# Touch Current measurement comparison:
## Looking at IEC 60990 measurement circuit performance

Peter Perkins
PE Perkins, PE
p.perkins@ieee.org
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***Abstract-*** **This paper will examine in some detail the performance of the IEC 60990 circuits considering specific conditions or waveforms.**

**Conditions of electric burn (eBurn) plus Touch Current response by these circuits will be shown.**

**The examples are intended to show a range of waveforms and their calculated response.**

**The discussion is divided into two parts. Electric burn (eBurn) then Touch Current comparisons across the two circuits – startle-reaction circuit and let-go circuit.**

**These results will be compared to a TC waveform to show a comparison to modern electronic equipment.**

**This paper continues to confirm the need for peak measurements for TC waveforms from electronic equipment.**

## I. ELECTRIC BURN

- Product safety standards commonly give limits for electric burn from HF sources
- HF applies somewhere above 30kHz (as commonly believed)
- Measurement specifies the use of unweighted (IEC 60990 fig 3) circuits
- Sinusoidal waveforms are assumed
- RMS measurements are specified

**Figure 1: Historic Electric Burn summary**

The purpose of an eBurn specification is to limit the burn to a person touching such a circuit.

Earlier workers had been concerned with contact with HF circuits – wires, screwheads or connectors – which would primarily be finger contacts. Contact with wires – either end-on (wire diameter) or along the wire (very narrow width by 3 mm to 10 mm long) – is a very small area. Larger finger contacts in the range of 3 mm to 10 mm across seem to be the right order of magnitude. For a circle or a square contact this area is in the range of 7 to 100 $mm^2$; more generally this is on the order of tens of $mm^2$.

A small black burn spot from a quick contact with a small wire diameter is very acceptable; a narrow line burn seems similarly acceptable. Larger burns, e.g. from a screw connector or the like, is more of a problem. Even larger area contact & burn can be available on a circuit board. A dinner plate sized reddened area eBurn doesn't seem acceptable. Large carbonized areas are not acceptable.

| | |
|---|---|
| IEC 60065: | 70 mA pk > 100kHz |
| IEC 61010: | 70mA (normal limit) |
| IEC 61010: | 500 mA rms (fault limit) |
| IEC 60950: | 70 mA rms |
| prIEC 62368: | 50mA @ 100kHz (ES1) |
| prIEC 62368: | 100mA @ 100kHz (ES2) |

**Figure 2: Some product standard electric Burn limits**

From the product standard limits shown in Fig.2 it is shown that IEC 60065 specifies 70 mA pk AC using the unweighted TC measuring network. This applies to frequencies above 100 kHz.

IEC 61010 specifies 70 mA rms normal limit and 500 mA rms fault limit which relates to possible burns at higher frequency.

IEC 60950 specifies for LCC: 0.7 mA pk < 1kHz; 0.7*freq(kHz) ~ 70ma (cl 2.4.2).

The new, proposed prIEC 62368 specifies AC (1 kHz up to 100 kHz) current: ES1 limit ≤ 0.5 mA rms x f in kHz [= 50 mA rms at 100 kHz] and ES2 limit ≤ 5 mA rms + 0.95 x f in kHz [= 100 mA at 100 kHz].

The unweighted measurement circuit shown in Fig. 3a is also a basic part of each weighted measurement circuit shown in IEC 60990.

This fundamental body model circuit has been used for the last 50 years or so in electric shock evaluations.

The Fig. 3b example shows the increase in current with frequency due to the bypass capacitor in the model. This increase is about a factor of 4 from LF to HF and the transition occurs in the region of about 0.5 kHz to 5 kHz or so.

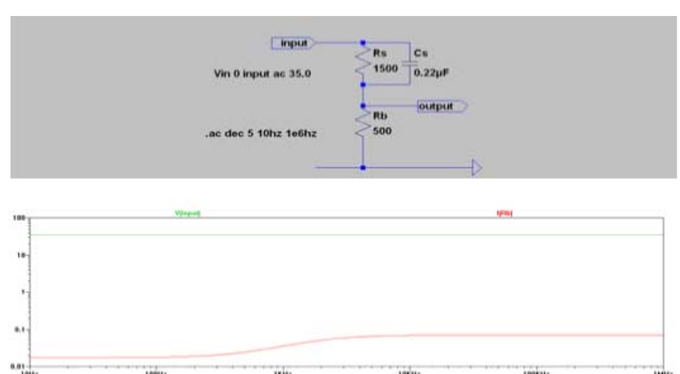



**Figure 3: Unweighted measurement circuit (a) & current (b); IEC 60990, fig 3**

| Current / Std | LF current | HF current |
|---|---|---|
| **IEC 60065** | 12.5 mA rms | 50 mA rms |
| **IEC 60950** | 17.5 mA rms | 70 mA rms |
| **IEC 61010** | 17.5mArrms, 126 mA rms | 70 mA rms, 500 mA rms |
| **prIEC 62368** | 12.5 mA rms, 25 mA rms | 50 mA rms, 100 mA rms |

**Figure 4: eBurn data summary**

This example in Fig. 3 shows 70 mA rms HF current which corresponds to some of the values used in the standards shown in Fig. 2.

The shape of the curve is the same for any sinusoidal input signal; the LF & HF current values change as the input changes.

Fig. 4 summarizes the calculated results of the SPICE analysis for the several eBurn limits given in the standards discussed.

Note that IEC 60065 specifies a peak limit but, since eBurn only applies to sinusoidal waveforms, this has been converted to rms values for this analysis.

The Low Frequency (LF) values are noted as they provide a basis for starting the discussion which is frequency dependant, as was shown.

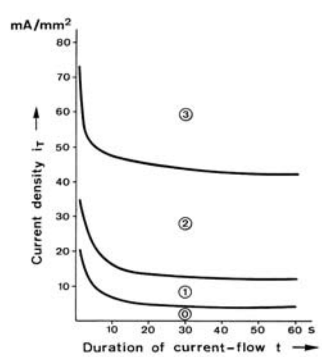
From Fig. 5 it is generally understood that a short term RF burn, reddening the skin, occurs at about 20 mA/mm$^2$ in a second or so – the shortest time a person can pull away by reaction. For a finger contact of 100 mm$^2$ this is 2000 mA (2 Amps) – a large current to which to subject a person. Fig. 5 shows these relationships.

Leaving current marks occurs at about 35 ma/mm$^2$ – 3500 mA (3.5 Amps).

Carbonization of the skin occurs at about 75 mA/mm$^2$ – 7500 mA (7.5 Amps). Longer term effects, 10's of seconds, are lower.

The Fig 5 data from IEC 60479-1 does not show frequency dependence for eBurn.

Combining the data from the current density curve with the contact areas expected provides the Fig. 6 table of expected currents.




**Reddening the skin** occurs at about 20 mA/mm$^2$ in a second or so – the shortest time a person can pull away by reaction. For finger contact of 100 mm$^2$ = 2000 mA (2 Amps).

**Leaving current marks** occurs at about 35 ma/mm$^2$ – 3500 mA (3.5 Amps).

**Carbonization of the skin** occurs at about 75 mA/mm$^2$ – 7500 mA (7.5 Amps). Longer term effects, tens of seconds, are lower.

**Figure 5: skin eBurn effects (IEC 60479-1 fig 14)**

| Area, mm$^2$ | 20 mA/mm$^2$, mA rms | 35 mA/mm$^2$, mA rms | 75 mA/mm$^2$, mA rms |
|---|---|---|---|
| **7** | 140 | 245 | 575 |
| **10** | 200 | 350 | 750 |
| **20** | 400 | 700 | 1500 |
| **50** | 1000 | 1750 | 3750 |
| **100** | 2000 | 3500 | 7500 |

**Figure 6: eBurn currents vs. area**

Note that the highest value considered here is 7.5 Amps over a 10 cm by 10 cm area.

The LF currents calculated ranged from 12.5 mA to 126 mA.

Fig. 7 (from IEC 60479-1) shows that a one second contact at 50 mA will produce ventricular fibrillation (VF).

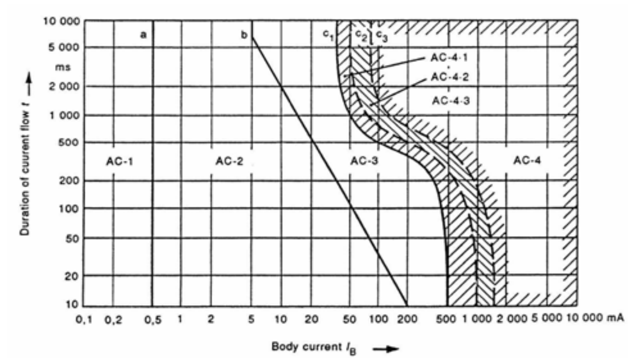


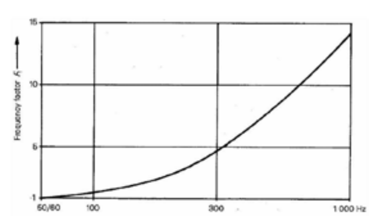

**Figure 7: LF AC duration vs. body current; (IEC 60479-1, fig 20)**

The body can withstand more current at high frequency for the same effect. The frequency factor curve for VF in IEC 60479 is shown in Fig. 8. This curve can be extended to HF as has been done for the similar curves in IEC 60990.

The current shown above is about 8.5 times higher than the threshold for let-go at the same frequency. This means that slightly below this value one would be protected from VF but would not be able to let-go of the circuit.

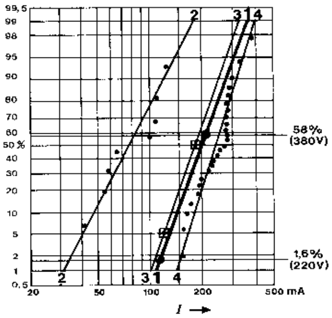
No frequency compensating circuit has been developed in IEC 60990 for this curve since it is expected that products would not drive performance up against this limit.

Certainly one would not want to put a person into VF upon contact with any eBurn current. Curve C1 (the 5% VF curve, protecting 95% of the population) would be the absolute upper limit without any margin for safety.



Freq factor for VF; waveforms > heart cycle, longitudinal thru the body (IEC 60479-2, Fig 3)

**Figure 8: Frequency factor for Ventricular Fibrillation**




0.5% VF @ 100mA
IEC 60479-1, fig 19

**Figure 9: Comparative VF statistics**

The 1984 version of IEC 60479 had a footnote: ‘The point 500 mA/100 ms corresponds to a fibrillation probability in the order of 0.14%’. (This note appears to be the basis for choosing 500 mA as a limit.) This note has not been carried forward in the revision of the standard.

The latest version of the standard provides Fig. 9 which is a comparative curve of Fibrillation data that provides a curve calculated from line voltage and frequency accidents showing 0.5% VF at 100 mA.

The purpose of an eBurn specification is to limit the burn to a person touching such a circuit; but burns are not the only effect that needs to be considered. Coming in contact with such a circuit could lead to inability to let-go at levels well below those that would set off VF. Inability to let-go is defined by the b-curve body current levels of IEC 60479 ‘conventional time/current zones of effects of ac currents’.

From this point forward we will examine these traditional eBurn current values along with determining the frequency at which they fall below the let-go curve, curve b.

Using this frequency as a lower limit assures that any contact with the circuit will not result in inability to let-go (including its effect at high frequency, see Fig. 10 example).

In Fig. 11 a summary of the results of these SPICE calculations adding the let-go lower limit frequency is shown.

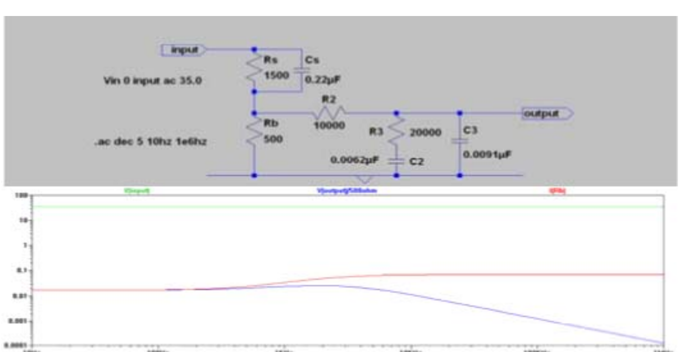


**Figure 10: eBurn current from let-go weighted circuit**

| Current / product std | LF current | HF current | 5 mA Let-go freq |
|---|---|---|---|
| IEC 60065 | 12.5 mA rms | 50 mA rms | > 22kHz |
| IEC 60950 | 17.5 mA rms | 70 mA rms | > 25 kHz |
| IEC 61010 | 17.5 mA rms,126 mA rms | 70 mA rms, 500 mA rms | > 25kHz, > 180Khz |
| prIEC 62368 | 12.5 mA rms, 25 mA rms | 50 mA rms, 100 mA rms | > 22kHz > 36kHz |

**Figure 11: eBurn data summary plus let-go frequency limit**

These limits should always be specified above the frequency shown.

The plot shown in Fig. 12 summarizes the eBurn 5 mA let-go lower frequency point calculated for Fig. 11.

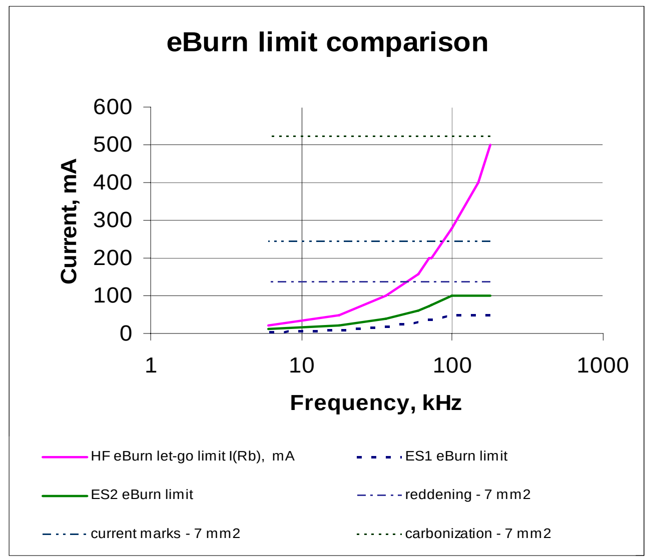



**Figure 12: eBurn current comparison**

Skin effects (reddening, current marks and carbonization, as shown in Fig. 5) lines are shown for a small contact area.

Operating below (and to the right of) the HF eBurn let-go curve always insures being below curve b of Fig. 7 to ensure let-go from allowable eBurn currents.

Operating above (and to the left of) the curve is forbidden under these conditions.

Each of these effects must be taken into account in setting a limit.

- Sinusoidal signals only
- Small, finger tip contact
- Reaction contact
- Adjusted for experience or training
- Always below let-go limit
- For all accessible circuits

**Figure 13: eBurn limit conditions summary**

*Summarizing eBurn:*

The eBurn limit only applies to sinusoidal signals.

The area of contact should be limited to small, finger tip contact to HF circuits.

The time of contact should be specified as being limited to reaction (< 1 sec).

The allowable limit should be specified for each type of person covered in the standard (ordinary normal user, supervised user or trained serviceman). Why would we subject ordinary users to an eBurn?

The allowable limit should ensure that the hazard never exceeds the let-go limit vs. frequency curve above.

These requirements should apply to accessible circuits which can be contacted at both poles. This includes all grounded secondary circuits and any isolated circuits where both contacts are easily available to touch.

## II. TOUCH CURRENT

IEC 60990 provides circuits for measurement of Touch Current for:

- Startle-reaction conditions
- Let-go conditions

**Figure 14: IEC 60990 TC conditions**

IEC 60990 provides 2 Touch Current measurement circuits which meet the frequency factor curves of IEC 60479 under the following conditions.

A circuit weighted for startle-reaction (formerly called perception-reaction) – fig 4 ) – which is called s-r in this paper

A circuit weighted for let-go – fig 5 – called l-g here.

From Fig. 15, Startle-reaction is defined by curve a (the 0.5 mA line).

Let-go is defined by curve b (which is 5mA under steady state conditions but can go much higher under short time contact.

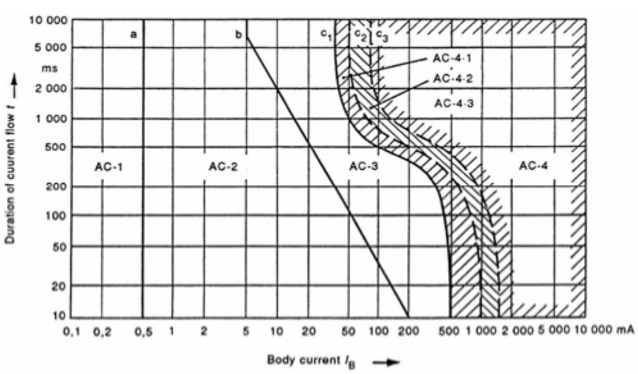



**Figure 15: LF AC duration vs. body current; (IEC 60479-1, fig 20)**

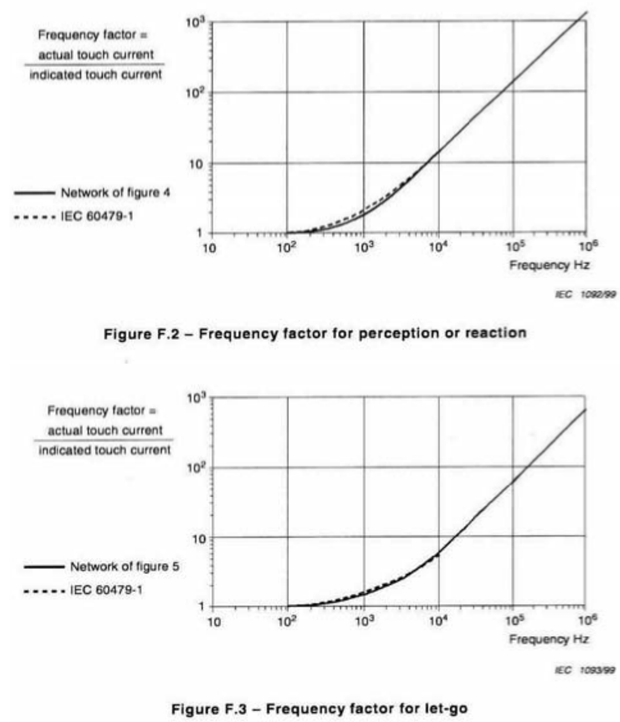



**Figure 16: TC freq factor curves; startle-reaction ckt (a); let-go ckt (b)**

The c curves identify the region of ventricular fibrillation (VF) which is fatal, if not quickly reversed.

The human body can take more current at higher frequency for the same effect.

The curves of Fig. 16 are from IEC 60990 and show the frequency factor for startle-reaction (F.2 and let-go (F.3) as well as show the adequacy of the IEC 60990 circuits in adjusting the high frequency components according to this curve.

In Fig 17 gives a comparison of the frequency factor curves for startle-reaction and let-go circuits directly.

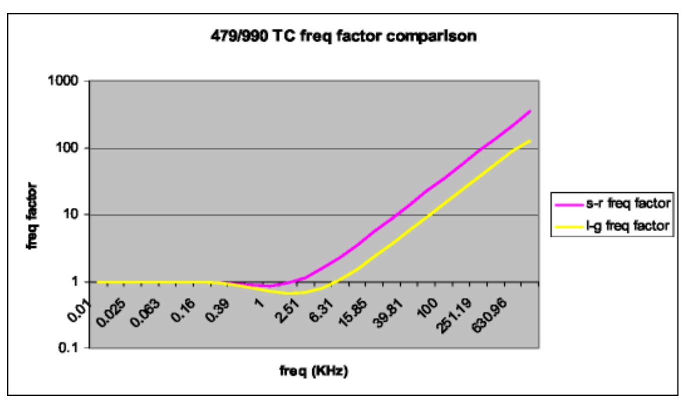



**Figure 17: Touch Current frequency factor comparison**

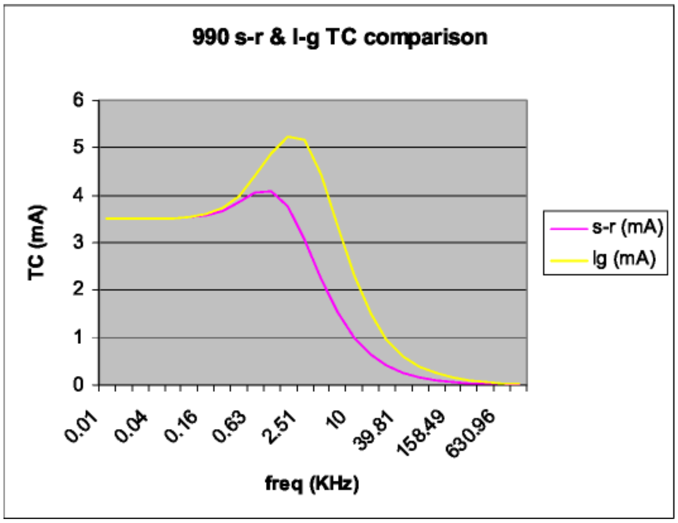



**Figure 18: TC comparison**

The TC comparison is shown in Fig 18 for the same input conditions.

*A. Sinusoidal waveforms*

The IEC 60990 circuits meeting the frequency factor curves just described are shown in Fig. 19. In each circuit the basic body model has a high frequency filter attached to meet the appropriate requirements.

The performance of each circuit is shown in Fig. 20 for the specific case chosen.

For this discussion, the case of 3.5 mA touch current has been selected. This case pushes the startle-reaction situation beyond the 0.5 mA expected, but has been commonly used in IEC standards such as IEC 60950 and IEC 61010.

Note that the touch current curve (the V(output)/500ohm - blue curve) is falling. The circuit has been designed to be the inverse of the frequency factor curve so that the same value

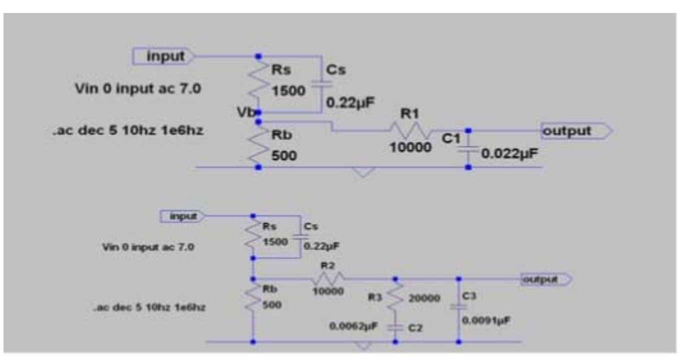



**Figure 19: IEC 60990 TC circuits: startle-reaction ckt (a); let-go ckt (b)**

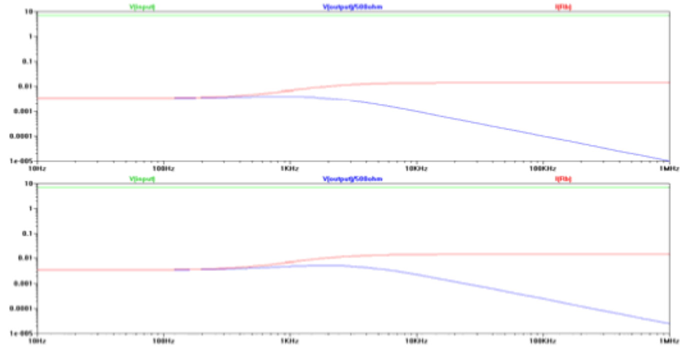


**Figure 20: IEC 60990 measurement response; startle-reaction ckt (a); let-go ckt (b)**

can be read from the meter and compared to the limit irrespective of the frequency of the TC signal.

In this case we expect the rms TC to be 3.5 mA and the peak value to be square root of 2 * rms = 5 ma. The peak to rms ratio should them be the square root of 2 as shown in Fig. 21.

The startle-reaction (s-r) curve should be used for cases where the TC limit is 2 mA or less and the let-go (l-g) circuit above that. This will ensure that children will be able to let-go of the circuit when touched.

In all of the cases examined here, there will be an emphasis on peak measurement as the body responds to peak values of current for electric shock, not rms values.

| Current | Peak | RMS | Pk/rms ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 4.94 mA | 3.49 mA | 1.415 |
| l-g cktTC = I(V(output)/500ohm) | 4.96 mA | 3.50 mA | 1.417 |

**Figure 21: 50 Hz sine wave TC: startle-reaction ckt; let-go ckt**

In each case shown in Fig. 22 we see the 50 Hz fundamental and no harmonics.

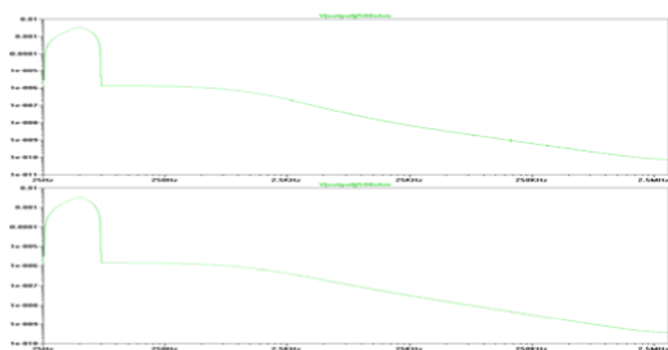


**Figure 22: 50 Hz sine wave FFT: startle-reaction ckt (a); let-go ckt (b)**

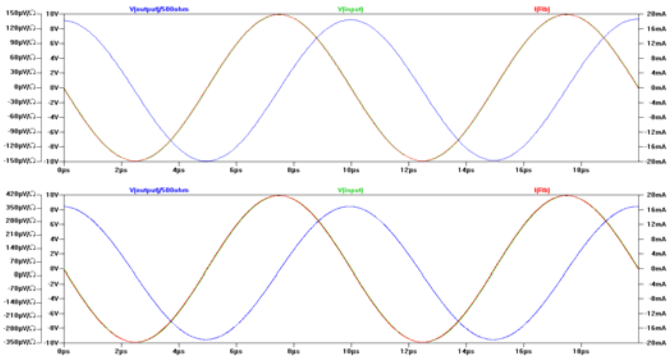


**Figure 23:100kHz sin wave response; startle-reaction ckt(a); let-go ckt(b)**

Fig. 23 looks at a 100 kHz sin wave input to each circuit. Comparing the peak and rms values for each circuit as before.

| Current | Peak | RMS | Pk/rms ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 0.143 mA | 0.101mA | 1.416 |
| l-g cktTC = I(V(output)/500ohm) | 0.346 mA | 0.245 mA | 1.412 |

**Figure 24: 100kHz sin wave TC**

The frequency factor circuit reduces the TC value as expected at this frequency as shown in Fig. 24.

Each circuit treats the value in a different way – the TC is higher for the let-go measurement. The increased current starting with the middle frequencies increases the total current.

The peak/rms ratio is still square root of 2.

Again, only the fundamental frequency appears in the FFT as shown in Fig. 25.

*B. Triangular waveforms*

The triangular waveform might be considered a ‘stretched out’ sin wave, see Fig. 26.

Triangular waveforms have been seen in some equipment drawing substantial regulated power for heaters or similar loads.

For this case the rms TC is lower than the 3.5mA that would be allowed while the peak value is higher – about 5mA, one value below and one above as shown in Fig. 27.

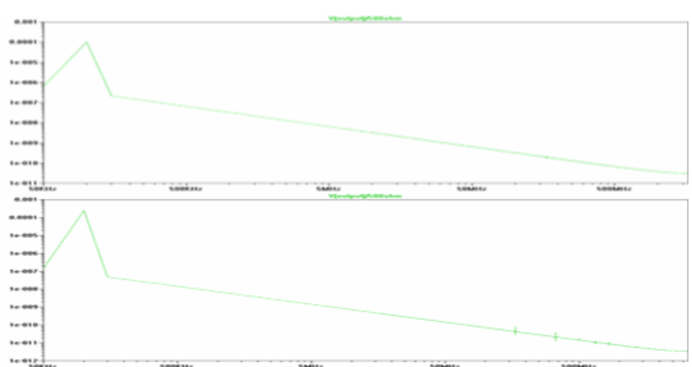


**Figure 25: 100kHz sin wave FFT;startle-reaction ckt (a); let-go ckt (b)**

| Current | Peak | RMS | Pk/rms ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 4.98 mA | 2.868 mA | 1.736 |
| l-g cktTC = I(V(output)/500ohm) | 5.05 mA | 2.869 mA | 1.760 |

**Figure 26: Triangular waveform response; 20 ms (50Hz) period**

The peak/rms ratio is no longer square root of 2.

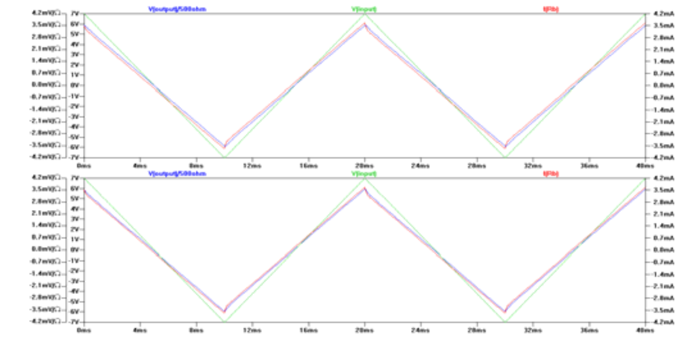


**Figure 27: Triangular wave TC; s-r (a); l-g (b)**

Somewhat to our surprise, Fig. 28 shows that there are considerable harmonics associated with the triangular waveform.

The filter circuit component of the TC circuits properly acts on these high frequency components of each waveform.

*C. Square waves*

The response to a line frequency square wave is shown here in Fig 29.

The differences in the TC response (blue curve) between these circuits is easily distinguishable here. This square wave has a 1% risetime – a very short portion of the pulse.

There are enough high frequency components here that the circuits treat them differently.

Although the rms values are about the same, the peak values are quite different.

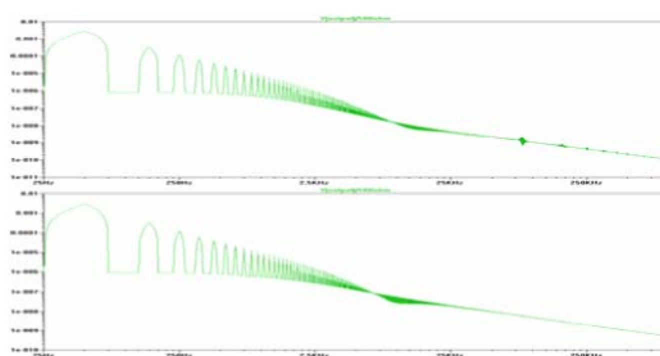


**Figure 28: Triangular wave FFT; startle-reaction ckt (a); let-go ckt (b)**

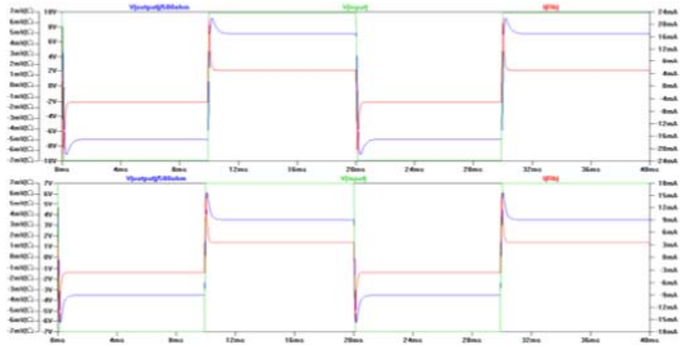


**Figure 29: 20ms (50Hz) Sq Wave response; s-r ckt (a); l-g ckt (b)**

Because of these differences the peak/rms ratios are quite different.

| Current | Peak | RMS | Pk/rms Ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 6.39 mA | 4.991 mA | 1.280 |
| l-g cktTC = I(V(output)/500ohm) | 8.758 mA | 5.054 mA | 1.733 |

**Figure 30: 20ms (50Hz) sq Wave TC**

The peak values are the important measurement here and the values are given in Fig 30.

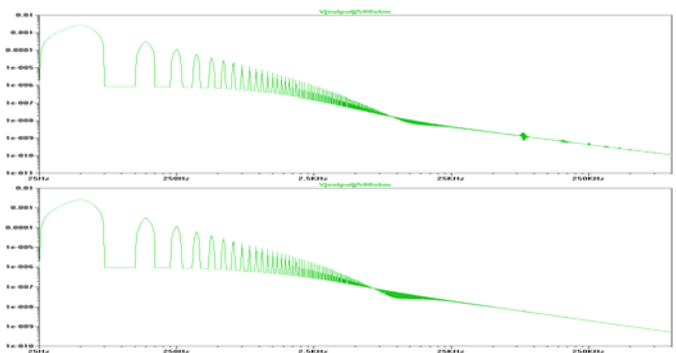


**Figure 31: 20ms (50Hz) Sq Wave FFT; s-r ckt (a); l-g ckt (b)**

Some high frequency differences can be seen in comparing these two FFTs of the circuit response to this waveform as shown in Fig. 31.

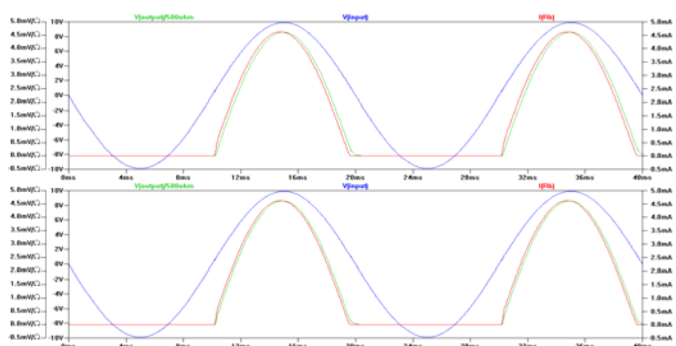


**Figure 32: Half-wave rectified line-frequency sine wave response; s-r ckt (a); l-g ckt (b)**

*D. Rectified sin wave*

Fig. 32 begins the discussion of rectification of line voltage which is an essential part of utilization of electric energy in equipment today.

As we might begin to suspect, Fig. 33 shown that the rms values are lower than our sinusoidal base case but the peak values are proportionally higher.

The peak/rms ratio is over 2.

| Current | Peak | RMS | Pk/rms Ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 4.61 mA | 2.264 mA | 2.036 |
| l-g cktTC = I(V(output)/500ohm) | 4.62 mA | 2.265 mA | 2.036 |

**Figure 33: Half-wave rectified line-frequency sin wave TC**

The high frequency differences appear above 25kHz and up as shown in Fig. 34.

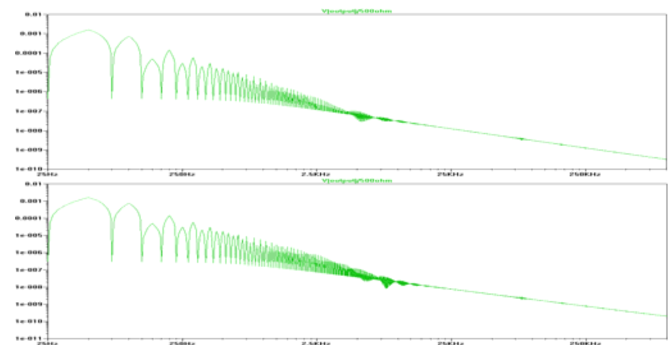


**Figure 34: Half-wave rectified line-frequency sin wave FFT; s-r ckt (a); l-g ckt (b)**

*E. 1 ms square wave response*

100 ms pulse, 1 sec rep rate (within the heart cycle), 1ms (1%) risetime shown in Fig. 35.

This calculation was looking for a TC below 14 mA pk to prevent VF for the particulars of this case.

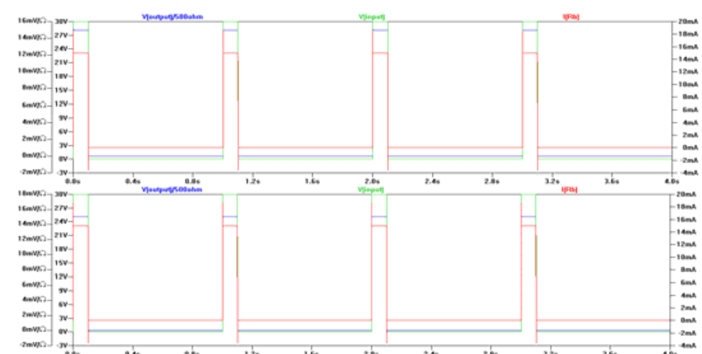


**Figure 35:1 ms risetime pulse response: s-r ckt (a); l-g ckt (b)**

| Current | Peak | RMS | Pk/rms Ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 8.319 mA | 4.761 Ma | 1.747 |
| l-g cktTC = I(V(output)/500ohm) | 8.917 mA | 4.762 mA | 1.873 |

**Figure 36: 1ms risetime pulse TC**

With this risetime there is only a slight difference in the circuit responses between circuits as shown in Fig 36.
The pk/rms ratio is not sqrt 2, however.

The higher frequency components show as slight differences here as seen in Fig 37.

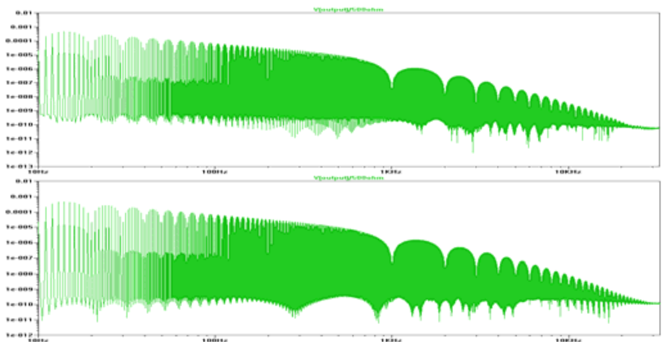


**Figure 37: 1ms risetime pulse FFT; s-r-ckt (a); l-g ckt (b)**

Looking at Fig. 38, at the slow risetimes the TC is about 7.5 mA in each case.
At the fast risetimes the TC is almost 10 mA for the s-r case and almost 14 mA for the l-g case.
The control of risetime is the key to using impulse circuits in applications where TC approaches the limit.

Although the FFT waveforms seem similar here in Fig. 39, the TC magnitude differs as we saw in the last slide.

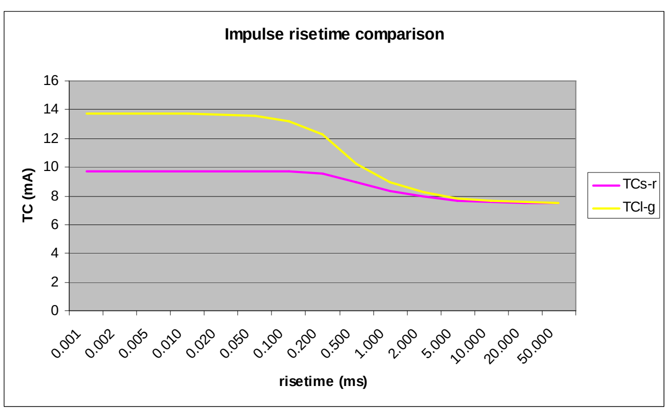



**Figure 38: Impulse risetime comparison: s-r ckt; l-g ckt**

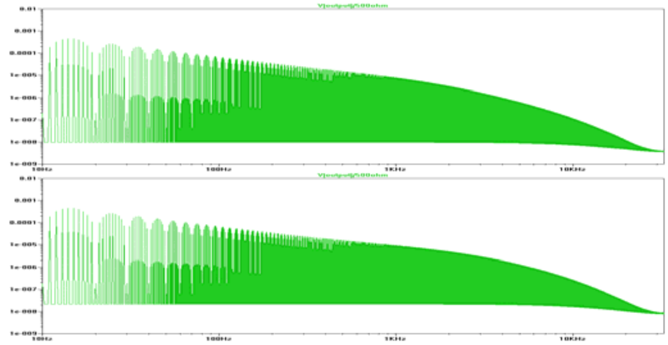


**Figure 39: 0.01ms risetime pulse FFT; s-r ckt (a); l-g ckt (b)**

Both the magnitude and the pk/rms ratio are different for a fast RT when filtered by each TC circuit as shown in Fig 40.

| Current | Peak | RMS | Pk/rms Ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 9.732 mA | 4.746 mA | 2.051 |
| l-g cktTC = I(V(output)/500ohm) | 13.687 mA | 4.749 mA | 2.882 |

**Figure 40: 0.01ms risttime pulse TC**

*F. Limited current Circuit analysis*

Limited Current Circuit evaluation described in Fig. 41 replicates a real world case.

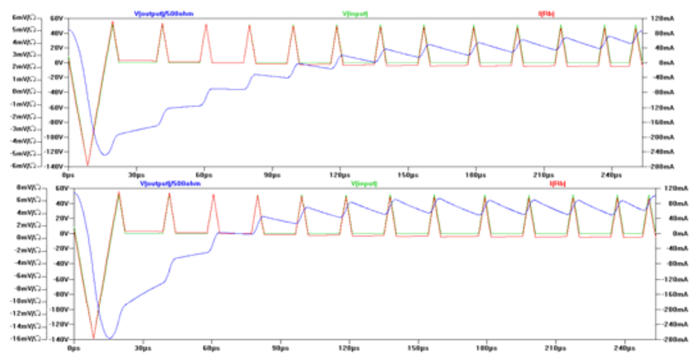


**Figure 41: LCC circuit; s-r ckt (a); l-g ckt (b)**

IEC 60950 allows access to circuits which will not be an electrical shock hazard.
This specific waveform was submitted for analysis because of its characteristics.

When reviewing the LCC waveform using the s-r circuit it shows the peculiar characteristic of being less than 3.5 mA rms but more than 5 mA pk (IEC 60950 limits), see Fig 42.
Again, reviewing this LCC waveform using the l-g circuit the values are substantially larger and the pk/rms ratio is also larger.

| Current | Peak | RMS | Pk/rms Ratio |
|---|---|---|---|
| s-r cktTC = I(V(output)/500ohm) | 5.070 mA | 3.090 mA | 1.641 |
| l-g cktTC = I(V(output)/500ohm) | 11.536 mA | 5.645 mA | 2.044 |

**Figure 42: LCC TC comparison; s-r ckt; l-g ckt**

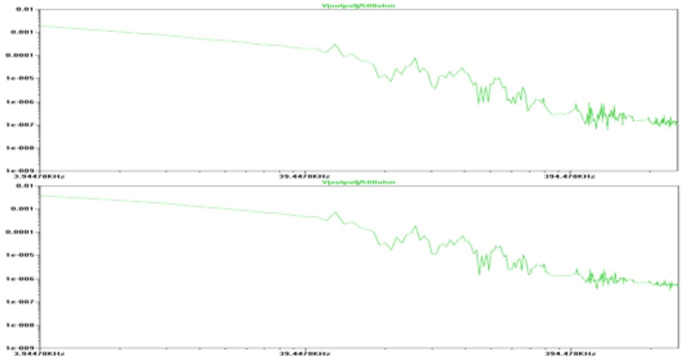


**Figure 43: LLC circuit FFT: s-r ckt (a); l-g ckt (b)**

Comparing these FFT's in Fig. 43 (which appear quite similar and contain harmonics starting about 40kHz.

This complex waveform cannot be evaluated by simply consulting the frequency factor curves.

The use of peak measurement is the only way to evaluate this complex waveform.

### *G. TC Conclusions*

This paper compares the performance of the IEC 60990 eBurn, startle-reaction and let-go circuits against basic waveforms.

This leads to a better understanding as to the action of TC waveforms and encourages the proper evaluation of TC waveforms in equipment.

The simple waveforms shown here are not yet representative of the TC waveforms for modern equipment using mains switching techniques.

Switching electronics is used in switch mode power supplies and variable speed drives in equipment today. This technology is spreading to many other types of equipment – commercial, industrial and residential.

Peak measurements are needed for the s-r and l-g cases; these are specified in many standards but not uniformly applied today.

- From the review of these examples, we see the following:
  1) Both of these circuits evaluate LF waveforms in a similar way – properly accounting for HF components.
  2) Moving to the use of the let-go circuit (for limits approaching the l-g limit curve) requires a more conservative design to meet the limits.
  3) The general use of peak TC measurements is needed for today's complex TC waveforms.

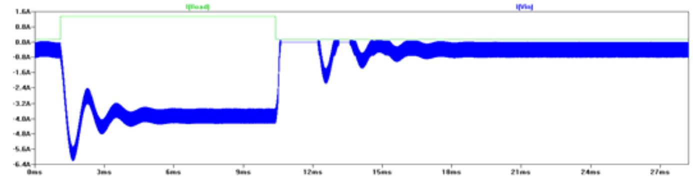
**Figure 44: TC conclusions**

## III. EXPLORING FURTHER

How did we get there and what can we say about real SMPS?

Power supply manufacturers tout the performance of their modules in meeting the needed performance criteria for the applications they support.

Note from the fig 45 example, however, that the input



Input and load currents as the supply is switched on then off

**Figure 45: Proto DC-DC power supply I/O currents**

current is never a fixed value, it oscillates over a small range (ooo 1amp or so in this case) to maintain the output regulation needed.

This current oscillation is capacitively coupled to earth and contributes to the TC for the product.

Many products use a multiplicity of these DC-DC converters for the distribution of power in the product; each of these will contribute to the TC for the product in their own way. The measured TC will, of course, sum these sources.

Note that both the output and the input show a continuous harmonic spectrum for this power supply as shown in Fig. 46.

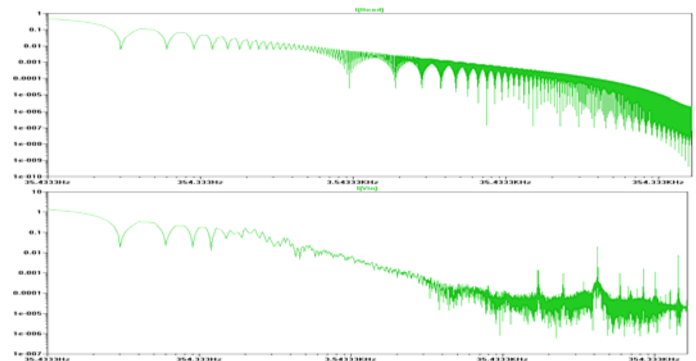


**Figure 46: Proto DC-DC converter I/O FFT's**

The measured Touch Current for a pfcSMPS in a product is shown in Fig 47 (top waveform) along with the pfc input current waveform (bottom waveform), see Fig. 47.

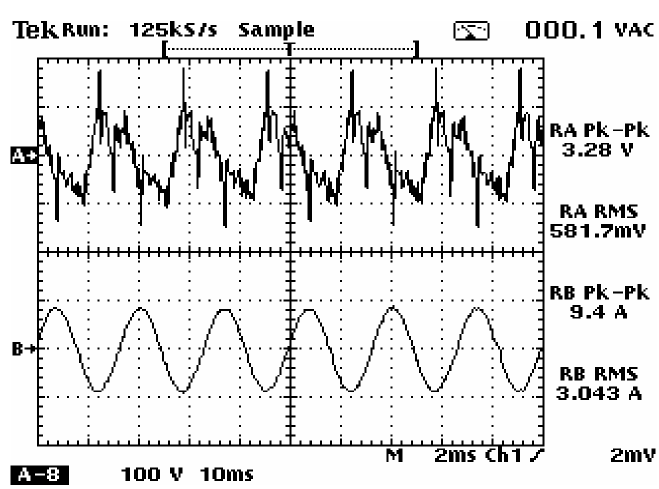



**Figure 47: pfcSMPS Touch Current waveform (top)**

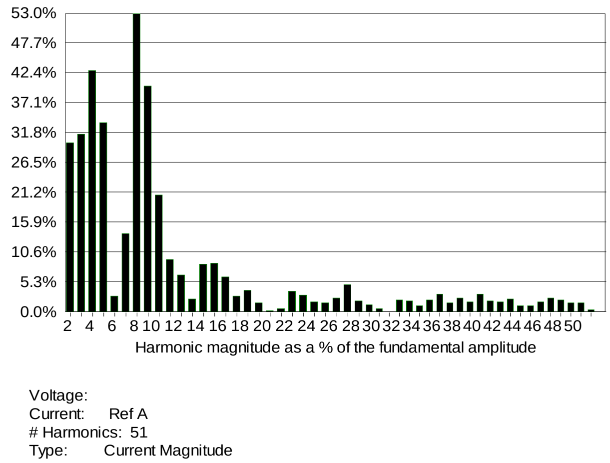



**Figure 48: Measured Frequency Spectrum for pfcSMPS TC**

The measured harmonics for a pfcSMPS Touch Current waveform shown above are shown in Fig 48.

This oscilloscope analysis shows lots of harmonics near the fundamental as we've seen in many of the non-sinusoidal examples (triangular, square wave, rectified sine wave & pulse). The scope analysis is limited to the first 50 harmonics (2.5 - 3 kHz); the SPICE analysis includes these first 50 harmonics and then goes to higher frequencies.

This paper clearly shows the need to move to peak measurements for Touch Current in all electronic products.

This paper also forms a solid basis for further understanding of the effect of system generated waveforms on the TC results for any product which can be more complex than the simple waveforms used as examples here.

Touch Currents have become the low frequency counterpart to EMC currents – a residual of the design process and not clearly controlled.

## References

[1] IEC 60479 Effects of electric current on the human body and animals; -1 General; -2 Special aspects

[2] IEC 60990 Measurement of touch current and protective conductor current.

Touch Current measurement comparison jnl