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HIGH LINEARITY ANALOG OPTOCOUPLERS - APPLICATIONS INSIDE THE RF SHIELDED ENCLOSURES

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Abstract: The paper presents several technical issues and hardware implementations to analyze from the perspective of the galvanic isolation the problematic concern of separation between the transceiver currents flow and the PC common ground. Only the information exchange is allowed through two different types of optocouplers: the first allows transceiver control and monitoring and the second, only analog information exchange. In this paper, the effect of the strong RF field over the PC ground, especially under the reactive behavior of the load (impedance mismatching), has been analyzed. The result stands in favor of the new integrated linear optocouplers. These integrated circuits designed for analog signals are using linearization to increase bandwidth. An optocoupler for audio-interface, designed and tested by the author, experiences the best performance in the proximity of the RF field, enclosed in a metallic box together with the RF power amplifier.

Keywords: *Computer aided transceiver (CAT), GNU radio, galvanic isolation, EMI Electromagnetic interference*

I. INTRODUCTION

A modern RF transmitter is entirely under the controlled of the computer which continuously monitoring the specific parameters like SWR (Standing wave ratio), frequency band, modulation, power and so on. Not only the monitoring but the full control of those parameters is relying on the proper functioning and continuously data exchange between the PC and the transceiver. Unless the errorless exchange of data is guaranteed, the transceiver will work without the control and according to this the radio-link will become unstable (a hazardous behavior occurred). The isolation will avoid this behavior even under very difficult circumstances like EMI (electro-magnetic interference). RF current displacement responsible for EMI is here the main constraint of working in near field zone and in the presence of strong mutual coupling. The paper is focusing on the interference caused by the near field inside the metallic box of the transceiver when the common mode current is allowing throughout the electrical lines outside the enclosure shield. These currents must be rejected by the galvanic isolation at the input of the PC. Even though the RF currents can break through this isolation especially when the load shows a reactive behavior. This is happening when the transmission line at one side remains open or in the case of impedance mismatching of the load. In these circumstances, there is a phase difference between the current and the voltage signal which causes EMI (or TVI [1] for PC display).

This paper underline the effect of EMI over the common inductive couplers which became in some circumstances incapable of blocking the RF currents at the input of the PC. The effect of EMI becomes obvious only at higher RF powers over 50 watts when disrupts the link between the PC and the transceiver or leads to false PC commands through CAT interface[2][3].

This research focuses on the comparison between the common galvanic couplers based on inductive or capacitive transformers against optocouplers for both the digital and the analog signal respectively. The hardware platform designed specifically for this kind of comparison follows some innovations that emerge with outstanding technology of the moment.

The paper is structured as follows. Section II shortly describes the CAT optocouplers for transceiver control and monitoring. Section III proceeds on with the implementation of the analog optocouplers that isolate the sound board from the transceiver modulator stage. Section IV describes the use of the GNU radio companion signal flows and the test setup for the calibration procedures. Section V presents the plotting of the results (processing) and the effect of the RF near field over the PC ground. Finally, section VI concludes with the remarks and underlying some drawbacks.

II. ISOLATION OF THE CAT INTERFACE

This section provides descriptions about evaluation of the optocouplers used at the level of the CAT interface against capacitively coupled interface. CAT commands are using in modern transceivers trough the RS232 serial interface [4]. When the serial interface is not present, it is emulated on USB port using a USB to RS232 converter. Usually it converters the DC $\pm 5V$ into 0 V or 5V

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respectively at the transceiver RXD/TXD input/output. A dedicated IC like MAX232 fulfills this DC to DC conversion, in both directions. In order to increase the isolation and proceeds on with the comparison, it has been designed an interface with 4N35 ICs. These series of optocouplers have a NPN silicon planar phototransistor optically coupled to a gallium arsenide diode. The 4N35 series fulfill the data rate of the CAT demands, between 4800 to 35300 bps [3]. In figure 1, the isolation between the transceiver ground AGND and PC-RS232 ground (GND) is assured with two ICs 4N35 on the same board with the MAX232 IC. The power for biasing the phototransistor's collector is supplied separately by the transceiver at pin 5 of the ICs.

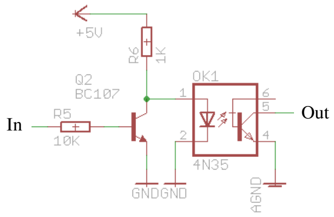


Figure 1. Schematic of one optocoupler cell - OPT

The voltage applied across the resistor R5 from the output of the MAX232 converter, provides the ON/OFF logic state to switch between the *True* state (0V) or the *False* state (5V) at pins one and five (figure 1). Two different optocouplers with 4N35 offer a very good isolations between the PC and the transceiver (figure 2).

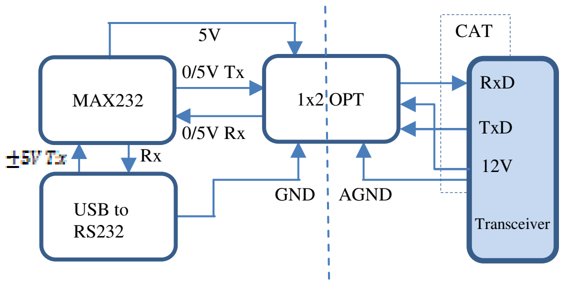


Figure 2. Schematic diagram for the PC-CAT optocoupler

The first comparison has been made between the working interface from figure 1 and the same interface without the OPT module. The result confirms the expectations in terms of computer EMI reduction. Without the OPT, at higher powers (that exceed 50 watts), both the PC display and the link between the PC and transceiver, where disrupted.

In the presence of the OPT module, the ground separation as well as power supply isolation, diminishing the effect of the EMI but not entirely. The display is affected and very small perturbations like *salt and paper* noise are visible together with very smooth horizontal lines during the transmission period [1].

Actually this is because of the capacitive only isolation between the PC soundboard and the transceiver. The ground separation depicted in figure 2, is not entirely efficient because the ground of the soundboard is not properly isolated against the common ground of the USB to RS232 interface. Therefore, the separation between the transceiver and the PC, through the presented interface from figure 1, is not sufficient, especially for high powers between 80 to 100 watts. This result leads to the idea according to a second optocoupler for audio signal's path, should fulfill the demand of the isolation. An optocoupler for analog signal is not as simple as for the digital due to photodiode nonlinear characteristic. An *audio optocoupler* must experiences extremely high linearity and very low distortions at least under 1% according to the audio boards' fidelity, in terms of the signal quality. An *audio optocoupler* must not diminish the performances of the audio interface, so the distortions, must be at most equal to those exhibited by the audio board.

III. OPTOCOUPLER FOR AUDIO PATH

An analog optocoupler is isolating the audio common ground GND from the transceiver audio ground GNDA (figure 3). This isolation is also available for the 5V power supply on USB and also for 12V. The IC HCNR 200 is an innovative analog optocoupler made by Agilent/ Hewlett Packard that exhibits very low nonlinearity under 0.01%. The circuit bandwidth is in between DC and 1 MHz, covering all the audio spectrum of the human voice.

The HCNR 200 consists of high performance AlGaAs LED that is closely coupled with two photodiodes. One photodiode is working on to drive and stabilize the LED. According to the producer the nonlinearity and drift characteristics of the LED can be diminished in this way by using a flyback loop. The main application of the HCNR 200 is in low cost audio isolations for telecommunications (modems) as well as in industrial process&control (for transducers isolation).

The schematic depicted in figure 3 follows the test schematic circuit used by Hewlett Packard in its datasheet but some minor changes made by the author to suit the use of the LM358N instead of the LT1097.

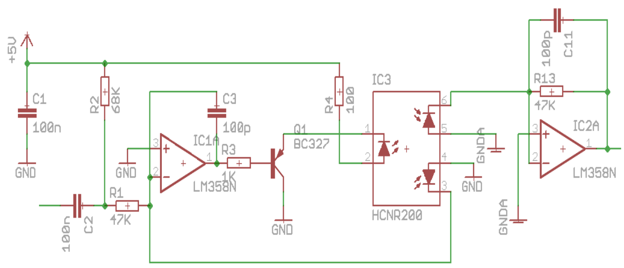


Figure 3. Schematic of one optocoupler audio cell - AudioOPT

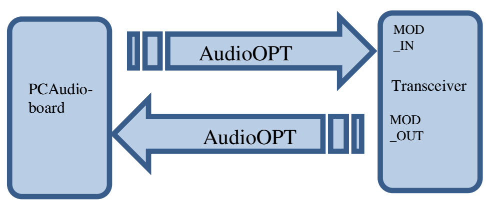


Figure 4. Schematic diagram for the PC-CAT optocoupler

The second OA (IC2A) has been designed as a current to voltage converter. The resistor R13 is compensating the loss of the optocoupler and adjusting the gain of the IC2A.The overall gain of the AudioOPT cell from figure 3 is equal to unity in order to avoid unbalance between the audio paths. This is achievable by using two adjustments (IN/OUT) and balancing the modules internally entirely by software using the sound board (more in section IV).

Figure 4 shows the way in which two identical audio optocouplers from figure 3 can separate audio paths in both directions. In order to balance both paths it is more convenient to use the software audio level adjustment, this option being available for every sound card. If this is not possible for some reasons, one can make some hardware adjustments as well by replacing the resistor R13 with a potentiometer.

IV. USING GNU RADIO COMPANION TO OPERATE THE TESTS

GNU radio companion (under Linux OS) is a graphical tool suited to create signal flow graphs and generating source code in C. With its powerful graphic tools the FFT/IFFT processing becomes handy. Besides, GNU radio can operate with any sound boards and can also avoid the use of the slow scripts like *Java* or *Basic* that could slow down the processing unit. GNU radio can also use the sound board as a NULL modem for calibration.

The test setup was built by the author following the same signal flows of classic analyzers. Following this rule the galvanic separation acts as a device under test (DUT1-figure 5) between output (P1) and input (P2). The idea of using the sound board as a device analyzer allows more accurate sensing of the EMI effects over its ground.

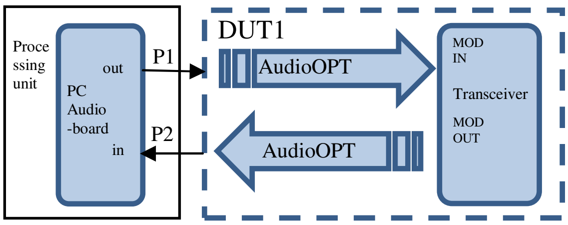


Figure 5. Schematic diagram for the PC-CAT optocoupler

A sinusoidal signal is generated at the output of the PC audio board as test signal with known parameters (frequency and magnitude).

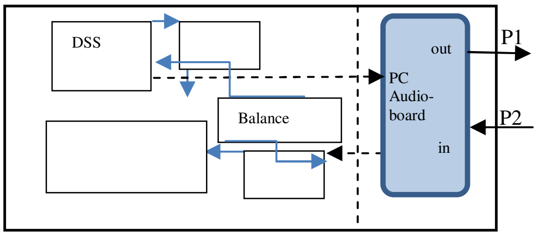


Figure 6. Signal flows diagram of the processing unit

The test signal is passing through the optocoupler interface, and it goes further to the transceiver modulator unit. In transmission mode, the transceiver RF signal interferes with the port P2 (the audio board input). After the suppression of the test signal, the remaining frequency components represent the effect of the DUT during transmission. The processing unit compares the received signal with the test signal in calibration mode and detects any differences. During the calibration, a short cable connects the port P1 (output) to the P2 (input). The FFT transform makes this comparison easier in the frequency domain. Any extra components in the received signal spectrum are treated as being the effect of unbalance.

In figure 6 is shown the flows signal diagram of the processing unit. Every block is written in python language under Linux. The signal generator is using the digital converter of the sound board to synthetize the test signal. This can generate one tone as well as multi-tone signal using the IFFT transform. The spectrum of the test signal is also available for plotting after the use of the FFT block for both signals (test or reference) the test and the received signal. The block named *Balance* adjusts the level of the FFT coefficients and balancing the entire system to fit the received signal to the exact shape of the test signal. This is going on only during the calibration when the short cable is replacing the DUT from figure 5 and put the output to the input of the PC sound board. The effect of the nonlinearities and the attenuation drops and it is kept low for the working frequency domain from 50 to 3000 Hz. The block named *balance* adjusts every FFT coefficient from 1 up to 1024. When the received signal matches the transmitted one, (the test signal) the processing unit is ready for measurements and the DUT1 is replacing the short cable.

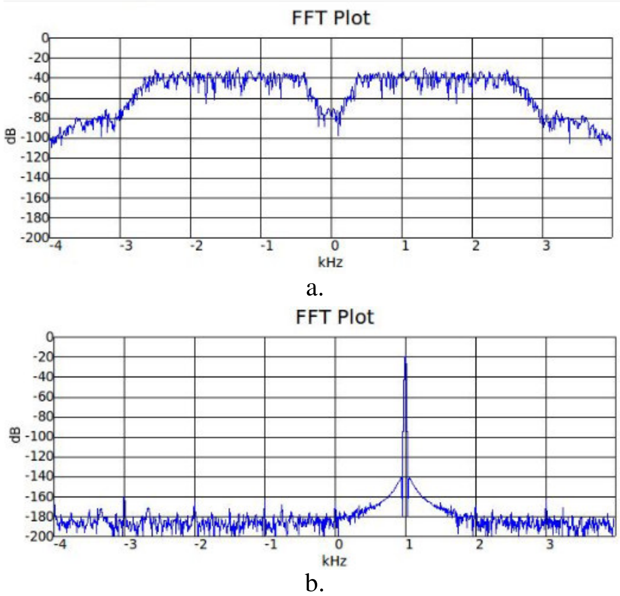


Figure 7. Displayed spectrum (50 W - RF transmitted power) a. Noise floor b. Test signal

The margin frequency (of 8000 Hz) is upper bounded here not by the sound board or processing unit but the transceiver input filters. Anyway the linearity of the AudioOPT by means of the CI HCNR 200 is guaranteed beyond this bound up to 1 MHz.

In the figure 7.b is the FFT spectrum at the port P1 (see also figure 5) and in figure 7.a is depicting the noise floor at the port P2 when the transmitter (TX) is still on. The RF power is only 50W applied to a 20 m transmission coaxial line which is open at the other side. Despite the reactive behavior of the line, one can see that the port P2 remains isolated by the effect of mismatching (only noise is present and no spurious harmonics component). From now on the test bench is ready for measurements.

V. THE REFERENCE – DUT2

In order to make a comparison between the classical galvanic isolators, we have to describe the build in galvanic isolator of the transceiver. Most of the transceivers have capacitive coupling with I/O interfaces. Even though for better magnetic coupling, transformers are commonly used in most of the cases. At this power, the capacitive only de-coupling is not safe for the most PC interfaces like sound board. This is because of the weak isolation trough. The device under test DUT2 is a simple magnetic coupler using a toroidal ferrite core with 1:1 transformation ratio.

The ferrite type is FT-240-77 which exhibits very good characteristics below 7MHz. This ferrite has a blue or green toroidal core according to color codes for ferrites. The color used for the core body indicates the applications the ferrite is fitted for. In the case of the DUT2, the ferrite transformer has four and a half turns for each coil and replaces the AudioOPT optocoupler from figure 5. The characteristic of the transformer has been tested with a Vector Network Analyzer. The transmission S21 parameters for both the magnitude and the phase is shown in figure 8. The parameter TL is the magnitude that stands for S21 and is dropping suddenly when the frequency goes beyond 100 KHz. At 100 KHz the attenuation is under -1dB and at 1 MHz, TL drops to -26 dB. When the frequency is far beyond this margin the attenuation is at least 30 dB and the signal is 1000 times smaller. Even though the attenuation is not higher enough. The next section shows where the problem is.

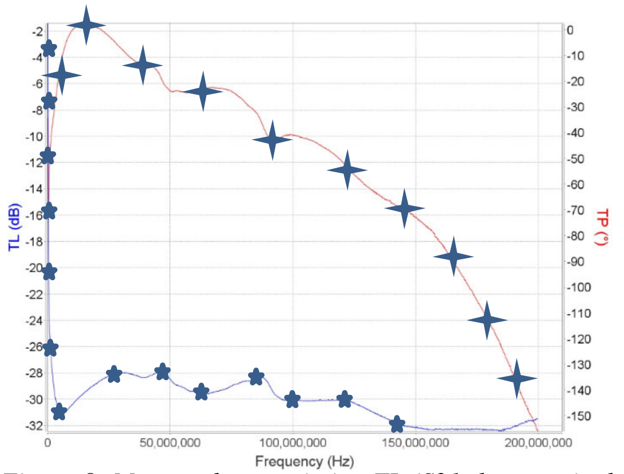
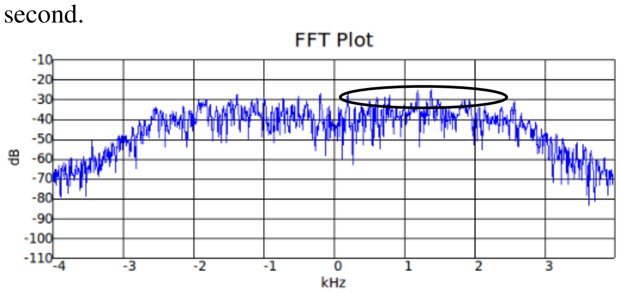


Figure 8. Measured transmission TL (S21-the magnitude in dB-7 point star) and TP (S21-the phase - 4 point star) parameters for DUT2

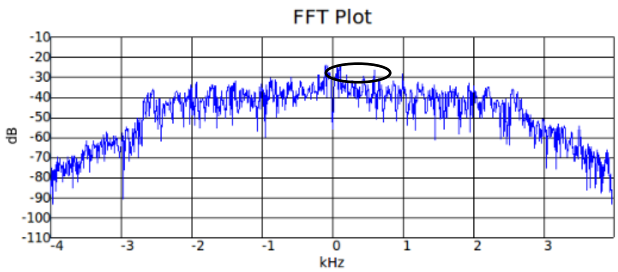
V. TEST SCENARIOS

When the RF power is under the 65 W, the port P2 remains protected against the effect of mismatching. It means that the ground currents which flying on AGND (see figure 2) cannot arrive on PC ground GND. There is no PC perturbations measurable or visible on the PC monitor. Common currents problem is known in the domain of EMI mitigation and arises when the differential currents between the inner and the outer conductors along coaxial cable are unbalanced. The worst case in which these common ground currents make problems is when the load behaves reactively, and the reactance of the line shows a nonlinear variation even for a short period, with the increasing of the RF power.

Here this problem arises when the RF transmitted power goes beyond 65W and approaches 100W (in this experiment is the maximum transceiver RF power available). The coaxial line shows a reactive behavior due to the open end. This open will be named "*fault*" from now on and can occur anytime almost suddenly, especially when the cable line is broken. This is, in fact, the moment in which the common ground currents can put in danger the PC, before the protection, like ALC (automatic level control) can react on time. The *fault* effect has been simulated with a coaxial relay that is switching between on and off state two to three times per second.



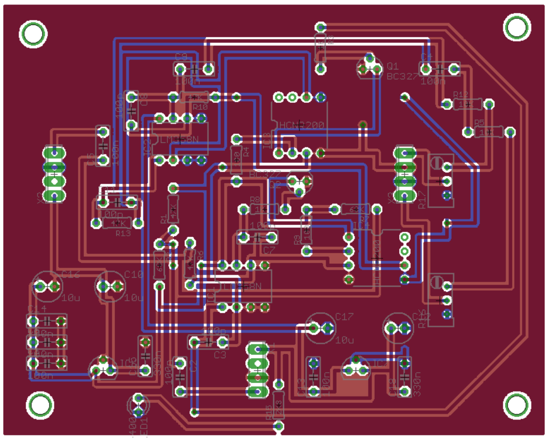
a.



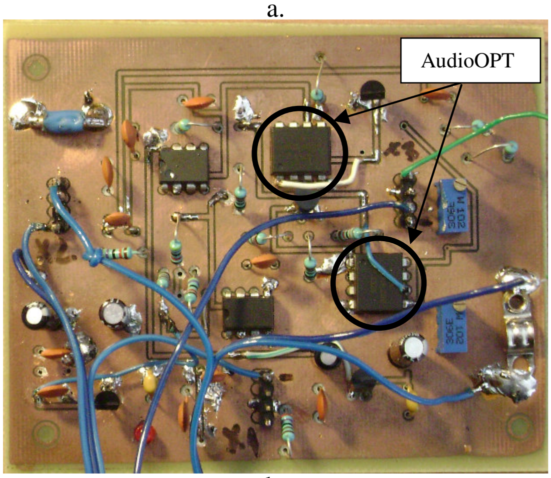
b.

Figure 8. FFT plotting using Hamming window, voltage at the P2 – Comparison between DUT2 and DUT1- a. DUT2 (ferrite transformer) –b. DUT1 (optocoupler)

The result depicted in figure 8 confirms the better isolation of the DUT1 vs. DUT2. The isolation with a ferrite based transformer (DUT2-figure 8.a) shows some picks over the -30dB under the fault simulation stress and the noise floor increases as well with 8 dB from -40 dB to -32 dB. In the figure 8.b the optocoupler (DUT1) shows a variation also but the increase of the noise floor is under 3 dB in the same circumstances. Also, the variation is spreading more toward the lower frequencies from 50 to 100 Hz, not along the entire audio spectrum as it is for the DUT2. When a *fault* is not present, and the load matches the coaxial line characteristic impedance, the result looks like the one in the figure 7.a, and the galvanic isolation works well for both DUT's. In this experiment, it is no measurable evidence toward a frequency dependency between these peaks and the test signal. That leads to the idea that there is no intermodulation due to the nonlinear behavior of the DUT. The experiment shows a dependency for different powers between the variation density and the switching rate of the relay. This dependency has been observed only in the FFT plotting. The higher the switching rate, the higher the peaks density is, but the level of the peaks depends only by the RF power. No mathematical relations can be established to explain the phenomenon.



a.



b.

Figure 9. Practical implementation of the opto-coupler for audio signal - a. PCB CAD design – top view b. PCB board – top view

There are also no measurable effects (peaks) under 60W transmitted power. Those peaks are hardly measurable between 60 to 80W and measurable above 90W. According with the experiment peaks level increase only with the increase of the RF power. The quality of the isolation should decrease even more with the increase of the power over 100 W, but this further increase was not available here. In figure 9.a is the PCB CAD design made in Eagle version 6.4. The PCB board is FR4 with double sided copper layers. The practical implementation of the optocoupler for the audio signal is shown in figure 9.b. The picture represents the top view of the board.

VI. CONCLUSIONS

A novel test set based on linear optocouplers envisages the effect of the strong near field enclosed in a metallic box over the PC ground. This approach aims to simulate some extreme conditions in the presence of the fault (an open end) along the coaxial line at high RF transmitted powers. The research is focusing mainly over the effect of the fault over the PC ground, during its operation. It has been investigated the quality of the isolation when the common ground current goes through the galvanic isolation in this circumstance. The measurements validate the expectations in favor of the linear optocouplers against of the common ferrite transformers. The common currents effect over the PC ground it is an important issue in avoiding EMI (Electro Magnetic Interference) and some hazardous behavior of the control unit (the PC).

The problem encounters the circumstance only in the presence of the fault, and usually a transceiver has other protection levels that isolate the fault in its attempt to keep the system safe. Nevertheless there are situations in which the RF power stage must remain under the control of the logic unit even during this period [5]. Under these circumstances, the linear optocouplers remain the best tradeoff for the analog signals galvanic isolation.

Although the right choice stands in favor of ferrite transformers, under normal circumstances, when the coaxial line is matching to the load most of the time. This is because the ferrite transformers are very cheap and go easily broadband. The bandwidth constraints of the linear optocouplers are not fulfilling the demands of all devices especially those designed for broadband approaches.

A cheap linearization [6] solution for analog photo-couplers under the demands and constrains of broadband communications system remain an open issue.

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