RADIO-OVER-FIBER ORIENTED PREDISTORTION CIRCUITS FOR SIMULTANEOUS II AND III ORDER DISTORTION REDUCTION

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ABSTRACT

In this work a complete design procedure for Radio-over-Fiber (RoF) systems, specifically oriented to the development of linearization techniques for directly modulated semiconductor lasers, is presented. Based on such a procedure, several low-cost, multi-service predistorter prototypes, working within the European TETRA, GSM and DCS cellular bands, have been realized and experimentally characterized. Depending on the predistorter configuration implemented, average reductions of 10-15 dB and of 8-10 dB have been observed in the laser II and III order distortions, respectively. The design procedure also involves the development and use of a laser circuit model.

INTRODUCTION

In Radio-over-Fiber (RoF) systems microwave/mm-wave signals (RF-signals) modulate the intensity of an optical carrier generated by a semiconductor laser and are transmitted from a central site through an optical fiber link to the receiver, where the original RF information is recovered. The performance of such a scheme can be influenced negatively by the laser non-linearity. When many RF-subcarriers modulate together the laser, intra-band and inter-band harmonic distortions (HD) and intermodulation products (IM) are generated and deteriorate the quality of the signal at the receiver [1]. To solve such a problem, aiming to large-scale productions, economical considerations suggest the use of compensated low-cost lasers rather than extremely linear but expensive devices. Predistortion can be a suitable approach since it implies only the insertion of an electronic predistorter somewhere in front of the light source to generate correcting frequency components equal in amplitude, but opposite in phase, to the undesired ones introduced by the laser non-linearity.

To keep costs and complexity as low as possible, being interested in industrializable prototypes, we have realized some multi-service, completely analog predistortion circuits able to reduce of at least 10 dB II and III order distortions, respectively, of an entire class of commercial lasers, in the frequency range 350 MHz - 2 GHz, where TETRA, GSM, DCS and also GPRS cellular communication bands can be allocated simultaneously. The design and development of the predistorters have been performed by iterating CAD and lab procedures. A suitable configuration has been selected, implemented and optimized through the commercial software package *Agilent EEsof EDA Advanced Design System* (ADS). To this aim, a laser equivalent circuit model, respecting the average behavior of the commercial devices to be compensated, has been cascaded to the predistorters.

LASER MODELLING

The design procedure involves first of all the development and characterization of a laser model. Fig.1 shows the equivalent circuit [2] used; its development and characterization are the subject of a previous work [3]. To have a laser model characterized in such a way as to reproduce the behaviour of the real devices, a parameter extraction procedure has been performed. To this aim four samples of the same class of lasers, namely thermo-stabilized DFB devices, with an emission wavelength of 1310 nm, have been measured. Then, through the optimization tools of ADS, having as optimization goals the measured curves averaged over the four laser samples, the parameters of the model have been obtained. The relevant results are synthesized in Fig.2. Then, it has been verified that such a model predicts in a satisfying way the non-linear behaviour of the real devices, as shown by Fig.3. It should be noted that the model can be also modified to describe the behaviour of different laser configurations.

FIRST PROTOTYPE DESIGN AND DEVELOPMENT

The following step has been the Computer Aided Design of the predistorter. A suitable configuration has been implemented, the laser circuit model cascaded to it and the whole system simulated. The configuration selected [4],

shown in Fig.4, is characterized by the presence of two non-linear channels (paths) that generate II and III order correction signals, to compensate both II and III order laser distortions. The compensation procedure is based on a shaping of the correction signals that have to reproduce the laser II and III order HD frequency curves, while having an opposite phase; these signals are then combined with the original information and sent to the laser. By a suitable shaping in a frequency range as wide as possible, a broadband compensation of both HD and IM can be obtained, as testified by Figs.5 and 6, respectively.
This CAD activity has led to the realization of the first predistorter prototype shown in Fig.7. The same compensation procedure has been repeated experimentally by using a vector network analyzer HP 8753. Firstly, to point out the relevant maximum performance, the II and III order correction channels have been tested separately. Average reductions of 12 dB and 10 dB have been recorded in HD2 and IM2 and in IM3, respectively, over the GSM and DCS bands. Figs.8 and 9 show, as examples, the measured HD2 and IM3 corrections in DCS and GSM bands, respectively. However, a spurious mutual coupling between the two correction channels, when acting simultaneously, has been observed. This effect, mainly due to the RF components, deteriorates the predistorter compensation capability to unacceptable levels. Nevertheless, as confirmed by the measurements, such a configuration can be the basis for the development of two different broadband and multi-service predistorters specifically devoted to one breed of distortion.

FINAL PROTOTYPE

Being our ultimate goal the realization of a predistorter able to reduce II and III order laser distortions simultaneously, we have iterated the design procedure. To the aim of improving the RF isolation between the two correction channels, suitable modifications to the original configuration have been investigated and implemented at the CAD (see Fig.10). In particular, the spurious floor generated by the RF components has been minimized and a very linear post-amplifier, common to the correction channels, has been purposely designed. As a result, a predistorter capable of reducing simultaneously the laser HD2 and IM2-sum of about 10-12 dB, and IM3 of about 6-7 dB, over the whole DCS band has been so far achieved. Figs.11 and 12 show, as examples, the measured HD2 and IM3 corrections in DCS and GSM bands, respectively.
It is foreseeable that the frequency range where the II order distortions are effectively corrected can be extended at least down to the whole GSM band. On the contrary, for the III order distortions a similar correction within the TETRA and GSM bands has not been possible at this level of development. The explanation of that is the following: the residual spurious generation within the correction channels increases almost linearly with the frequency; below the DCS band its level becomes comparable with that of the laser HD3 which, on the contrary, increases with the frequency as the third power; thus, moving down the spectrum, the shaping of the III order correction signal is always more and more difficult, until becoming impossible. Such a problem does not arise for the II order correction signal because the laser HD2, used for the shaping, has a level always sufficiently higher than the residual spurious floor.

CONCLUSIONS

In conclusion, it is worth noting that the design of the predistortion circuits here presented is strongly oriented to industrial applications; thus it refers to low-cost, completely analog solutions for large-scale productions. The configurations implemented are based on simple architectures, where most of the simulated components have cheap commercial counterparts and no digital or adaptive technique is used. To improve the correction capability particularly in terms of bandwidth, two solutions could be investigated: first of all, the substitution of those components that contribute to generate the residual spurious floor, with other ones having better linearity performances, but that means cost increase; a second more radical solution could be a different design of the non-linear channels.

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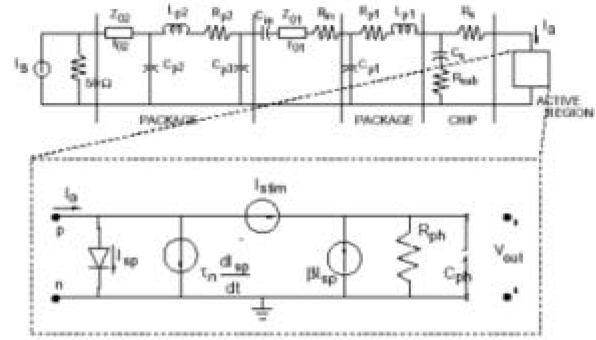

Fig.1. Laser equivalent circuit. For the parameters definition see [2,3].

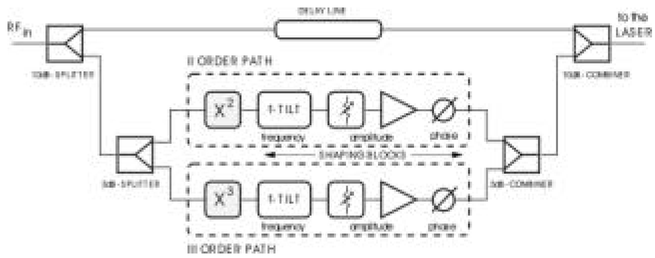

Fig.4. First predistorter configuration.

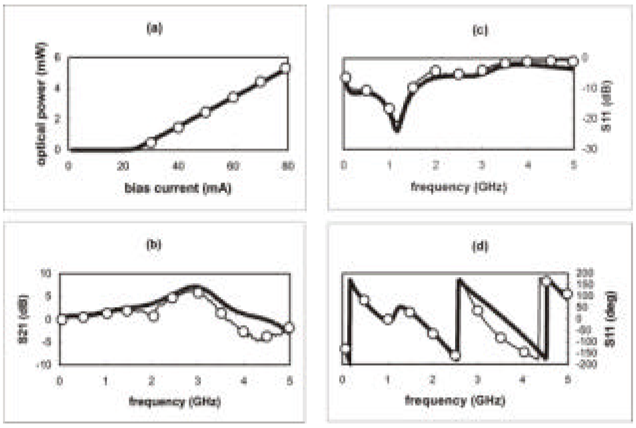

Fig.2. Laser circuit model parameter extraction. Comparison between measurements (circles) and simulations (solid line): (a) light current, (b) S_{21}, (c) S_{11} – modulus, (d) S_{11} – phase.

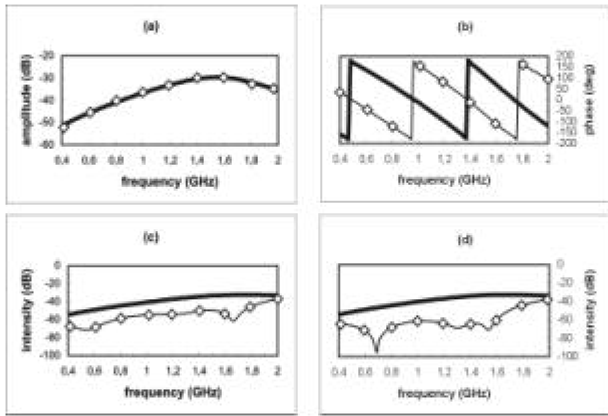

Fig.5. Laser II order compensation: higher graphs illustrate the shaping of the correcting signal (diamonds) amplitude (a) and phase (b), performed using laser HD2 curves (solid line). Lower graphs show a comparison between compensated (diamonds) and uncompensated (solid line) HD2 (c) and f_1+f_2 IM2 product (d). Sinusoidal tones with an RF power of 3 dBm have been used in both cases.

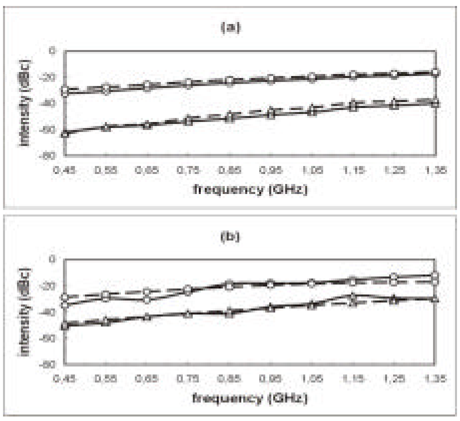

Fig.3. Laser HD2 (a) and IM3 product $2f_1$-f_2 (b). Comparison between measured (solid line) and predicted (dashed line) curves for two values of the laser bias current, I=38 mA (circles) and I=50 mA (triangles). Sinusoidal tones with an RF power of 3 dBm have been used in both cases. For the IM3 f_1 is variable and f_2=815 MHz.

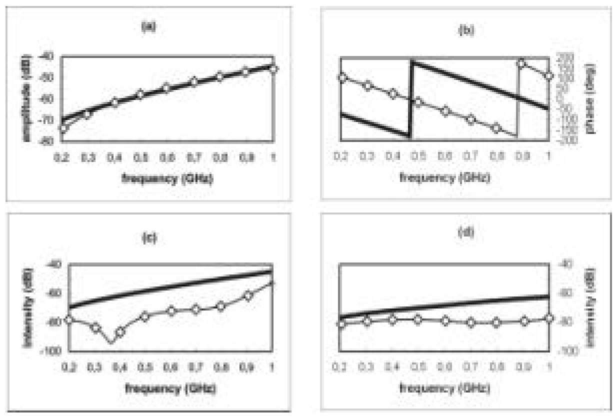

Fig.6. Laser III order compensation: higher graphs illustrate the shaping of the correcting signal (diamonds) amplitude (a) and phase (b), performed using laser HD3 curves (solid line). Lower graphs show a comparison between compensated (diamonds) and uncompensated (solid line) HD3 (c) and $2f_1$-f_2 IM3 product (d). Sinusoidal tones with an RF power of 3 dBm have been used in both cases.

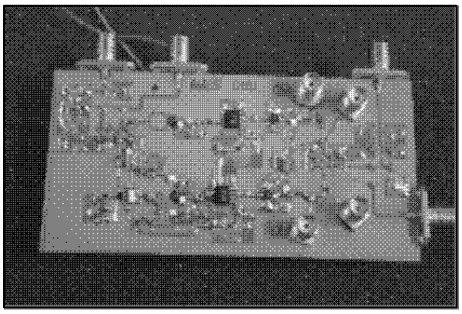

Fig.7. First predistorter prototype.

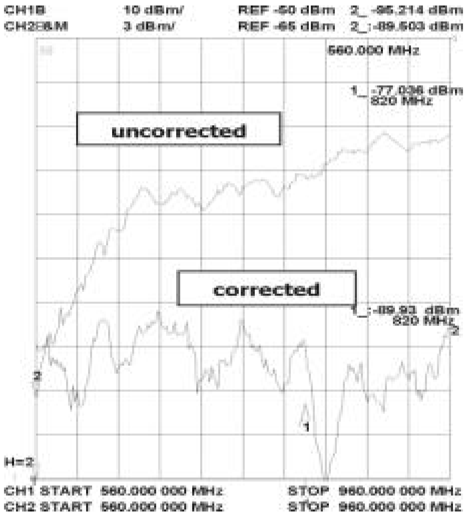

Fig.8. First predistorter prototype – II order path measurements: laser HD2 compensation in 1120-1920 MHz band, containing the DCS band.

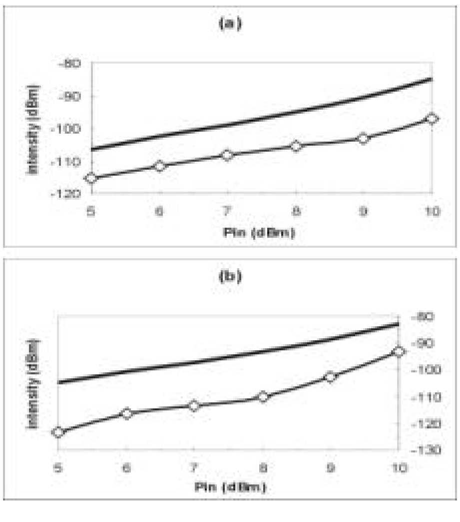

Fig.9. First predistorter prototype – III order path measurements: laser IM3-difference compensation in 780-1080 MHz band, containing the GSM band. (a) $2f_1$-f_2, (b) $2f_2$-f_1

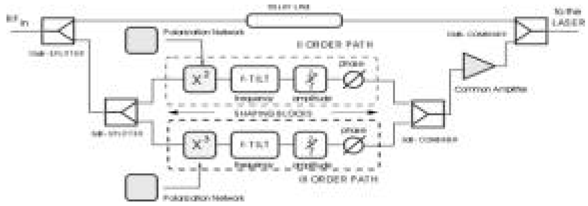

Fig.10. Second predistorter configuration.

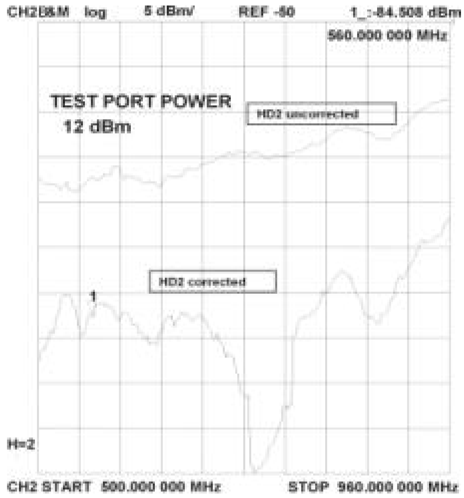

Fig.11. Final predistorter prototype – II order path measurements: laser HD2 compensation in 1000-1920 MHz band, containing the DCS band.

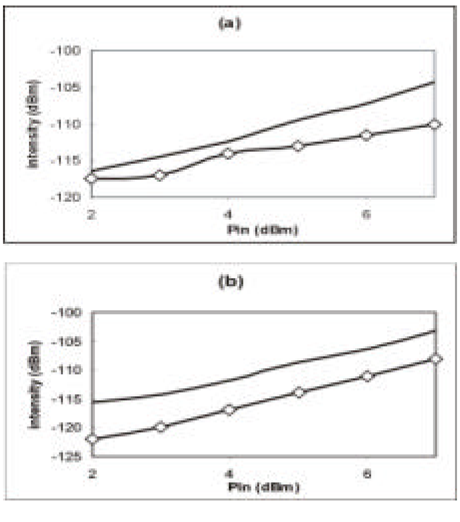

Fig.12. Final predistorter prototype – III order path measurements: laser IM3-difference compensation in 1500-1980 MHz band, containing the DCS band. (a) $2f_1$-f_2, (b) $2f_2$-f_1.