

# X BAND MMIC direct 8 Phase Shift Keying modulator for high data rate earth observation applications

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**Abstract - We present a new topology of 8 Phase Shift Keying modulator that allows achieving a very high accuracy of 0.4dB and 3° on the 8-8.4 GHz band in the -10°C to +55°C temperature range, with only one tuning voltage and a very low consumption.**

The device has been manufactured on the D02AH OMMIC GaAs PHEMT process but has been transposed to other FET foundries. This new topology is covered by a patent [1].

It has been transferred and improved by Alcatel Space Industries, to fit industrial quality requirements, in order to define a commercial product of high data rate transmission channel for micro-satellites.

## I DESCRIPTION

For future spatial communication systems up to 155 Mbps or more, it will be imperative to improve the coding part of the transmission channel in order to limit consumption, mass and spectral occupation. One emerging solution for space applications is Trellis Coded Modulation. In the frame of earth observation satellite, the CNES has led studies on high rate telemetry channels that could be easily transposed to telecommunication applications.

To reduce mass and consumption Trellis Coded Modulation has been developed. This code becomes very efficient with high states number modulation like direct 8 Phase Shift Keying modulator (8 PSK).

In order to avoid a linear modulator, associated to Digital Analogic Converter that increases the consumption budget, we have worked on a NRZ 8 PSK modulator.

The scheme of this new 8 PSK modulator is described on figure 1. It's composed of a distributed line equivalent to the one of a distributed amplifier at the input of the circuit providing four signals of equal amplitude and a relative phase shift of 0°, 45°, 90° and 135°. These

four signals drive four 180° BPSK and are summed in phase by Wilkinson couplers.

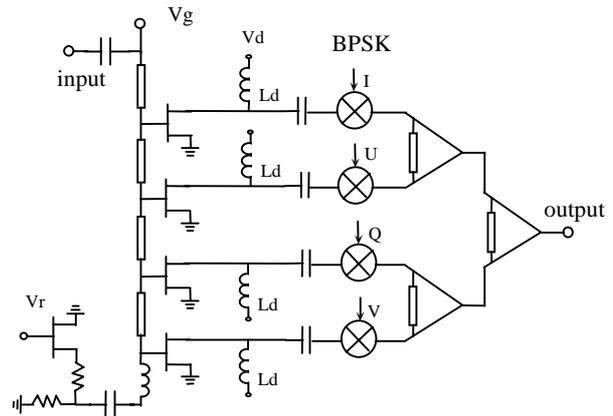


Fig 1 : electrical scheme of the modulator.

The four BPSK modulators have a balanced cold FET structure and their phase states are driven by two complementary digital input signals. This structure provides two 8 PSK concentric constellations (cf figure 2).

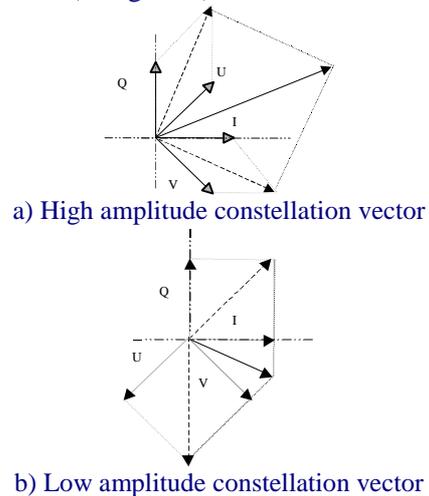


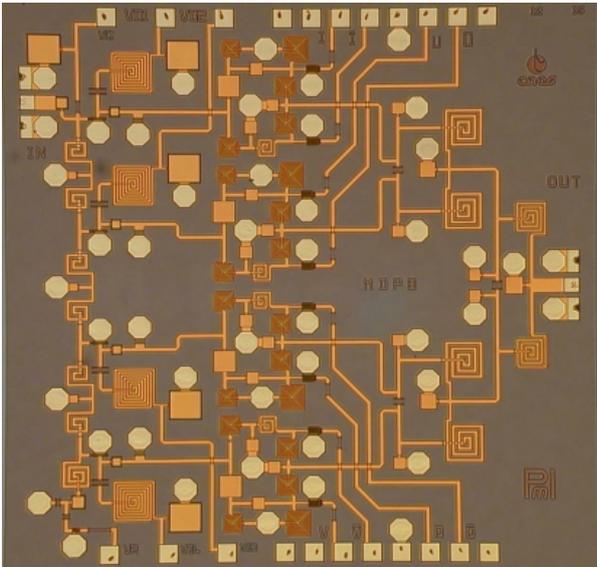
Fig 2 a) and b) : signal construction

When consecutive vectors are all 45° phase shifted, the output signal amplitude is maximum. Otherwise (in the exemple of the figure 2 by

shifting in the opposite state the U modulator) the amplitude is 7.66 dB lower. A simple transcoder added in the data processing is enough to address the highest gain constellation. The circuit is represented on figure 3.

The input distributed line can be modeled by cascaded LC cells. The inductances are realized by microstrip inductors and the capacitors by MIM components or by the equivalent input impedance  $C_{gs}$  of the four biased PHEMTs. The values of these elements are chosen to provide a  $45^\circ$  phase shift between two consecutive transistors and to obtain a  $50 \Omega$  characteristic impedance.

A yield analysis has shown that this resistive termination of the distributed line was the most critical component, so we decided to replace it by a variable resistor made with a cold transistor.

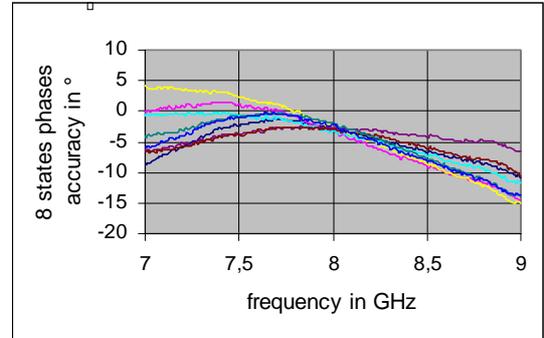


**Fig 3 :** The chip is  $3 \times 3 \text{ mm}^2$  and the consumption is lower than 70mW

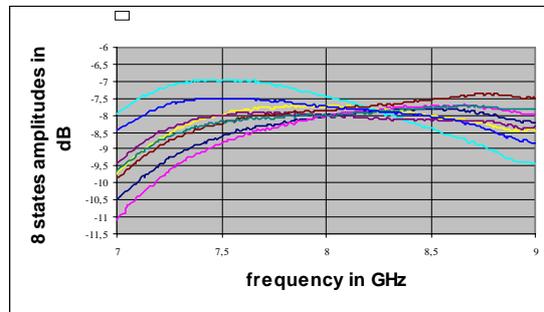
The high input impedance of the PHEMTs doesn't load the line and allows having a small difference between the four vectors levels. On the one hand these active components give a high isolation between the BPSK elementary modulators on the input of the complete circuit. On the other hand, the isolation is given by the Wilkinson couplers arborescence. By these ways, the commutation of one BPSK doesn't affect the others and doesn't change the matching of the circuit. That also reduces the buffer stages between

the modulator and the local oscillator needed to protect this one against pulling effects.

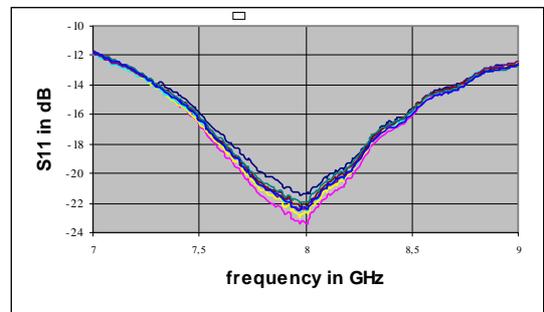
## II MEASURED RESULTS



a) phases of the different states



b) amplitudes



c) input matchings

**Fig 4:** results of the 8 states of the constellation

The curves above have been measured at ambient temperature on an encapsulated circuit and present optimal performances of **0.4 dB and  $3^\circ$ pp** at 8.2 GHz. This optimal point can be adjusted in the 8-8.4 GHz bandwidth by tuning the common  $V_{gs}$  voltage and so changing the four biased transistors  $C_{gs}$  value. Without any tuning we obtain 0.8 dB and  $4^\circ$ pp on the whole 8-8.4 GHz in the  $-10/+55^\circ\text{C}$  temperature range. Insertion losses are limited to -7dB.

The matching results have been retrosimulated at **20 dB** at the input and **15 dB** at the output taking the bonding effects into account. In order to fit standard measurement elements, the bonding wires used were longer than simulated, that's why the input matching is a bit higher.

At ambient temperature, on one wafer, we have obtained up to 70% of electrical manufacturing efficiency.

This circuit has been measured from  $-10^{\circ}\text{C}$  to  $+55^{\circ}\text{C}$  and its performances are very stable with the two digital levels 0V and  $-1.5\text{ V}$  for  $V_p = -0.9\text{V}$ .

### III COMPLETE SYSTEM MEASUREMENTS

The complete bench is representative of a satellite to earth downlink. We present on figure 5 the Multidimensional 255/239 Reed Solomon Concatened Trellis Coded Modulation results. The first curve is the theory, the second one is obtained at IF frequency with 720 MHz reference modulator and the third one represents the whole system performances, including all microwave circuits.

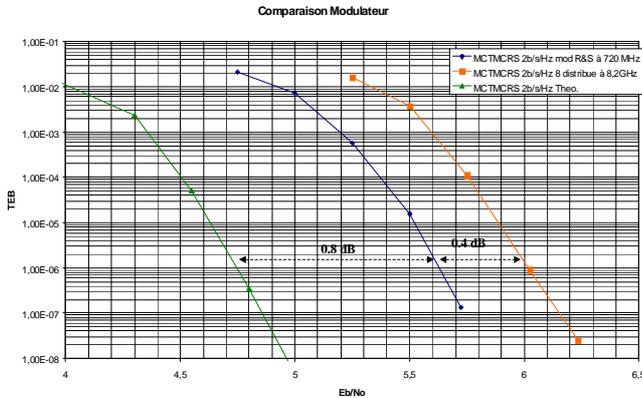


Fig 5 :BER versus  $E_b/N_0$

The degradation due to microwave components (sources, SSPA, filters, modulator...) are only 0.4 dB with a very compressed SSPA.

The figure 6 shows the signal spectrum at the modulator output. The first lobe is 100 MHz wide (100 Mbits/s) for a 93.3Mbits/s useful data rate. With a 100 kHz resolution bandwidth, no interlobe line is visible. The second lobes are symmetric and 13.5 dB under the main one.

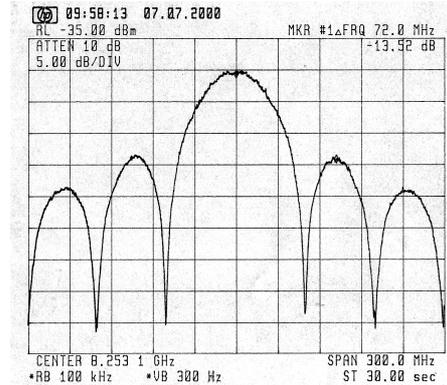


Fig 6 : output modulator signal spectrum

### IV INDUSTRIAL APPLICATION

Based on CNES breadboard activity, ASPI is currently developing a high data rate, X band telemetry transmitter for space application. The system architecture and the MMIC modulator have been provided by CNES. Data rate up to 155 Mbits/s with one modulator (and up to 620 Mbits/s with four modulators in parallel) can be achieved.

The DEMETER satellite is the first application of this telemetry payload. The aims of this satellite are :

- Observing the electromagnetic emissions due to earthquakes or volcanic eruptions, the ionosphere and high atmosphere perturbations and the associated particles precipitations.
- Validating new concepts and new technologies developed by CNES.

This telemetry payload is compatible with others scientific or commercial applications.

### V CONCLUSION

We have demonstrated the feasibility of a very high precision 8 PSK direct modulator. This topology is very stable in temperature and this design is easily transposable to others frequencies and technologies. It will be implemented in a flight model telemetry payload for a scientific micro-satellite.

### VI REFERENCES

- [1] L. Lapierre, C. Boulanger, C. Zanchi. « Circuit électronique modulateur par déplacement de phase à structure distribuée », patent n° PCT WO-98.38730 in the name of Centre National d'Etudes Spatiales.