A Compact Isolated Filter for Industrial Devices

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Abstract- In industry there are lot of major devices which have to be run through surrounding noise generating sources. More specifically, programmable logic controllers and microcontrollers requires filtered inputs to avoid the conducted noise so that their operation will be reliable and satisfactory which will lead to continuous industrial process and operation. There are variety of modes of noise interference with signal cable and variety of traditional methods to reduce conducted noise. In this project we are designing an electronic circuit targeting industrial electronic devices which have to be run under noisy environment. This circuit includes filter centered at 50 Hz and 5 KHz, opt coupler for isolation, current source and voltage divider to improve logical stability. This is a compact circuit since only few components are used and it isolates conducted noisy signals which leads to efficient operation under noisy environments.

Index Terms- opto-coupler, microcontroller, current source, programmable logic controller

I. INTRODUCTION

In Industry every microcontroller and programmable logic controller collects signal from field sensors or other devices and helps to manage the whole system efficiently. In order to control the system any machine requires many types of input.

Any microcontroller or Programmable Logic Controller (PLC) collects the signals from environment and manage the system in a flexible and comfortable way. For any machine or application, many inputs are needed to control the system. In industry there lot of lengthy wires which connects the sensors and the electronic device. The noise signals may be conducted through the signal by variety of modes such as direct electrical contact, electrostatic coupling, and Electromagnetic induction or by radio frequency interference.

Therefore it is necessary to protect the microcontroller or programmable logic controllers from the conducted noise. One of the most efficient way to protect their inputs is to use opto-isolators. Opto-isolators transfers electrical signals between two isolated circuits by using lights and prevent high voltages from affecting the system receiving the signals.

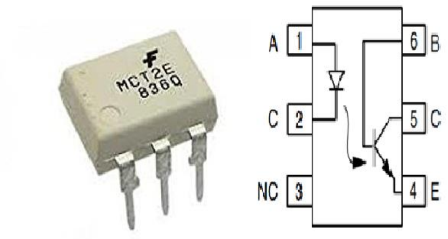
In this project an attempt is made to design a low pass filter with two poles along with opto-isolator , transistor and few capacitor and resistors

II. PROPOSED DESIGN

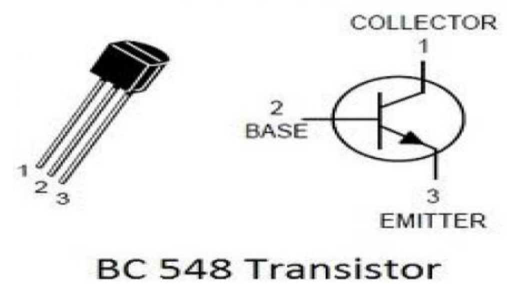
The major aim of designing this circuit is the reduced cost with the compact size which will lead to usefulness in industrial application. To reduce switching and conducted noise signals the filter is mainly centered at 50Hz and 5Khz.The circuit will provide a feature of reduced cost since only ten components are used. With the proper combination and arrangement this components will provide filter, wide range of voltage input and optical isolation.

III. CIRCUIT COMPONENTS

1. Opto-coupler- An opto-coupler also known as opto-isolator is a semiconductor device that uses a short optical transmission path to transfer an electrical signal between circuits or elements of circuit, while keeping them electrically isolated from each other. These component is used in a variety of communications, control and monitoring systems that uses light from affecting a low power system receiving a signal.



2. Transistor- Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or conductor by the application of a small signal voltage. The transistors ability to change between this two states enables it to have two basic function: switching (digital electronics) or amplification (analog electronics).

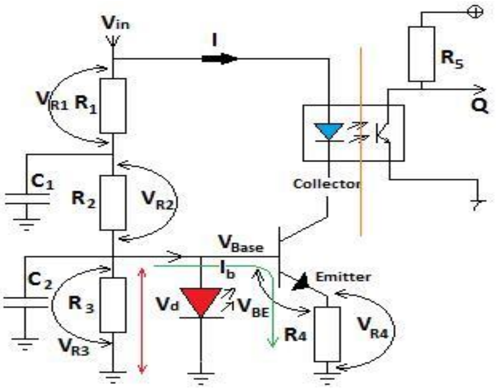


3. Light Emitting Diode (LED)- A light emitting diode (LED) is a semiconductor device that emits light when an electric current is passed through it. light is produced when the particles that carry the current (known as electrons and holes)combine together within the semiconductor materially light is generated within the solid semiconductor materials, LED are described as solid-state devices.

IV. CIRCUIT DIAGRAM

The circuit is designed such that the low pass filter will have two poles to filter out conducted electromagnetic interference at mains frequency i.e., 50Hz and possible switching frequency i.e., 5 kHz or above. This low pass filter is included in the circuit along with transistor. For mains frequency, centered components are R_1 and C_1 while for switching frequency, centered components are R_2 and C_2.Fig.1shows the circuit diagram of proposed circuit.

Voltage drop V_{BE} equals to about 0.6 and LED voltage drop is 1.8V for red LED. Transistor base voltage equation is given in (1). As long as V_{in} voltage is over 12volts, collector current is limited by R_4 at 10mA and input voltage situation can be seen as logical true on the opto-coupler output side.



In order to obtain base current V_{out} must be higher than V_{BE}. Equation (2) shows the limitations of R_1, R_2 and R_3 related to LED voltage.

$$\frac{V_{in} \times R_3}{R_1 + R_2 + R_3} = V_d \qquad (1)$$

where, V_{out} is limited to V_d over the 12Volts input.

$$\frac{12 \times R_3}{R_1 + R_2 + R_3} = 1.8$$

$$10.2R_3 = 1.8(R_1 + R_2) \qquad (2)$$

Hence, $R_3/(R_1+R_2)$ equals to 0.17647. But initial running point can be determined by V_{BE} voltage.

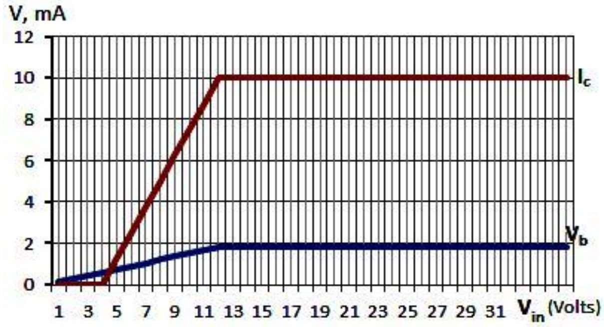
$$V_i \times 0.17647 = 0.6 \Rightarrow V_i = 3.4Volts$$

Hence, over the 3.4V input voltage, transistor switches on. But at the 12Volts, collector current reaches maximum level at 10mA. Emitter current can be calculated by (3).

$$I_E \cong I_C = (V_b - 0.6) / R_4 \qquad (3)$$

where Vb equals to $Vout$ and limited by red LED at 1.8Volts. Maximum emitter current is limited to 10mA taken into account the optical isolation driving current [17], [18]. For 10mA emitter current, $R4$ can be calculated from (2) as 120Ω. Fig. 2 shows collector current and base voltage changing through the input voltages.

In order to obtain the final circuit, low pass filter included built around one transistor and resistor arranged regarding the capacitors. Filter designed as two poles to reduce conducted electromagnetic interference at mains frequency and possible switching frequency. Switching frequency generally is designed as 5 kHz or over. One pole is centered at 50Hz and second pole at 5 KHz. For 50 Hz, centered components are R_1 and C_1, second pole of filter is characterized with R_2 and C_2.



Filter cut off frequency is calculated using (4).

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{R_1C_1R_2C_2}}{s^2 + s\left[\frac{1}{R_1C_1} + \frac{1}{R_2C_1} + \frac{1}{R_2C_2}\right] + \frac{1}{R_1R_2C_1C_2}} \qquad (4)$$

Regarding (2) and (4), resistors and capacitors are calculated as R_1=33kΩ, R_2=3.3kΩ, C_1=100nF, C_2=10nF and R_3=6.8kΩ. Fig. 3 shows the simulation of the proposed circuit according to V_d point.

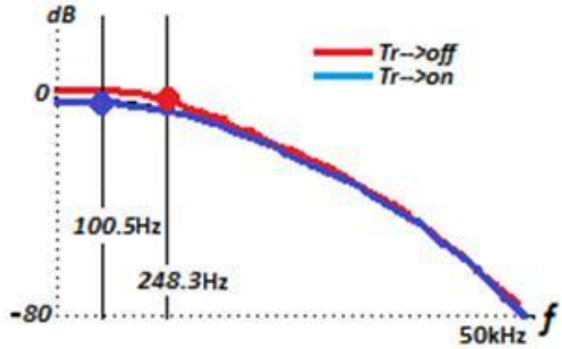


Fig.3: Frequency response of low pass filter for second order.

Thus combination cut off frequency changed from 248.3Hz to 100.5Hz. Lower cut off frequency increase the reliability of circuit on the opto-coupler output side, as virtually.

V. IMPLEMENTATION OF DESIGNED CIRCUIT

Above circuit was implemented and also compared with simulation circuit. Thus we found that proposed circuit will provide filtered and isolated signal from signals to the industrial microcontroller or Programmable logic controller. In order to reduce cost and size of the proposed circuit only few components are included in the circuit such as a transistor, filter, LED along with few resistors and capacitors. Transistor Makes the whole strategy easier and leads to form current source. Fig. shows actual zeroPCB.

Proposed circuit was tested under wide input range voltage. Table I shows comparisons of simulated and implemented results.

TABLE I.COMPARISON OF SIMULATED AND IMPLEMENTED RESULTS

		Simulated	Measured
V_{in}=12V	V_{R1}	9.28V	9.46V
	V_{R2}	0.92V	0.94V
	V_{R3}	1.8V	1.6V
	V_{R4}	1.2	1.05
	V_d	1.8V	1.6V
	I	10 mA	8.75mA
V_{in}=36V	V_{R1}	31.09V	31.05V
	V_{R2}	3.11V	3.1V
	V_{R3}	1.8V	1.85V
	V_{R4}	1.2	1.22
	V_d	1.8	1.85
	I	10mA	10.1mA

Input voltage varies three times larger but driving current varies only 13% percent. Driving current increases only 1.35mA in case of rising input voltage up to 36V. For industrial control panels, wirings are generally built as 12, 24 or 36volts according to requirements. Current source is common way to obtain constant current to be used for reference [19], [20]. Obtained constant current was used for opto-coupler driving current to obtain robust and regular lightning.

Proposed circuit was designed for microcontroller applications under high noise environments. Microcontroller needs clean and restricted signal levels to run. Constant current protect the opto-coupler life span and leads to stable running. Designed patch circuit for industrial devices has been tested for maximum noise for valid logical situations. Table II shows details of the circuit logical input under noise and without noise for the real implementation. In order to create the features of the proposed circuit, circuit was tested for logical input voltages under the simulated noise voltages. For simulating noise AC voltage applied and given as V_{pp} at Table II.

TABLE II. PROPOSED CIRCUIT FEATURES FOR REAL APPLICATION

Circuit Conditions		Measured
a	Maximum noise level for low logic	17.8V_{pp}
b	High logic input @ zero noise	9.51V_{DC}
c	Cut off frequency	197.212Hz
d	Maximum input voltage	36V_{DC}
e	Collector current @ max input voltage	12mA
f	Minimum valid voltage for high logic	12V_{DC}
g	Power dissipation @ 36V	0.432Watts

a) In order to measure the noise level, maximum sine wave applied to input until observing logical changing on the output side of opto-coupler. 17.4Vpp is an extreme high noise. Due to divider resistor, high noise resistance ability has been obtained.

b) High logic input: this feature is related to pure DC input voltage which leads to change the opto-coupler output.

c) Cut off frequency was measured on the transistor base which makes reduces the voltage level at $0.707*V_d$.

d) Maximum input voltage was normalized and tested up to 36V_{DC}. 12-36Volts is a common wiring style for industrial or similar applications.

e) Collector current has importance to obtain long life span for optical isolation. High current damages the opto-coupler transmitter side or reduce the optical life dramatically. In order to obtain long life period, collector current is restricted and accorded to 10mA.

f) Designed minimum input voltage is accepted as 12V_{DC}. Target is to cover industrial wiring voltage from 12V-36V_{DC}. Logical high voltage is starting around the ten volts DC, (measured 9.47V_{DC}).

g) Power dissipation has much importance under high voltage input. Total power dissipation for 36V_{DC} is less than 0.5Watts.

VI. CONCLUSION

For any application, microcontroller needs an input voltage as 5V or less to operate. However, especially industrial signals have wide range and may include noise, because of the closing to noise sources. Long wiring or ordinary wiring systems intend to affect by the noise sources through the capacitive or inductive ways. Noise are carried by mains supply cables and called as conducted electromagnetic noise. Another noise source is switching circuits. Switching circuits such as chopper, inverter and etc are common and strong noise sources. Moreover, Noise level is generally higher than millivolts and may rise up to hundreds of volts according to distance to noise source and power of the noise in industrial applications. This study is especially related to noise as conducted ones. Proposed circuit includes voltage divider, filter, optical isolation and current source in same structure. All abilities designed ten components as most of them are passives.

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