LOW-COST, LOW-MASS LTCC DOWN CONVERTER FOR COMMUNICATION SATELLITE PAYLOADS

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***Abstract* - This paper describes a low cost, low mass down converter for communication satellite payloads. The hybrid module benefits from the latest qualified production technology based on multi-layer Low Temperature Co-fired Ceramic (LTCC). This material permits a very high level of circuit integration in which down conversion (mixing), IF amplification, and Microwave phased-locked-loop Local Oscillator (MPLLO) functions are included on a single substrate. The robust design exhibits minimum RF section tuning, improved performance repeatability, and lower production costs as a result of the concerted effort to implement a dedicated family of MMIC devices (in Ku band) as well as low cost LTCC fabrication processing. All this translates into lower overall costs and reduced lead times, as well as considerable mass savings for Down converter and Receiver Payload Units. The down converter hybrid is then housed, in a common module, with a compact DC/DC converter card and reference oscillator all together weighing only 420 grams.**

I. INTRODUCTION

The baseline converter design was conceived at the start to cover all the standard communication bands in C, Ku and Ku+; 5.925 to 6.425 GHz, 12.75 to 14.5 GHz and 17.3 to 18.1 GHz, respectively. The presented EQM unit covers the Ku band. The hybrid Down converter module will normally be integrated with a reference oscillator and DC/DC converter in a common aluminium alloy module. A separate hybrid module front-end using discrete devices optimized for the lowest noise figure can be interfaced to the top of the Down converter module for eventual ***Receiver*** applications. Depending on the performance requirements, the unit can be easily configured to accept either a TCXO or OCXO, both of ALS design, without the necessity of packaging modifications. For ***Down converter*** applications, the top-mounted WR-62 or WR-75 iso-adaptor, or SMA connectorized isolator (for C band version only) with corresponding LNA hybrid are replaced by a SMA connector flange.

The key element for the success of these units is the use of LTCC multi-layer substrate technology which permits high integration and small size. Plus, the development of a complete line of application specific MMIC(s) in Ku band minimizes or totally eliminates post-production tuning which dramatically reduces production lead-time. Macro-hybrid packaging using "chip-and-wire" also eliminates the additional cost of individual packaged parts. This results in considerable overall cost savings when applied to moderate volume production (10 to 50 units typical per program).

Dedicated MMIC chip sets covering the various RF and IF bands have been developed to allow easy reconfiguration of the Down converter hybrid without the modification either to the LTCC layout or package. In addition, filtering functions and mixers are realized purposely in microstrip on alumina seperate substrates (and not in the LTCC top layer) are then epoxied; again permitting performance optimization for the various frequency plans.

The LTCC hybrid converter is the "heart" of next generation payload equipment for broadband multimedia satellite communication systems, both regenerative and transparent. The use of MMIC devices and advanced packaging technology allows significant reduction of mass and volume mandatory for the realization of large, complex, multi-channel payloads. In fact, the use of LTCC technology in particular has permitted mass of the complete, stand-alone unit including LNA to be reduced to less than 500 grams. This offers very significant improvement when compared to present market, off-the-shelf equipment weighing from 700 to 900 grams depending on configuration.

II. LTCC DOWN CONVERTER HYBRID DESCRIPTION

Referring to the functional block diagram (Fig. 1), input return loss is guaranteed by low-noise monolithic buffer realized with a 0.25um pseudomorphic HEMT process and integrates two P-HEMT stages. The design employs a self-biased configuration with inductive source feedback on the first stage in order to achieve optimum noise figure associated with good input VSWR. This stage also provides sufficient gain to limit NF degradation due to mixer and IF section contributions and stabilize it over temperature. The microstrip image reject filter minimizes the contribution of image band noise to the converter noise figure, plus rejects transmit band signals that may leak through the finite isolation of the mixer and appear at the output as inband spurious. A hybrid balanced mixer uses beam-lead GaAs Schottky diodes mounted on alumina substrate fabricated with thinfilm technology. This mixer topology implements a wideband microstrip balun proven on various programs covering RF/IF frequencies over the full Ku band range, 10.5 to 14.5 GHz, and LO frequencies from 1.5 to 3.3 GHz. This topology provides strong rejection of odd (or even, depending on version) LO harmonics falling close to the IF band. This topology is easily "scalable" and therefore able to provide the same performance over C and Ku+ bands.

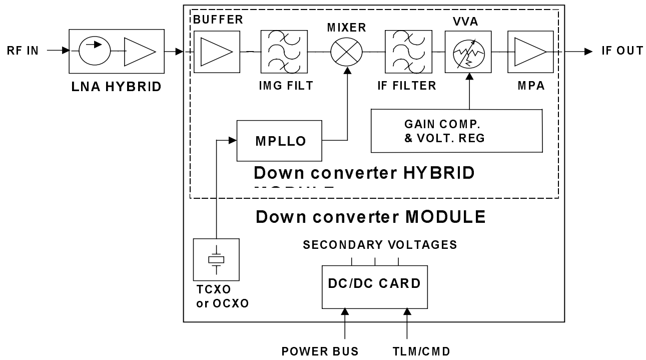

Fig. 1: Block diagram of complete Receiver Unit featuring LTCC converter hybrid module

A bandpass filter is the first element of the IF section, providing suppression of out-of-band mixing products. The active IF section is composed of recurring MMIC devices which provide the required gain and dynamic gain control. The first gain stage is the same MMIC LNA as utilized in the RF buffer section. In addition to the large passband, its low intrinsic noise figure guarantees negligible contribution of the IF stage to the overall noise figure. The gain control block is a PHEMT Voltage Variable Attenuator MMIC using a cold FET configuration. Two cascaded MMIC MPA(s) are used as the output stage in order to obtain good linearity at high output levels. The circuit design is single-ended and consists of a two stage amplifier. Output FET gate periphery was selected to achieve up to +31 dBm third order intercept point (single device level) while keeping the channel temperature below 110 °C when subjected to the maximum environmental temperature. Each amplifier can be biased seperately via negative gate voltage in order to optimize power consumption against linearity.

The principal circuits of the ***LO Section*** are HMIC VCO and LTCC synthesized PLL as shown in block diagram (Fig. 2).

ALS has developed a range of HMIC VCOs in L, S, and C bands. The S-band version (up to 3.3 GHz) for this application uses a transmission line dielectric resonator to guarentee optimum stability over temperature without auxiliary compensation and low phase noise. Center frequencies are easily obtained by changing only the high-Q stripline resonator and some "lumped element" values. Due to the flexibility of the synthesized internal LO most typical frequencies in the range 1.5 to 3.3 GHz (e.g. multiples of 20 MHz) can be generated without changing reference oscillator. This benefit can greatly reduce non-recurrent procurement costs for quartz crystals utilized on in-house TCXOs and OCXOs. Custom crystals are, however, procured for specific Program frequencies. Referring to the block diagram below, the VCO is locked by a microwave PLL to a high stability reference signal generated by the internal reference oscillator. Division ratio inside the loop is set by a microwave synthesizer "chip" whose parallel load interface is hardwired to the required division ratio. This component boasts direct inputs up to 3 GHz, inherent RAD hardness due to a proprietary process, SEU immunity and low power consumption. This improved design replaces static, “flip-flop” type prescalers with consequent benefits in design flexibility, component cost reduction and significantly improved reproducibility.

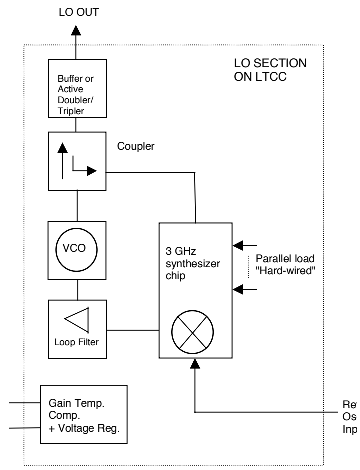

Fig. 2: Block diagram detail of LO Section

III. Reference Oscillator Description

The reference oscillator is based on a grounded-base configuration with an AT (or SC for OCXO)-cut quartz crystal resonator oscillating in fifth overtone mode; its angle of cut is chosen to attain maximum frequency stability over the operating temperature range. Analog thermal compensation is necessary to guarantee ±1.0 ppm OFTR.

The Thermal Compensation Circuit drives a capacitance-variable-diode, or varactor. This circuit is a network of diodes and resistors that provide voltages vs. temp. functions summed with an op-amp providing final composite voltage function (approx. 6th order) across the varactor to compensate the typical quartz characteristic.

Conversion freq. Stability:

- ageing: ± 3.5 ppm standard ± 2.0 ppm option. (procured quartz)
- over temp.: ± 1.0 ppm
- over 10°C: ± 0.6 ppm
- initial setting: ± 0.5 ppm

For applications that require higher stability and lower close in phase noise an OCXO reference is foreseen. The LO module housing and associated circuits have been designed to accept both versions without modification to the module housing.

The OCXO boasts the following characteristics:

- DC Power at turn-ON: 3 W peak
- DC Power at steady state (+25°C): 1.7W
- Warm-up Time: < 6 min.
- Stability (-20 to +71°C): +/-0.1 ppm

- Aging (15 years): < +/-1.5 ppm
- Phase noise: @10 < -115 dBc
  @100 < -130 dBc
  @1K < -140 dBc
  @10K < -150 dBc
  @100K < -155 dBc

The following additional functions are included on the LTCC substrate:

- supply voltage regulation and filtering
- loop filter/amplifier
- gain compensation network
- microwave synthesizer chip

IV. ALENIA SPAZIO'S QUALIFIED LTCC PROCESS

Alenia Spazio has the capability to design and manufacture LTCC substrates with a fully space qualified process. ALS can also develop and produce the tools needed for the substrate production; in particular CAD facilities for the technological engineering of the circuit and a pattern generator for glass mask production. ALS facilities also produce the stencils for the printing of vias and the screens for the printing of conductors. Average substrate production time is 7 to 10 days compared to the 20 to 30 day processing time for thick film considering the same number of layers.

V. DOWN CONVERTER HYBRID MECHANICAL DESIGN

RF converter chain, MPLL circuits, and voltage regulation are all integrated on a ceramic multi-layer substrate (Fig. 4).

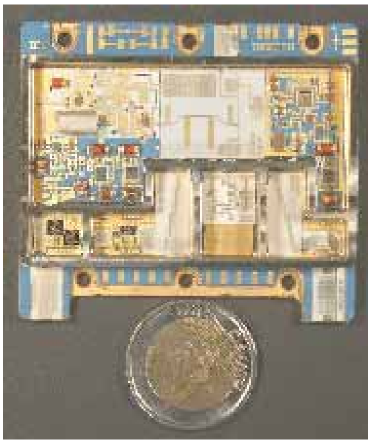

Fig. 4: Hybrid Down conv. EQM on LTCC

The top layer mounts all naked-die components using "chip-and-wire" technology. Hermeticity is obtained "locally" with brazed Kovar ring and laser-sealed lids. The "rings" also form cavities dimensioned below cut-off thereby reducing ripple due to parasitic coupling and improving isolation between RF and IF sections. ALS has developed and manufactured the hermetic stripline transitions for RF IN/OUT connection and between cavities. In order to maintain a common substrate for all eventual Ku sub-bands ALS chose to maintain filter mixer and VCO circuits on standard thinfilm Alumina substrates that are then epoxied to the LTCC. These functional blocks can easily be re-configured depending on the program specific frequencies plans. Further re-configurability for applications in C-band (6 to 4 GHz) and Ku+band (18 to 12 GHz) are possible by changing not only the top-mounted thinfilm circuits but the MMIC chip set; again, without modification to either the LTCC substrate or Kovar ring. The Down converter hybrid is then mounted, together with reference oscillator, on the "front-side" of a double-sided aluminium module

The "back-side" of the housing contains the DC/DC converter Card optimized for medium efficiency, multi-output, low-noise applications up to 10 W (Fig. 3).

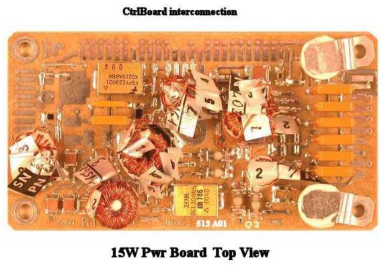

Fig. 3: 10W DC/DC Converter Assembly mounted "directly" to housing for improved heat transfer

VI. EQM PERFORMANCE

The overall performance requirements for the complete Receiver version are as follows:

INPUT FREQUENCY BAND :	13450÷13950 MHz
OUTPUT FREQUENCY BAND :	11700÷12200 MHz
GAIN :	55 dB± 1dB
NOISE FIGURE:	1.5 dB max
GAIN VARIATION OVER FREQ. :	0.8 dBpp
GAIN VARIATION OVER TEMP. :	1 dBpp
3rd ORDER INTERCEPT POINT:	30 dBm min.
L.O. FREQUENCY :	1750 MHz
L.O. STABILITY:	±0.1 ppm B.O.L.
	±2.0 ppm EOL
POWER CONSUMPTION :	9 W max (with OCXO)
OVERALL DIMENSIONS	138 x 57 x 94 mm
MASS :	500 gr max

Bandpass gain and outside loop bandwidth phasenoise measurements performed on the LTCC Down converter EQM are included in (Figures 5 & 6, respectively). In addition, Noise Figure of the Hybrid LNA front-end as part of the Receiver unit EQM is presented in the plot of (Fig. 7).

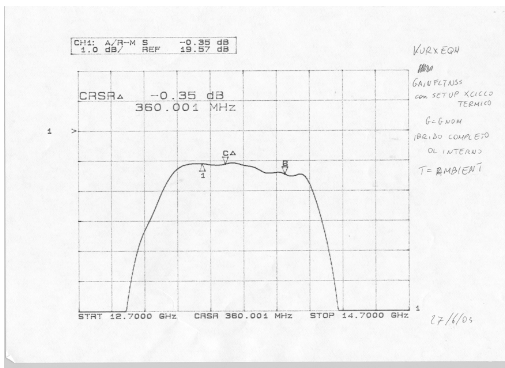

Fig. 5: Down converter passband gain = 22 dB

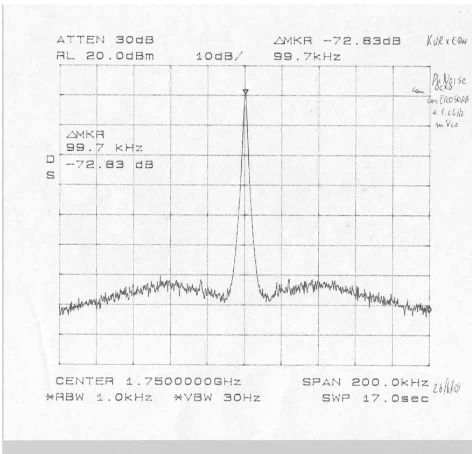

Fig. 6: Measured phase noise at 100 kHz offset = -102 dBc

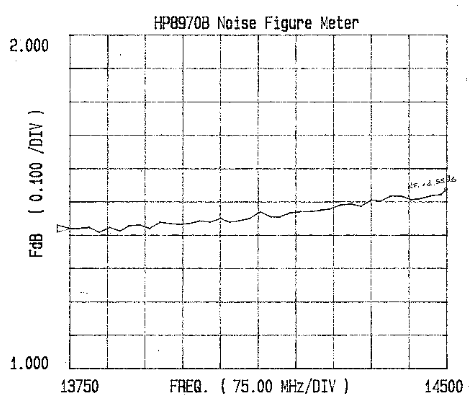

Fig. 7: Measured Ku band noise figure of hybrid LNA front-end = 1.5 dB (typical) at ambient Temp.

VII. Conclusion and Future Work

A highly integrated down converter hybrid module has been presented. The EQM is presently under test and has already demonstrated significantly reduced production lead-time and consequent cost reduction. Typical performance of the down converter chain was obtained with minimal operator dependent alignment. An EQM of the complete unit including hybrid LNA front-end (for the Receiver version), DC/DC converter, and reference oscillator is scheduled for completion during Summer 2003 (refer to Figures 8, 9 & 10). LTCC technology has been shown to offer significant advantages not only in reducing both production costs and lead-time but minimizing overall unit mass and dimensions. This means that for a given payload mass and volume a greater number of converter units can be allocated responding to the market demand for ever increasing data link capacity on communication satellites.

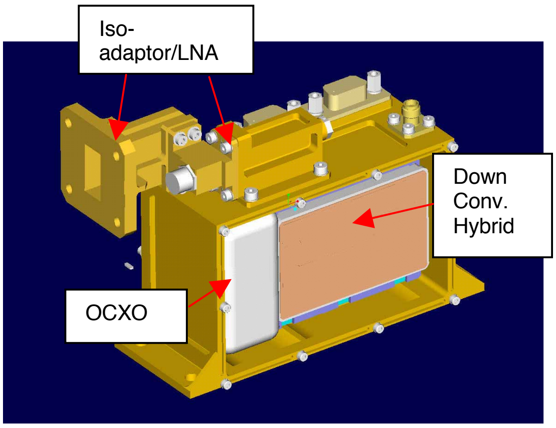

Fig. 8: Complete Receiver Assembly

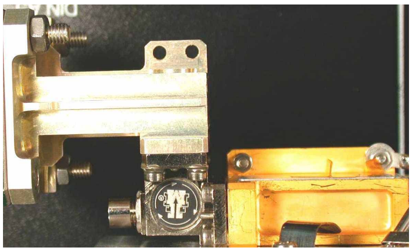

Fig. 9: Photo of LNA hybrid front-end EQM with Iso-adaptor in WR-75

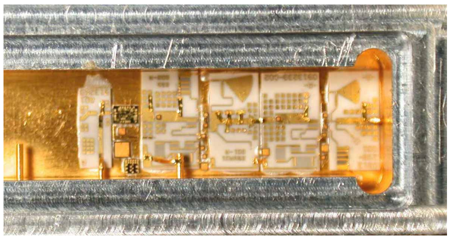

Fig. 10: Photo of LNA hybrid EQM lownoise gain stages

Acknowledgement

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References

[1] M.C.Comparini, C.Leone, J.R. Linkowski, P.Ranieri, A.Suriani, "Next Generation Payload Equipment for Broadband Multimedia Satellite Communication" *GAAS 2001 - 31st European Microwave Conference*, London, UK, September 2001.

[2] M.C.Comparini, S.Di Nardo, C.Leone, P.Montanucci, P.Ranieri, A.Suriani, M.Tursini, "Advanced Components for Channelization and Reconfiguration in Broadband Satellite Repeaters", *ESA Microwave Technology and Techniques Workshop*, Noordwijk, Netherlands, Oct 2002.