MINIATURE GPS TRANSLATOR MODULE

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ABSTRACT

A GaAs MMIC gain/frequency conversion chip set and its integration into a module which frequency translates the C/A-coded L1 GPS signals to the 2200-2290 MHz telemetry band for use in tracking artillery projectiles is demonstrated. The custom downconverter, upconverter and power amplifier MMICs which form the transmission chain as well as the 36 cm^3 module which provides over 125dB of gain with 3dB noise figure, survives firing shock of over 8,000G and operates from 0°C to 70°C are detailed.

INTRODUCTION

The Global Positioning System (GPS) provides position determination on earth by analyzing signals from NAVSTAR satellites. One application of this position location system is for tracking munitions. In this application, the positioning data received by an artillery shell is relayed to the data collection site for processing. The only on-board equipment needed is a frequency translator to generate a new carrier frequency for the analog GPS data stream. Equipment built using conventional hybrid circuits technology [1,2] cannot be accommodated in smaller projectiles because of excessive size and cost. However, by developing a custom Monolithic Microwave Integrated Circuit (MMIC) chip set, it is possible to miniaturize a translator to a much greater extent than previously reported, allowing it to fit within the fuze portion of an artillery shell and withstand high acceleration. This MMIC approach also enhances ruggedness, reliability and lowers power consumption. By integrating packaged MMICs together with procured components, a form-fit translator module is realized which provides over 125dB of gain with 3dB noise figure, survives firing shock of over 8,000G and operates from 0°C to 70°C.

SYSTEM ARCHITECTURE

The basic function of the translator is to convert the incoming C/A-coded L1 GPS signals from the NAVSTAR constellation to a higher frequency within the 2200-2290 MHz telemetry band and to provide the amplification required to overcome path loss. The dual conversion translator architecture, shown in Figure 1, was selected due to the extremely high gain of the module and low isolation between transmit and receive antennae. Active circuit functions are performed within the seven GaAs MMICs shown. Passive L-C and Surface Acoustic Wave (SAW) filters maintain stability and noise figure while limiting output power requirements. The signal path consists of low noise amplification to establish system noise figure, downconversion to an IF within the VHF band which allows for substantial amplification and the integration of a high selectivity SAW filter to limit noise bandwidth, upconversion to the telemetry band and amplification to the required output power level. The local oscillators are provided by two phase-locked loops using a common reference oscillator to maintain close-in phase coherence. A harmonic of the crystal reference oscillator is coupled into the IF strip to form a pilot signal which allows the translated GPS signals to be acquired by the ground receiver following doppler-, temperature- and shock-induced shifts in the output frequency. The phase-locked oscillators are based on custom VCO and phase-frequency detector MMICs discussed previously [3]. This paper describes the signal path MMICs.

The 125 dB overall translator gain includes all the losses associated with the passive components in the signal path, making the total active gain budget for the MMICs higher. The large number of gain stages results in significant gain variation over temperature which is temperature compensated through an AGC leveling loop, consisting of a detector in the output stage of the power amplifier, a low-pass filter and a variable gain IF amplifier in the down-converter.

SIGNAL PATH MMICS

The custom downconverter, upconverter and power amplifier MMICs are shown in Figure 2. They were fabricated using a standard 1 μm gate-length, enhancement/depletion GaAs MESFET foundry process. Table 1 summarizes the performance of the packaged downconverter, upconverter and power amplifier. A commercial MMIC LNA (MAAM 12000) provides 1.6dB noise figure with 25dB of associated gain.

This work was partially funded by the Army Research Laboratory, Adelphi, MD under contract DAAL02-92-C-0331.

**Presently with Analog Devices Inc., Wilmington, MA.*

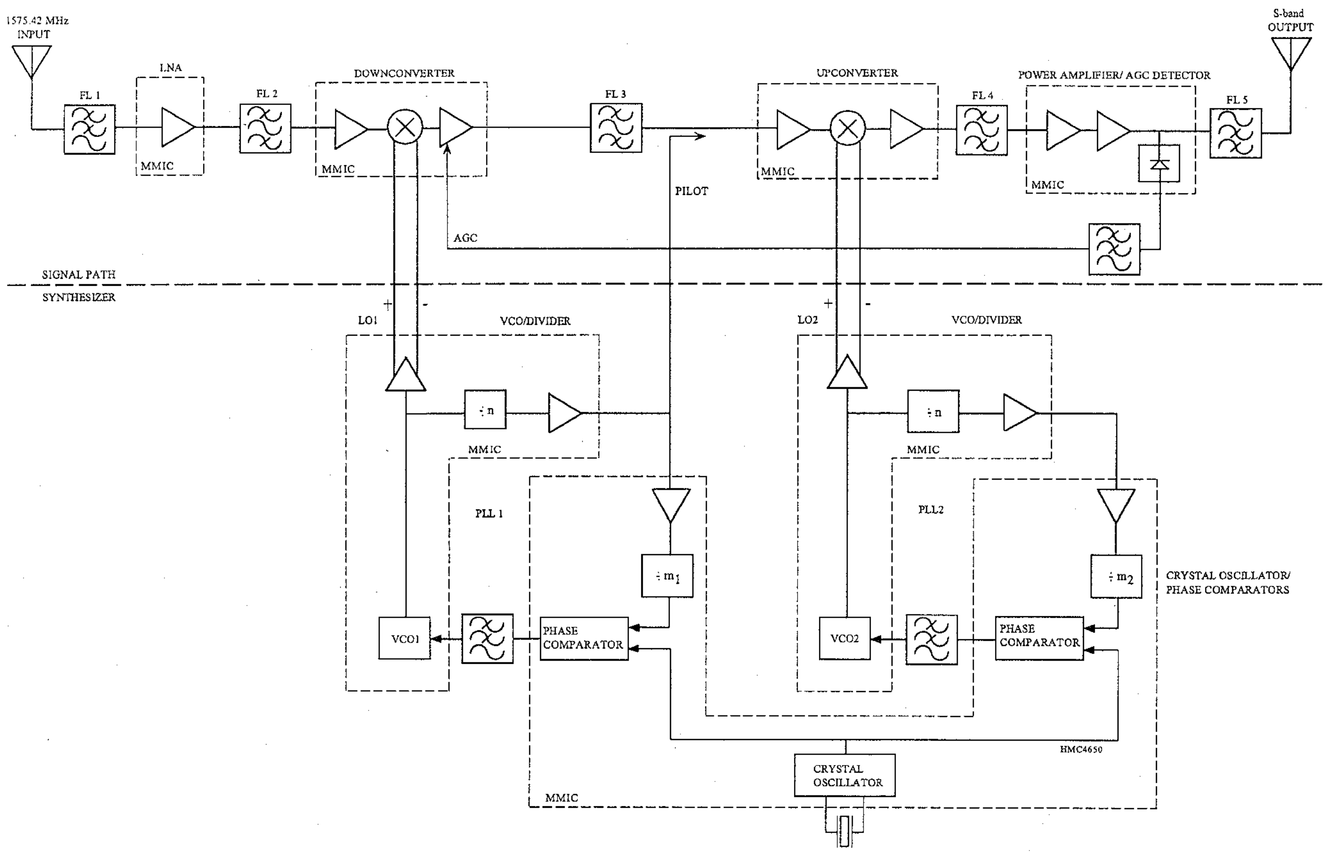
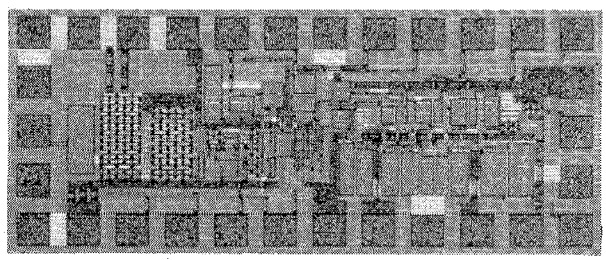
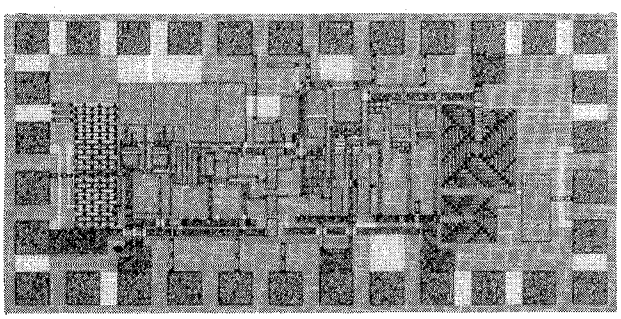


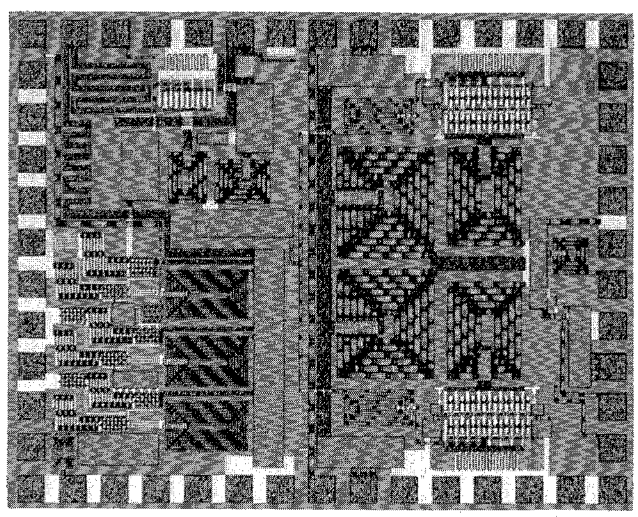
Figure 1. GPS translator block diagram.



a) Downconverter



b) Upconverter



c) Power amplifier

Figure 2. Microphotographs of signal path MMICs.

DOWNCONVERTER	
Conversion Gain Control Range	37 - 77 dB
-1 dB O/P Power Gain Compression	+9 dBm*
Noise Figure	13.5 dB*
Supply Bias	80 mA @ 8V*
Input/Output VSWR	<1.6:1*
* @ 70dB conversion gain	
UPCONVERTER	
Conversion Gain	36 dB
-1 dB O/P Power Gain Compression	+1 dBm
Noise Figure	8.8 dB
Supply Bias	69 mA @ 5V
Input/Output VSWR	<1.4:1
POWER AMPLIFIER	
Small-Signal Gain	40 dB
-1 dB O/P Power Gain Compression	21.5 dBm
-3 dB Bandwidth	32%
Noise Figure	5.4 dB
Supply Bias	400 mA @ 8V
Input/Output VSWR	1.9:1 / 2.8:1

Table 1. MMIC performance summary (@ 25°C).

The downconverter, which provides conversion gain over an extremely wide 37 to 77dB range, consists of a two-stage RF common-source amplifier with negative feedback, a double-balanced Gilbert cell mixer and a five-stage variable gain IF amplifier. The IF amplifier consists of a differential input stage, three gain control stages and an output buffer stage. Chip dimensions are 1.9 x 0.8 mm^2. The upconverter includes a four-stage IF amplifier, a double-balanced Gilbert cell mixer and a four-stage RF amplifier. Chip dimensions are 1.9 x 1.0 mm^2. The power amplifier consists of a three-stage pre-amplifier followed by driver and output amplifier stages. The pre-amplifier stages are based on common-source/source-follower pairs with negative feedback. The output stage is a stacked-FET design [4] which distributes the output tank RF voltage swing evenly across two FETs connected in series. The power-leveling AGC control voltage is generated by a diode detector coupled to the output stage. Chip dimensions are 2.3 x 1.9 mm^2.

The power amplifier is soldered into a 7.6 x 9.1 x 1.4 mm^3 six-lead ceramic package with a high thermal conductivity copper-tungsten base. The other MMICs are epoxied into 6.9 x 6.9 x 1.8 mm^3 ten-lead glass flatpacks with a kovar base to provide RF grounding. Additional chip capacitors, resistors and inductors are included within these packages for bias decoupling/filtering and gold bond-wires form interconnections.

TRANSLATOR ASSEMBLY AND EVALUATION

The translator circuitry is contained on three boards, as shown in Figure 3. Miniature coaxial cables are used to carry RF and tuning signals between the lower and middle/upper boards. Coaxial feedthroughs interconnect the middle and upper boards which are assembled back-to-back. The 0.21 kg, 4.1 cm diameter by 2.8 cm high translator fits within a standard artillery shell fuze, withstands a firing acceleration of 8,000G, flight dynamics and a 0°C to 70°C temperature range.

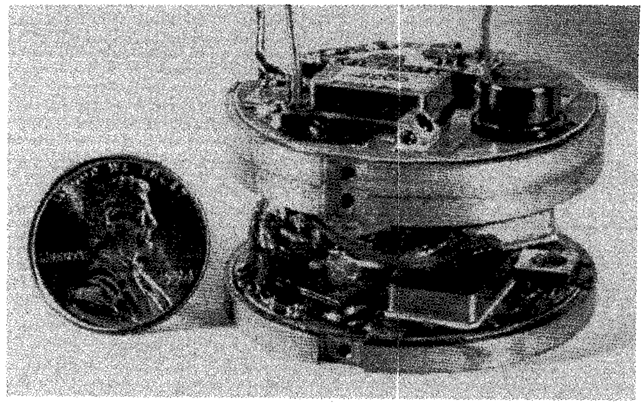


Figure 3. Photograph of a translator module.

The packaged MMICs, crystal, L-C filters, SAW filter, capacitors, resistors and inductors are surface mounted on 10 mil duroid circuit boards which are attached to copper-tungsten metal matrix disks. Circuitry on each disk is individually tested and de-bugged prior to module assembly.

Figure 4 shows the S-band output spectrum of a prototype translator module at room temperature. The frequency translated spread-spectrum GPS signal is embedded within the thermal noise hump defined by the SAW filter passband while the pilot is visible at a positive frequency offset. In-band ripple does not exceed ±0.5 dB over an extended temperature range of -40°C to 70° C with 15dB of input/output isolation. Figure 5 shows plots of the RF gain, noise-figure and translated output frequency deviation versus temperature. Measurement errors result in an uncertainty window for the overall translator gain and noise-figure of ±0.5 dB. Output power variation is less than 1.2dBm over temperature due to the high AGC control-loop gain. Long-term frequency drift tracks the inverse parabolic dependence of the unloaded SC-cut quartz crystal resonant-frequency. Power consumption at room temperature is 5.6W.

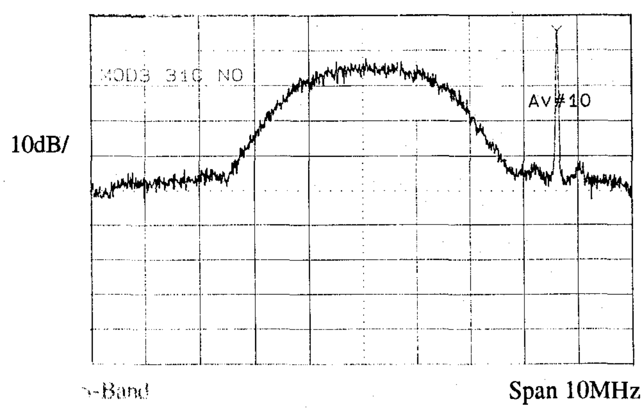
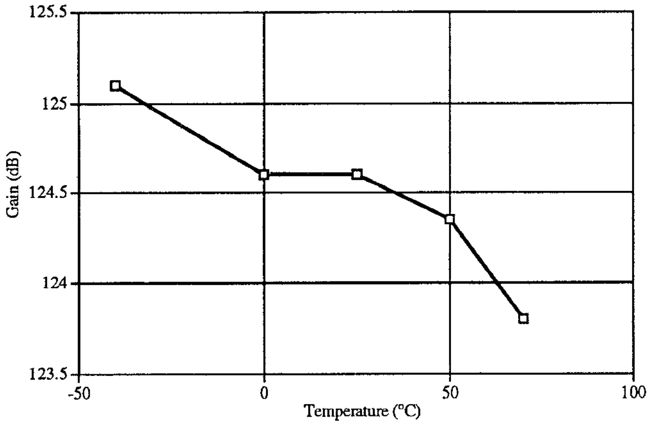
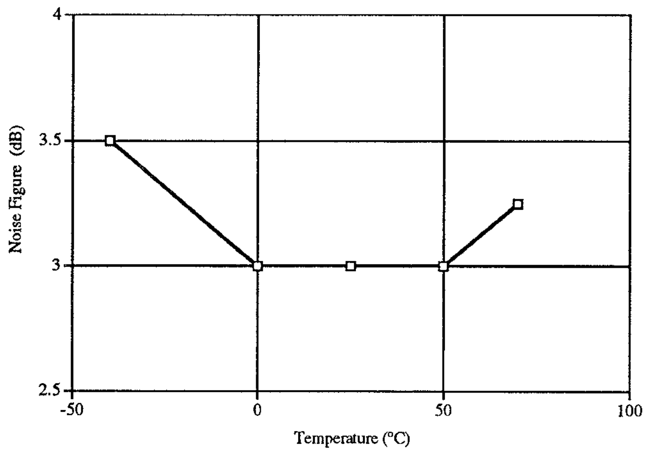


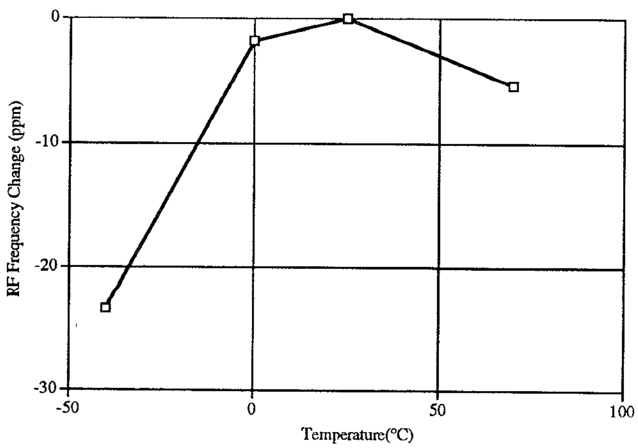
Figure 4. Translator output spectrum (@ 25°C).



a) Gain versus temperature.



b) Noise Figure versus temperature.



c) RF frequency drift versus temperature.

Figure 5 Translator performance versus temperature.

Prototype translators mounted on 155mm artillery projectiles were test fired by Army Research Laboratory personnel at the Yuma Proving Ground. Data from five of eight visible NAVSTAR satellites was successfully translated during the entire 45 second flights. [5]

DISCUSSION AND CONCLUSION

Five different MMIC circuits were designed, fabricated, and evaluated. These were used in the fabrication of a miniature translator module, together with a MMIC LNA, custom filters, crystal, circuit boards, and other hardware and components which were procured. The 36 cm^3 prototype translator module is the first reported to fit within the envelope of a standard artillery fuze, survive firing shock and meet all required electrical specifications over a 0° to 70°C operating temperature range.

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