Calculation of Design Margin for C

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1. Introduction:

Optocouplers are used in switchmode power su
primary to secondary isolation boundary. Typical uses are in the feedback and shutdown circuits. Such circuits are critical to the correct operation of the PSU and for the protection of the customer's equipment. Since the performance of an optocoupler degrades with age, it is not sufficient to assume that if a PSU is working today that it will therefore be working correctly tomorrow. A calculation of the predicted performance is necessary.
This paper details a procedure which will allow the engineer to calculate the worst case design margin of an optocoupler circuit, including the effects of aging.

For every new design which incorporates an optocoupler, it is recommended that the design margin is calculated and documented for each device. The calculation should include detailed notes to indicate how each parameter value was chosen, as shown in the examples.

2. Current transfer ratio (CTR):

An optocoupler consists of a light emitting diode (LED) which is optically coupled to a light sensitive bipolar transistor via a transparent electrical insulator. The degree of coupling between the two is called the current transfer ratio (CTR) and is given by:

$CTR = I_C/I_{LED}$ Where I_C is the collector current (output)
I_{LED} is the LED current (input)

Examination of a manufacturer's data sheet will show that CTR depends on several factors including production spreads, temperature and LED current. An important factor which is usually *not* given in the data sheets is the effect of aging and such data must be requested from the manufacturer.

3. Requirements for CTR:

Any circuit which uses an optocoupler must be capable of normal operation using the worst case value for CTR as well as the worst case values for other circuit parameters such as reference voltages and saturation voltages. Since the absolute worst case values for all circuit parameters are used simultaneously, any positive design margin, no matter how small, is considered acceptable.

a) Feedback optocoupler:
It is assumed that an increase in optocoupler current causes the output power of the PSU to decrease, which is usually the case in Astec. Therefore, if the CTR is insufficient, the output voltage of the PSU will rise out of control when the load current is near zero. Therefore, the aim of the calculation is to show that there will always be sufficient output current from the optocoupler to cause the PSU to decrease its output voltage to zero volts at no load.

b) Logic signal optocoupler:
In general, the optocoupler output must be sufficient to cause it's output voltage to cross the worst case logic threshold.

The procedures below show how to calculate the design margin for CTR in typical circuit examples. The same philosophy can be extended to other circuits. (Additional examples may be added later).

4. Calculation example 1:

Figure 1 shows a common example of a feedback circuit where an AS431, IC3, is used as an inverting error amplifier. The +5V PSU output voltage is divided by 2 by R5 and R6 and then compared with an internal +2.5V reference. LED current is limited by R3. The collector of the optocoupler, IC2, sinks current supplied by R1 plus current from an internal current source connected to pin 1 of IC1. At no load, pin 1 must go low enough to cause zero duty cycle.
A temperature range of 0 to 60 degC will be assumed.

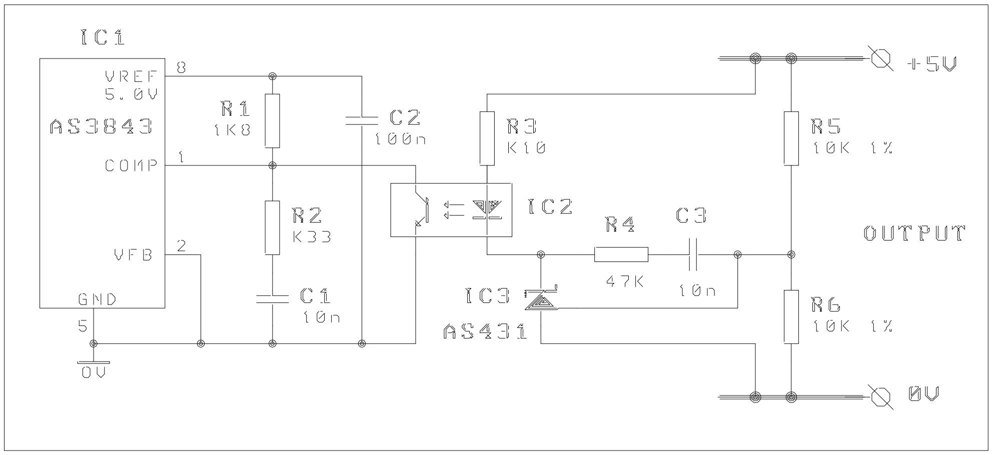

Fig 1 - Using an AS431 as an error amp.

a) Phototransistor current:

Note: The Siemens SFH617A-2 is assumed to be the preferred optocoupler part.
The Sharp PC123 is the alternative part (CTR_{MAX} is screened to less than 200 for Astec).
The worst case specs for *both* parts must be considered together.

Calculate the maximum phototransistor current required to reduce the duty cycle to zero.

For the AS3843 (and similar chips), zero duty occurs when pin1 (COMP) is low.
In the data sheet, no pin1 data is given for zero duty.

However, it is assumed that the chip has been designed to achieve zero duty.
Therefore, a guarranteed figure will be the maximum pin1 saturation low voltage.
From the data sheet:

$$V_{COMPL(max)} = 1.1V$$

The maximum regulator voltage at pin 8 is:

$$V_{REG(max)} = 5.05V$$

Therefore, the maximum voltage across R1 to just achieve zero duty is:

$$5.05 - 1.1 = 3.95V$$

The current in R1 is:

$$3.95 / 1800 = 2.195 \text{ mA}$$

The maximum value for the internal current source at pin 1 is not given in the data sheet.
A maximum value was obtained from ASD:

$$I_{COMPH(max)} = 1.0mA$$

Therefore, the maximum phototransistor current to just achieve zero duty is:

$$1.0 + 2.195 = \underline{3.195\ \text{mA}}$$

b) LED current:

Calculate the minimum LED current available when the LED drive is maximum.

The data sheet does not show the maximum saturation voltage for the AS431.
A measured value (typically 2.2V) cannot be used since it is not guarranteed.

The data sheet does characterise the AS431 when used as a shunt 2.5V regulator.
From the data sheet, the lowest guarranteed cathode voltage as a regulator is:

$$V_{REF(min)} = 2.449\text{V}$$

From the data sheet curves of LED voltage vs temperature at 10mA and 0 degC,
the maximum LED voltage (PC123) is:

$$V_{F(max)} = 1.25\text{V}$$

The minimum supply voltage is the minimum output voltage.
In this case it will be assumed to be trimmed within ±1%, ie:

$$V_{O(min)} = 4.95\text{V}$$

Therefore, the mimimum voltage across R3 is:

$$4.95 - 1.25 - 2.449 = 1.251\text{V}$$

Therefore, the minimum LED current is:

$$1.251 / 100 = \underline{12.51\ \text{mA}}$$

c) Minimum required CTR:

Calculate the minimum required CTR of the optocoupler:

$$CTR_{(req)}(\%) = I_C/I_{LED} \times 100$$

Where I_C is the collector current (output)
I_{LED} is the LED current (input)

$$= 3.195 / 12.51 \times 100$$

$$\underline{= 25.5\ \%}$$

d) SFH617A-2 minimum CTR:

From the data sheet, at $I_{LED} = 10\text{mA}$:

$$CTR_{(min)} = 63\%$$

The graph of CTR vs temp at $I_{LED} = 10\text{mA}$ indicates approx 10% reduction of CTR at 60 degC.

Therefore: $CTR_{(min)} = 63\% \times 0.9$

$$= 56.7\%$$

Siemens define "end of life" of an optocoupler when the CTR falls to 50%. Their curves predict that 50% reduction occurs after 40 years at I_{LED} = 10mA, which is well outside the lifetime of an Astec product. A more practical life is 10 years, which yields a 75% reduction of CTR when extrapolated from the same curve.

Therefore: $CTR_{(min)} = 56.7\% \times 0.75$

$\underline{= 42.5\%}$

e) CTR margin for the SFH617A-2:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (42.5 / 25.5 - 1)$$

$$\underline{= 67\%}$$

Since the margin is positive it is considered a "pass".

f) PC123 minimum CTR:

From the data sheet, at I_{LED} = 5mA:

$CTR_{(min)} = 50\%$

The curve of CTR vs I_{LED} shows only a very slight reduction of CTR at 10mA and will be ignored.

The graph of CTR vs temp at I_{LED} = 5mA indicates approx 18% reduction of CTR at 60 degC.

Therefore: $CTR_{(min)} = 50\% \times 0.82$

$= 41\%$

In the absence of aging data from Sharp we will assume the same figures as for Siemens. (These figures are also supported by other independent investigations).

For a life of more than 10 years, a 75% reduction of CTR is assumed.

Therefore: $CTR_{(min)} = 41\% \times 0.75$

$\underline{= 30.8\%}$

g) CTR margin for the PC123:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (30.8 / 25.5 - 1)$$

$$\underline{= 20.8\%}$$

Since the margin is positive it is considered a "pass".

5. Calculation example 2:

Figure 2 shows alternative approaches to both the primary and secondary side circuits.
The +5V PSU output voltage is divided by 2 by R5 and R6 and then compared with a +2.5V reference (AS431) by an LM358 op-amp used as the error amplifier. LED current is limited by R3. An op-amp inside the AS3843 is connected as a unity gain inverting buffer using R1 and R2. Note that the minimum value of R1 (4K7) is limited by the minimum output source current of the op-amp (0.5mA). The internal reference for the op-amp is +2.5V. With a gain of 1.0 the quiescent voltage at pin1 will be 5.0V when there is no opto current. This voltage is sufficient to achieve maximum duty.
Emitter current from the optocoupler will flow through R1 into pin 1 and will cause the voltage at pin 1 to decrease. The current in R2 is constant. At no load, pin 1 must go low enough to cause zero duty cycle. A temperature range of 0 to 60 degC will be assumed.

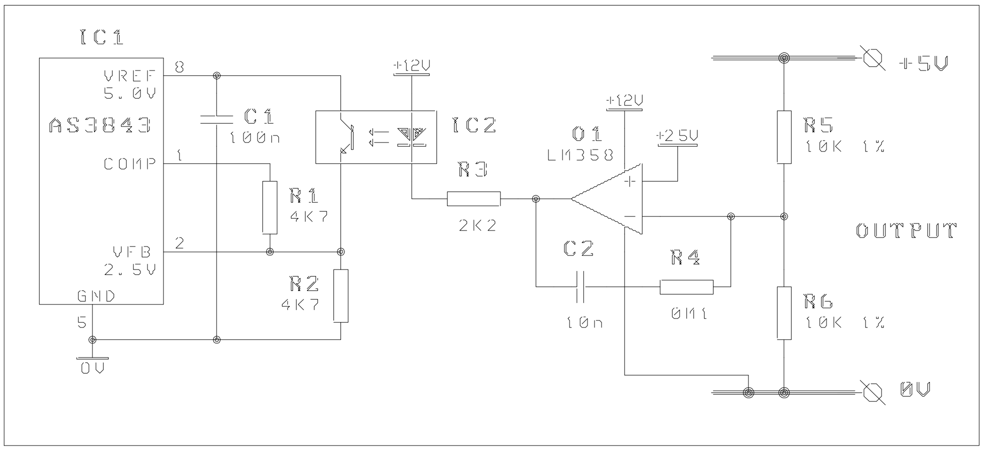

Fig 2 – Using an LM358 as an error amp.

a) Phototransistor current:

Note: The Siemens SFH617A-2 is assumed to be the preferred optocoupler part.
The Sharp PC123 is the alternative part (CTR_{MAX} is screened to less than 200 for Astec).
The worst case specs for *both* parts must be considered.

Calculate the maximum phototransistor current required to reduce the duty cycle to zero.

For the AS3843 (and similar chips), zero duty occurs when pin1 (COMP) is low.
In the data sheet, no pin1 data is given for zero duty.

However, it is assumed that the chip has been designed to achieve zero duty.
Therefore, a guarranteed figure will be the maximum pin1 saturation low voltage.
From the data sheet:

$$V_{COMPL(max)} = 1.1V$$

Therefore, the maximum voltage swing across R1 to just achieve zero duty is:

$$5.0 - 1.1 = 3.9V$$

Therefore, the current swing in R1, which must be supplied by the optocoupler, is:

$$3.9 / 4700 = \underline{0.83mA}$$

b) LED current:

Calculate the minimum LED current available when the LED drive is maximum.

From curves, the maximum saturation low voltage for the LM358, at a sink current of 5mA is:

$$V_{SAT} - = 1.0V$$

From the data sheet curves of LED voltage vs temperature at 5mA and 0 degC,
the maximum LED voltage (PC123) is:

$$V_{F(max)} = 1.2V$$

We will assume that the +12V power supply is an auxiliary supply with poor regulation.
Under worst case loading conditions we find that:

$$V_{AUX(min)} = 11.0V$$

Therefore, the mimimum voltage across R3 is:

$$11.0 - 1.2 - 1.0 = 8.8V$$

Therefore, the minimum LED current is:

$$8.8 / 2200 = \underline{4.0\ mA}$$

c) Minimum required CTR:

Calculate the minimum required CTR of the optocoupler:

$$CTR_{(req)}(\%) = I_C/I_{LED} \times 100$$

Where I_C is the collector current (output)
I_{LED} is the LED current (input)

$$= 0.83 / 4.0 \times 100$$

$$\underline{= 20.8\ \%}$$

d) SFH617A-2 minimum CTR:

From the data sheet, at $I_{LED} = 10mA$:

$$CTR_{(min)} = 63\%$$

The data sheet does not give information for CTR at $I_{LED} = 4mA$.

We will use the CTR vs I_{LED} curve on the SFH601 data sheet as a guide (similar device).

From the curve, at $I_{LED} = 4mA$, I_{LED} reduces to 82%.

Therefore: $CTR_{(min)} = 63 \times 0.82$
$= 51.7\%$

The graph of CTR vs temp at $I_{LED} = 10mA$ indicates approx 10% reduction of CTR at 60 degC.
We will assume it has a similar characteristic at 4mA.

Therefore: $CTR_{(min)} = 51.7 \times 0.9$

$= 46.5\%$

Siemens define "end of life" of an optocoupler when the CTR falls to 50%. Their curves predict that 50% reduction occurs after 40 years at I_{LED} = 10mA, which is well outside the lifetime of an Astec product. A more practical life is 10 years, which yields a 75% reduction of CTR when extrapolated from the same curve.

Therefore: $CTR_{(min)} = 46.5\% \times 0.75$

$$\underline{= 34.9\%}$$

e) CTR margin for the SFH617A-2:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (34.9 / 20.8 - 1)$$

$$\underline{= 68\%}$$

Since the margin is positive it is considered a "pass".

f) PC123 minimum CTR:

The data sheet specifies CTR at 5mA, which is close enough to our 4mA figure.
The curve of CTR vs I_{LED} is very flat in this region.

From the data sheet, at I_{LED} = 5mA:

$$CTR_{(min)} = 50\%$$

The graph of CTR vs temp at I_{LED} = 5mA indicates approx 18% reduction of CTR at 60 degC.

Therefore: $CTR_{(min)} = 50\% \times 0.82$

$$= 41\%$$

In the absence of aging data from Sharp we will assume the same figures as for Siemens. (These figures are also supported by other independent investigations).

For a life of more than 10 years, a 75% reduction of CTR is assumed.

Therefore: $CTR_{(min)} = 41\% \times 0.75$

$$\underline{= 30.8\%}$$

g) CTR margin for the PC123:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (30.8 / 20.8 - 1)$$

$$\underline{= 48.1\%}$$

Since the margin is positive it is considered a "pass".

6. Calculation example 3:

Figure 2 shows a typical example of a logic level circuit. An AS2316 is used for output OVP and UVP monitoring and generates a logic high level at pin16 during a fault condition. R2 limits the maximum LED current when pin 16 is low. The primary side uses an AS2214 pwm controller chip which has an overvoltage shutdown pin, pin9. The collector of the phototransistor sinks current via the pullup resistor, R1. The voltage at pin9 must remain below the minimum logic threshold voltage during normal operation to guarrantee that the power supply will not suffer a false shutdown.

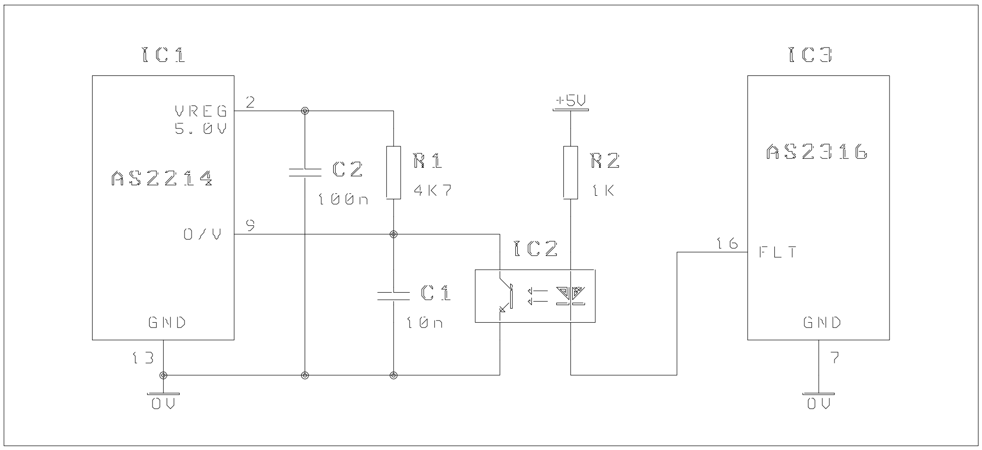

Fig 3 – A typical fault protection circuit.

a) Phototransistor current:

Note: The Siemens SFH617A-2 is assumed to be the preferred optocoupler part.
The Sharp PC123 is the alternative part (CTR_{MAX} is screened to less than 200 for Astec).
The worst case specs for *both* parts must be considered.

Calculate the maximum phototransistor current required to cross the minimum O/V level.

For the AS2214, the minimum O/V threshold is:

$$V_{OV(min)} = 2.50V$$

The maximum V_{REG} voltage is:

$$V_{REG(max)} = 5.10V$$

Therefore, the maximum voltage required across R1 to just cross the logic threshold is:

$$5.10 - 2.50 = 2.60V$$

Therefore the maximum current in R1 and the phototransistor is:

$$2.60 / 4700 = \underline{0.55\ mA}$$

b) LED current:

Calculate the minimum LED current available when pin 16 is low.

Assume a Vcc supply of +12V for the AS2316.
Note that the output current available from pin16 is much reduced when using a Vcc of +5V.

The maximum saturation low voltage at pin16, at a sink current of 3mA is:

$$V_{OL(max)} = 0.4V$$

From the data sheet curves of LED voltage vs temperature at 3mA and 0 degC, the maximum LED voltage (PC123) is approx:

$$V_{F(max)} = 1.2V$$

We will assume that the +5V auxiliary supply has a minimum value of:

$$V_{AUX(min)} = 4.9V$$

Therefore, the mimimum voltage across R3 is:

$$4.9 - 1.2 - 0.4 = 3.3V$$

Therefore, the minimum LED current is:

$$3.3 / 1000 = \underline{3.3\ mA}$$

c) Minimum required CTR:

Calculate the minimum required CTR of the optocoupler:

$CTR_{(req)}(\%) = I_C/I_{LED} \times 100$ Where I_C is the collector current (output)
I_{LED} is the LED current (input)

$$= 0.55 / 3.3 \times 100$$

$$\underline{= 16.7\ \%}$$

d) SFH617A-2 minimum CTR:

From the data sheet, at $I_{LED} = 10mA$:

$$CTR_{(min)} = 63\%$$

The data sheet does not give information for CTR at $I_{LED} = 3mA$.

We will use the CTR vs I_{LED} curve on the SFH601 data sheet as a guide (similar device).

From the curve, at $I_{LED} = 3mA$, I_{LED} reduces to approx 75%.

Therefore: $CTR_{(min)} = 63 \times 0.75$
$= 47.3\%$

The graph of CTR vs temp at $I_{LED} = 10mA$ indicates approx 10% reduction of CTR at 60 degC. We will assume it has a similar characteristic at 3mA.

Therefore: $CTR_{(min)} = 47.3 \times 0.9$

$$= 42.5\%$$

Siemens define "end of life" of an optocoupler when the CTR falls to 50%. Their curves predict that 50% reduction occurs after 40 years at $I_{LED} = 10mA$, which is well outside the lifetime of an Astec product. A more practical life is 10 years, which yields a 75% reduction of CTR when extrapolated from the same curve.

Therefore: $CTR_{(min)} = 42.5\% \times 0.75$

$\underline{= 31.9\%}$

e) CTR margin for the SFH617A-2:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (31.9 / 16.7 - 1)$$

$$\underline{= 91\%}$$

Since the margin is positive it is considered a "pass".

f) PC123 minimum CTR:

From the data sheet, at $I_{LED} = 5mA$:

$$CTR_{(min)} = 50\%$$

From the curve of CTR vs I_{LED}, at $I_{LED} = 3mA$ I_{LED} reduces to approx 90% of the 5mA value.

Therefore: $CTR_{(min)} = 50\% \times 0.9$
$= 45.0\%$

We will assume that the CTR vs temp curve at 3mA is similar to the 5mA curve in the data sheet. The graph of CTR vs temp indicates approx 18% reduction of CTR at 60 degC.

Therefore: $CTR_{(min)} = 45\% \times 0.82$

$= 36.9\%$

In the absence of aging data from Sharp we will assume the same figures as for Siemens. (These figures are also supported by other independent investigations).

For a life of more than 10 years, a 75% reduction of CTR is assumed.

Therefore: $CTR_{(min)} = 36.9\% \times 0.75$

$\underline{= 27.7\%}$

g) CTR margin for the PC123:

We can now express the minimum CTR of the device as a percentage of the minimum CTR required by the design. By subtracting a factor of 1 we get the margin.

$$\text{CTR margin (\%)} = 100 \times (CTR_{(min)} / CTR_{(req)} - 1)$$

$$= 100 \times (27.7 / 16.7 - 1)$$

$$\underline{= 66\%}$$

Since the margin is positive it is considered a "pass".