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Spikes and Transient Voltage Suppressors . . . a list server thread.

About mid March some conversation on the Kitfox list-server discussed a recommendation that builders add an array of Transient Voltage Suppressor (TVS) or Transorbs to the power feed of all devices considered potential victims of system aberrations. We'll join the thread where a proponent of Transorbs suggests . . . .

All these above failures from high voltage are preventable with a simple $1 part per protected device. This widely used part is missing from almost all avionics etc. in aircraft. The part is commonly called a Transorb. In this voltage range it will short a 50-amp load long enough to blow the circuit breaker while keeping the voltage under control.

Fuses yes, breakers no. The I-squared*T constant of a thermal breaker is so long that the Transorb will invariably short. However, it still DOES protect the circuit by sacrificing itself. The 50-amp pulses this device will stand are so short that neither fuse nor breaker will open. Stretching the pulse time out beyond its limits will short the device

SYSTEM VOLTAGE SPIKES **-** *Perhaps the least understood and certainly the least protected against problems with automotive electrical systems (and also "certified" aircraft) are the short duration high, voltage spikes that occur under some conditions and can and do destroy expensive avionics.*

Can you be more specific? What are the sources, magnitudes and duration of these "spikes?" I've poked around on airplanes for over 30 years with a variety of "spike catchers" (o-scopes, peak reading voltmeters, chart recorders, etc.) I've yet to identify a potential hazard that cannot be filtered off with very ordinary design techniques.

For reasons that defy logic, avionics manufacturers charge thousands of dollars for their product and omit a $1 Transient voltage suppressor (TVS) that will prevent damage in the event of a system transient or accidental battery reversal.

Some people DO include them. I use them in LOTS of places in equipment I design for the heavy iron birds . . . for LIGHTNING protection, not simple over voltage conditions. The reason most equipment doesn't use these devices is because they've been shown NOT TO NEED THEM. Furthr, battery reversal is a maintenance error that threatens lots of things and is not generally a protection issue to be designed into a system.

The most serious failure that sometimes occurs is when the battery becomes disconnected from the alternator. This can occur due to either a wire breaking . . .

Yes, contactors have been known to open in flight . . .

. . . or an internal battery open.

Extremely rare . . . never seen one myself. Given the construction methods in RG batteries, I'll expect it to remain rare. Even the classic "open cell" of the past was most often a very chemically compromised cell, seldom a broken conductor. We're not going to flog a battery into chemical compromise . . . right? We DEPEND on them to be there for certain duties . . .

. . . . In either case the result is a sudden removal of the load on the alternator. The result is the alternator wants to continue supplying power and cannot. Before the alternator regulator can react, the output voltage rises to many times the normal voltage and in the process damages the avionics. This is called a "Load Dump Transients". This transient can exceed 100 volts.

The battery does not normally "load" the alternator . . except when it's in a serious state of discharge where it appears to the alternator as one load of many. Under normal operating conditions, the battery is charged and represents near zero load. Load dump transients occur when the alternator over-reacts to the sudden reduction of loads on the bus. In airplanes this might be pitot heat, landing light, etc. This does NOT include starter because the alternator is not delivering power to the system when the starter is running. Load dump transients are a factor when (1) reaction time of the alternator regulator is poor and (2) when the load being dumped is a major percentage of alternator capacity and (3) when the battery condition is so soggy that it becomes a poor reservoir for short bursts of excessive bus voltage.

The largest load dump transient I was ever able to measure on a 14V Bonanza was with the landing gear in an UP cycle (drawing about 27 amps at shutdown) and a soggy battery (less than 25% capacity). The transient went to 20 volts for about 25 milliseconds and recovered rapidly from there as the regulator got with the program. A decent battery held this to 16 volts and the event was essentially over in about 50 milliseconds. Interestingly enough, the short term aberration did trip the OV relay. A better regulator design reduced the transient still further and stopped the nuisance trip but in no case was the transient worthy of the name "radio killer."

Many avionics boxes contain integrated circuits etc. that have an absolute maximum voltage rating under 20 volts. The included input filter capacitors prevent damage from short duration low energy transients but seldom help in the case of a transient resulting from a system bus failure like a open battery of broken connection.

Any manufacturer that puts a not-to-exceed 20 volt device right on the bus deserves to be flogged with his own soldering iron. DO-160 sez thou shalt take 40 volt, 100 millisecond shot right in the shorts and come out grin'n. Follow that with a 20 volt shot for 1 second with the same results. Where would this transient come from? The alternator. What do we expect an OV module to do? Tame that beastie in less time than it takes for a radio (or anything else) to smoke.

The engine starting process produces voltage transients. Turning off the ignition switch produces a negative voltage transient and must also be protected against.

Again, what's the source, magnitude and duration?

This has resulted in the long standing practice of being sure all the expensive avionics are turned off during the starting or shutdown process. Because of all the switches to throw in some aircraft, the avionics master switch became popular. If you have one, be sure you have a second switch in case the first fails.

Negative. When we put avionics master switches on the airplanes in 1960's, we THOUGHT there were "spikes" from the starter. This was YEARS before DO-160. I barely knew what a transistor was much less how to hook it up in anything more than a power supply or audio amplifier. Further, they were GERMANIUM, low voltage devices that were 1,000 times more fragile than modern transistors. The "long standing practice" you reference is simply a habit that has persisted in a highly regulated atmosphere of mis-understanding and ignorance. While avionics moved ahead, airframe systems designers stagnated under the "helpful" mandates of government. (Yes, you should have a second power path to an avionics bus to address several failure modes INCLUDING failure of the "avionics master switch." This is covered in detail in other works on this website.)

Load dump transients are high voltage, high energy positive transients. The response time of the output voltage of the alternator is very long. During normal operation this does not cause a problem because the battery can absorb this energy without a significant increase in voltage.

Exactly . . . this is why I am almost rabid about the way people treat the battery in their airplane. When it's the numero uno line of defense for a lot of the system's potential aberrations, why flog the thing until it fails to

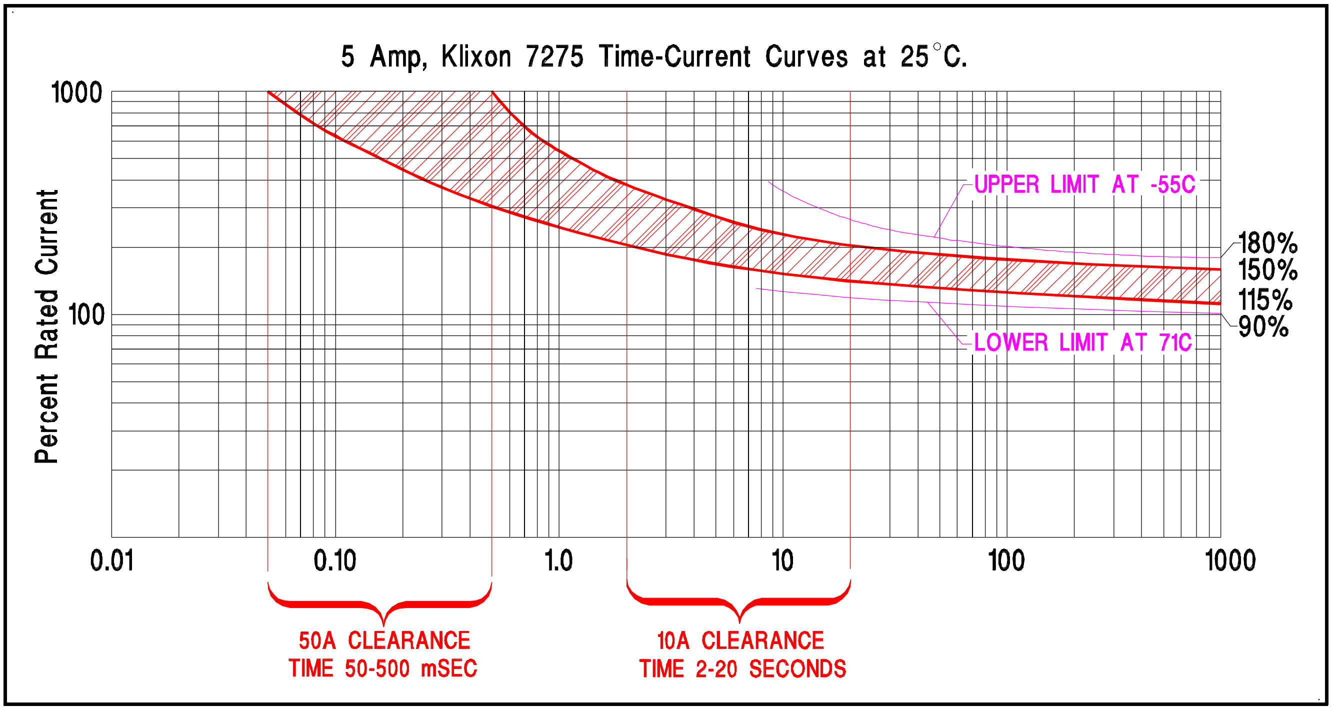

Figure 1. Current versus Time to Trip Klixon Miniature Breaker.

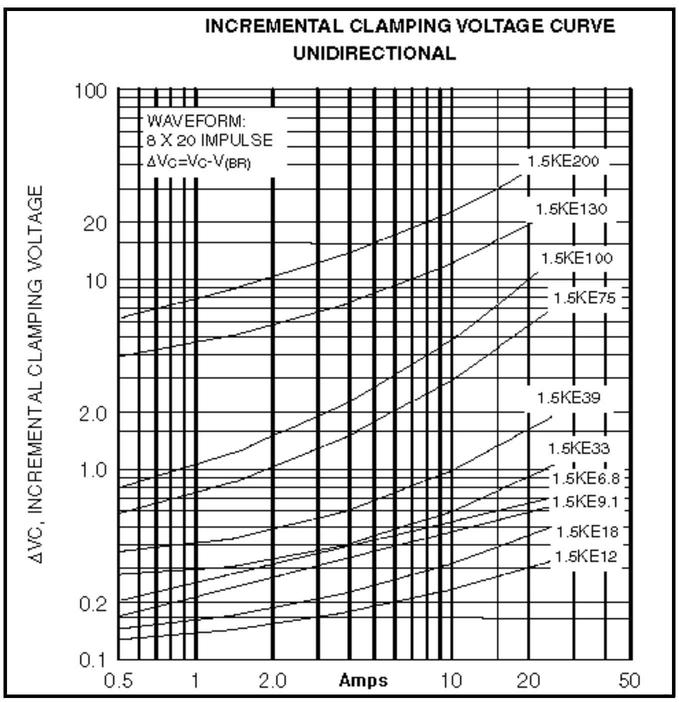

Figure 2. Incremental Voltage Values for 1.5KW Transorbs.

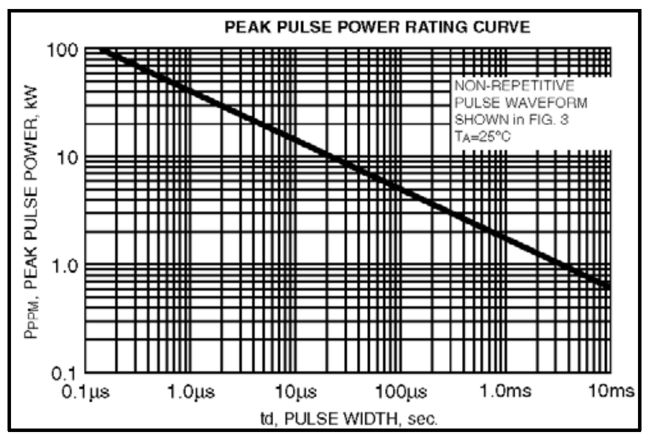

Figure 3. Max Power vs. Pulse Width for 1.5KW Transorb.

crank the engine? By then, it's been useless as either guardian of the bus -OR- standby power for too long.

Turning loads like landing lights on and off produce smaller transients that may be a problem depending on the electrical bus design and wire length and size. The *peak voltages can exceed 100 volts. This may be a problem when the source is on the same electrical bus as other sensitive components and the battery is electrically some distance away.*

Yes, the bus is noisy, it jumps around a bit every time something is switched off or on . . . but so what? Yes, there is some "inductance" in the wiring that can store energy and reduce the ability of the battery to filter . . . but the 100 volt figure is pure fiction under the described scenario (more on this later).

While not a voltage spike the accidental reversal of the battery leads or the miswiring of power to a expensive instrument or avionics box can result in instant and expensive damage. The same $1 device also protects against this human error.

If one is really worried about this event, a simple diode in series with the master switch coil lead prevents the master switch from being closed with a reverse-connected battery.

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On 4-2-98 he responds and I offer further comments . . . .

Perhaps you missed the Kitfox alternator failure where your regulator was installed and the later string of failures that destroyed thousands of dollars of electronics with a transient with a good battery installed. Clearly this set of electronics needed better protection.

I believe you're referring to Peter G.'s experience flying to Sun-n-Fun last year. Re-reading his post of March 11th I've confirmed my recollection that he started out with an LR3 regulator and a non-B&C alternator suitably modified for compatibility with the LR3. An *alternator* failure enroute prompted replacement of the whole system with an alternator having a built-in regulator and an OV protection system that I'm not familiar with. No B&C hardware was installed when the system smoked his radios.

If you're speaking about another airplane, I'm not aware of it and would appreciate knowing who the owner is.

Your lack of experience in load dump and other transients is not relevant to their universally recognized presence and the automotive industry spends millions each year in protecting equipment from them.

I apologize for hoof-in-mouth with reference to my earlier words about "load dump". I see that the automotive vernacular for the phenomenon is different than the aviation meaning. They do indeed speak of battery disconnect while the battery is simultaneously being a large "load" on the alternator. I'll suggest this is a poor choice of words because it muddies the water for other equally valid definitions of "load dump" used for years in the airplane business.

Your words supporting the use of Transorbs on every potential victim appear to be almost verbatim from the Harris Semiconductor section on Transient Voltage Suppressors. How does this document drive a notion of "universal recognition?" Is this document the Bible? Is it to be read and all words acted upon because we have faith?

But back to my point. The Harris TVS data describe an "Inductive Load Switching Transient" having amplitudes of -300 to +80 volts, a duration of up to 320 milliseconds and released energy of less than 1 Joule. Inductively stored energy is retained according to j=(L*I^2)/2. Assume a 10A load and work it backwards for a 1 Joule dump. I compute that the necessary inductance is 20 millihenries. Given that wire inductance is measured in nanohenries per foot, I have trouble visualizing a landing light or pitot heater circuit that's going to store even a tiny fraction of 1 Joule.

When the hypothetical load is shut off, where does the stored energy go? Most of it is lost in heating up the airgap between contacts of the switching device leaving little to go anywhere else. What about other assertions made in the Harris App Note? I have to assume there ARE some devices on cars that have higher energy storage abilities . . . perhaps door lock solenoids? Power seats? I don't KNOW and it doesn't matter. I'm working on airplanes. How does the application note apply to what we're doing? I'll suggest it's unclear without the kind of analysis I've asked you to participate in and have demonstrated. Further, if the astute system designer has identified a hazard, doesn't it make more sense to (1) clamp off hazardous energy at the SOURCE and/or (2) quantify the ability of victims to tolerate the antagonist than put a blanket of band-aids on every potential victim and hope we've done a good thing?

The Transorbs would have protected the electronics This would have limited the damage to $1 plus the time to fix the problem.

Agreed . . . in the Peter G. case I've cited, your proposed effect would have been achieved . . . but a properly architectured alternator system would have done as well with a whole lot less fuss.

Further with 5-10 of these Transorbs in the system the main "fuse" (yes I agree there should be a fuse in this case!) would have blown under the combined load of 250-500 amps.

Where's this 250-500 amp source? How does an alternator deliver at any greater current than it's magnetically limited design? How does a battery deliver energy to the Transorbs at a voltage above it's chemistry limits?

You jumped to the conclusion that the specified Transorb would fail before the CB opened. You jumped to the conclusion that I was full of BS and did not do analysis and testing to prove what I said. I have done both and not only does the Transorb blow the circuit breaker without damage but 5 cycles in 10 seconds resulted in no damage and the Transorb barely got warm. Even if it failed short it did the job of protection that multi thousand dollar avionics package. How you can say no to such an simple solution that is widely recognized as a fix to a real problem mystifies me.

Okay, let's look at the data sheets from which my conclusion was launched: Figure 1 is the reaction time for the Klixon miniature breakers. Note that a 5 amp breaker will clear 50 amps in 50-500 milliseconds. Figure 2 shows incremental clamping voltage versus current for a typical 1.5KW Transorb while Figure 3 describes power dissipation ratings versus time . Figure 2 sez that an 18V, 1.5KW Transorb will increment approx 1 volt at 50 amps. So, 50 amps times 19 volts is 950 watts. The curve tells us the device will stand off 950 watts for 3-4 milliseconds. The operating time for a Klixon 5A breaker is about 10X this value. Am I reading this data incorrectly? Have you located a 5A breaker that will clear 50A in less than 10 milliseconds? If so, do you expect *every* breaker to open this fast?

Further, during OV runaway "load dump" overshoot and alternator does not become endowed with any greater ability to deliver current. Therefore, I'll suggest the 50A pulse per Transorb you postulate would occur if and only if there is but one Transorb in the system.

Let's install, six 1.5KW, 18V Transorbs in our hypothetical airplane. Let's assume the mostly discharged battery disconnect ("load dump") occurs and the bus voltage climbs. As the Transorbs begin to clamp off the voltage rise, our 60-amp alternator will transition into current limit; it's total output will be distributed over the 6 Transorbs and what ever loads are already present on the system. Assuming PERFECT paralleling and no system loads, each Transorb might see about 10 amps or 180W. Figure 3 suggests that a 180 watt surge can be handled for about 400 milliseconds. How long does it take for the Klixon 5 amp breaker to open with 10A load? Figure 1 says between 2 and 20 seconds.

I suspect at least one Transorb will be toast. Interestingly enough, when the first Transorb shorts, it's clamping voltage drops from 18 to zero. If there's no battery on line to support the fault current through the failed Transorb, then alternator field excitation will be immediately lost; the alternator relaxes and the whole system simply shuts down. In a 14 volt system, OV protection generally disconnects the alternator at 16-17 volts and in less than 50 milliseconds from onset of the event . . . faster than the Klixon upstream of a tormented Transorb can trip.

If a "lost battery" load dump precipitates the event, then crowbar OV protection will stall the system as effectively as the shorted Transorb did. On the other hand, if it's a true OV condition brought on by a failed regulator, then the BATTERY is in place to provide the typical 200-300 amps of fault current that opens the field breaker in under 10 milliseconds after the SCR trips.

Why is it preferable to buckshot a system with Transorbs to protect against a few, easily identified antagonists as opposed to (1) knowing who the antagonists are, (2) doing the analysis to show that the potential for harm is real, (3) designing the system to eliminate the hazard with the lowest parts count and potential for maintenance, and/or (4) using components and appliances that are clearly designed to be happy in our airplanes?

Or the example of the radio currently being sold that has 18v max parts in the power input circuit with no real protection. I gave you a specific make and model and never got a response from you.

I'd sincerely appreciate a repost on the data. I'd like to speak to the manufacturer. Things do fall into

cracks around here . . . I sift through 200-300 pieces of e-mail a day . . . .

Bob you fill a needed nitch in aviation and you are a real asset. That does not mean you are always correct and clearly there is more than your solution to a problem. You might find more who question your positions if your response was not so overwhelming.

Overwhelming? Gee, have you never stood in front of 10-20 other engineers in a critical design review? I'm only one voice. You oughta come work where I do . . . .

Why should I have to prove my point. You should supply the factual detailed data to support your point.

Okay, just did . . .

Your article on LEDs implies a lack of understanding of what the manufacturer means by max ratings.

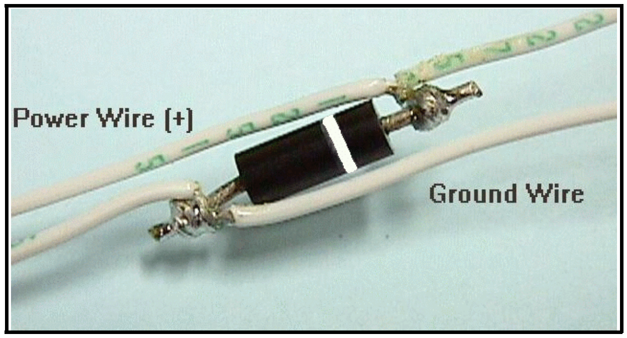
On the contrary, it nicely illustrates my point about latching onto the anybody's data sheets and preaching them as gospel applicable to every situation without a reality check. The TVS data is well intentioned and appropriate for some design environment. Our environment? How do we know without deducing which device(s) offer potential hazards and devising the best way to deal with them? I was asking you for information specific to our airplanes that *confirms* **the need for extra-ordinary action of installing TVS devices on** *any* **much less** *all* **potential victims. Wouldn't it be better to identify the antagonist and control it at the source than to sprinkle prophylactic measures about the airplane?**

I feel you need to apologize to me for your ill thought out trashing of my comments. I will not respond to this (public or private) in any way as it is not worth my time so do what you want.

Not worth your time to be an engineer? Doesn't it make a difference that potential victims of electro-gremlins in aviation are/should be qualified to DO-160? I am sorry if your feelings are hurt, and I'll not dwell on how much disinformation you recently disseminated about me, my products and my writings. This isn't religion or a popularity contest. It is science. I'm asking you to be an engineer, not a preacher of *anybody's* **gospel . You started this thread with a pronouncement that, "the actions of avionics manufacturers defy all logic". I'll suggest there is a lot of logic that will have to be shot down with more than out-of-context quotations from a transient voltage suppressor data book. Show me da numbers.**

Some folk have asked me, "Does it hurt to install all the suggested Transorbs? Seems they're not going to damage anything and they might do some good. Why all the fuss?" Fair questions.

First, how should a builder install these things? Transorbs look like a fat, plastic diode with SOLID wire leads designed to be soldered to etched circuit boards. You need both power and ground leads to wire up the device so I suppose I would do this:



And cover it with heatshrink like this:

How would you recommend that 5-10 such devices be installed? I see no graceful way to install these things *outside* **a product to be protected.**

"Salting" the system with the proposed prophylaxis against spikes is (1) a confession of our inability to control problems with analysis and design and/or (2) an expression of distrust of supplier ability and *responsibility* **to design products worthy of the money they ask. You say you've found a product with an 18v**

not-to-exceed device tied right to the bus. What's our responsibility as knowledgeable consumers? Should we willingly install band-aids on the system in acceptance of poor craftsmanship and design? I'd prefer to send the thing back and make the turkey do his homework.

People are spending a lot of dollars, time and effort to do the best job the current technology and state of the art will allow. Shotguned "protective" measures as you've proposed do nothing to advance the art and may in fact encourage careless work by manufacturers. We wouldn't tolerate sloppy designs on our cars and stereos, why encourage it in our airplanes? In another context on the same machines: Suppose you were suspicious of the qualification of a wing attach bolt. Would you confirm the installation of the right bolt or just wrap the joint with plenty of baling wire?