Electronics HW Design - Tolerances and Margins (with Example)

I have been designing electronic hardware for most of my 25 years of professional life. One of the things consistently observed is a lack of detailed circuit analysis, especially when it comes to tolerancing and margining the implemented circuits. Why is this? Here some of the (many) possible reasons.

1. It takes a bit of time. Management demands the hardware now and Engineering is developing around a tight project schedule. The market wants the product and corporate wants a piece of that market. The product needs to come out before competitors offer their version. Engineering pushes the design as quickly as possible (often cutting corners) in order to get hardware built.

2. It has never been taught and the Engineer simply does not understand impact and importance.

3. I don't like to do it. There is math required. It is boring. Too much documentation.

4. The company / management does not demand it, so why doing it. I never had to do this before…

5. It feels good to say I am done and no one will check anyway (gratification, recognition).

Does any of this sound familiar? I certainly have seen this happen.

We are living in a fast pace world. It can be dog eats dog out there in the corporate world. Disrupters are more highly celebrated than companies that have been in business for decades. Time and cost pressures force individuals and companies to make choices based on features and cost, not based on loyalty towards a specific supplier / manufacturer, even if quality and reliability has always been good.

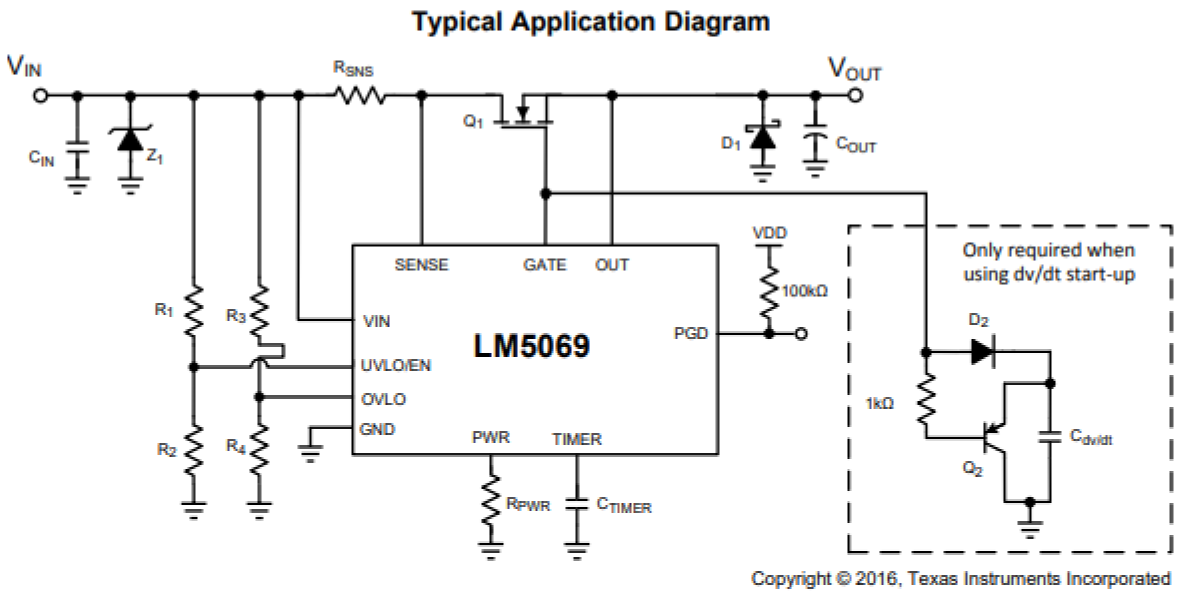
In North America we import Engineers from all over the world. While they all have their degrees, what was taught around tolerancing and margining is a big guess. The Universities themselves have fallen under the spell of creating excitement – the next big start-up. Preparing their students for the real world, for taking the responsibility of a product design, often falls to the companies that hire them by either having rigorous standards or by having experienced Engineers check every little bit.

Product quality and reliability suffers when Engineers or the development team take shortcuts (knowingly or unknowingly) and miss to check their product tolerances and margins. The cost and time spent on doing this early in the development cycle is orders of magnitude smaller compared to fixing problems later in the design or even having to recall product from the field.

In my area electronic HW design we typically design electronic circuits for a variety of applications. These circuits, when designed for a product that is expected to sell may be 100's, 1000's or more units a year, need to function reliably under all specified operating conditions. This includes production tolerances and environmental conditions. Unless the company had guidelines, you as the designer decide what you include and exclude when tolerancing the components you implement.

Companies like Berlin KraftWorks (www.berlinkw.ca) are trying to close that gap. If your company does not have the Engineering resources, the time, or the experience to verify your electronic HW design, they can do it for you.

Below is an example on what tolerancing might look like and the impact it can have on the product you are designing. The circuit uses a hot swap controller (LM5069) and is based on resistors for overvoltage (OV) and undervoltage (UV) monitoring. The diagram below is taken from the datasheet.



R1 and R2 determine the undervoltage lockout (UVLO), while R3 and R4 are for the overvoltage lockout (OVLO). Both, UVLO and OVLO have a hysteresis, thus they have a high (UVH / OVH) and low value (UVL / OVL). For more detail on these functions, check the datasheet.

$$R1 = \frac{V_{UVH} - V_{UVL}}{21\ \mu A} = \frac{V_{UV(HYS)}}{21\ \mu A} \qquad R3 = \frac{V_{OVH} - V_{OVL}}{21\ \mu A} = \frac{V_{OV(HYS)}}{21\ \mu A}$$

$$R2 = \frac{2.5V \times R1}{(V_{UVL} - 2.5V)} \qquad R4 = \frac{2.5V \times R3}{(V_{OVH} - 2.5V)}$$

Based on the above formulas (datasheet #34-37), the hysteresis is determined by R1 (UV) and R3 (OV) while R2 sets V_{UVL} and R4 sets V_{OVH}. Calculations are relatively simple. However, it is of utmost importance to not only calculate the nominal values, but to include the tolerances of all parameters as shown below. As per datasheet (over the operating temperature range) the UVLO threshold can take values from 2.45V to 2.55V. The OVLO threshold is even wider, 2.4V to 2.6V. The UVLO and OVLO hysteresis current is specified as 12-30µA with a nominal value of 21µA. All resistors values are E96, 1%, excluding temperature drift since it is typically negligible.

The calculations show the deviation from the nominal values. UVL has a margin of roughly 1.5V, UVH of around 2V, OVH 3.4V, and OVL of around 3V. It is very important that these min/max values comply with the intended voltage input specification and do not cause any inadvertent shutdowns. By only verifying the specification against the nominal values some produced devices will work as intended while others may not function properly.

		Nom	21			Nom	23.7		0.4977		Nom		20.3464		Nom
$I_{Hysteresis}$	µA	Min	13	R1	kΩ	Min	23.463	$V_{UV(HYS)}$	0.30502	V	Min	V_{UVL}	19.5931	V	Min
		Max	30			Max	23.937		0.71811		Max		21.1211		Max
		Nom	2.5			Nom	3.32		0.4977		Nom		20.8441		Nom
$UVLO_{TH}$	V	Min	2.45	R2	kΩ	Min	3.2868	$V_{OV(HYS)}$	0.30502	V	Min	V_{UVH}	19.8982	V	Min
		Max	2.55			Max	3.3532		0.71811		Max		21.8392		Max
		Nom	2.5			Nom	23.7						29.31		Nom
$OVLO_{TH}$	V	Min	2.4	R3	kΩ	Min	23.463					V_{OVH}	27.6279	V	Min
		Max	2.6			Max	23.937						31.0456		Max
						Nom	2.21						28.8123		Nom
				R4	kΩ	Min	2.1879					V_{OVL}	27.3229	V	Min
						Max	2.2321						30.3275		Max

When taking tolerances into account, this example shows how much the actual implementation can vary from product to product. A different design implementation may improve or worsen the results and it may be worth investigating that as part of the design effort. In this example the UV and OV behavior can only be influenced by using resistors with different values and tighter tolerances. It is highly recommended to not alter any of the LM5069 component specifications as presented in the datasheet even if operating temperature is narrower than what the specification describes.

Take the time early in your product development and calculate your circuit tolerances. Ensure your circuits comply with all product specifications. Document your calculations, the reason why you implemented what you did, and how the implementation will perform against the product specifications. Good documentation will help Engineers (including you) to be more efficient in future product maintenance.