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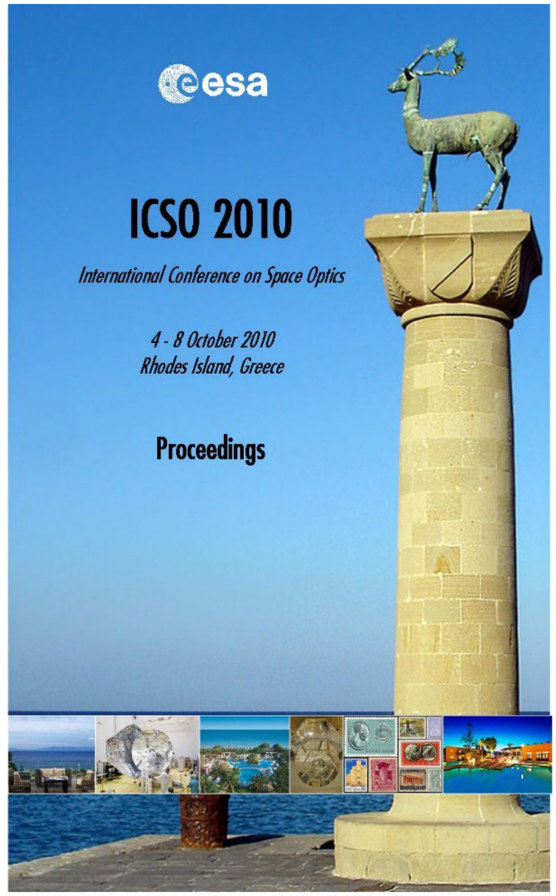

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SPACE EVALUATION OF OPTICAL MODULATORS FOR MICROWAVE PHOTONIC ON-BOARD APPLICATIONS

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I. INTRODUCTION

Since several years, perspectives and assets offered by photonic technologies compared with their traditional RF counterparts (mass and volume reduction, transparency to RF frequency, RF isolation), make them particularly attractive for space applications [1] and, in particular, telecommunication satellites [2]. However, the development of photonic payload concepts have concurrently risen and made the problem of the ability of optoelectronic components to withstand space environment more and more pressing. Indeed, photonic components used in such photonic payloads architectures come from terrestrial networks applications in order to benefit from research and development in this field.

This paper presents some results obtained in the frame of an ESA-funded project, carried out by Thales Alenia Space France, as prime contractor, and Alter Technology Group Spain (ATG) and Universidad Politecnica de Madrid (UPM), as subcontractors, one objective of which was to assess commercial high frequency optical intensity modulators for space use through a functional and environmental test campaign. Their potential applications in microwave photonic sub-systems of telecom satellite payloads are identified and related requirements are presented. Optical modulator technologies are reviewed and compared through, but not limited to, a specific figure of merit, taking into account two key features of these components : optical insertion loss and RF half-wave voltage. Some conclusions on these different technologies are given, on the basis of the test results, and their suitability for the targeted applications and environment is highlighted.

II. OPTICAL MODULATORS APPLICATIONS IN TELECOMMUNICATION SATELLITES AND REQUIREMENTS

Over the last two decades, optical modulators have been the object of intensive research and development activities in order to overcome the limited modulation bandwidth of laser diodes, and to meet the increasing bandwidth needs in terrestrial networks. Thanks to the effort to achieve higher modulation bandwidth (40 Gbit/s can currently be achieved using electro-optic modulators), lower driving voltage and smaller size as well, these components become suitable for space systems and, associated with other optical components, are expected to bring significant improvements in signal handling in satellite payloads [3].

Among the possible applications of optical modulators in photonic payloads can be highlighted the generation and distribution of high frequency local oscillators, unachievable by direct modulation of the injection current of laser diodes, and the photonic RF frequency-conversion achieved by driving the modulator with the microwave signal to be down- or up-converted and feeding the optical input with an optical local oscillator. The major requirements for these modulators and for the applications mentioned above are presented in Table 1.

III. OPTICAL MODULATOR TECHNOLOGIES

During past decades, several kinds of optical intensity modulators have been developed and marketed based on the following technologies [4] : Lithium Niobate (LN) electro-optical modulators, polymeric electro-optical modulators, semiconductor electro-optical modulators and semiconductor electro-absorption modulators.

Table 1. Major specifications for optical modulators

ITEM	TARGET FIGURE
Operating wavelength	1520-1600 nm
Max. input optical power handling	200 mW
Optical insertion loss	≤ 3 dB
RF operating frequency	up to 40 GHz
RF driving voltage (or power) @ 30GHz	≤ 4 V (≤ +16 dBm)
Linearity : carrier-to-3rd intermodulation	> 60 dBc
Impedance	50 ohms
RF return loss (in the band)	> 15 dB
Optical fibre input / output	PMF / PMF or SMF
Package	hermetic
Volume	< 8 cm3
Mass	< 20 g
Lifetime	> 15 years

Electro-optical modulators are based on the so-called Pockels effect, i.e the change of the refractive index of the material by applying an electrical field. Depending on the material used and the crystal orientation, the modulators can exhibit quite different characteristics.

Lithium Niobate (LN) electro-optical modulators : two configurations of modulators using Lithium Niobate are commercially available, which determine the locations of electrodes with respect to optical waveguides : the X-cut and Z-cut modulators. Both have respective assets and drawbacks : Z-cut have lower RF half-wave voltage than X-cut but their stability due to thermally induced effect is questionable.

Semiconductor (SC) electro-optical modulators : these modulators, which are based on III-V semiconductors of the GaAs or InP family possess a linear-electro-optic effect. The intensity modulation is based either on the classical integrated Mach-Zehnder interferometer or on polarization modulation. An important advantage of these modulators is their high potential of integration.

Polymeric electro-optical modulators : Mach-Zehnder modulator can also be realised using polymer materials. These modulators are based on molecules called chromophores, presenting strong dipole moments and strong hyperpolarisability, incorporated in the polymer host. These modulators offer high electro-optical coefficient and very high modulation bandwidth. Nevertheless, they suffer from significant optical losses and their chemical stability under high power and high temperature is still to be proven.

The electro-absorption modulator (EAM) is based on the Franz-Keldysh effect (or the quantum confined Stark effect in a quantum well structure), which consists in changing the absorption spectrum of a semiconductor (InP) by applying an electric field. The main assets of these modulators are their lowest driving voltage and the smallest size with respect to other modulator types. However, the maximum optical power handling is low and they are wavelength dependent.

IV. MODULATORS SELECTION AND TESTS

In order to assess the suitability and the critical design issues of commercial optical intensity modulators for applications in photonic sub-systems of future satellite payloads, performances of modulators, based on the different technologies previously described, have been first compared using informations gathered from datasheets and using features, such as the optical power handling capability and the following figure of merit (FoM):

$$FoM = \left(\frac{10^{-\frac{\alpha}{10}}}{V_{drive}} \right)^2 \tag{1}$$

where α is the optical insertion loss, and V_{drive} is the driving voltage for 100% modulation at the operating frequency (i.e V_π, the effective half-wave voltage in case of a Mach-Zehnder modulator), which was fixed at 30 GHz given the considered applications. This figure of merit expresses the amount of modulated optical power that can be made available at the output of a modulator, for a certain amount of RF drive power. Therefore, the higher the FoM, the higher the gain and the better.

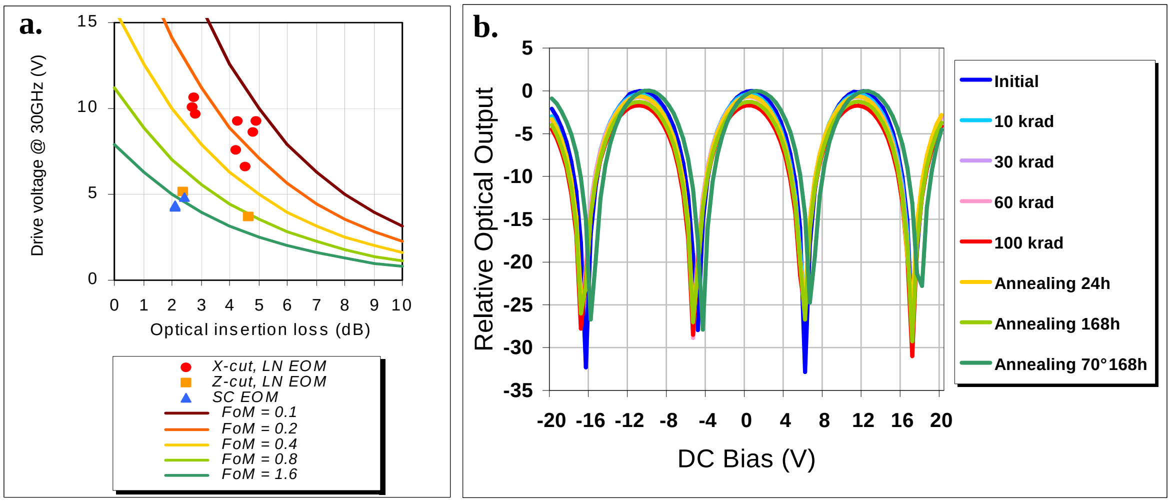

Fig. 1. a. Measured FoM of selected modulators. b. Static response of a Z-cut LN modulator during gamma radiation test.

This first selection stage discarded electro-absorption modulators because of their too low optical power handling capability for the targeted applications. A set of 14 modulators representing the remaining technologies from different suppliers has been procured and submitted to functional and environmental tests. Functional tests aimed at assessing several features such as optical insertion loss, DC half-wave voltage, extinction ratio, RF half-wave voltage at 10, 20 and 30 GHz. Some results of these functional tests is given in Fig. 1.a. through the measured FoM. Further tests aimed at assessing the evolution of these parameters when selected modulators are submitted to environmental stresses including maximum and minimum temperature (0°C and 70°C), mechanical shocks, vibrations, thermal vacuum cycling and radiations (gamma and protons), as shown in Fig. 1.b. In Fig. 2.a. and b. are respectively presented the bandwidth evolution during the environmental test campaign and the Figures of Merit before and after the whole test campaign of modulators having exhibited the best behaviors during all these tests.

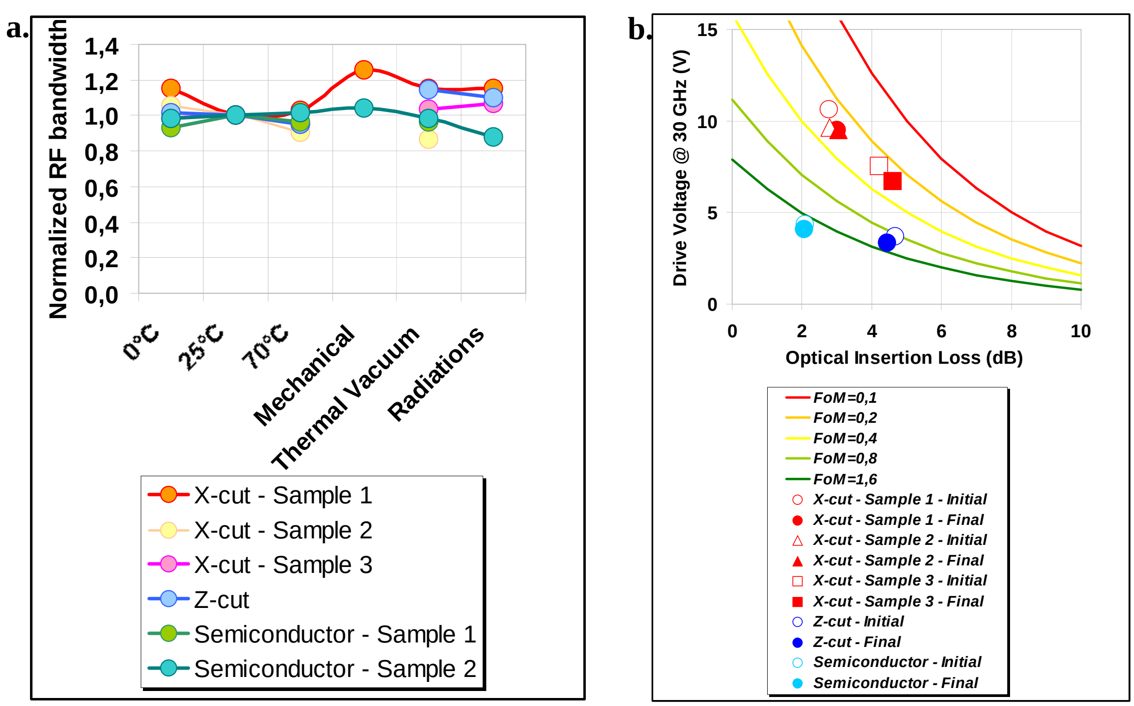

Fig. 2. a. Normalized bandwidth variations of several modulators during the environment tests. b. Measured FoM of best modulators, before and after the whole test campaign.

V. TEST RESULTS

The evaluation campaign including both functional and environmental test items was conducted on a number of samples selected so as to be representative of various technologies and procured from different suppliers [5].

Some conclusions from the functional test campaign are :

- X-cut Lithium Niobate modulators exhibit overall performance slightly worse than expected (compared to predictions from datasheets) ;
- Z-cut Lithium Niobate modulators exhibit overall performance slightly better than expected ;
- There was a substantial difference between functional performance of X-cut and Z-cut LN modulators;
- Polymer modulator sample was found immature (the test campaign was interrupted because of the component failure) ;
- Low drive voltages can be obtained with Semiconductor modulator and Z-cut LN modulators ;

Some conclusions from the environmental test campaign are given hereafter :

- Modulators based on different technologies exhibited very different behaviours (stable/not stable, degraded/not degraded) all along the environmental test campaign;
- Most of the tested modulator samples have the capability to operate at least in the [0-70°C] temperature range;
- The insertion losses of both semiconductor and lithium niobate modulators were not affected by temperature variations;
- In most cases, Lithium Niobate and semiconductor electro-optic modulators exhibited a slight decrease of the DC half-wave voltage with increasing temperature.
- Only a few modulator samples were found unstable in temperature, as the static response shifted during measurements (even some X-cut lithium niobate modulators);
- The RF bandwidths were not much affected by changes in the temperature range considered (variations lower than +/- 20 %);
- Some of the tested modulator have proven their capability to withstand the mechanical test conditions. Both optical and electrical continuity were well preserved;
- A few modulator samples were damaged during mechanical shock tests. The RF input was broken or damaged, and failure was revealed by S11 measurement;
- A number of modulators withstood all undergone environmental tests and did not exhibit any catastrophic damage;

VI. CONCLUSIONS

Optical intensity modulators have been identified as key components to perform functions such as generation and distribution of optical local oscillators or optical mixing in future telecommunication payloads. Several technologies are commercially available exhibiting different levels of performance and maturity for space applications. In order to assess these technologies, some modulators from different suppliers and covering these different technologies have been procured and submitted to a full test campaign encompassing functional as well as environmental tests.

Among them, lithium niobate and semiconductor electro-optical modulators turn out able to withstand most of environmental tests while keeping good overall performances and so appear as the best technologies for space applications at 1.55 μm.

REFERENCES

[1] N. Karafolas, J. M. Perdigues Armengol, I. McKenzie, "Introducing Photonics in Spacecraft Engineering : ESA's Strategic Approach", IEEE Aerospace Conference, Big Sky, Montana, March 7-14, 2009.

[2] J. M. Perdigues Armengol, N. Karafolas, I. McKenzie, "ESA Developments on Optical Technologies in Support of Advanced Photonic Flexible Telecom Payloads", *ESA Workshop on Advanced Flexible Telecom Payloads*, Noordwijk, The Netherlands, 2008.

[3] M. Sotom, B. Bénazet, M. Maignan, "A Flexible Telecom Satellite Repeater Based on Microwave Photonic Technologies", *Proc. 6th Internat. Conf. On Space Optics*, ESTEC, Noordwijk, The Netherlands, 2006.

[4] G. L. Li and P.K.L. Yu, "Optical Intensity Modulators for Digital and Analog Applications," *Journ. Of Light. Tech.*, vol. 21, no. 9, pp. 2010-2030, September 2003.

[5] M. Sotom, B. Bénazet, A. Le Kernec, L. Penate, J. Barbero, E. Cordero, F. Lopez, M. Maignan, "Assessment of Commercial High Frequency Optical Intensity Modulators for Space Applications", *International Symposium on Reliability of Optoelectronics for Space*, Cagliari, Italy, May 11-15, 2009.