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26 GHz MMIC linear vector modulator

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ABSTRACT

This paper reports on the design and measurement results of a monolithic linear vector modulator for the 25.5-27.5 GHz frequency band. This is a parallel type of I,Q modulator. The design is based on the use of cold PHemts to realise the linear modulation. Two versions have been made. In the first case the I and Q modulators are single balanced , while in the second case double balanced modulators are used. The 90 and 180 degree couplers as well as an output buffer are included on the chip. Chip size is 3mm x 4mm.

1. INTRODUCTION

Present designs using MIC modulators need to be tuned for specific allowable frequencies within the DRS(Data Relay Satellite) Ka-band return IOL(Inter Orbit Link) frequency plan after those frequencies are allocated to the UST(User Service Terminal). The aim of this ESA supported study was to develop a MMIC direct modulator which would permit to work over the entire frequency range without retuning and this for a wide range of data rates. Direct modulation precludes the possibility of introducing post modulation shaping filters, but use of a linear vector modulator will allow baseband shaping. Further objectives were to minimise the parts count, mass, volume and power consumption of a device realised in space qualifiable technologies. The main requirements were: 3 dB modulation bandwidth larger than 150 MHz, quadrature imbalance less than 2 degrees, amplitude imbalance smaller than 0.3 dB, carrier suppression better than 30 dB and harmonics of the modulating frequency 35 dB below the wanted sidebands.

Some examples of monolithic linear vector modulators are given in references [1] to [4]. In most cases the operating frequencies of these direct modulators were below Ka-band.

2. MODULATOR TOPOLOGY

The modulator uses the "classical" I, Q modulator topology: the input RF signal coming from the LO is split by a 90 degree coupler into two orthogonal components (Figure 1). These two vectors are modified in amplitude and sense by a pair of biphase modulators. The output of these modulators is combined and presented to the input of an amplifier stage which serves as an output buffer.

Two versions were realised: one with single balanced biphase and the other with double balanced biphase modulators.

The single balanced biphase modulator consists mainly of a 180 degree coupler, two amplitude modulation cells and a combiner. In a single balanced configuration of the biphase modulator very stringent requirements are imposed upon the 180 degree coupler. This knowledge made us to also consider a double balanced topology which would allow relaxed constraints on the couplers.

3. DESIGN

For the two versions the carrier signal is divided in quadrature through a Lange coupler. The wideband behaviour and the compactness of the Lange coupler for this frequency band made it a natural choice.

The 180 degree coupler for the single balanced version consists of a Wilkinson divider followed in each branch by a Lange coupler. One Lange coupler is loaded with short circuits and the other one with an open circuit to realise the 180 degree phase difference. For the double balanced version we needed a more compact design, as two 180 degree couplers are required and we wanted the two versions to fit in the same chip size. Again a Wilkinson was used, but this time it was followed in one branch by a low pass and in the other branch by a high pass circuit to obtain the 180 degree phase difference. For this coupler electromagnetic simulations have been made with the HP-Momentum software (version 2.0) for the parts where the electrical model could be inaccurate: the Wilkinson divider and the high pass section without the via hole. A comparison was made with the results provided by a HP-MDS simulation for the 20 to 30 GHz frequency band. There was a good agreement between the two types of results.

As we had to work with very tight specifications , we decided to include amplitude and phase correcting circuits to compensate for process variations and model inaccuracies. The amplitude tuning circuit is based on the use of a parallel connected cold PHemt. Its impedance is changed by a control voltage applied at the gate. To minimise the phase variation the capacitive part of this impe-dance is partially cancelled by a parallel inductance. The phase tuning circuit uses a series varactor diode matched on 50 ohm loads. The amplitude variation is negligible over a 10° range. For the two versions amplitude and phase correcting circuits were inserted in each branch of the Lange coupler. In the single balanced version amplitude and phase correction was also foreseen in each branch of the 180 degree coupler. For the double balanced version which is less critical, only phase adjusting circuits were included.

As amplitude modulation cells a serial cold PHemt is used. The modulating voltage is applied to the gate. For the non-linear modelling of the cold PHemts a modified Tajima model elaborated by Alcatel Lemmic was used [5]. The recombined I and Q modulated signals are amplified by an output buffer. This is a single stage amplifier with a 8.5 dB gain.

The layout is shown in figure 2 for version A(single balanced) and version B (double balanced) .

4. MEASUREMENTS

A short overview of the main results on the test structures.

(All these measurements were done on chip with a microwave wafer probe station)

The input 90 degree hybrid coupler (Lange coupler) has maximum 0.3 dB amplitude imbalance and less than 1 degree phase deviation. These results are very near to the simulated.

The 180 degree coupler used in the single balanced biphase modulator: an amplitude imbalance of 0.8dB and phase error less than 13 degrees. Here we have a rather important deviation from the expected results, but with the help of the amplitude and phase correction circuits there should still be a possibility to tune the biphase modulator.

The 180 degree coupler for the double balanced biphase modulator version: an amplitude imbalance of 0.7 dB and a phase error less than 2 degrees in the 25.5-27.5 GHz band. This is a very good result. In principle the double balanced biphase modulator should not require any tuning to function within the specification.

The buffer amplifiers showed a gain of approximately 8.5 dB, which is somewhat higher than expected.

The next tests were the static testing of the dual phase modulators. The results are valid for the full bandwidth.

Version A: without tuning, the amplitude imbalance and phase deviation were more important than expected from the measurement results of the 180 degree coupler. By a judicious choice of the gate bias voltage and tuning the amplitude and phase control voltages following results were obtained:

amplitude imbalance: $< \pm 0.2$ dB

phase deviation: $< \pm 0.5$ degrees

Version B: also in this case the amplitude imbalance and phase deviation without tuning were more important than should be expected from the measurement results of the 180 degree coupler. In fact the very good results of this coupler shouldn't require any tuning of the biphase modulator. To explain these deviations we had to come to the conclusion that the cold PHemts which are used as "switches" did not have as uniform characteristics as you normally would expect to be the case for devices in a same chip. This conclusion was confirmed by deliberately introducing in a simulation of a biphase modulator, PHemts with different threshold voltages.

before tuning:	amplitude imbalance	< 1 dB	after tuning:	amplitude imbalance:	< 0.2 dB
	phase deviation	< 7 degrees		phase deviation:	< 2.2 degrees

Test results of the complete linear vector modulator.

Without tuning the static constellation diagram (4 phase states) of version A was severely distorted. In trying to tune the separate dual phase modulators we observed that the settings of one biphase modulator seriously influenced the other biphase modulator. This made the tuning very difficult. A satisfactory procedure has not been found yet. The best result which was up to now obtained was: amplitude imbalance < 2 dB phase imbalance $\pm$ 4 degrees

For version B the static constellation diagram without tuning was still distorted but not so severely as for version A. Tuning of the dual phase modulators was also less problematic as the mutual influence is less pronounced due to a better isolation. For large signal static on chip testing (the input RF power is 11dBm) with the Wiltron network analyser we obtained following results after tuning for the constellation of a QPSK (Quadrature Phase Shift Keying) over the complete band (25.5-27.5 GHz):

- amplitude imbalance: 0.7 dB
- phase imbalance: -4 to +2.5 deg

over the restricted band (26-27.5 GHz):

- amplitude imbalance: 0.7 dB
- phase imbalance: -2.5 to +2.5 deg

These results are presented in figure 3.

Some improvements can probably still be realised by a fine tuning procedure or on some samples.

For the next presented tests we mounted one sample in a test fixture made of Kovar.

In a first instance we wanted to verify the linearity of the separate biphase modulators on the output spectrum. Sinusoidal modulating signals were applied to one of the biphase modulators, to the other one the static offset voltages were applied.

Over the full band a carrier rejection of 22 dBc and a harmonic rejection better than 31 dBc could be reached. Carrier rejection is very sensitive to the value of the offset voltage. The main harmonic components are those resulting from the third harmonic (fRF $\pm$ 3 * fmod) and to a lesser extent the second harmonic (fRF $\pm$ 2 * fmod).

Figure 4 shows the output spectrum for quadrature sinusoidal modulating signals of 1 MHz applied at the I and Q inputs. At the carrier frequency of 26.45 GHz a 32 dB image rejection is obtained. This image rejection further improves towards the low end of the frequency range and reduces to 25 dB at the high end (27.5 Ghz).

Bandwidth measurements performed with a network analyser showed a 3 dB modulation bandwidth larger than 500 Mhz.

We did also hard-keyed tests. The constellation was displayed with the help of a HP8981B vector modulation analyser. We measured the amplitude imbalance and the quadrature error with a digital modulating signal of 5Mbit/s.

Over the band the amplitude error is less than 1.15dB and the quadrature error is maximum 5.3 degrees (see figure 5).
With the microwave transition analyzer HP71500A we measured the transition times as well for the I biphase modulator as the Q biphase modulator. When measuring one of the biphase modulator, one was excited with a 1010101010 sequence at 5Mbit/s and the other was polarised with the offset voltages. The transition times are in the order of 1nsec.

5. CONCLUSIONS

On the separate test structures in general very good results were obtained.
Inhomogenities of the cold device characteristics have a serious influence on the results of the dual phase modulators and the linear vector modulators.
Version A (based on the single balanced dual phase modulator) is very difficult to tune due to a coupling between the two constituting dual phase modulators.
Version B (based on the dual balanced phase modulator) gives better results after tuning. These results are very close to the specified targets.
The project demonstrated the possibility of realising a direct linear vector modulator at 26 Ghz on a MMIC chip. Further improvements are possible by the reduction in spread of cold device parameters and by some design modifications.

6. ACKNOWLEDGEMENT

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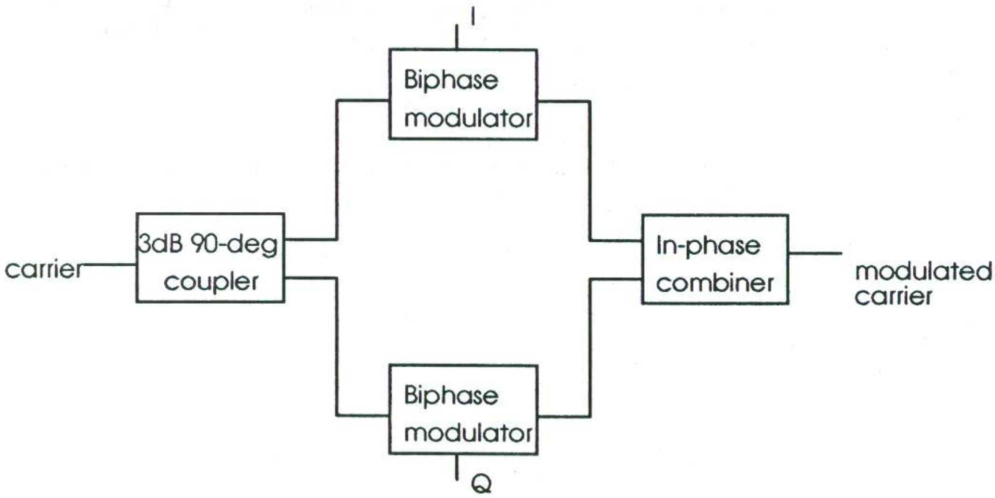


Figure 1: Parallel connected I Q modulator

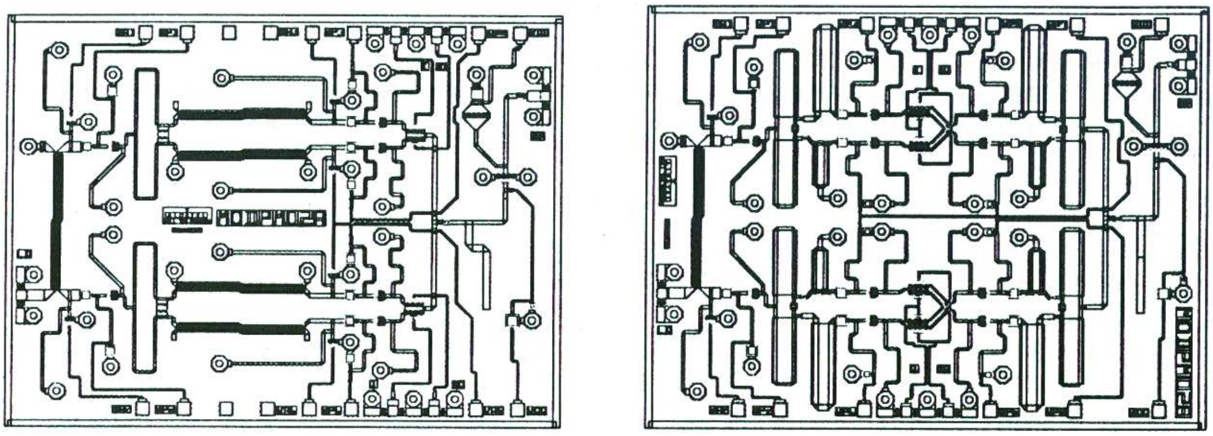


Figure 2 Linear vector modulator: version A (single balanced/left) and version B (double balanced/right)
The two drawings are not represented with the same scale.

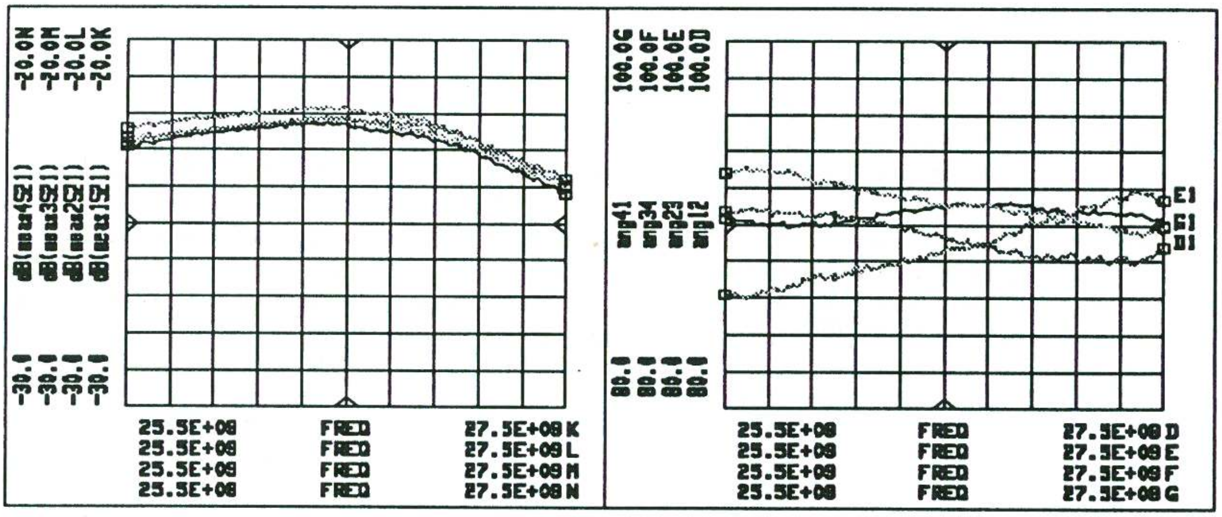
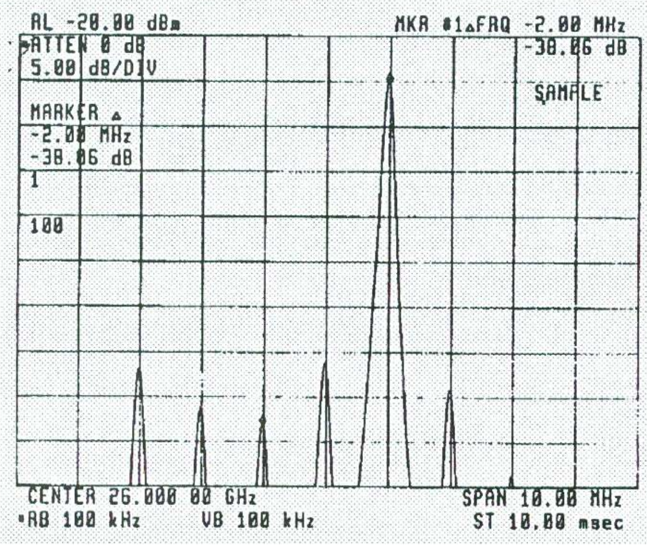
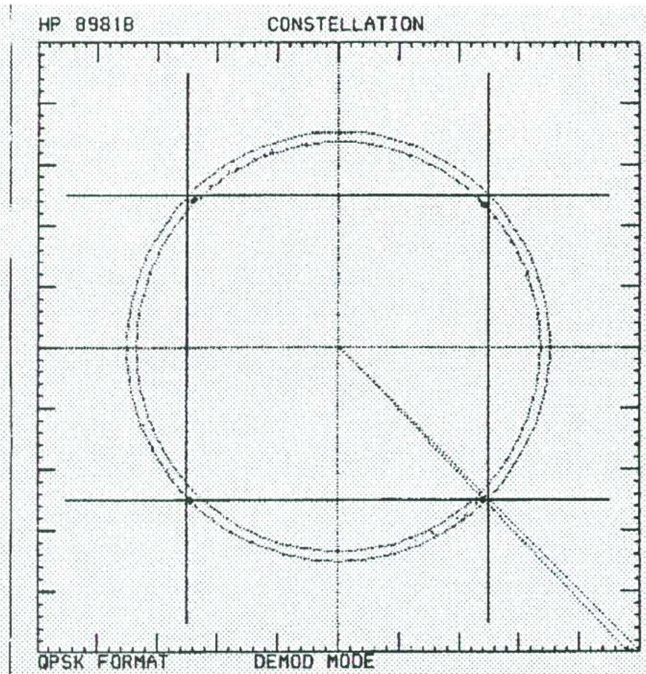


Figure 3 QPSK static constellation. Left: the S21 in dB for each state vector. Right: phase relationship between the 4 state vectors.



Frequency	Pmod dBm	Imrej dB	Crej dB	Hrej dB
25.5GHz	-26	42.2	29	32
26 GHz	-25	38	31.5	32
26.45GHz	-24	32	29	32.5
27GHz	-24.3	27.6	26	31.6
27.5GHz	-26	25	23	32

Figure 4 Output spectrum with quadrature sinusoidal signals at 1Mhz. On the diagram the carrier frequency is 26 Ghz.



Frequency	Δα dB	Δϕ degrees
25.5GHz	0.43	2.3
26 GHz	0.77	3.2
26.5GHz	0.4	1.3
27GHz	1.02	3.9
27.5GHz	1.15	5.3

Constellation: amplitude imbalance and quadrature error

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Figure 5 QPSK constellation with a digital modulating signal of 5Mbit/s. The carrier frequency on the diagram is 26.5GHz.