FlexRay Transceiver in a 0.35 μm CMOS High-Voltage Technology

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Abstract

This paper presents one of the first fully functional FlexRay transceivers manufactured in a 0.35 μm CMOS High-Voltage technology, which provides high voltage MOS devices together with standard 3.3 V gates. The circuit operates as interface between a generic controller and the copper wire FlexRay physical bus, to be used in fault tolerant and fail safe applications. In particular, the transceiver meets the operating requirements of the automotive environment. The design was validated by means of simulations and experimental measurements on fabricated prototypes.

1. Introduction

The last four decades have witnessed an exponential increase of the amount of electronic systems used in vehicles. The great advances in semiconductor technology, more stringent environmental regulations and the customer increasing demand of improved performance, safety, and comfort have driven this trend. As a result, many of the control functions previously accomplished with mechanical and hydraulic systems are now performed using electronic systems, which make possible the realization of more sophisticated and flexible control algorithms. The electronic control units (ECUs) for the management of engine, powertrain, and breaking systems are only a few but significant examples. Moreover, new features and new applications have been introduced, such as collision avoidance systems, navigational aids, multimedia systems, night vision systems, and ITS (Intelligent Transportation System) services integration, to make a journey safer and more enjoyable [1], [2].

We notice that all the above mentioned electronic systems are based on the cooperation between several subsystems (ECUs, sensors, and actuators) spread all over the vehicle. This fact determines the need of an efficient and reliable inter-vehicle communication infrastructure that cannot be satisfied by the conventional point-to-point wiring system [3]. Indeed, the wiring harness length and weight increases with the number and complexity of the electronic systems employed in a vehicle, creating difficulties in the assembling process, reducing the reliability and making unaffordable the harness cost. Therefore, multiplexed systems, in which the communication between the devices is accomplished with a serial bus, were developed and introduced starting from the 1980's. Nowadays, multiplexing is widely used in automobiles and heavy trucks in which more than one network is used to connect devices with different bit-rate and reliability requirements [4]-[7].

Inside the above described scenario, the new FlexRay protocol [8] is very promising, since it features high-speed (up to 10 Mb/s) communication along with deterministic behavior and fault-tolerant capability that are not addressed by the Controller Area Network (CAN) [9], which is the current *de facto* standard for automotive applications. Therefore, it is expected that the FlexRay bus may become the future automotive communication standard, at least for safety and high bandwidth control systems, such as x-by-wire applications (i.e. drive-by-wire, steer-by-wire, brake-by-wire, etc.).

As a consequence, the availability in silicon of high data-rate transceivers, meeting the very demanding automotive operating range requirements (in terms of temperature and supply voltage), may result of fundamental importance for the future diffusion of this protocol into the automotive environment and the consequent development of advanced control systems in vehicles.

The aim of this work is to give an overview on the design and the experimental characterization of one of the

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first realization of a high-speed transceiver fully compliant with the FlexRay physical layer specification. The device is specifically designed to operate in the automotive environment, providing a temperature operating range from -40ºC to 150ºC and supporting the 42 V battery power-supply system.

2. FlexRay transceiver design

The first factor that determines the success of this design is the availability of a technology that could meet the tough requirements of the automotive environment. The FlexRay bus transceiver described in this work was designed using a robust 0.35 µm CMOS high-voltage technology (H35). The H35 technology is based on a standard 2-poly 4-metal (2P4M) 0.35 µm CMOS process, with 3.3 V logic gates and optionally 5 V gates, on top of which only two additional mask levels are required to provide the high voltage (HV) MOS devices. As a consequence, a high gate density of 17,000 gates/mm^2 is reached, together with the availability of HV MOS devices, capable of operating from 20 V to 120 V. Moreover, the H35 technology features very low on-resistances of the MOS devices, similar to those obtainable with more complex BCD (Bipolar CMOS DMOS) process and high blocking voltages at the same time. As an example, Fig. 1 shows the blocking voltage experimental measurement carried out on a 120 V NMOS. The experiment points out that this technology provides devices with a breakdown voltage higher than 150 V. We also notice that accurate SPICE models are available for the high-voltage MOS devices, thus leading to an easy design of complex power ICs, as demonstrated by the example described in this paper. More details on the technology used can be found in [10]-[12].

It is worth noticing that the robustness and reliability of the H35 technology allows us to meet the stringent operating requirements for automotive applications. In fact, the bus transceiver maximum ratings, as reported in Table 1, allow us to cover the most demanding automotive applications also. In particular, the upcoming 42 V battery systems can be supported by this technology. In addition, protection against damages due to short circuit conditions on the bus (positive and negative battery voltage) is obtainable.

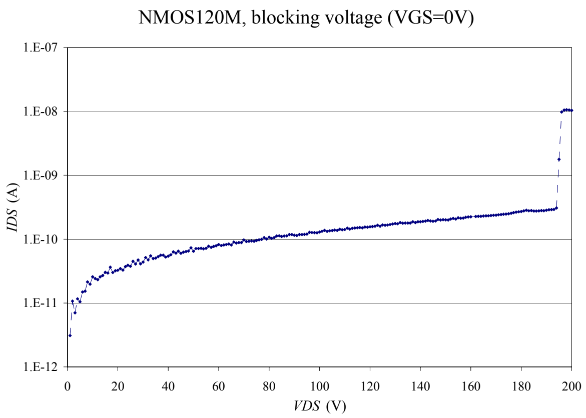

Fig. 1: Blocking voltage measured on a 120 V NMOS device.

Parameter	min.	max.
Battery Supply Voltage	-0.3 V	+58 V
Bus DC Voltage	-58 V	+58 V
Junction Temp. TJ	-40ºC	+150ºC
ESD (HBM)	-4 kV	+4 kV
Latchup immunity	-100 mA	100 mA

Table 1: Maximum ratings of the FlexRay bus transceiver.

Fig. 2 reports the block diagram of the bus transceiver. As we can see, the circuit can operate as interface between a generic FlexRay controller and the copper wire physical bus. In particular, it provides a host controller interface, which enables the host to select the mode of operation of the transceiver (normal operation mode, receive only mode, and three low-power operation modes: standby mode, power-on standby mode and sleep mode) and to read diagnostic information. In addition, the transceiver can leave the sleep state once a wake-up event, which consists of the reception of a wake-up signal either from the bus (remote wake-up) or from the wake-up pin (local wake-up), is revealed. A wake-up detector block accomplishes this function.

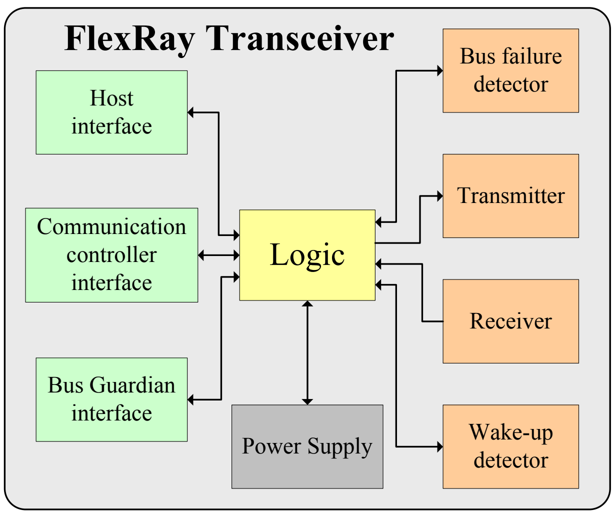

Fig. 2: Block diagram of the FlexRay transceiver.

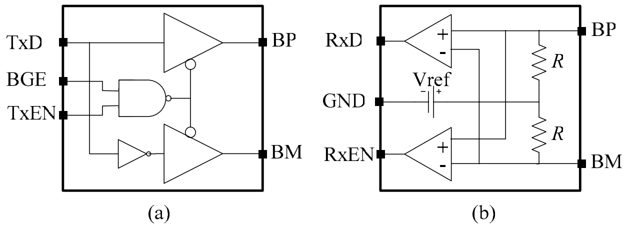

Fig. 3: (a) Transmitter principle schematic. (b) Receiver principle schematic.

A key element of the transceiver architecture is the transmitter, which consists of a pull-up driver and a pull-down driver for the high-side BP line as well as the low-side BM line, as shown in Fig. 3(a). This structure has been chosen to guarantee as much as possible the symmetry of the voltage swings on BP and BM lines, with respect to half of the supply voltage level, also during the transition phases. This symmetry feature is very important to keep the electromagnetic interferences (EMI) as low as possible, and to match the stringent timing requirements of the FlexRay protocol. Moreover, the drivers are protected against short circuit to the positive and negative battery voltage. This feature prevents destruction of the transmitter output stage during such faulty conditions. The BP and BM lines are also protected against electrical transients, which may occur in the automotive environment. Fig. 3(b) depicts a schematic view of the receiver block, which is responsible for biasing the bus and receiving the signal streams. In order to improve the immunity against disturbances a hysteretic behaviour is implemented.

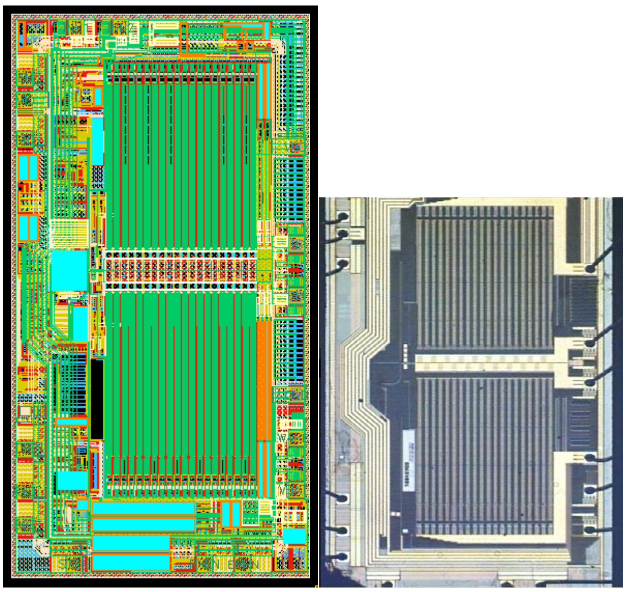

Fig. 4: Layout (left) and microphotograph of the driver (right) of the FlexRay bus transceiver manufactured in H35 technology.

3. Experimental results

The above described FlexRay bus transceiver was manufactured in the H35 technology. A large number of fabricated chips was tested in order to verify that the transceiver is able to properly work in the full automotive operating range and to accurately characterize the behavior of the transmitter circuit.

Fig. 4 shows the layout of the bus transceiver die. It can be noted that most of the area is due to the driver transistors (see microphotograph in Fig. 4), the layout of which was carefully designed to achieve the best possible symmetry in the driving capabilities of the bus lines and the required high voltage performance. In fact, as stated above, one of the critical parameters of the FlexRay physical layer specification is the matching of the differential voltages between the high side bus (BP) and the low side bus (BM), which should be achieved as much as possible. In order to measure the performance of the transmitter, the voltage levels on the bus lines were measured under the 4 conditions reported in Table 2.

VDIFF_0	Difference between high side bus and low side bus when transmitting a 0 (TxD = 0).
VDIFF_1	VDIFF_1: difference between high side bus and low side bus when transmitting a 1 (TxD = 1).
VDIFF_HIGH	Absolute difference of high voltage levels for high side bus and low side bus.
VDIFF_LOW	Absolute difference of low voltage levels for high side bus and low side bus.

Table 2: Bus test conditions.

The current consumption in the sleep mode of the transceiver was also measured and found to be below 50 µA. Fig. 5 shows the measured voltages on the BP and BM lines of the FlexRay bus as generated by the transceiver, during a transmission sequence (the data to be transmitted *TxD* and the enable signal *TxEN* are also displayed). It should be noted the symmetry of the response on the two bus lines, so that a maximum delay-time mismatch of 4 ns between each of them is found.

As an example of the extensive experimental characterization that has been carried out, Fig. 6 shows a typical distribution of the value of the bus differential voltage, measured when the transceiver transmits a 0, over 535 different samples. These experiments allow us to calculate the statistics of the measurements in term of mean value and standard deviation. These values are

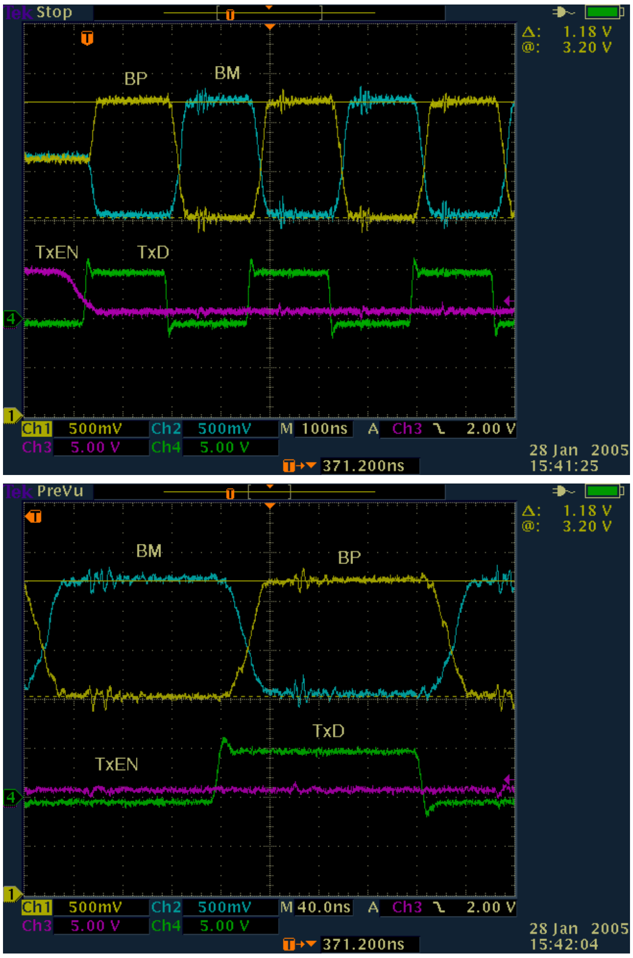

Fig. 5: Measured voltages on the bus (BP and BM) during a transmission of a *TxD* digital sequence (above); enlarged view (below).

reported in Table 3, which summarizes the measured values of the differential voltages under the bus test conditions described in Table 2. In addition, Table 3 also reports the values of the same experiments, as simulated according to a Monte Carlo simulation, which takes into account accurate device models of the high-voltage transistors and mismatch parameters [13].

First of all, we notice that the values obtained by the experimental characterization show a very good repeatability from sample to sample, since the standard

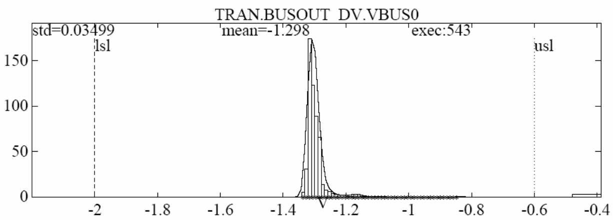

Fig. 6: Measured distribution of the differential bus voltage VDIFF_0 on the FlexRay transceiver.

deviation is rather little. Moreover, the measured mean values over the two lines are very close each other and also the absolute differences lay in the order of 10 mV. This shows once again the good response in term of driving symmetry of the transceiver. Finally, we also like to point out the good correspondence between the measured and simulated data, for both the mean and the standard deviation values. This demonstrates that the device models and the mismatch parameters adopted are of good quality and the results obtained by the Monte Carlo simulations are reliable. This makes the designer confident on the performance results achievable since the simulation phase.

	Sim Mean [V]	**Meas Mean [V]**	**Sim Std. Dev. [mV]**	**Meas Std. Dev. [mV]**
VDIFF_0	-1.28	-1.29	29	34
VDIFF_1	1.28	1.25	25	34
VDIFF_HIGH	0.011	0.014	13	17
VDIFF_LOW	0.010	0.013	11	15

Table 3: Measured and simulated values of the voltage differences between the high side bus and the low side bus at different conditions.

4. Conclusion

The design of a FlexRay bus transceiver in a 0.35 µm CMOS high-voltage technology (H35) has been presented. This is one of the first realization of a fully functional FlexRay bus transceiver. The circuit is able to operate in the harsh automotive environment, as shown by the large number of tests carried out on the fabricated chips. This is due to the robustness and reliability of the H35 technology used for manufacturing the device.

In addition, the experimental results have pointed an excellent match between the high side and low side bus levels, which is a very important feature of the transmitter circuit to guarantee a reduced amount of EMI. This result was achieved because highly accurate SPICE model for the high-voltage MOS devices were available, and the mismatch effects were taken into account in the early phase of the design. Indeed, a very good matching has been obtained between the experimental results and the simulated ones.

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