

A 2-18GHz ESM Receiver Front-End

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This paper describes the design and evaluation of a dual channel 2-18GHz front-end module for Electronic Support Measures (ESM) applications. The module converts signals anywhere in the 2-18GHz frequency band to an IF suitable for digitisation. It includes limiting, filtering and amplification. The frequency conversion is realised by an intermediate transition to a frequency around 22-23GHz. The module contains 12 GaAs MMICs including 5 different designs 4 of which are full custom parts. It exhibits a gain of 10dB, a noise figure of around 7dB and a typical output 1dB compression point of -10dBm.

INTRODUCTION

ESM for electronic intelligence (ELINT) applications places stringent fidelity demands on a receiver over a multi-octave bandwidth. Practical solutions must not only meet the electrical specification but also be compact, robust and immune to microphonic effects and thermal fluctuations.

A novel ESM module is described that meets these requirements and provides a dual channel architecture with close amplitude and phase matching. The module may not only be used as a generic front-end for conventional ESM applications but also for monopulse or interferometry techniques. The amplitude and phase match that can be achieved between the channels is the fundamental limitation on the accuracy of the bearing assessment for direction finding techniques.

The module is essentially a low noise, broadband, dual channel downconverter that converts signals anywhere in the 2-18GHz band down to an IF suitable for digitisation.

DESIGN AND OPERATION

The broadband downconversion is realised by first upconverting, using a swept LO, to around 22GHz and then downconverting this 22GHz signal to the required IF. A block diagram of the module is shown in Figure 1.

Although all of the MMICs within the module cover the complete 2-18GHz simultaneously, this is not the case with the external antennas and the band is split into two. The module thus has four inputs, a dual channel pair to cover the low part of the band (2 to 6.5GHz – band 1) and a second dual channel pair to cover the high part of the band (5 to 18GHz – band 2). It is vital that the two channels of each sub-band are well matched, in terms of amplitude and phase balance, if optimum performance is to be achieved.

The module comprises a total of 12 GaAs MMICs (5 different types) together with mixed printed/lumped element filtering, bias conditioning and control circuitry. Four of the MMICs were full custom designs realised as part of this development.

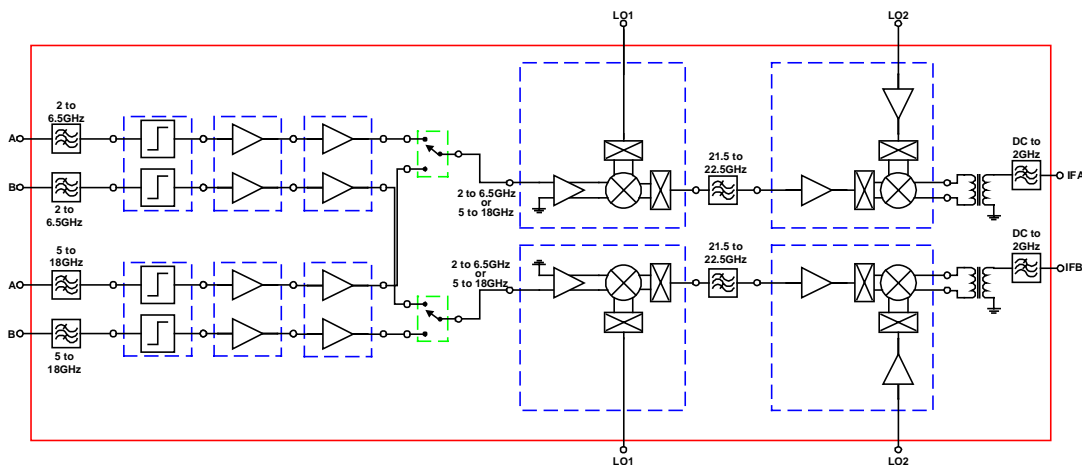


Figure 1: Block diagram

The full custom MMICs are shown in blue outline in the block diagram of Figure 1 and are:

- 0.5-20GHz dual channel limiter
- 2-18GHz dual channel LNA
- 2-18GHz upconverter to 22-23GHz
- 22-23GHz downconverter to 0.1-1GHz

Photographs of these MMICs are shown in Figure 2 to Figure 5. Details of the design and performance of the limiter can be found in [1] and the upconverter in [2]. The SPDT MMICs, shown in green outline in Figure 1, are commercially available parts. A dual channel version of this MMIC has now also been developed and is reported in [3].

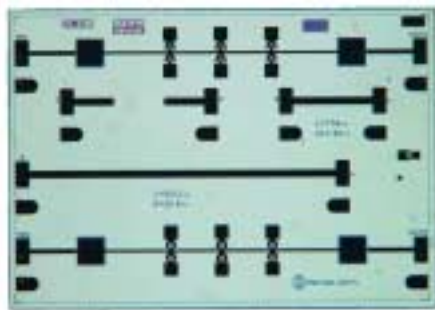


Figure 2: Photograph of the dual channel 0.5 to 20GHz limiter MMIC

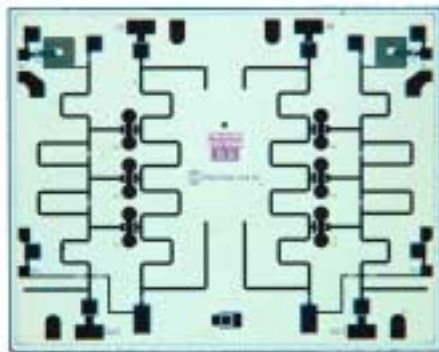


Figure 3: Photograph of the dual channel 2 to 18GHz LNA MMIC

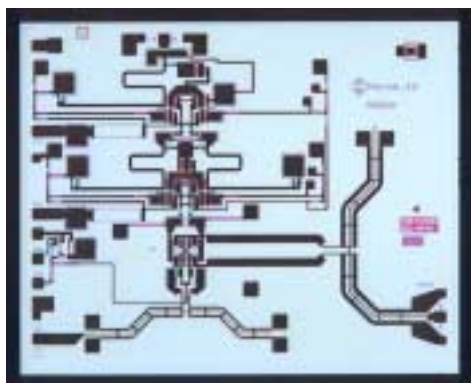


Figure 4: Photograph of the 2 to 18GHz upconverter MMIC

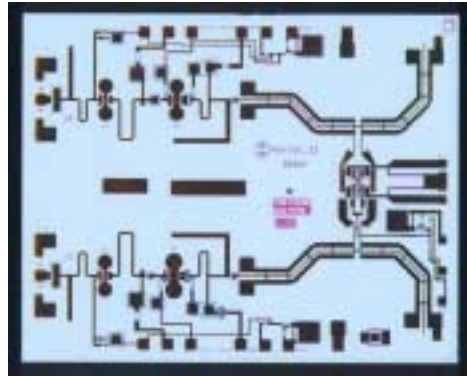


Figure 5: Photograph of the 22 to 23GHz downconverter MMIC

The module has a Band Pass Filter (BPF) at each input. For band 1 the filter is a mixed printed/lumped design with a 2 to 6.5GHz passband. For band 2 it is a printed design with a 5 to 18GHz passband.

After the input BPF the module realisation is identical for both the bands. The first component is the dual channel limiter MMIC that protects the components that follow it from damage due to high level input signals. This was fabricated as a single die using the Triquint Texas commercially available Vertical PIN diode process (VPIN). A distributed topology was adopted with antipodal PIN diode pairs in a shunt configuration. The measured performance shows a small-signal insertion loss of less than 0.8dB from 0.5 to 20GHz with excellent channel matching. The limited output power (at 10dB saturation) measures between 15 and 16.5dBm and the CW power handling is 2W.

After the limiter two dual channel LNA MMICs are used to ensure the module has an acceptable noise figure. The LNA was realised on a 0.25 μ m Pseudomorphic High Electron Mobility Transistor (PHEMT) process from Triquint Texas. A three transistor distributed topology was adopted resulting in a gain of 10dB and a mid-band noise figure of 2.5dB.

Following the LNAs, two SPDTs route either the band 1 or the band 2 pair of signals to a pair of 2-18GHz upconverter MMICs. These translate signals anywhere in the 2-18GHz frequency band to 22-23GHz for subsequent downconversion. The required LO range is 23-41GHz. The RF, LO and IF ports of the IC are all single ended but the internal mixer is balanced at all ports and single-ended to differential conversion is realised on-chip, using novel broadband active and passive balun structures. This IC has also been fabricated on the Triquint Texas' 0.25 μ m

PHEMT process and has a measured conversion loss of 7dB at 14GHz, rising to 10dB by 18GHz with an LO rejection of over 30dB.

After the upconverter a coupled line printed bandpass filter routes the signal to the downconverter MMICs. These were also fabricated on the 0.25 μ m PHEMT process and comprise a resistive mixer with on-chip RF and LO amplification. The conversion gain of the downconverter MMIC is around 5dB.

The IF output of the downconverter is differential and an off-chip wire-wound balun is used to transform this to a single ended signal. A mixed lumped/distributed low pass filter is then used to remove out of band spurious products before the signal is routed to the IF output connector.

MODULE REALISATION

The module houses two boards; a microwave board containing the GaAs MMICs and printed filters and a control board containing the bias conditioning and control circuitry.

Brass backed Rogers RT/Duroid 5880 with a 0.01" thick substrate height was selected for the microwave board. The MMICs are mounted on to the surface of the board along with 0402 SMT components for de-coupling. Interconnection between the board and the MMICs is made with 0.001" diameter gold wire bonding.

The control board is a low-cost multi-layer FR4 PCB. This is positioned above the microwave board within the module and connections between the two boards are made with spring-loaded "pogo pin" connectors. An internal metal layer of the FR4 board is connected to the module housing, and so to the RF ground, at the board edges. The underside of the FR4 board (sitting directly above the microwave board) is left clear of conductor. The bare FR4 is a lossy material within the microwave cavity that helps suppress potential box-mode resonances. The grounded "roof" of the module is actually the internal ground layer within the FR4 board.

The module housing is gold plated aluminium and measures approximately 180mm x 100mm x 23mm, including a separate 3mm flat lid. An exploded view of the complete assembly is shown in Figure 6 and a photograph of one of the modules is shown in Figure 7. The FR4 control board, at the top of the photograph, sits above the microwave board inside the housing.

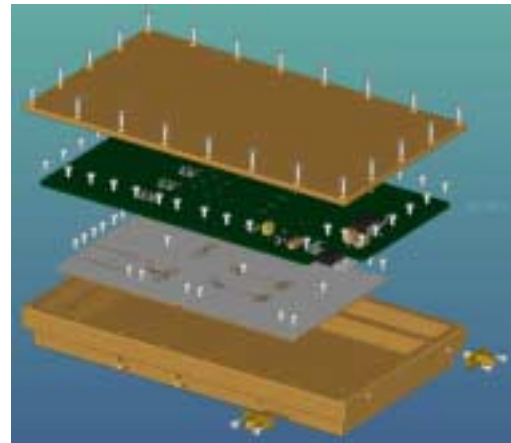


Figure 6: Exploded view of the module

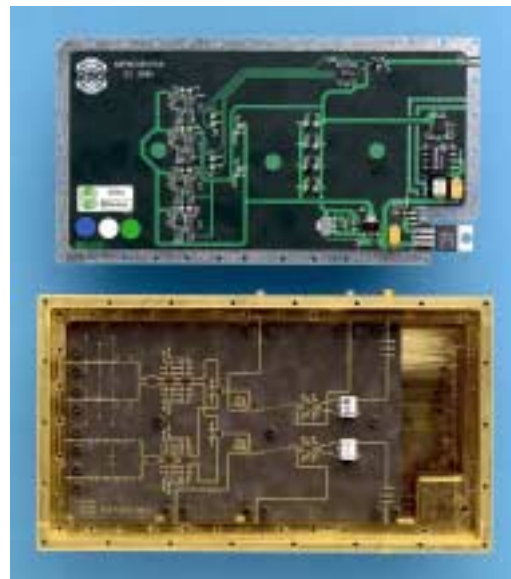


Figure 7: Photograph of module

MODULE REALISATION AND MEASURED PERFORMANCE

In all of the measured results reported here, unless otherwise stated, LO2 was set to 0dBm and LO1 was set to +10dBm. LO2 drives the downconverter, which has an on-chip LO buffer amplifier, hence its level can be much lower than that of LO1.

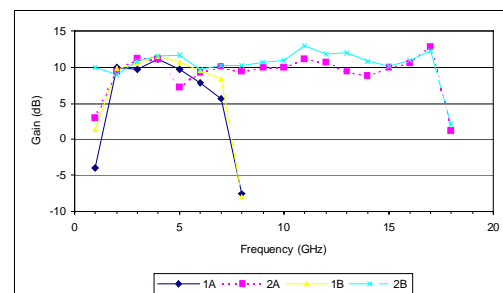


Figure 8: Measured conversion gain

Figure 8 is a plot showing the measured gain of each channel (A and B) of the module for both bands (1 and 2). A gain of around 10dB is

exhibited across each band. Gain match between channels is good but some variation is observed and this is due to the production spread in the conversion gain of the upconverter and downconverter MMICs as these are single channel parts.

The input return losses for both channels is shown in Figure 9 for band 1 and Figure 10 for band 2. Matches are generally better than 10dB and show good agreement between channels.

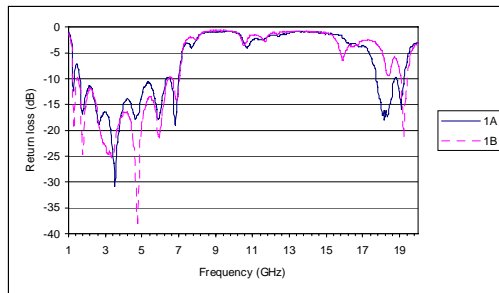


Figure 9: Measured band 1 return loss

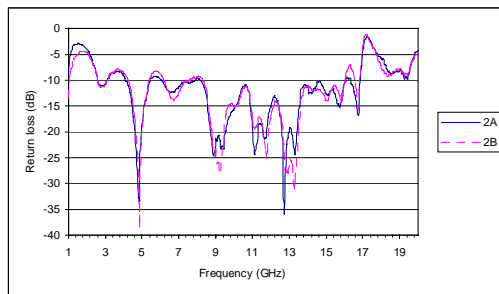


Figure 10: Measured band 2 return loss

The measured noise figure of the receiver versus frequency is plotted in Figure 11 and is around 7dB across the band.

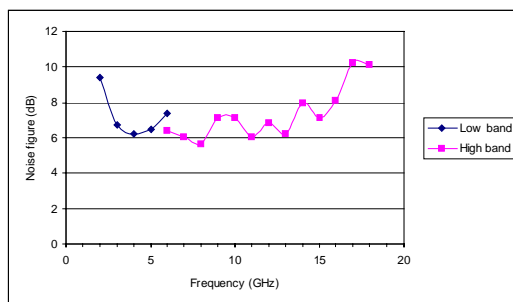


Figure 11: Measured noise figure

Power compression measurements were made for both channels and both bands at a range of input frequencies. The results are summarised in Figure 12 and show the input referred 1dB gain compression point to be around -10dBm to -12dBm , although falling slightly at the top end of the band.

The gain of the module increases with LO1 power level because the conversion loss of the upconvert mixer reduces. A plot of gain versus LO1 power level, for an input frequency of

12GHz, is shown in Figure 13. The gain flattens as the LO1 level reaches 14 to 15dBm.

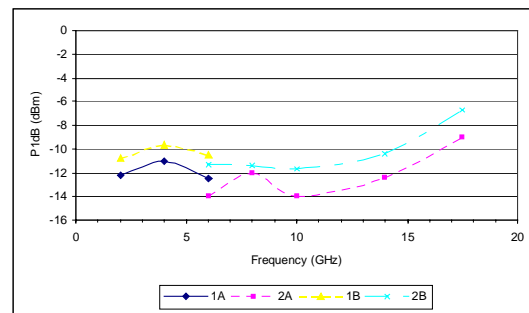


Figure 12: Output referred P-1db point

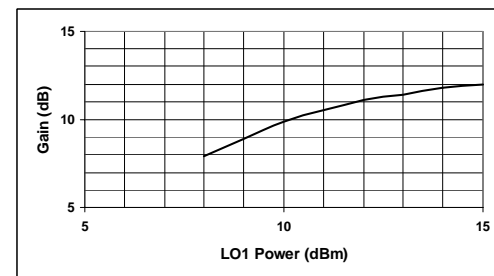


Figure 13: Gain versus LO1 power level

Similar measurements on the variation of gain with LO2 power level showed very little variation for levels of above -3dBm .

SUMMARY

The design and evaluation of a dual channel 2-18GHz front-end module for ESM applications has been described. It converts signals anywhere in the 2-18GHz frequency band to an IF suitable for digitisation. It includes limiting, filtering and amplification.

The measured performance of the module shows a gain of 10dB, a noise figure of around 7dB and a typical output 1dB compression point of -10dBm .

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REFERENCES

- [1] L.M.Devlin, A.W.Dearn, P.D.L.Beasley "A Monolithic, Dual Channel, 0.5 to 20GHz Limiter", Proceedings of the European Microwave Conference 2000, pp 172-175
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- [3] S.Williamson, L.M.Devlin, G.A.Pearson, P.D.L.Beasley, "A Monolithic, Dual Channel, DC to 20GHz SPDT", proceedings of the Wireless Design Conference, May 2002