Predistortion Circuit Design for II and III Order Simultaneous Linearization in Multiservice Telecommunications Apparatuses

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Abstract—**We have developed a completely analog, low-cost, multi-octave predistortion circuit to compensate second- and third-order distortions in Radio-over-Fiber laser-based telecommunications apparatuses. The predistorter has been designed on the basis of both a circuit model of commercial DFB lasers and a complete compensation procedure previously developed. A first prototype has been realized and fully tetsted in the frequency range 500 MHz - 2 GHz, used with GSM, DCS and GPRS cellular services. Some modifications to the relevant architecture have led to a second final predistorter prototype able to reduce of about 9 to 15 dB both the laser second- and third-order harmonic distortion components falling within the DCS band (1710 - 1880 MHz).**

I. Introduction and Basic Concepts

We describe here the development of a low-cost, completely analog predistortion circuit used to reduce second- and third-order harmonic distortions (HD2 and HD3) due to semiconductor lasers used in Radio-over-Fiber (RoF) industrial systems.

In RoF-systems microwave/mm-wave signals (briefly 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 modulation can be direct, by immediately driving the laser with the RF-signal, or external, with the use of an electro-optical modulator; both these schemes are shown in Fig.1. In this paper we refer to an apparatus of the first type. The performance of such a scheme is mainly influenced by the non-linearity of the laser. When many RF-subcarriers are multiplexed together and modulate the laser, harmonic and intermodulation distortions (IMD) are generated and influence negatively the quality of the signal at the receiver [1]. In particular, in those RoF-systems, where the bandwidth of a single laser can be used to allocate several services, there can be an interband negative influence due to the HD or IMD that, generated in a certain band, fall into that one dedicated to another service. In view of large-scale productions, economical considerations suggest the use of compensated low-cost lasers rather than extremely linear but expensive devices. This implies the resort to compensation techniques that must be low-cost solutions themselves.

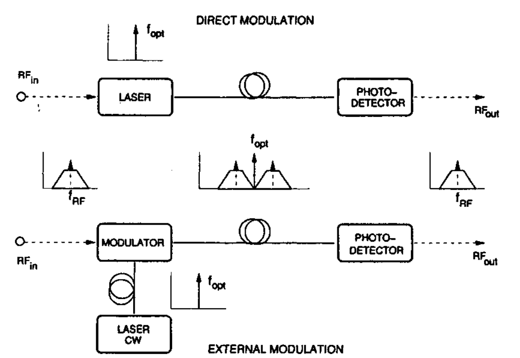

Fig. 1. Intensity-Modulation Direct-Detection schemes: the optical carrier generated by a semiconductor laser diode is directly or externally modulated by an RF-subcarrier multiplexed signal; the modulated optical signal is transmitted at the receiver through an optical fiber link, where a photodetector recovers the RF-information.

There are two major methods to reduce the non-linear distortions generated by lasers, namely feedforward compensation and predistortion. The feedforward technique seems to be superior because it also reduces the laser intensity noise [2]; however it has a techno-economical drawback represented by the fact that it requires a greater number of components such as additional laser diodes, photodiodes and optical couplers resulting in increasing costs and complexity. Predistortion can be a simpler approach since it implies only the insertion of an electronic predistorter

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somewhere in front of the light source to generate correcting frequency components equal in amplitude, but opposite in phase to those ones undesired introduced by the laser non-linearity. Remarkable results have been obtained with adaptive predistortion: in [3] the compensation of an analog predistortion circuit is maximized through the use of a micro-controller, thus reducing by 20 dB third-order IMD over the frequency range 1750 - 1870 MHz.
To keep costs and complexity as low as possible, being interested in industrializable prototypes, we have realized a completely analog predistortion circuit able to reduce of at least 10 dB second- and third-order distortions of an entire class of commercial lasers in the frequency range 500 MHz - 2 GHz, where, for instance, GSM, DCS and GPRS, cellular communication bands can be allocated simultaneously. This bandwidth is wide enough accomodate also CATV channels; the predistorter is then virtually suited to multiservice RoF-systems, the only limitation being the difference of the output power typically requested to each service.

The design and development of the predistorter have been performed by iterating CAD and lab procedures. A first configuration has been selected, implemented and optimized through the commercial CAD software package *Agilent EEsof EDA Advanced Design System* (ADS). To this aim, a laser equivalent circuit, respecting the average behavior of the commercial devices to be compensated, has been cascaded to the predistorter. The development and experimental characterization of such a laser model are illustrated in a previous work [4]. The design of a first predistorter prototype and the relevant simulation results are presented in section II. In particular, these results have pointed out the need for matching the laser and predistorter phase and amplitude variations in frequency to the aim of obtaining a broadband compensation. This step of the work has predicted the possibility of realizing a low-cost, analog predistorter, able to reduce of at least 10 dB second- and third-order laser distortions; however, the following experimental measurements, performed on the relevant prototype, have shown the need for some modifications to get the simultaneous correction. These improvements and the characterization of the subsequent final pre-industrialized prototype of the linearization circuit are illustrated in section III.

II. First Level Design

The laser model used to implement, simulate and optimize the selected predistorter configuration, has been identified and developed in a previous work [4]; in that work the laser parameters have been extracted and optimized for one specific laser family. Using this model, we have implemented in the simulator an ideal predistorter configuration made by using ideal building blocks and keeping, at the same time, the laser model as much real as possible, in order to identify the theoretical maximum linearization performance. The predistorter configuration adopted has been derived from [5] and is shown in Fig.2.

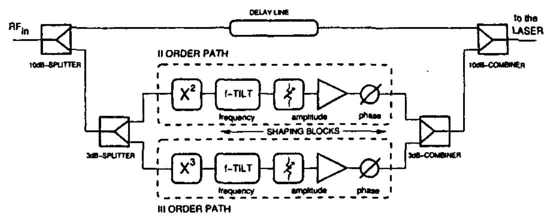

Fig. 2. Predistorter schematic.

The circuit consists of two parts: a linear part and a non-linear part; the former is simply a time delay line, the latter is further on subdivided into second-order and third-order paths. Portions of the RF-input signal are extracted to feed both the quadratic-law (X^2) and cubic-law (X^3) generators. The two generated correction signals, with amplitude and phase suitably adjusted through a chain of shaping blocks, are then recombined with the original delayed RF-signal and sent to the laser. In this way the circuit can simultaneously compensate second- and third-order distortions. To feed and recombine the linear and non-linear paths of the predistorter, 10 dB and 3 dB splitters/combiners have been adopted. The X^2-device can be realized with a couple of diodes in push-push configuration, fed with two 180-degree shifted inputs. To have a large operational frequency range a differential amplifier has been used to realize the input 180 degrees phase-shift. The X^3-device can be also realized with a couple of diodes, but in a push-pull configuration and with no input phase-shift [6]. The functionality of the shaping chains is to generate correction signals having the same amplitudes of the distortion components generated by the laser, in a frequency range as wide as possible. To this aim two LNAs have been inserted after the non-linear generators to adjust the amplitude level of the drawn correction signals, which suffer an overall attenuation of about 30 dB due to the input and output splitters and combiners; a fine control on the amplitude level can be assured by variable attenuators. Also a fine phase-adjustment stage, to match the laser harmonic phase variations, has been inserted in both the non-linear paths. Finally, frequency-tilt shaping networks have been implemented to let the correcting signals match the laser HD2 and HD3 curves in the whole operational band.

As clearly proved by the simulations, only the simultaneous amplitude and phase shaping of the correction signal in the whole operational band, as represented in Figs.3 and 4, for second- and third-order harmonics respectively, (a) and (b), allowed for the broadband compensation of laser HD and IMD shown by Figs.3 and 4 (c) and (d). Such a shaping can be obtained by suitably designing and dimensioning the frequency tilt adjusting blocks of the non-linear paths shown in Fig.2. Capacitance networks can be used [7] to this aim.

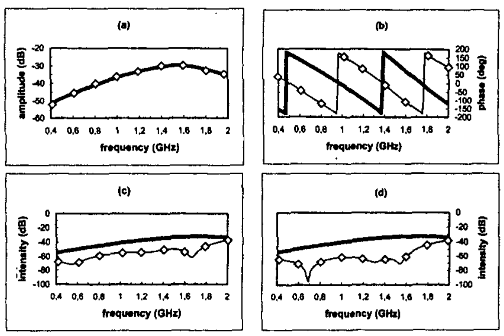

Fig. 3. Simulated second-order compensation: higher graphs illustrate the shaping of the correction signal (diamonds) amplitude (a) and phase (b), performed using the laser HD2 curves (solid line); lower graphs show a comparison between compensated (diamonds) and uncompensated (solid line) laser HD2 (c) and IM2 (d). Input sinusoidal tones with an RF-power of 3 dBm have been used in both cases.

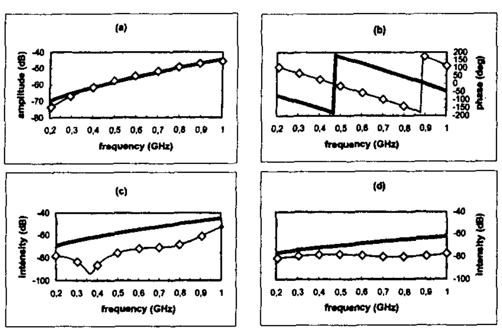

Fig. 4. Simulated third-order compensation: higher graphs illustrate the shaping of the correction signal (diamonds) amplitude (a) and phase (b), performed using the laser HD3 curves (solid line); lower graphs show a comparison between compensated (diamonds) and uncompensated (solid line) laser HD3 (c) and IM3 (d). Input sinusoidal tones with an RF-power of 3 dBm have been used in both cases.

III. Development and Results

Once having characterized the whole system, the subsequent step consisted of the implementation of the indications given by the simulation phase illustrated above. A first predistorter prototype has been realized, according to the block diagram in Fig.2, and subjected to an extensive experimental characterization, also by means of the harmonic measurement tool of a network analyzer HP 8753. Although a compensation capability by each one of the non-linear paths, near to the CAD predictions, has been observed, the measurements have shown also some critical aspects, mainly due to the interdependency of the correction paths. In fact the spurious second-order component generated by the amplification stage in the third-order path and the spurious third-order component due to the non ideal rejection of the X^2-generator in the second-order path, influence negatively the behaviour of the circuit. Electrically, such an effect does not allow for the simultaneous correction of both the second- and third-order distortions in the particular cases of interest. To solve this problem, the predistorter scheme has been modified by inserting two polarization networks for the non-linear generators and by replacing the two LNAs of the non-linear paths with a common amplification stage inserted after the output 3 dB combiner, as shown in Fig.5. The polarization of the diodes increases the spurious rejection and, at the same time, improves the diodes transduction. The use of a common amplifier stage, designed to have maximum linearity, allows for a better line-up of the whole system in terms of linearity, thus reducing further the generation of undesired distortion components by the second- and third-order paths.

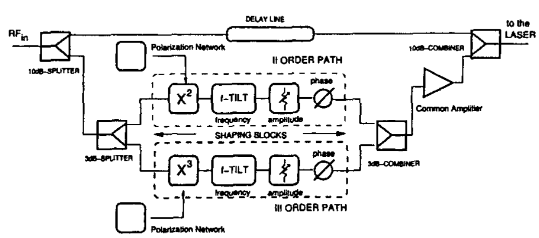

Fig. 5. Modified predistorter schematic.

A new prototype has been then realized and measured to validate these improvements. The network analyzer with harmonic capabilities has been useful to obtain the broadband amplitude matching and phase opposition of the correction signals whose need has been shown by simulations. To obtain an input signal free from spurious harmonics, the source of the network analyzer has been suitably filtered.

A variable sinusoidal tone with an RF-power of 11/12 dBm has been produced; this value is related to an Optical Modulation Index (OMI) of 0.56, above which the laser is overmodulated. Since about 3 dBm are lost through the delay path, 9 dBm is the real input RF-power to the laser.

Fig.6 shows the measured laser HD2 frequency curves relevant to the uncompensated and compensated device. The measurements have been realized in the 500 - 960 MHz frequency range, for the fundamental tone (1000 - 1920 MHz for the second-order harmonic), to evaluate the potentially broadband correction capability of the circuit, despite of the real GSM band is 820 - 960 MHz. As it could be observed, an average correction of about 15 dB has been obtained. The same measurements have been repeated to evaluate the third-order compensation capabilities of the predistorter. Fig.7 shows the measured laser HD3 frequency curves relevant to the uncompensated and compensated device. On the whole band, which is 500 - 660 MHz to evaluate the HD3 falling in the DCS band, an average correction of about 9 dB has been observed. The corrections shown in Figs.6 and 7 have been obtained with both the non-linear paths working simultaneously.

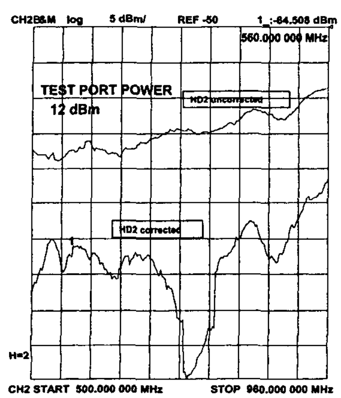

Fig. 6. Laser HD2 compensation measurement. The band of the fundamental tone is 500 - 960 MHz; consequently, the HD2 correction is shown within the whole DCS band.

IV. Conclusions

An industrializable prototype of a predistortion circuit for Radio-over-Fiber systems has been realized and fully tested in the 500 MHz - 2 GHz band where services like CATV and GSM, DCS and GPRS cellular communications are typically allocated. The predistorter has been designed based on a semiconductor laser circuit model previously developed. The initial configuration has been simulated and measured and then modified by inserting polarization networks, to drive the second- and third-order correction signal generators, and by increasing the linearity of the amplification blocks which have been replaced by a common, more linear, stage. The improvements allowed for the simultaneous correction of laser HD2 and HD3 components within the DCS band, as shown by the experimental results.

It is worth noticing eventually that the predistortion circuit seems to be flexible enough to be adapted to other classes of lasers simply by setting different values of its characteristic parameters.

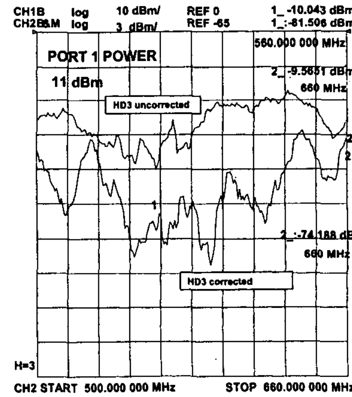

Fig. 7. Laser HD3 compensation measurement. The band of the fundamental tone is 500 - 660 MHz; consequently, the HD3 correction is shown within the whole DCS band.

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