Bidirectional opto-antenna design for 5G wireless nodes

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Abstract: An advanced bidirectional opto-antenna is proposed that accomplishes impedance matching between a photodetector, a laser and a low-profile antenna in a specified frequency bandwidth and with bidirectional communication over a single path. This results in a highly compact design, which also avoids losses and spurious radiation. The photodetector is almost directly connected to the antenna, which is also connected to the laser, such that the signal from the photodiode arrives directly at the antenna, and the signal received from the antenna arrives directly to the laser. The required equivalents circuits and further analysis of the antenna and duplexer are obtained using the ADS software. The simulations show a great cost-effective and power efficient in the radio band of 1.9 GHz- 2.3 GHz.

I. INTRODUCTION

Nowadays, research in 5G is in the spotlight of multiple companies and institutions as it will introduce an improvement in speed, efficiency, and latency compared with the current characteristics of 4G. Moreover, this technology is believed to start operating in late 2019, so it will likely be used worldwide sooner or later. From the economic point of view, a lot of companies want to be the first at acquiring this technology because they will get the first mover advantage [1] which will carry the benefits of defining the standards and protocols, returning a lot to them. Companies such as Qualcomm [2], Huawei, Samsung, and other high-tech companies are starting to release their first 5G smartphones but the technology is not ready yet.

One of the most interesting things in which 5G will exhibit a great potential is on remote factories working without local intervention, a remarkable characteristic of the so-called smart factories. This project is inspired by this 5G feature, thinking on a way to make the communication infrastructure possible based on a radio frequency over fiber (RFoF) architectures [3]. The goal of the architecture is to have a high-density population of remote antenna units that communicate bidirectionally with the different elements of the factory. The architecture is designed so that the signal is processed and routed on a central office so that the complexity of the antennas that will transmit and receive the information decreases. The use of fiber-optics to propagate the optical signal from the central office to the antennas and vice-versa has the advantage of its favorable propagation properties, such as high bandwidth and low propagation loss.

Of all the components the RFoF architecture, this paper focuses on the design of a bidirectional opto-antenna, which also contains the photodiode that will convert the incoming light signal into RF signal and the laser that will transmit back to the central office the signals the antenna receives, always aiming to a design which is cost-efficient and low-powered. The structure of the paper is the one that follows. In section II, it is explained an overview of the general system, then from section II to section V each of the subunits of the general system is explained in deeply, and the last section explains the results and a brief discussion of the overall project.

II. OPTO-ANTENNA STRUCTURE

The system can be seen in two differentiated parts or paths, taking into account the direction of the signal. On the one hand, we have the downlink part, which is understood as the path the signal follows from the central office to the antenna. On the other hand, the path that goes the other way around is the uplink. In order to be consistent with 5G standards, the uplink is designed to work at frequencies in the range 1920-1980 MHz and the downlink at 2110-2170 MHz, which are a very commonly used ones [4].

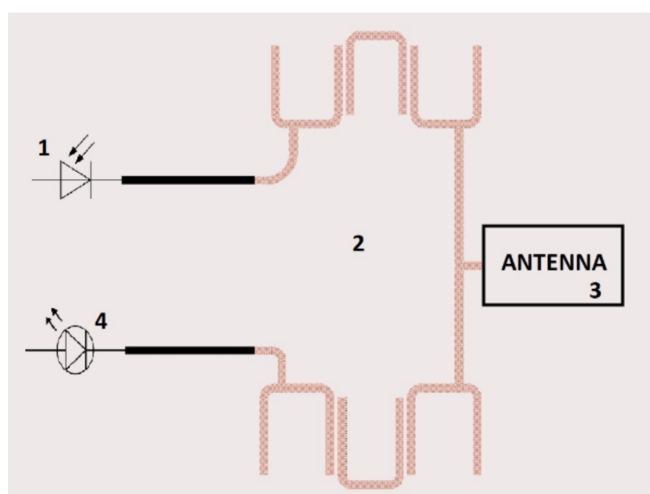

FIG. 1. Opto-antenna structure

Moreover, as shown in Figure 1, the system can be decomposed in four different parts. The function of the first part is to receive the signal from the central office that we want to transmit, the second part is a series of resonators that constitute the filter which will prevent the mixing of the uplink and downlink signals, the third is the antenna that will both emit and receive the signal, and the final part is the transmitter, which will send information back to the central.

The signal arrives through an optic fiber to the photodiode which is feed in reverse through a 1 mm microstrip line. The main function of the photodiode is to convert the light signal from the optic fiber into the RF signal of around 2.1 GHz, which is the downlink frequency of our system.

The RF signal passes through series of resonators with U-shape, called the duplexer. The duplexer is the element of the system that regulates the frequencies that arrives at the photodiode and at the laser. The duplexer is optimized such that the frequencies coming from the photodiode do not reach the laser and the only frequencies that arrive at the laser are those received at the antenna. Also, the duplexer works the other way around, not allowing the frequencies received from the antenna to reach the photodiode.

The antenna is the device responsible for both transmitting the signal generated with the photodiode and responsible for receiving the signal and transmitting it to the laser. Once the signal reaches the laser, it is converted into a light signal which will be propagated through optic fiber.

III. PHOTODIODE AND LASER CHARACTERIZATION

A. Photodiode

The chosen photodetector for the project is the RPD-P067XHM-S-02-G from HG-TECH. First of all, a characterization of the photodetector was made regarding its behaviour variation with frequency, computing the scattering parameters (S-parameters) from frequencies going from 500 kHz to 3 GHz. To perform that measurement, a previously calibrated network analyzer was used. A very important procedure, known as de-embedding, had to be done first in order to remove the effects of fixtures, port-discontinuities, and transmission line effects in our measurement. The de-embedding was performed using the port extension function of the network analyzer, which modifies the phase length of the S-parameters. To calibrate the port extension, a port of the network analyzer was connected to the ground of the photodiode board, and visualizing the S-Parameters in a Smith-Chart representation, the port extension length was modified to get

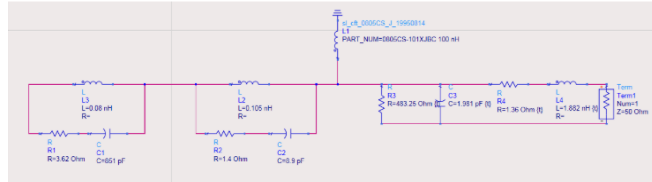

FIG. 2. The photodiode was modelled with a parallel resistance and capacitance and a series resistance and inductance, and our chosen DC-block and inductance are also represented.

the minimum phase. After the de-embedding was performed, a port extension of 170.22 ps was found to be the most proper one to get accurate results in future measurements. Before the S-parameters measurement, we had to consider that the photodiode would be DC powered while receiving RF signal, so a bias tee should be used to not allow the DC signal to pass through to the receiver, and vice versa. With the bias tee connected, the S-parameter measurement was obtained and used to obtain an equivalent circuit. To model the circuit, Keysight's software Advanced Design System (ADS) was used, but due to the fact that the bias-tee components were not known, the model fitting increased in complexity. The solution to the issue was to include a known DC block and inductance in our board to mimic the bias-tee behavior. Once new measurements were made, the tune feature of ADS was used to modify the values of the elements of our circuit until the impedance of our model had similar behavior to the one exhibited in the measurements for the range of frequencies of interest, in this case around the downlink frequency. The equivalent circuit and the impedance matching are shown in Figure 2 and 3.

In order to study more the photodiode, a laser was used to simulate the response to a signal. The parameter we measured was the responsivity of the photodiode as it gives crucial information about what is the output current when the photodiode is feed in reverse mode, knowing the input power given by the laser. The measurement gave us that when the laser's input current was of 0.08A, the output power that the laser gave was of 3.327 mW. When we connected the laser to the photodiode, this now input power of 3.327 mW was converted into an output power of 3.65 mW. Hence, the responsivity of the photodiode was computed to be of 1.09.

B. LASER

The laser chosen for this project was the pigtail laser diode. First of all, some measurements of the laser had to be done to characterize it. The most important property of the laser is the slope efficiency, which is the slope of the plot between the dependence of the output power on the input power once the laser output is dominated by stimulated emission. To perform the corresponding mea-

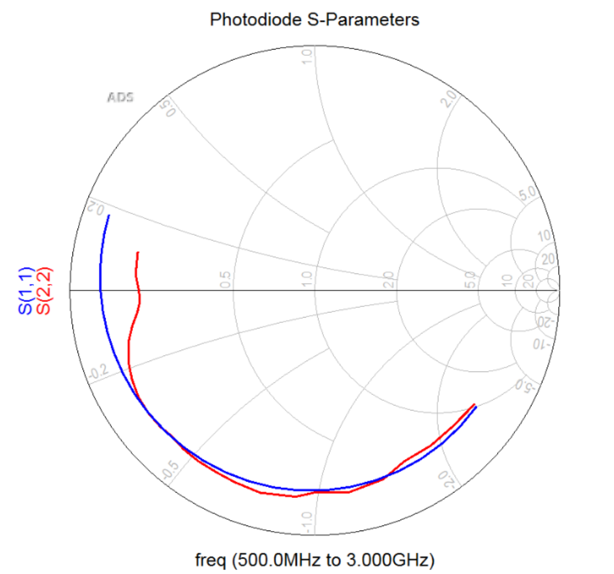

FIG. 3. A representation of the S-paremeters of the photodetector, in a Smith chart, the equivalent circuit fits the measurements in the frequencies of interest

surements, the laser was fed by a current limited voltage source (0.150A) whose current was monitored by an amperemeter to get more accurate results. The laser output was sent to an optical power meter, set at 1550 nm, from where the results were obtained. After the calculations, the laser's slope efficiency was found to be of 0.066W/A.

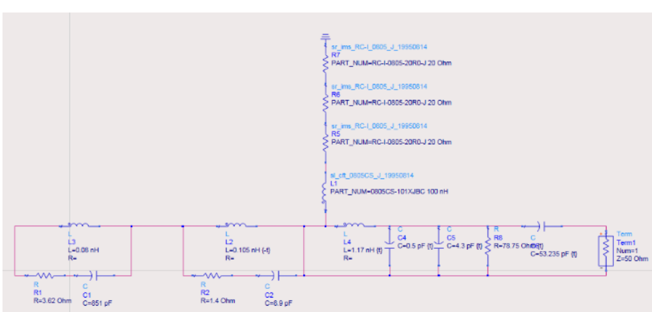

FIG. 4. Laser's equivalent circuit

An equivalent circuit for the laser was also created using the same procedure as in the characterization of the photodiode. In this case, during the previous measurements it was observed that the laser's output current varied a lot with small changes on the voltage. Hence, in order to have better control of the laser's current, three 20 resistances in series were placed after the inductance. The equivalent circuit and the S-parameters variation can be seen in Figure 4 and 5.

IV. DUPLEXER DESIGN

Due to the fact that the photodiode (the receiver) and the laser (the emitter) share the same antenna, a duplexer is needed. A duplexer is an electronic device that allows bidirectional communication over a single path, isolating the transmitter from the receiver but still allowing them to share a common antenna. In this case, the method used was isolation via frequency domain because the photodiode and the laser use different frequencies. Also, this is a promising technique for 5G as it tackles key issues such as throughput, spectral efficiency, latency, and connectivity. [5]

The duplexer used is made of six U shaped resonators, three connected to the photodiode and the antenna and the other three connecting the laser and the antenna. The general design of the duplexer was provided to us by Christian Ballesteros Snchez a Ph.D. Student. However, the substrate had to be changed and the parameters had to be tuned in order to operate in the range of frequencies discussed in Section II. The chosen substrate was the RO4003c, which is characterized by a 1.524 mm width and an electric permeability of 3.55.

First of all, in order to adapt the duplexer with the antenna, the laser, and the photodiode, a 50 transmission line had to be designed for the specific substarte. It was done using the feature line calc of ADS and a width of 3.393 mm was found to be the desired one. Once the 50 line was set, different parameters of the design were varied using the ADS feature tuning, in

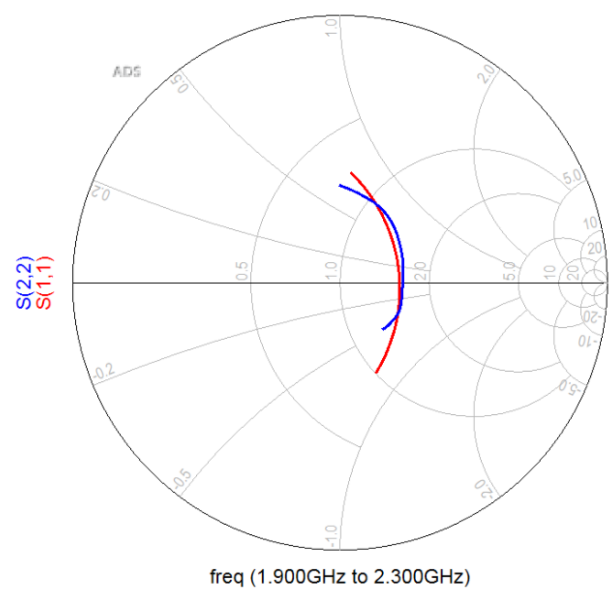

FIG. 5. A representation of the S-paremeters of the laser, in a Smith chart, the equivalent circuit fits the measurements in the frequencies of interest

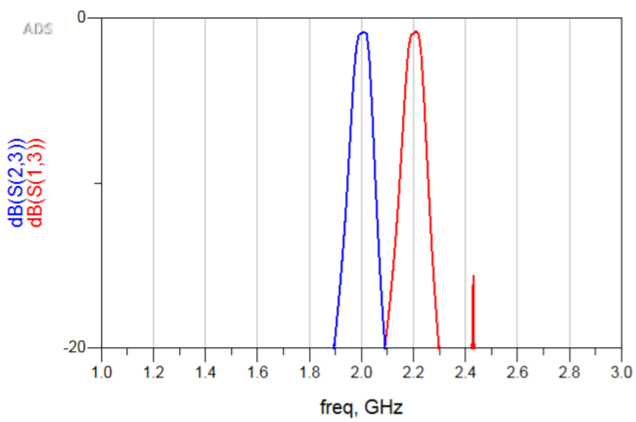

FIG. 6. Transmission for each frequency. The blue band corresponds to the uplink band and the red band to the downlink band.

order to achieve the expected behaviour of our duplexer. After that, the design was introduced to Momentum, another ADS tool used to run simulations not with the mathematical models of the components but taking into account the geometry and electromagnetic effects, including coupling and parasitics. The same simulations were run again and it was observed that the behaviour was not altered.

As shown in Figure 6 the optimization gave two transmitting brands, the band around 2 GHz corresponds to the frequencies that reach the laser and the band around 2.2 GHz corresponds to the frequencies used by the photodiode. Moreover, the power reflected on the the port connected to the antenna was also simulated. As expected, two pronounced minima were found around the uplink and downlink frequencies, verifying that the port is adapted at those frequencies and that signal mixing between the two paths wil be extremely attenuated.

V. ANTENNA DESIGN

A rectangular bow tie antenna and a rounded bow tie antenna around 2 GHz were simulated following a known antenna design which operates at 60 GHz, using Computer Simulation Technology software (CST). Unfortunately, the rescale of the parameters was not obvious and the simulation did not give the desired results. At the time of writing this paper, work is still in progress in order to find an antenna structure that would fulfill the specifications: the main challenge associated with this task is the reduced thickness of substrate which makes very difficult to cover the whole operation bandwidth at this frequency band with conventional planar antennas.

VI. CONCLUSION

Although the design of the full opto-antenna system was not accomplished, we have shown that working with a compact system that deals with two different frequency bands is a valid solution to achieve a power effective system for a bidirectional communication.

In the near future, the antenna could be completed and the full opto-antenna system should be simulated in order to see that everything works as expected. Whatsmore, the whole system should be created and measured so a comparative between the simulations and the real data could be done.

VII. ACKNOWLEDGMENTS

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