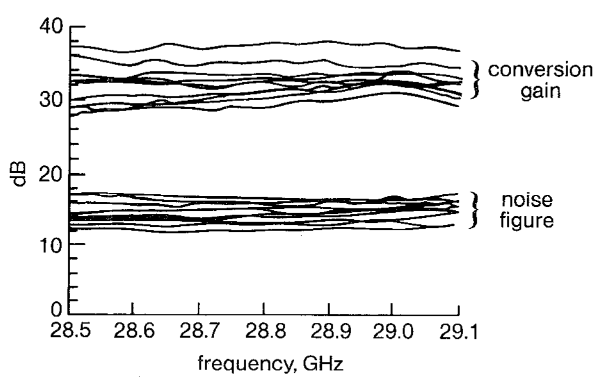

Figure 11. Performance of ten downconverters

FUTURE WORK

The downconverter reported on is the prototype version and is not suitable for mass production in its present form. Two major developments are in hand to achieve the target price in manufacture. The E-plane filter will be replaced by one in microstrip and the isolator eliminated, hence reducing the size and cost of the housing considerably. Also, our on-going programme is aimed at integrating the mixer, IF amplifier and local oscillator onto one chip. Simulations predict lower noise figure from modified designs.

CONCLUSIONS

The ten downconverters have been deployed, and have been operating satisfactorily for nearly a year. The downconverters have been successful in demonstrating the feasibility and cost-reduction potential of MMIC and MMWIC technology for this application. During design the chip areas were kept to a minimum, with an eye to affordability. Cost projections, including foundry prices for the chips, are below the $200 ceiling. This is an opportunity for bringing high performance high technology monolithic technology out of the research labs and into mass production, possibly in quantities of millions, with the consequent spin-offs benefitting other microwave and millimetre-wave systems.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. Pilgrim and R. P. Searle, "mm-Wave Direct-to-Home Multichannel TV Delivery System", IEEE MTT-S 1989 International Microwave Symposium Digest.

[2] S. A. Maas, Microwave Mixers, Artech House, 1986.

[3] P. G. Wilson and R. D. Carver, "An Easy-to-use FET DRO Design Procedure Suited to Most CAD Programs",IEEE MTT-S 1989 International Microwave Symposium Digest.