Transceiver for an Unmanned Airborne Vehicle

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Abstract — **This paper describes a transmission/reception (transceiver) system for the 456MHz - 459MHz band, which allows data communication between a ground station and an unmanned airborne vehicle. The transceiver makes use of quadrature frequency translation techniques, coherent indirect methods for signal generation and supports input signals with several types of modulation. The intermodulation products harmonics and spurious signals are 60dB below the carrier for an output power of 6dBm. The receiver has a sensitivity of -110dBm, a dynamic range of 80dB and an image rejection better than 28dB. The central frequency and the tune steps (100kHz) are digitally controlled by a PLL-based synthesizer. The transceiver draws 500mA from a ±12V supply. These characteristics were found to be good enough for the application referred above.**

I. INTRODUCTION

This paper describes a radio-frequency (RF) transceiver to be used in an unmanned airborne vehicle (UAV), under development by a consortium created by the *Universidade da Beira Interior*, *Escola Superior de Tecnologia e Gestão de Leiria* (ESTG-IPLeiria) and *Plasdan*, known as SkyGu@rdian [1].

The SkyGu@rdian communication system, where the transceiver will be placed, must set up a bidirectional half-duplex communication link between the UAV and the ground station (GS), with a maximum range of 50km. According to the specifications of ANACOM [2], this system can operate within the frequency range from 456MHz to 459MHz, with a maximum bandwidth (BW) of 12kHz and maximum transmitted power of 27dBm.

The transmitter has an output signal power of 6dBm (before the transmitter antenna), rejection of spurious signals higher than 60dB, attenuation of the unwanted side band of 35dB and a local oscillator (LO) leakage 31dB below the output signal power. The receiver performance is characterised by a sensitivity of -110dBm for a signal to noise ratio (SNR) of 10dB (after the receiver antenna), a dynamic range of 80dB and an image rejection greater than 28dB. The above performance allows to the system to work in perfect conditions at least in a range of 50km in line-of-sight.

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The transceiver operates with a power supply of ±12V and has a current consumption of 500mA. The prototype has 350g of weight and a volume of 280×170×25mm.

This paper is organised in five sections. Section II gives a general overview on the transceiver architecture and in the third section it can be found some important details about the implementation of the transceiver. The measurement results are presented in section IV and section V concludes the overall work.

II. SYSTEM OVERVIEW

This section presents the chosen transceiver architecture and describes the functionality of its principal modules.

A. Transceiver Architecture

The transceiver block diagram is represented in the Fig. 1. The system is divided into four major modules: transmitter, receiver, LO and transmission/reception (Tx/Rx) switch.

The input signal comes from a digital signal processor (DSP - located in the SkyGu@rdian communication system). This signal is centred on the intermediate frequency (IF) of 15kHz, has a maximum BW of 12kHz and can have any type of modulation. The upconverter in the transmitter shifts this signal to a RF central frequency located between 456MHz and 459MHz. The structure of the upconverter is based on quadrature frequency translation techniques [3], allowing the direct conversion from IF to RF.

The receiver downconverter does the opposite of the upconverter, shifting the RF signal to the central IF

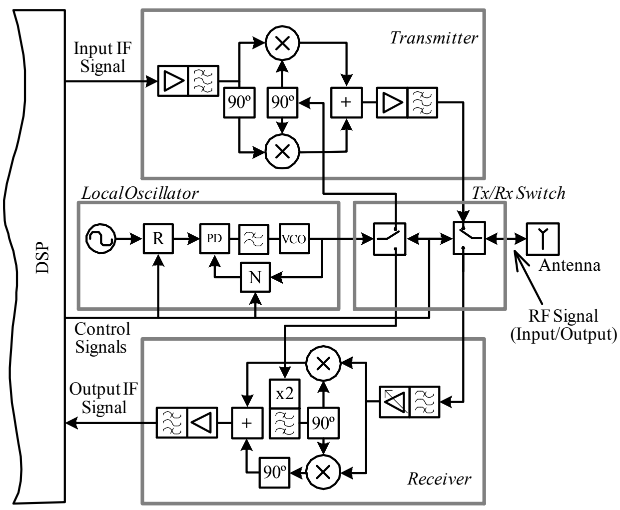


Fig. 1 – Transceiver block diagram.

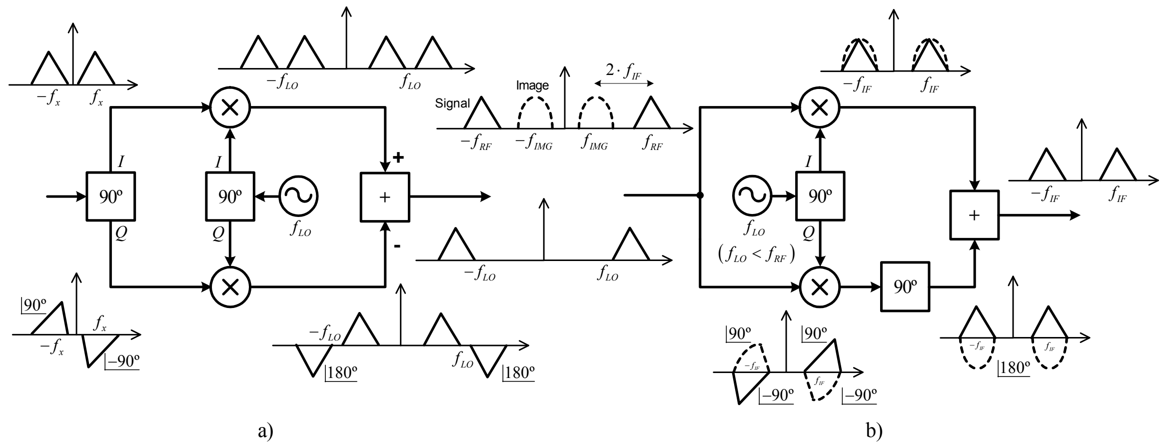


Fig. 2 – a) Upconverter and b) downconverter architecture with frequency spectra at different points.

frequency. This signal is fed to the DSP for further processing. The downconverter architecture is based on an image reject frequency converter, which also allows the direct conversion of the signal, rejecting the image without the requirement of very high selective filters [4].

The main function of the LO module is the generation of a sinusoidal signal that will be used by the up and downconverter. A phase locked loop (PLL) was used in order to accomplish high LO stability, low noise and high tuning precision. With this approach the stability and tune precision are attained due to the high quality reference oscillator. Also, the reconfiguration of the central frequency is very simple, since the synthesizer is controlled digitally by the DSP.

The selection between the transmitter or receiver operating modes of the transceiver is done by the Tx/Rx switch module, controlled by the DSP.

B. Upconverter

The block diagram of the upconverter is represented in Fig. 2a. The architecture is based on the classic phasing method for single side band generation [5]. This topology was chosen due to its simplicity and to eliminate the need for high selective filters. As it can be seen in Fig. 2a, the upconverter consists of a polyphase network, a quadrature converter and an adder. It also shows the frequency spectra at different points of the upconverter. The polyphase network, also known as polyphase filter, generates two signals with a phase difference between them of 90º (in-phase (I) and quadrature (Q) signals). These signals are the inputs of the quadrature converter. Depending on the combination of the two output signals of the quadrature converter, the chosen side band is different. In this case the signals are subtracted, so the chosen side band is the upper one. To achieve high rejection of the lower side band, all quadrature signals must have very small phase error and magnitude imbalance.

C. Downconverter

Fig. 2b shows the block diagram of the downconverter. This is an image reject converter and is based on the Hartley image reject receiver [4]. The downconverter consists of a quadrature converter, a polyphase network and an adder. Like in Fig. 2a, Fig. 2b shows the frequency spectrum of the several signals of the downconverter. The desired signal and the image interferer are downconverted together in both branches of the downconverter. However, the desired signals at the end of the two branches are in-phase, while the image signals are 180º out of phase. When the upper and lower paths are recombined, the image interferer will be cancelled out and the desired signal will be left, as shown in Fig. 2b. The image rejection depends on the precision between of the quadrature signals.

D. Local Oscillator

The LO module (Fig. 1) has the function of generating a sinusoidal signal for the upconverter and downconverter. Basically, the LO architecture is a PLL-based synthesizer [6], which allows the digital control of the output frequency and tune steps. As shown in Fig. 1, the LO module consists on a voltage controlled oscillator (VCO), two programmable frequency dividers (FDs), a phase detector (PD), a charge-pump (CP), a loop filter (LP) and a reference oscillator.

In this circuit, the reference frequency is divided by a digitally controlled number (R) and the same happens to the LO output frequency, although the frequency division number is different (N). If the phase of the two input signals of the PD is different, then an error signal is generated. In this situation the CP changes the control voltage of the VCO to compensate the phase difference of the PD input signals. Under lock conditions, the two inputs of the PD have a constant phase relationship and thus equal frequency. When one or the two division numbers changes, the LO output frequency is re-tuned to a different value.

E. Tx/Rx Switch

The Tx/Rx switch selects the transceiver operating mode; either transmission or reception. In the transmitting mode, this module routes simultaneously the LO to the upconverter and the output RF signal to the antenna. In the receiving mode, the Tx/Rx switch guides the LO to the downconverter and the input RF signal to the receiver front-end. This solution uses two RF switches that are controlled by the DSP.

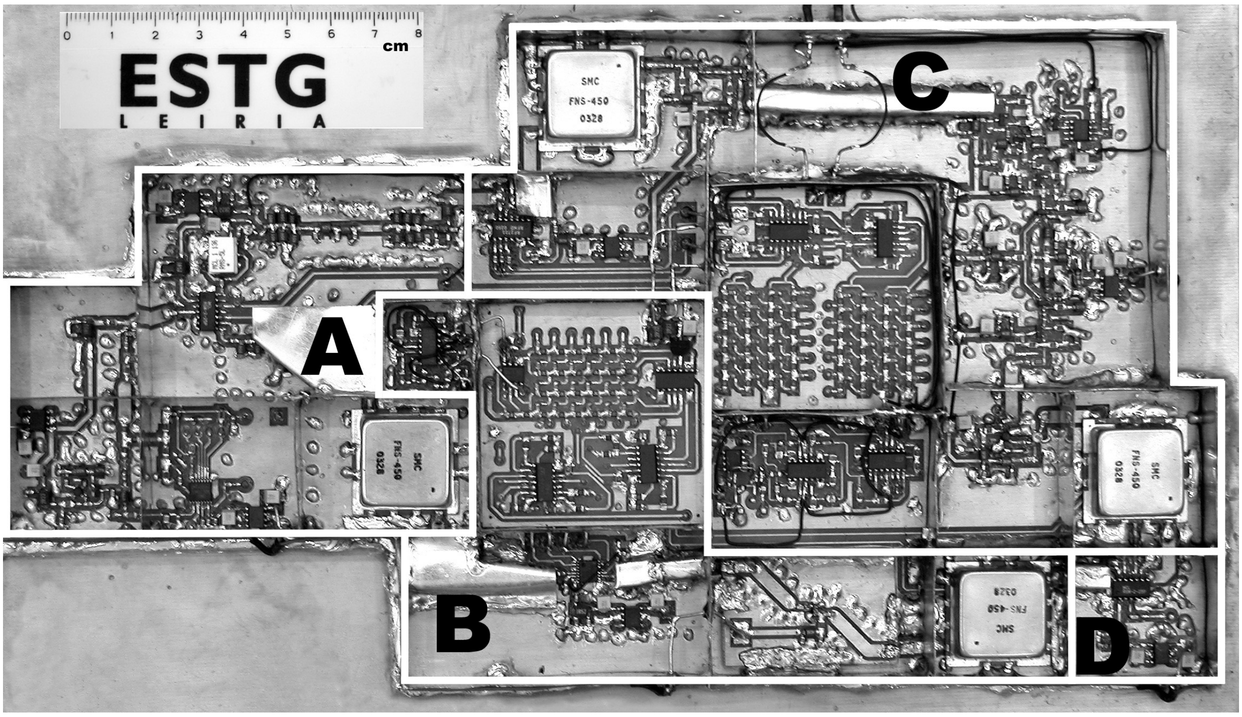


Fig. 3 – Transceiver prototype.

The switch that routes the LO to the frequency converters increases the isolation between the transmitter and receiver circuits, since the frequency converters do not work when the LO is not applied to their LO input.

III. SYSTEM IMPLEMENTATION

Noise and interference are major issues in the design of transceivers. In order to fully characterise the final prototype, and also to gain some insight, the implementation was done in two sequential stages. In the first stage all the sub-systems were implemented, tested and characterised individually. Next, all modules were integrated together, with special care regarding both noise and interferences.

The prototype (depicted in Fig. 3) was implemented on a two layer printed circuit board of type FR-4.

A. Transmitter

The transmitter consists of a quadrature upconverter, an amplification stage and an output filtering stage. This module in the final prototype is located in the area B of the Fig. 3.

The quadrature modulator is based on the integrated circuit (IC) AD8345 of Analog Devices, which provides direct implementation of the quadrature converter and adder, referred in section II-B. The generation of the I and Q IF signals, necessary to implement the quadrature upconverter, were done by a polyphase RC network. This circuit has a differential input and two differential quadrature outputs. The central frequency is 15kHz and the BW is 12kHz. To reach this bandwidth, several cascaded stages were used, each of them with a different central frequency.

The amplification stage is based on the IC VAM-6 from Mini-Circuits. This stage provides 15dB of gain and matching of both input and output ports. The filtering stage consists on the surface acoustic wave (SAW) filter FNS-450 from Synergy, which allows a spurious free transmitted frequency spectrum.

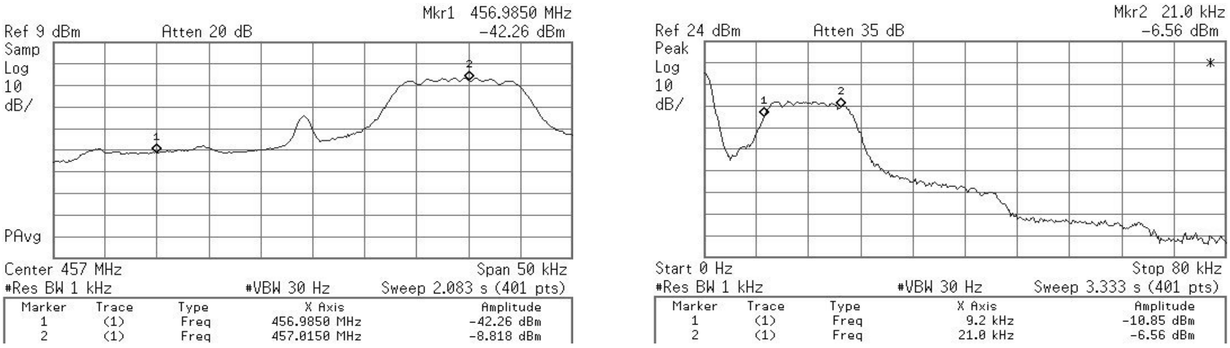
B. Receiver

The receiver consists of a low-noise amplifier, a variable amplification stage and an image reject downconverter. These modules are located in area C of the Fig. 3.

The amplifiers used in the low noise amplification stage were the RAM-6 and ERA-1 from Mini-Circuits. This stage has 30dB of gain and imposes a 2.8dB minimum noise figure on the receiver.

The second stage is an automatic gain control (AGC). The main part of this circuit consists of a variable gain attenuator followed by a variable gain amplifier. These modules were developed with discrete components, such as bipolar transistors and PIN diodes. The achieved dynamic range with this configuration is 80dB.

The downconverter implementation uses the IC RF2721, from RF Micro Devices. This component is a quadrature converter. Two polyphase RC networks were used to change the phase relation of the I and Q outputs of the quadrature converter (like the one used in the up-converter). Then, a differential amplifier was used to combine the outputs of the two polyphase networks. The RF2721 operates with a LO frequency two times greater than the transceiver operating frequency (Fig. 1). The reason for this relies on the generation of the I and Q LO outputs by a frequency divider, with one output triggered by the rising edge and another by the falling edge. The necessary frequency duplication was implemented with a mixer, followed by a band pass filter.



a) b)

Fig. 4 – Spectrum of the a) FM signal at the RF transceiver output and b) at the IF transceiver output.

C. Local Oscillator

The LO consists on a PLL-based synthesizer followed by a buffer stage. This module is depicted in area A of Fig. 3. The synthesizer uses the IC LMX2306 from National Semiconductor, a crystal oscillator and a VCO. The IC integrates two programmable FDs, a PD and a CP.

The VCO is based on a discrete tuned amplifier with feedback loop. The varicap used in the feedback network control the frequency of operation. This VCO can be tuned from 400MHz to 500MHz with a control voltage between 0V and 5V. The VCO as an output power of 3dBm, a phase noise of -70dBc/Hz for a frequency offset of 10kHz. The reference oscillator is a low noise crystal oscillator with central frequency of 10MHz.

The implemented LP is a 2^{nd} order passive RC filter that was developed for a 1kHz loop BW. So, the synthesizer is a 3^{rd} order PLL. To achieve 100kHz re-tuning steps, the FDs were programmed to PD work with a comparing frequency of 100kHz.

C. Tx/Rx Switch

The Tx/Rx switch consists of two RF integrated switches, which are placed in two different locations: one on the LO module and the other before the Tx/Rx antenna, which is 30cm from the transceiver. The IC used is the RSW-2-25P from Mini-Circuits, which is characterised by an insertion loss of 0.7dB and a port isolation of 49dB, in the transceiver operating BW. Both switches are controlled by the DSP. This module is in area A and D of Fig. 3.

IV. Experimental Results

To evaluate the transceiver performance, several tests were done. One of them used a FM signal, centred in 15kHz and with 12kHz of BW. This was considered the IF input signal. The spectrum at the output of the transmitter is represented on Fig. 4a, showing a lower side band rejection of 35dB and a LO leakage of -25dBm. The receiver was tested with a FM signal, like the one used to test the transmitter, but with different central frequency (457MHz). The spectrum of the downconverted signal is shown in Fig. 4b. As it can be seen, the shape of this spectrum is similar to the transmitted one (Fig. 4a), showing correct operation. To verify the correct signal reception, a FM demodulator was used on the receiver output. The recovered signal was equal to the signal used in the input of the FM modulator, which proves the correct operating of the receiver.

These tests were repeated using other types of analog and digital modulations, allowing to conclude that the transceiver is capable to transmit signals with several types of modulation, since the central frequency and BW are the same of the IF stage.

Other tests were done to evaluate the correct transceiver performance. From these, the following characteristics were observed: output power of 6dBm, spurious emission less than -54dBm, LO leakage of -25dBm, suppressed side band of 35dB, sensitivity of -110dBm, reception dynamic range of 80dB, image rejection of 28dB, maximum power consumption of 6W, weight of 350g and volume less than $1200cm^3$.

V. Conclusions

This paper describes a RF transceiver based on a quadrature upconverter and on an image reject downconverter. This system was developed for an unmanned airborne vehicle. The presented performance characteristics are sufficient for the aimed application.

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