

Analysis of noise properties of an optocoupler device

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In the paper, localization of a source of random telegraph signal noise (RTS noise) in optocoupler devices of CNY 17 type was defined. The equivalent noise circuit in low frequency noise for these types of optocouplers was proposed.

Keywords: noise measurement, RTS noise, optocoupler device.

1. Introduction

During the past two decades, optocouplers were often applied in telecommunications, robotics, and micro-systems [1]. It was pointed out that especially in their telecomm applications very often disturbances occur. The disturbances were probably caused by the random telegraph signal noise (RTS noise) generated by an optocoupler device [2].

The aim of this paper is to localize the source of RTS noise in the optocoupler equivalent noise circuit. Three possibilities were taken into account. A source of RTS noise is located either in LED or phototransistor or is caused by an optical couple.

2. Equivalent noise circuit of optocoupler

The optocoupler device is typically a gallium arsenide infra-red emitting diode, optically coupled to a silicon npn phototransistor [Fig. 1(a)]. On the basis of an analysis of noise sources of LED and a phototransistor, a model of the equivalent noise circuit of the optocoupler for a low-frequency range was proposed [1,3–5]. The model is shown in Fig. 1(b).

The model includes the following noise sources:

- for LED, i_d is the shot noise caused by the diode current I_D , i_{fd} is $1/f$ noise of the diode, and v_d is the thermal noise of the serial diode resistance,
- for a phototransistor, v_{bb} is the thermal noise of the base resistance r_{bb} , i_{ft} is $1/f$ noise source located in the emitter-base junction, i_B is the shot noise caused by the base current I_B , and i_C is the shot noise caused by the collector current I_C .

If the phototransistor operates in the, so-called, open-circuit regime, then the source of the thermal noise v_{bb} of the base resistance should be excluded from the optocoupler equivalent noise circuit presented in Fig. 1. But if the phototransistor operates with the base polarization (for decreasing the turn-on and turn-off times of the optocoupler),

the source of the thermal noise of the base resistance should be included in the optocoupler equivalent noise circuit. In the reported investigations, the phototransistor operates in the open-circuit regime, and the source v_{bb} is omitted from the equivalent circuit, as shown in Fig. 2.

In the model, the source of noise caused by the presence of an optical channel in the structure of the optocoupler device is also marked and named as “light noise”.

In the optocoupler, a diode and a phototransistor are electrically isolated and the signal from the LED to the phototransistor is processed optically. It was taken into account that this kind of coupling can generate the noise caused by light signal. This noise is the result of the phenomena connected with the quantum nature of light, non-homogeneity in transistor’s base, random generation of photons in the diode, etc [1,2,4].

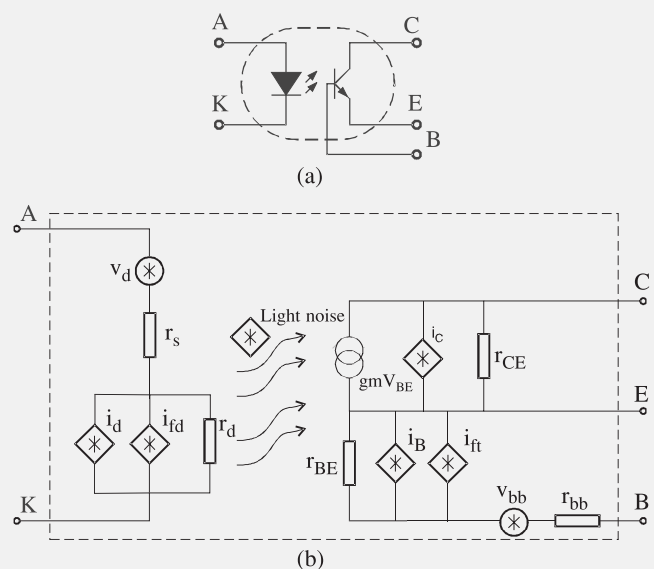


Fig. 1. Optocoupler device, (a) an electrical circuit and (b) a model of an equivalent noise circuit for the low frequency range. B – phototransistor base, C – phototransistor collector, E – phototransistor emitter, A – diode anode, and K – diode cathode.

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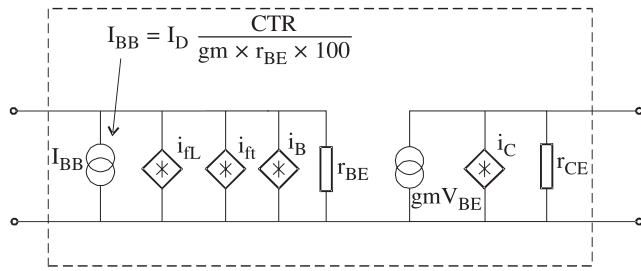


Fig. 2. Equivalent noise circuit of optocoupler, with the noise source representing the diode and optical channel noise.

Also, if electric separation between the diode and phototransistor is not correct, some electrical noise of the diode can be present at the transistor input. The source of diode noise and light signal noise (marked as i_{fL}) transferred to the transistor is proposed to be located at the input of a phototransistor, as shown in Fig. 2. In this way, in the equivalent optocoupler noise circuit, the noise circuit of the diode can be omitted.

The source i_{fL} includes the diode's noise (dependent on the sources i_d , i_{fd} , and v_d) and also the noise of the optical channel. Granted that optocouplers were fabricated correctly (galvanic isolation of diode and transistor), the source i_{fL} would depend only on the optical channel's noise.

In Fig. 2, the current source I_{BB} , considering DC conditions and the current gain of the optocoupler is also added to the input of the transistor equivalent circuit.

It has been assumed that to locate the source of RTS noise, the tests should be carried out on the optocouplers generating RTS noise and such which do not generate such a noise. If RTS noise is generated in the diode or in the optical channel, they will be identified by i_{fL} source. If they are generated in the phototransistor, they should be identified with the i_{fT} source of the noise in the phototransistor.

Taking into account all the assumptions presented above, it was proposed to carry out the following inherent noise measurements:

- for the optocoupler device at the diode current I_D ,

- only for a phototransistor (without a diode) operating in identical conditions as for the optocoupler inherent noise measurement.

It was assumed that for evaluation of noise properties of the measured optocouplers, the power spectral density functions of inherent noise of the optocoupler and the phototransistor, estimated in the low frequency range in which $1/f$ noise occurs, should be applied. The differences in the intensity of inherent noise of the optocoupler and the phototransistor resulting from noise spectra allow for evaluation of the intensity of the noise source i_{fL} . If there will be no essential difference between the intensity of internal noise of the optocoupler and that of the phototransistor, we may assume that the transistor is the source of RTS noise.

3. Measurement and discussion of results

The research was carried out on twenty commercially available optocouplers of CNY 17 type. The devices had been divided into two groups (each group containing ten devices) based on the values of the current transfer ratio (CTR), group A – CTR of 40–80% and group B – CTR of 160–320%.

The CTR is defined as $CTR = (I_C/I_D)100\%$, where I_C is the phototransistor collector current and I_D is the diode current.

The low-frequency noise of the optocouplers from both groups was measured in the frequency range from 1 Hz to 1.5 kHz. The output noise of the optocoupler was filtered and sampled, and then processed and stored in the memory of PC under LabVIEW control. The cut-off frequency of the antialiasing filter and the sampling frequency were 1500 Hz and 3072 Hz, respectively [3]. The results of noise measurements were collected as time records and spectra.

The main parts of the noise measurement system are presented in Fig. 3.

A value of the resistance R_B (see Fig. 3) applied for the phototransistor base polarization is equal to 100 k Ω , as to ensure the open-circuit regime of a transistor.

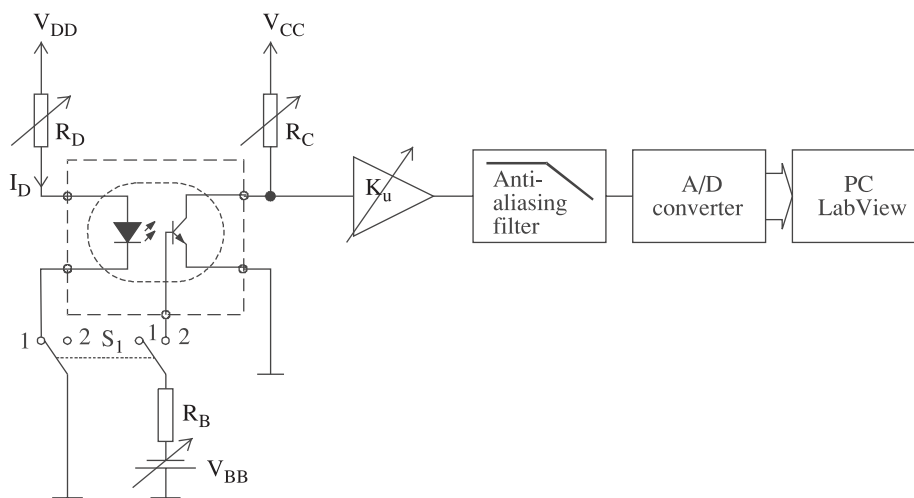


Fig. 3. System for low-frequency noise measurements of optocouplers, I_D is the diode current.

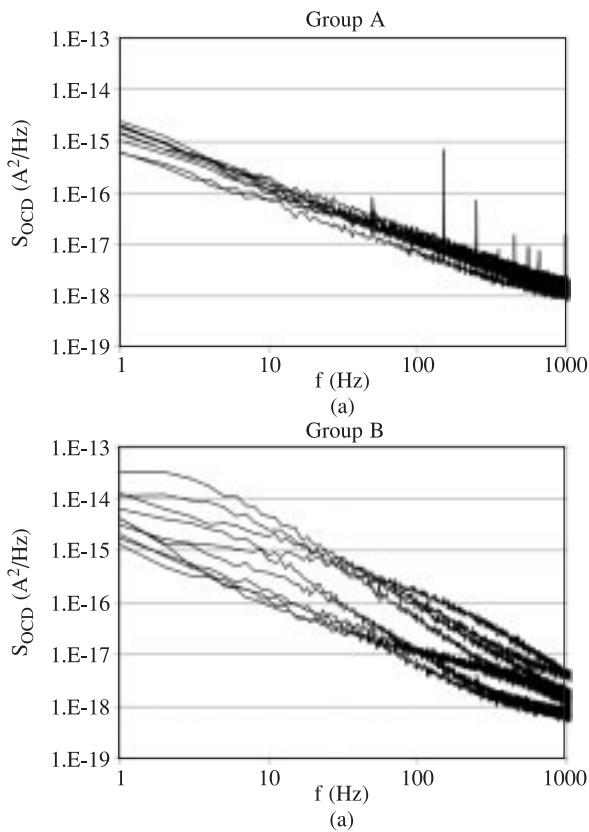


Fig. 4. Result of noise measurement of optocouplers, (a) – group A and (b) – group B.

The measurements were carried out in two stages. First, the output noise of the optocoupler devices was measured for the diode current $I_D = 5$ mA and $U_{CE} = 5$ V (the switch S_1 in position 1). For these conditions, the phototransistor collector current I_C was noted. The measurement results for both groups are presented in Fig. 4. In the group A, the optocouplers are free of RTS noise, in the group B all optocouplers generate RTS noise.

Next, the switch S_1 disconnected the diode and connected phototransistor base to the voltage source V_{BB} through the resistance R_B (the switch S_1 in position 2). In order to simulate the phototransistor activation by the light as in the previous measurement, V_{BB} was set to that value for which the collector current I_C was equal to the value noted in the first measurement (for diode polarization) and at $U_{CE} = 5$ V. Then, the output noise of the phototransistor was measured. The results of those two measurements should allow one to distinguish if the noise component generated by the LED and optical channel is significantly important in the total output noise of the optocoupler.

Exemplary measurement results of the optocoupler and transistor noise are presented in Fig. 5.

Both, in the group A and in the group B, noise spectra of the optocoupler devices and transistors can be assumed to be alike, moreover of the group B generate RTS noise.

As it can be seen in Fig. 5, the difference between intensity of the noise from the optocoupler, controlled by a diode, and the phototransistor itself is small but evident.

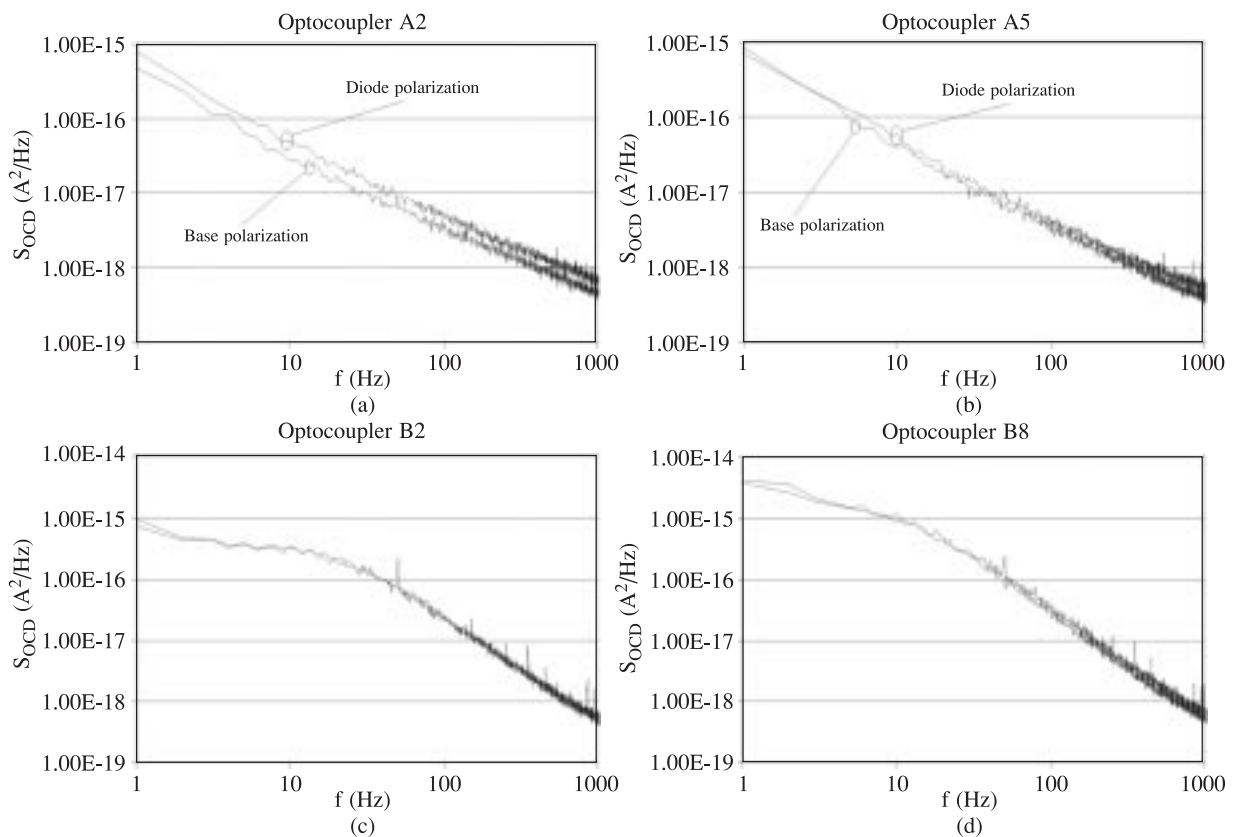


Fig. 5. Noise spectra of optocouplers with diode and phototransistor base polarization, (a) – device A2, (b) – device A8, (c) – device B2, and (d) – device B8.

Only three optocouplers in the group A have shown the same dependence. For the remaining seven devices, the properties were such as shown in Fig. 5(b). This means that in the optocouplers which do not generate RTS noise, it will be possible to identify the source efficiency i_{fL} . This will be the subject of a separate investigation. In the optocouplers generating RTS noise, the level of $1/f$ noise of the optocouplers and phototransistors show essentially no difference.

The conclusion is that the intensity of the noise source i_{fL} is negligibly low. In the group A, (except the three with very small differences between measurement results) as well as in the group B, this source of noise can be neglected in the analysis of the optocoupler noise. It means that the galvanic isolation of the diode and the transistor in the measured optocouplers is very good. Also the noise of the optical channel does not influence the level of the output noise of the optocoupler.

Summing up, the low frequency noise of the optocoupler device depends mainly on the noise sources occurring in the optocoupler phototransistors. The RTS noise observed in the optocouplers is caused by transistor defects and usually appears in the optocouplers with the higher values of CTR.

To estimate the noise properties of LEDs, the noise measurements of the diodes at $I_D = 5$ mA were carried out. The measurement results in the frequency range from 10 Hz to 10 kHz are shown in Fig. 6.

$1/f$ noise represented by i_{fd} appears in the spectrum of the optocoupler diodes in the frequency range from 10 Hz to 100 Hz. It can be clearly seen that the diode noise of the optocoupler A2 is the greatest, what is also confirmed by the results of noise measurements of the optocoupler A2. The diode noise of the optocouplers B2 and B8 is lower in the diodes from the group A. It should be pointed out that the optocouplers from the group B generate RTS noise. A greater number of the diodes in the optocouplers should be investigated in order to be able to treat the above relation as a rule.

The noise level of the optocoupler diodes from the group A and B is comparable in the frequency range from 100 Hz to 10 kHz. The noise spectrum of the optocoupler diodes (in this range of frequency) can be recognized as white noise.

The noise intensity of the optocoupler diode in the range of white noise consists of a shot noise of diode current and a thermal noise of a diode's series resistance.

The intensity of shot noise of the optocoupler diode at $I_D = 5$ mA is equal to $S(I_D) = 2qI_D = 1.6 \times 10^{-20}$ A²/Hz and the intensity of thermal noise of a series resistance, for example, for $r_s = 0.1 \Omega$ and $T = 300$ is equal to $S(r_s) = 4kT/r_s = 1.6 \times 10^{-19}$ A²/Hz.

Both of the source intensities are on the lower level than the measurement results (about 6×10^{-18} A²/Hz). In the range of the measurement frequencies, the inherent noise of the system is equal to about 6×10^{-18} A²/Hz (background noise). The shot noise and thermal noise of a diode cannot

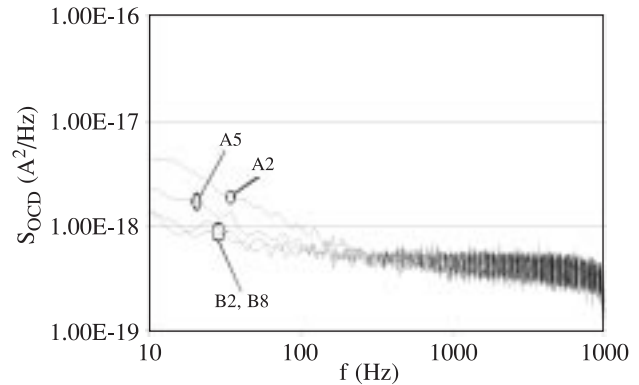


Fig. 6. Examples of noise spectra of optocoupler diodes from the group A (A2, A5) and the group B (B2, B8) at $I_D = 5$ mA.

be detected by the applied measurement system. However, the measurements of white noise of the diodes are not our target. The background noise of the measurement system in the frequency range from 1 Hz to 1 kHz is low enough to measure the $1/f$ noise of the diodes, phototransistors, and optocouplers.

The noise intensity of the optocoupler's diode is much smaller than the optocoupler noise. If we had the galvanic coupling between the diode and the phototransistor, the diode noise delivered to the input of the phototransistor would be always smaller than that generated by the diode.

4. Conclusions

The experimental results presented in the paper allow for assumption that participation of inherent noise of the diode as well as of the noise generated by an optical channel in the optocoupler total output noise is negligible, especially in the optocouplers generating RTS noise. That conclusion is valid for the optocoupler devices which do not generate RTS noise, as well as for those which do that. Moreover, the low frequency noise measurements of the optocouplers and optocoupler transistors indicate that the RTS noise source is located in the phototransistor.

The results of the conducted investigations allow for indicating that the noise of the optocoupler devices has to be evaluated before their applications. Especially, presence of RTS noise in the inherent noise signal of the optocoupler devices has to be detected.

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