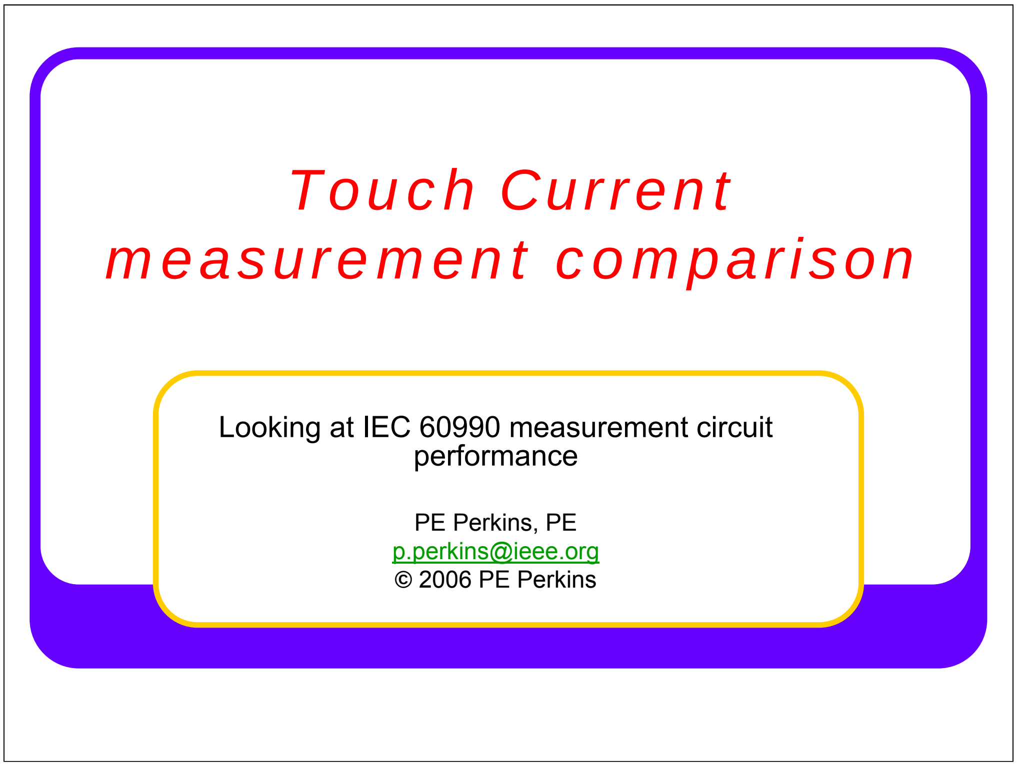

Touch Current measurement comparison
Looking at IEC 60990 measurement circuit performance

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

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

Earlier workers have 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 to 10 mm long) – is a very small area. Larger finger contacts in the range of 3mm to 10mm 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 10’s 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.

Product limits

IEC 60065:	70mApk > 100kHz
IEC 61010:	70mArms (normal limit)
“	500mArms (fault limit)
IEC 60950:	70mArms
prIEC62368:	50mArms @ 100kHz
“	100mArms @ 100kHz

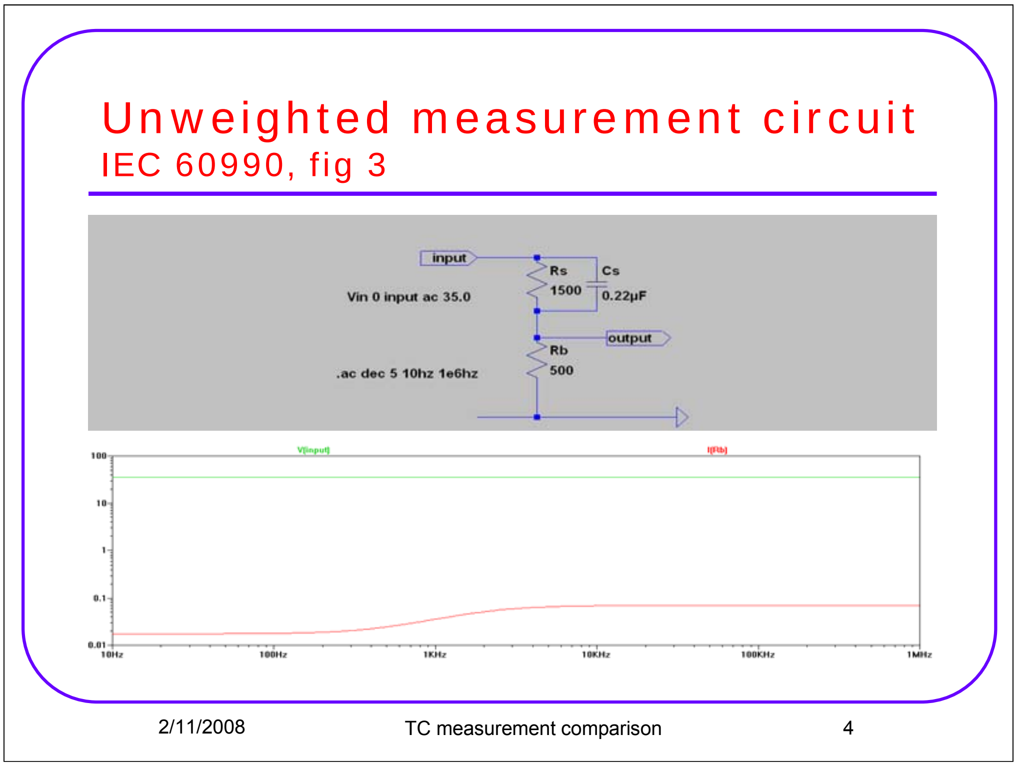
Product Limits:

IEC 60065 specifies 70mApk AC using the unweighted TC measuring network. This applies to frequencies above 100kHz.

IEC 61010 specifies 70mArms normal limit and 500mArms fault limit which relates to possibles burns at higher frequency.

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

prIEC 62368 specifies ac (1kHz up to 100kHz) current: ES1 limit ≤ 0.5mArms x f in kHz [= 50mArms at 100kHz] and ES2 limit ≤ 5mArms + 0.95 x f in kHz [= 100mA at 100 kHz].



The unweighted measurement circuit 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.

This example shows the increase in current with frequency due to the bypass capacitor. 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.

This example shown 70mArms HF current.

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

eBurn data summary

Current /product std	LF current	HF current
IEC 60065	12.5mArms	50mArms
IEC 60950	17.5mArms	70mArms
IEC 61010	17.5mArms, 126mArms	70mArms, 500mArms
prIEC 62368	12.5mArms, 25mArms	50mArms, 100mArms

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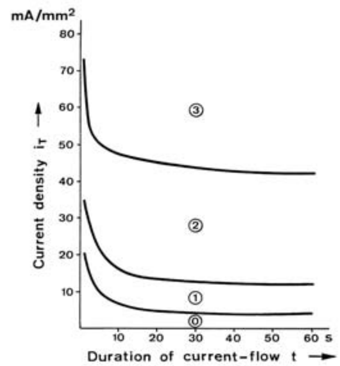
This table summarizes the calculated results of the several eBurn limits given in the standards discussed.

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

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

Skin eBurn data

- **Reddening the skin** occurs at about 20mA/mm2 in a second or so – the shortest time a person can pull away by reaction. For finger contact of 100mm2 = 2000mA (2 Amps)
- **Leaving current marks** occurs at about 35ma/mm2 – 3500mA (3.5 Amps).
- **Carbonization of the skin** occurs at about 75 mA/mm2 – 7500mA (7.5 Amps). Longer term effects, 10's of seconds, are lower.



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It is generally understood that a short term RF burn reddening the skin occurs at about 20mA/mm2 in a second or so – the shortest time a person can pull away by reaction. For a finger contact of 100 mm2 this is 2000mA (2 Amps) – a large current to which to subject a person.

Leaving current marks occurs at about 35ma/mm2 – 3500mA (3.5 Amps).

Carbonization of the skin occurs at about 75 mA/mm2 – 7500mA (7.5 Amps). Longer term effects, 10's of seconds, are lower.

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

eBurn currents vs. area

Area, mm2	20 mA/mm2, mArms	35 mA/mm2, mArms	75 mA/mm2, mArms
7	140	245	575
10	200	350	750
20	400	700	1500
50	1000	1750	3750
100	2000	3500	7500

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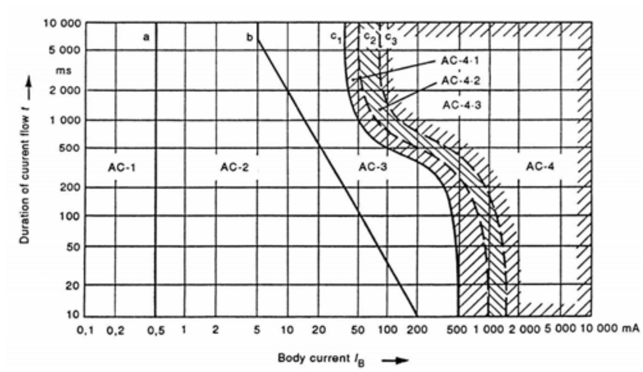
Combining the data from the current density curve with the contact areas expected provides the table of expected currents.

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

LF AC duration vs. body current
(IEC 60479-1, fig 20)



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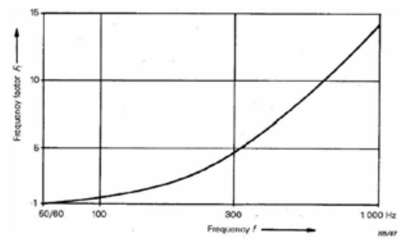
The LF currents calculated ranged from 12.5 mA to 126 mA.

This shows that a one second contact at 50mA will produce ventricular fibrillation (VF).

Frequency Factor for Ventricular Fibrillation

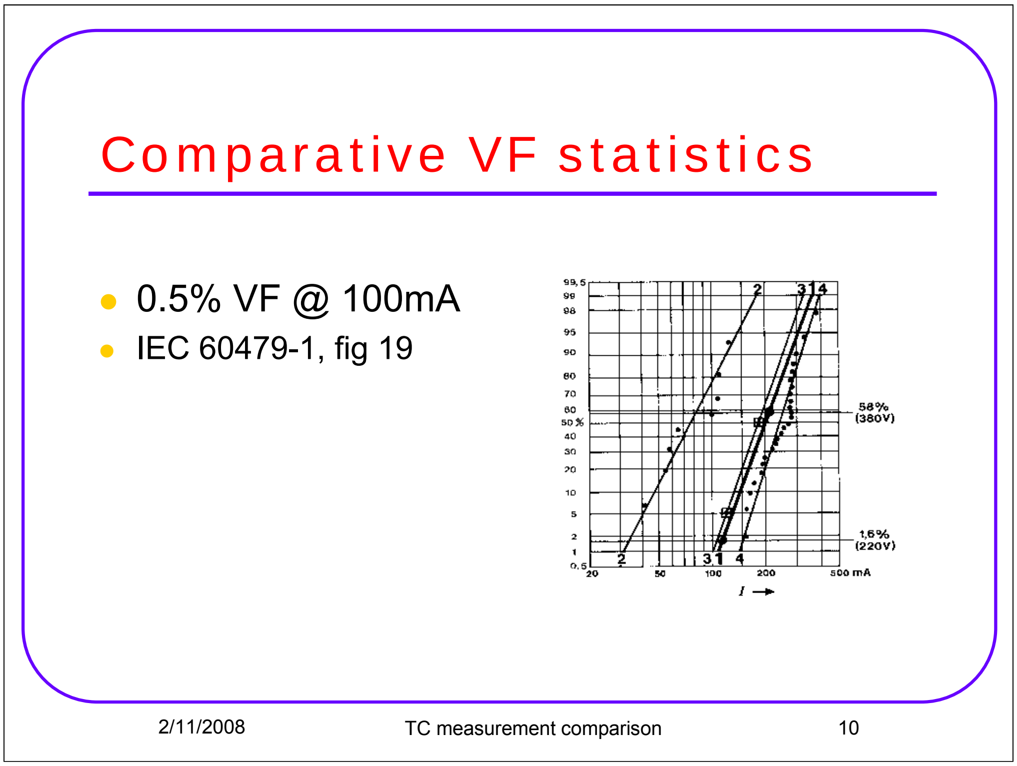
- Freq factor for VF;
- waveforms > heart cycle,
- longitudinal thru the body
- (IEC 60479-2, Fig 3)



The frequency curve for VF in IEC 60479 is shown here. This curve can be extended to HF as has been done for the similar curves in IEC 60990.

The current shown above is about 8.5x 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.

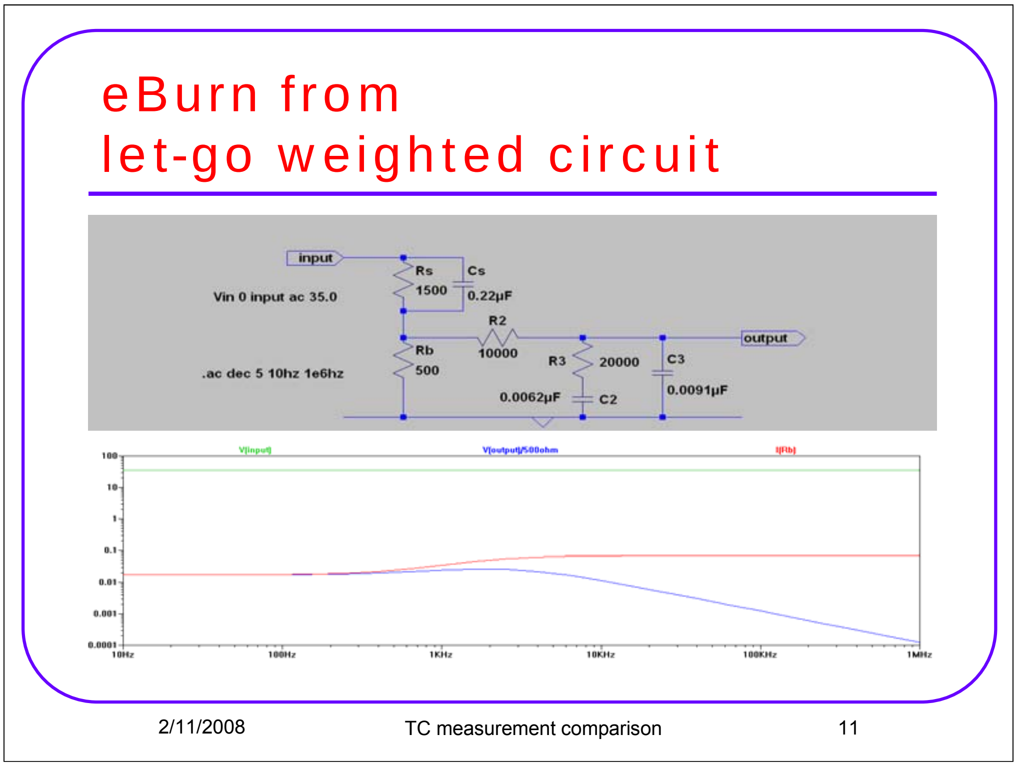
No frequency compensating circuit has been developed in IEC 60990 for this curve since it is expected that products would not drive performance up against this limit.



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.

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

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



The purpose of a 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 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).

eBurn data summary
plus let-go frequency limit

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

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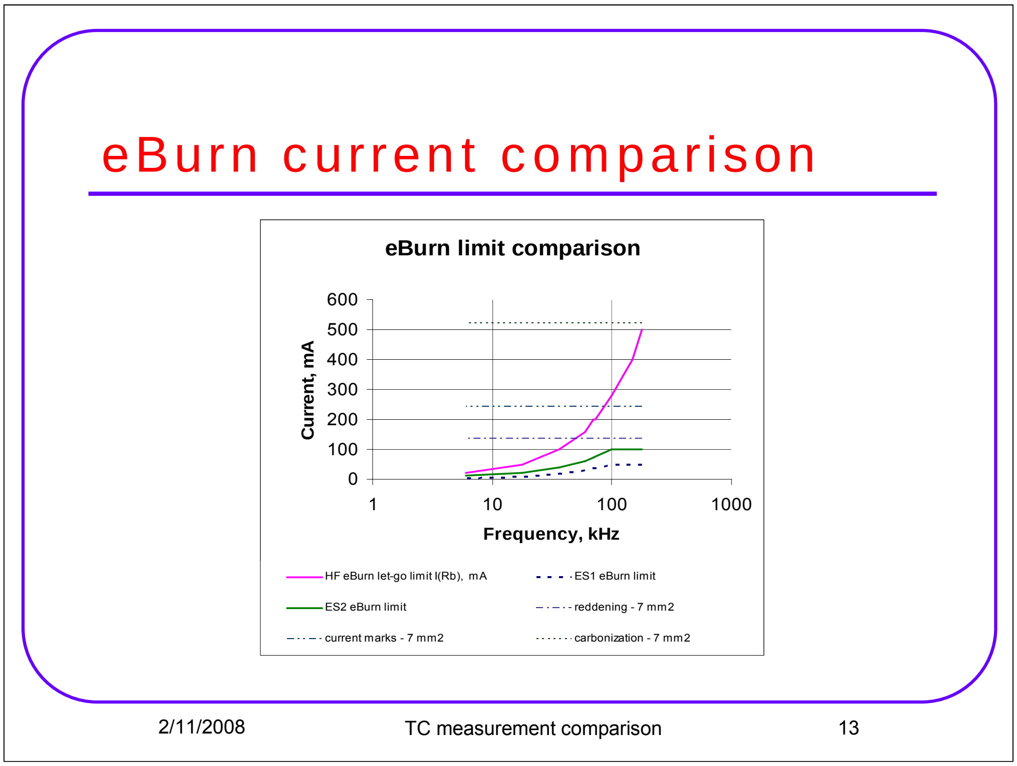
Here we summarize the results of these calculation adding the let-go lower limit frequency.

These limits should always be specified above the frequency shown.



The plot shown summarizes the eBurn 5mA let-go point calculated above.

Skin effects (redenning, current marks and carbonization) lines are shown for a small contact area.

Operating below (and to the right of) the curve always insures being below curve b insure 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.

eBurn limit conditions summary

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

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The eBurn limit only applies to sinusoidal signals.

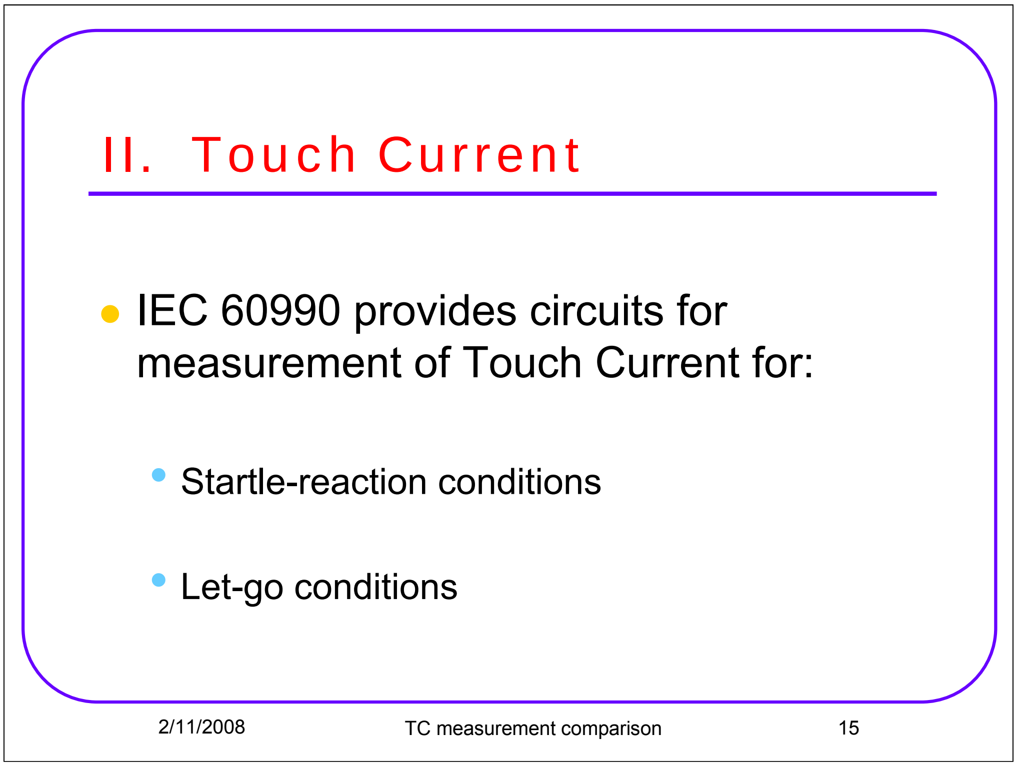
The area of contact should be limited to small, finger tip contact to HF circuits.

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.

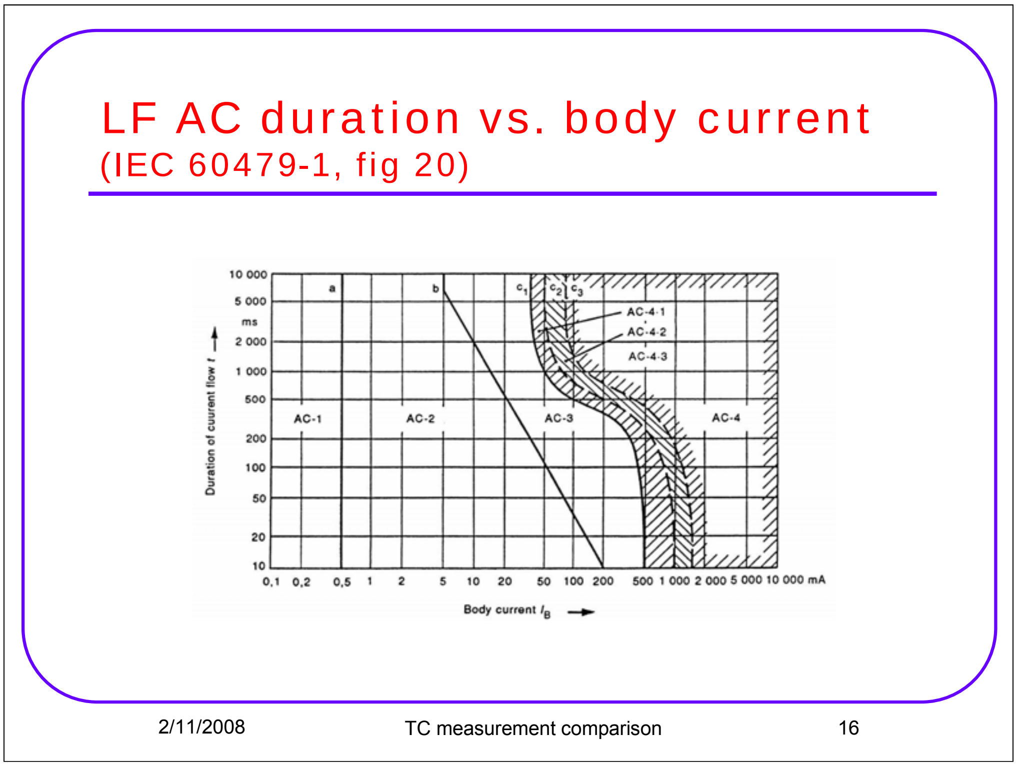
These requirements should apply to accessible circuits which can be contacted at both poles. This includes all grounded secondary circuits and any isolated circuits where both contacts are easily available to touch.



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

A circuit weighted for let-go – fig 5



Startle-reaction is defined by curve a (the 0.5mA line).

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

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

TC frequency factor curves

startle-reaction ckt; let-go ckt

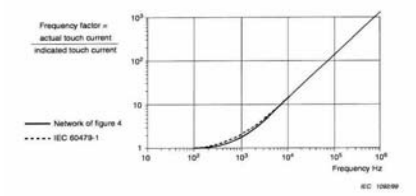


Figure F.2 – Frequency factor for perception or reaction

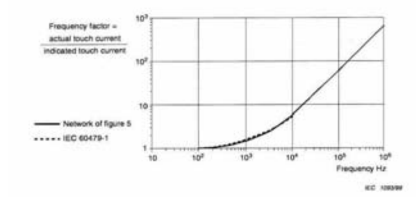
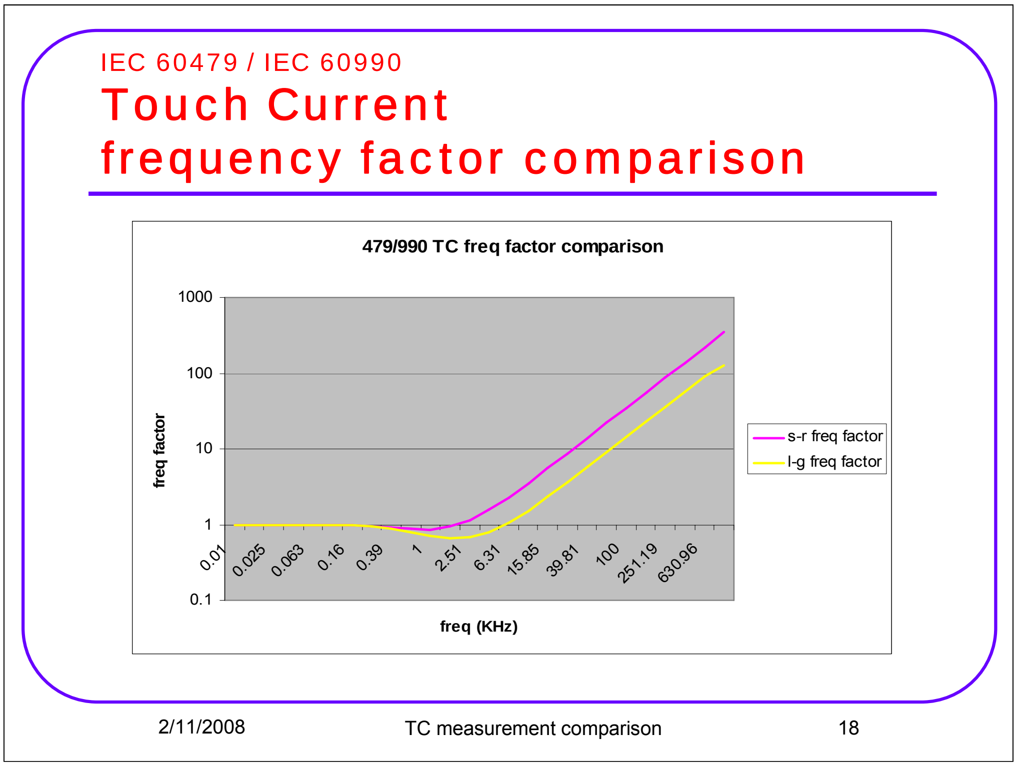


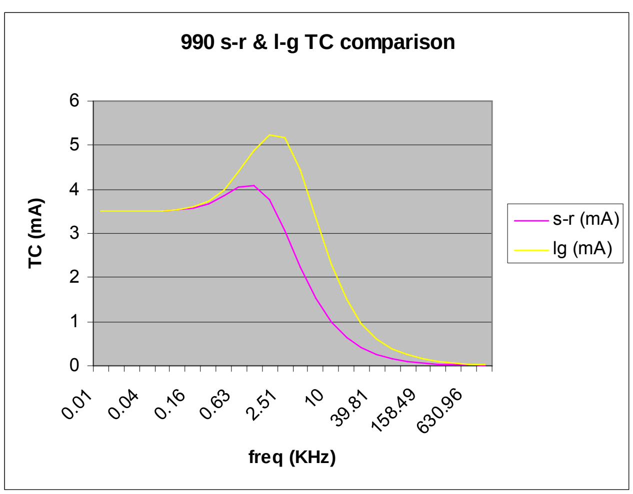
Figure F.3 – Frequency factor for let-go

These curves show the frequency factor for startle-reaction and let-go as well as show the adequacy of the IEC 60990 circuits in adjusting the high frequency components according to this curve.



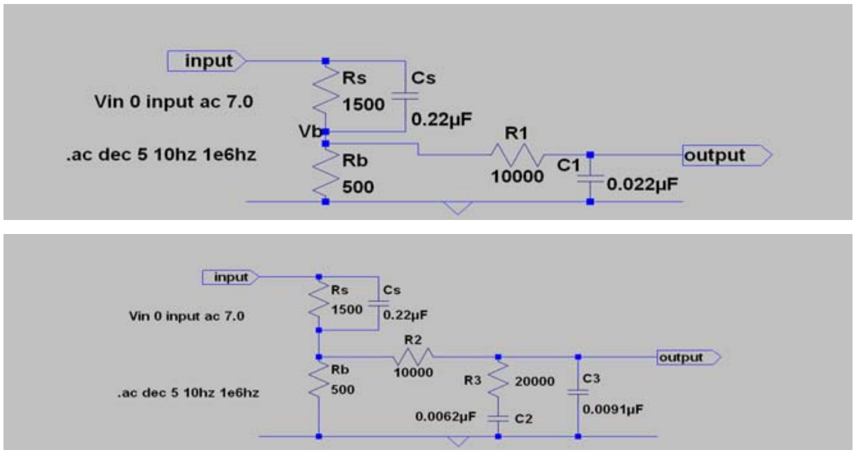
Here we compare the frequency factor curves for startle-reaction and let-go directly.

The TC comparison is shown below for the same input conditions.



IEC 60990 TC circuits

startle-reaction ckt; let-go ckt



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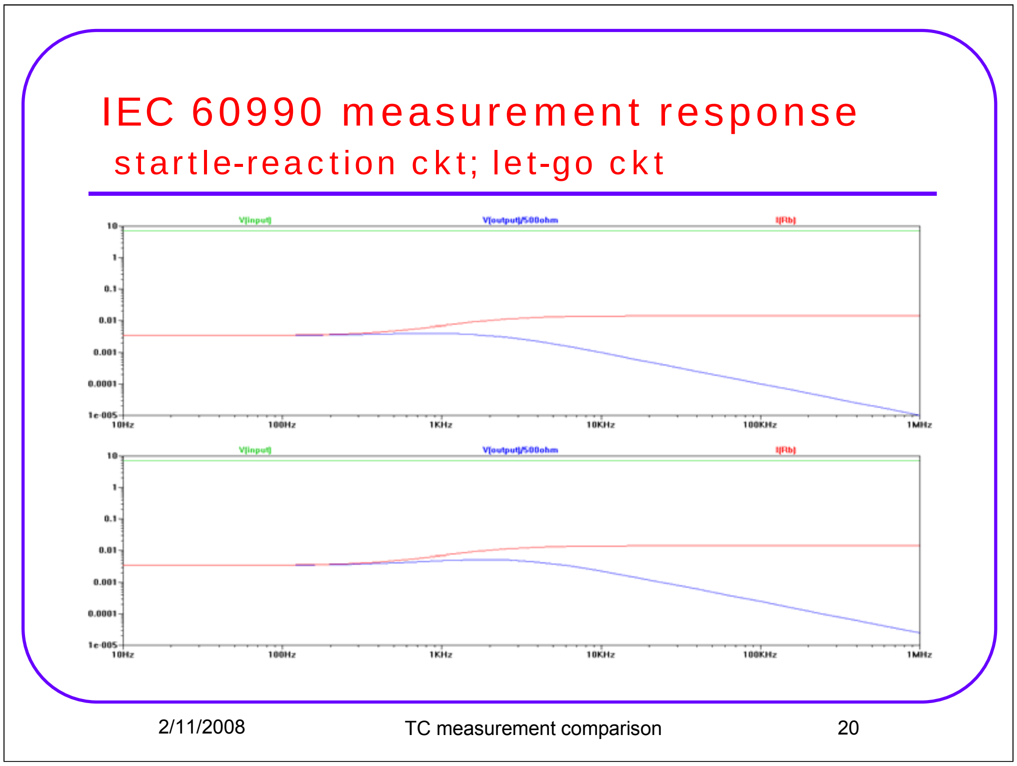
The IEC 60990 circuits meeting the frequency factor curves just described are shown here.

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 here for the specific case chosen.

For this discussion, the case of 3.5mA touch current has been selected. This case pushes the startle-reaction situation beyond the 0.5mA 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 can be read from the meter and compared to the limit irrespective of the frequency of the TC signal.

50 Hz sine wave TC

startle-reaction ckt; let-go ckt

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

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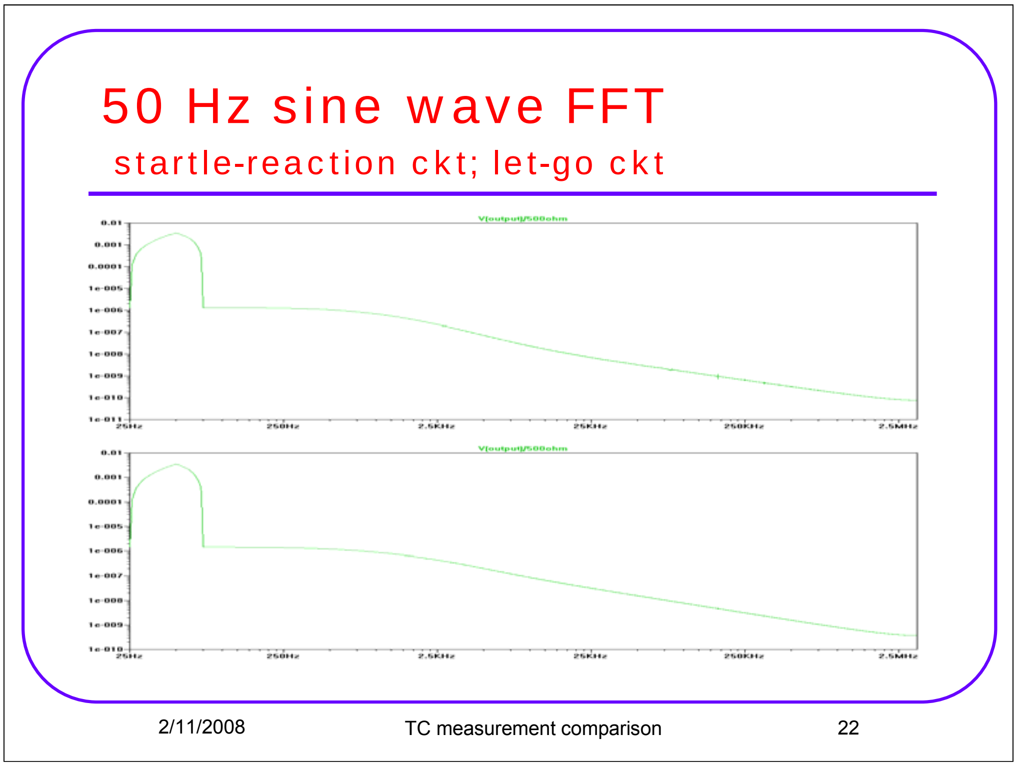
In this case we expect the rms TC to be 3.5mA and the peak value to be sq rt 2 * rms = 5ma. The peak to rms ratio should them be the sq rt 2.

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

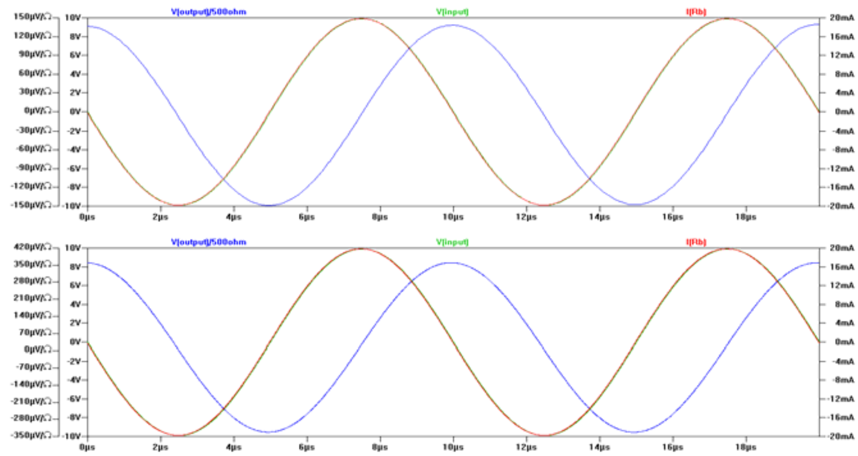
In all of the cases examined here, there will be an emphasis on peak measurement as the body responds to peak values of current for electric shock, not rms values.



In each case we see the 50 Hz fundamental and no harmonics.

100kHz sin wave response

startle-reaction ckt; let-go ckt



This case looks at a 100 kHz sin wave input to each circuit.

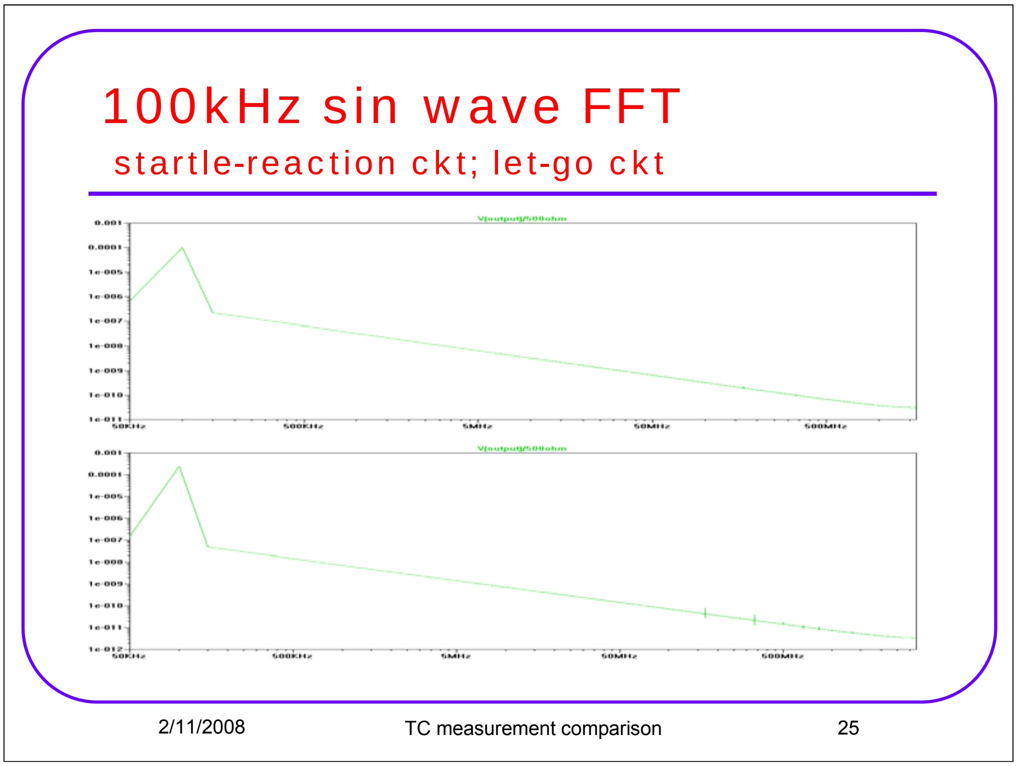
100kHz sin wave TC

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

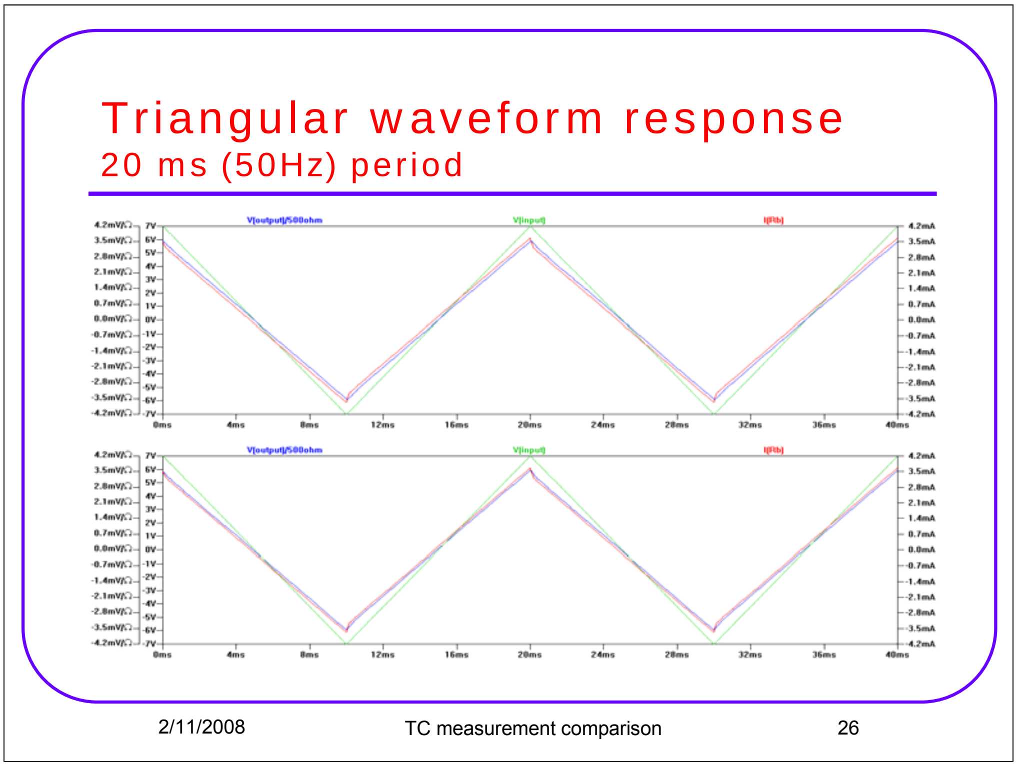
The frequency factor circuit reduces the TC value as expected at this frequency.

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 increase the total current.

The peak/rms ratio is still sq rt 2.



As before, only the fundamental frequency appears in the FFT.



The triangular waveform might be considered a ‘stretched out’ sin wave.

This type of waveform has been seen in some equipment drawing substantial regulated power for heaters .

Triangular wave TC

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

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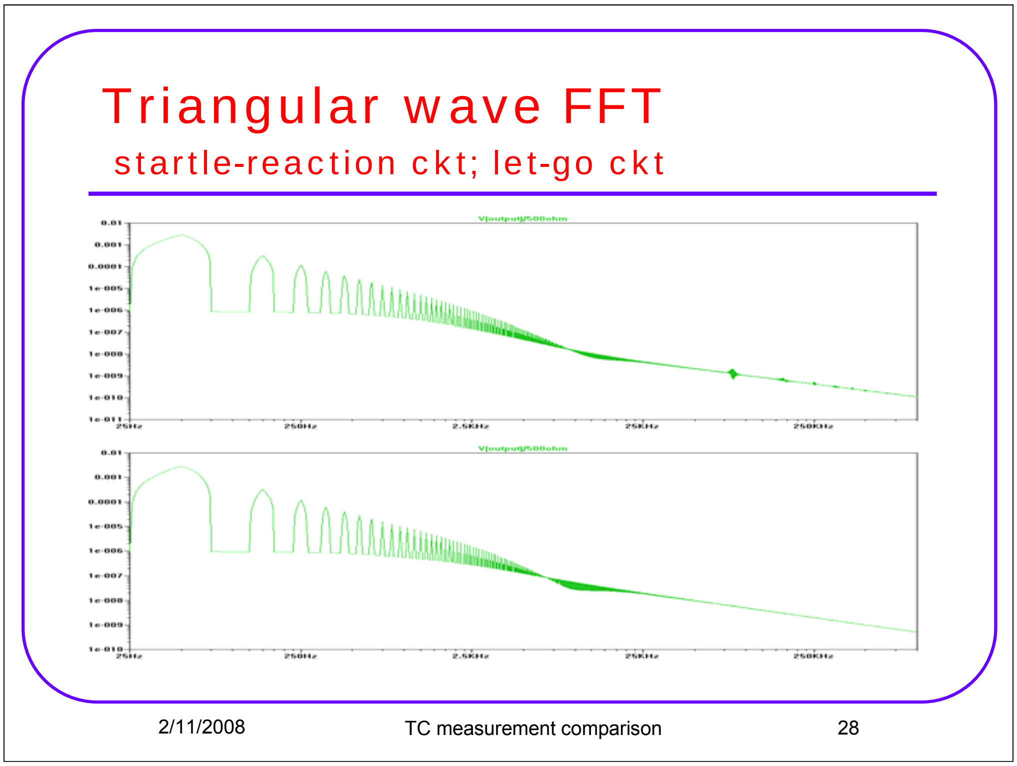
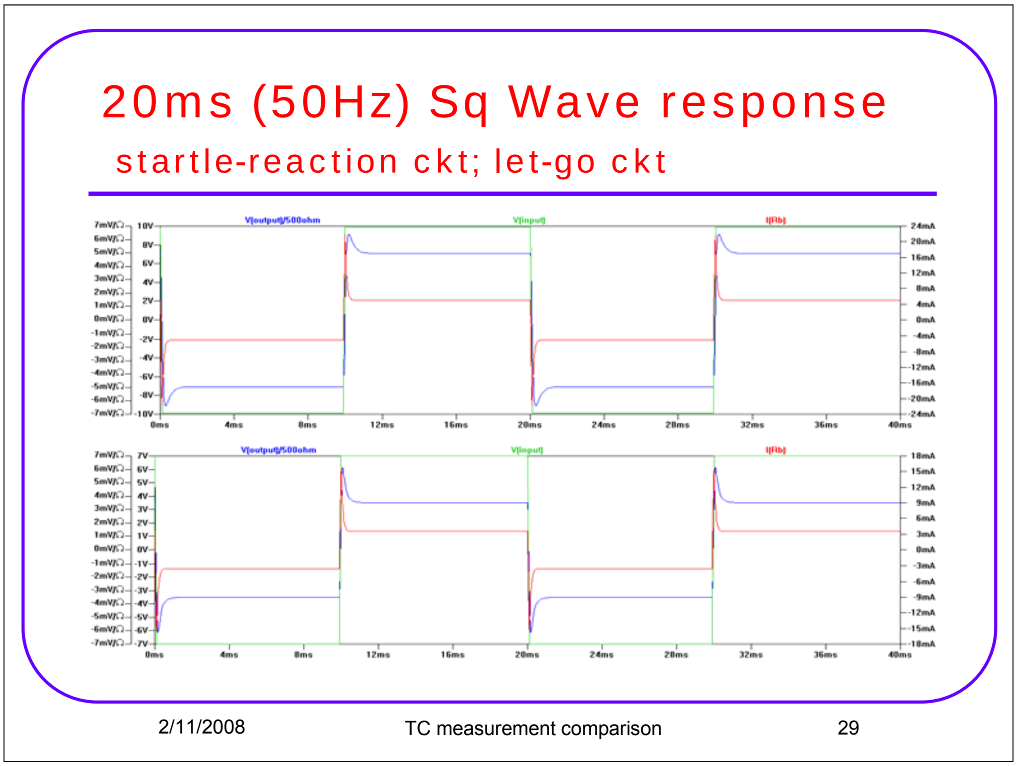
For this case the rms TC is lower than the 3.5mA that would be allowed while the peak value is higher – about 5mA, one below and one above.

The peak/rms ratio is no longer sq rt 2.



Somewhat to our surprise, there are considerable harmonics associated with the triangular waveform.

The filter circuit component of the TC circuits acts on the high frequency components of this waveform.



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

The differences in the TC response (blue curve) is easily distinguishable here.

This square wave has a 1% risetime.

20ms (50Hz) Sq Wave TC

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

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

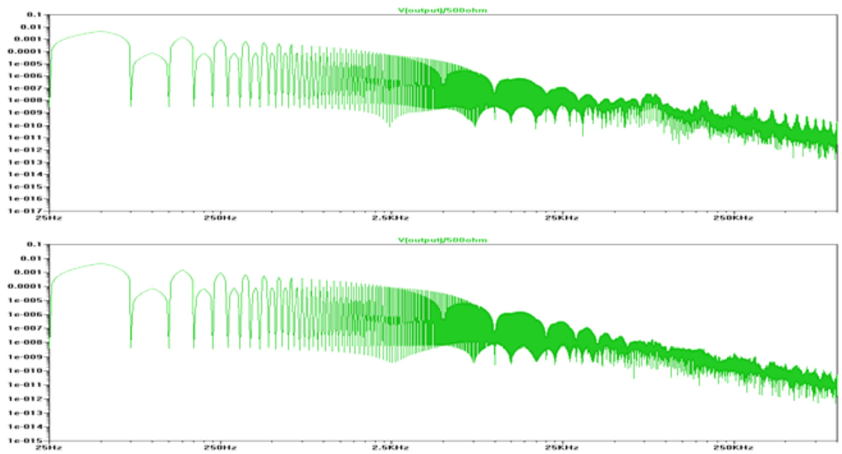
Although the rms values are about the same, the peak values are quite different.

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

The peak values are the important measurement here.

20ms (50Hz) Sq Wave FFT

startle-reaction ckt; let-go ckt



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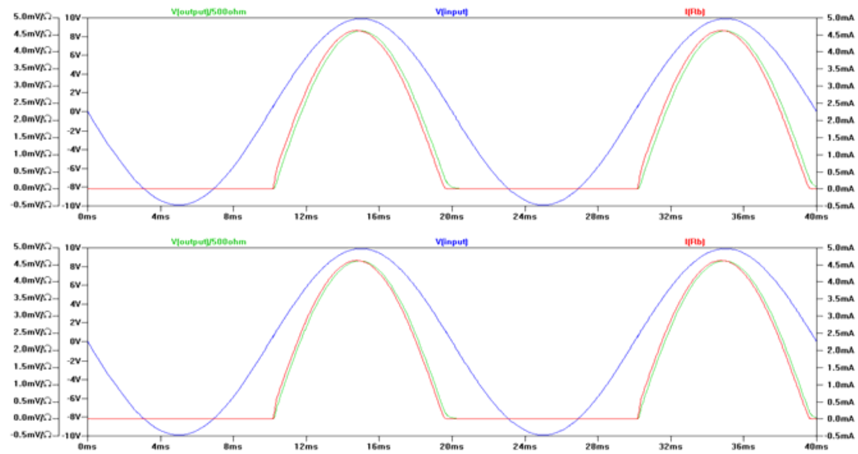
Some high frequency differences can be seen in comparing these two FFTs of the circuit response to this waveform.

Half-wave rectified line-frequency sin wave response



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Rectification of line voltage is an essential part of utilization of electric energy in equipment today.

Half-wave rectified line frequency sin wave TC

Current	Peak	RMS	Pk/rms ratio
s-r cktTC = I(V(output)/ 500ohm)	4.61 mA	2.264 mA	2.036
I-g cktTC = I(V(output)/ 500ohm)	4.62 mA	2.265 mA	2.038

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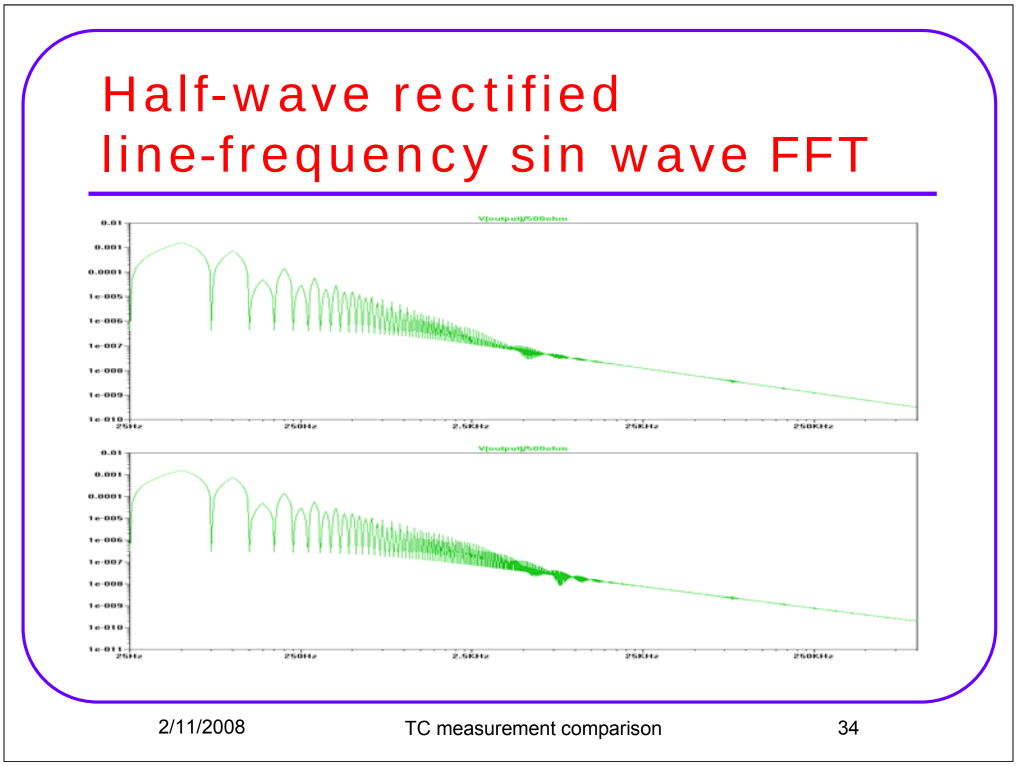
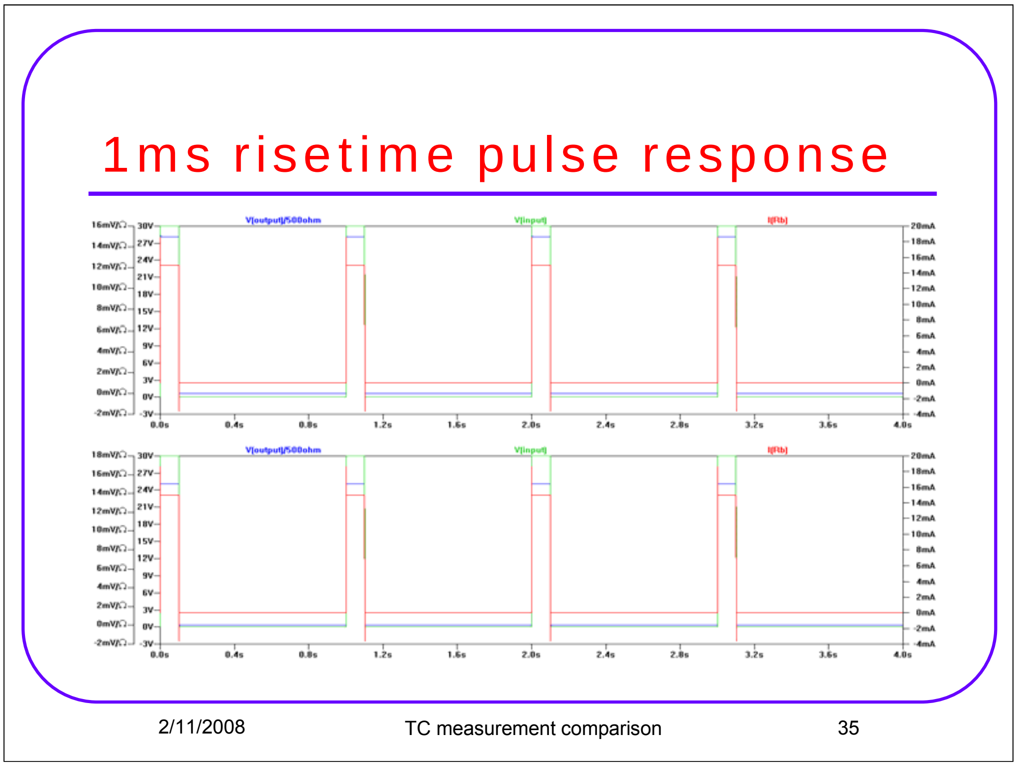
As we might begin to suspect, the rms values are lower than our sinusoidal base case but the peak values are proportionally higher.

The peak/rms ratio is over 2.



The high frequency differences appear above 25kHz and up.



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

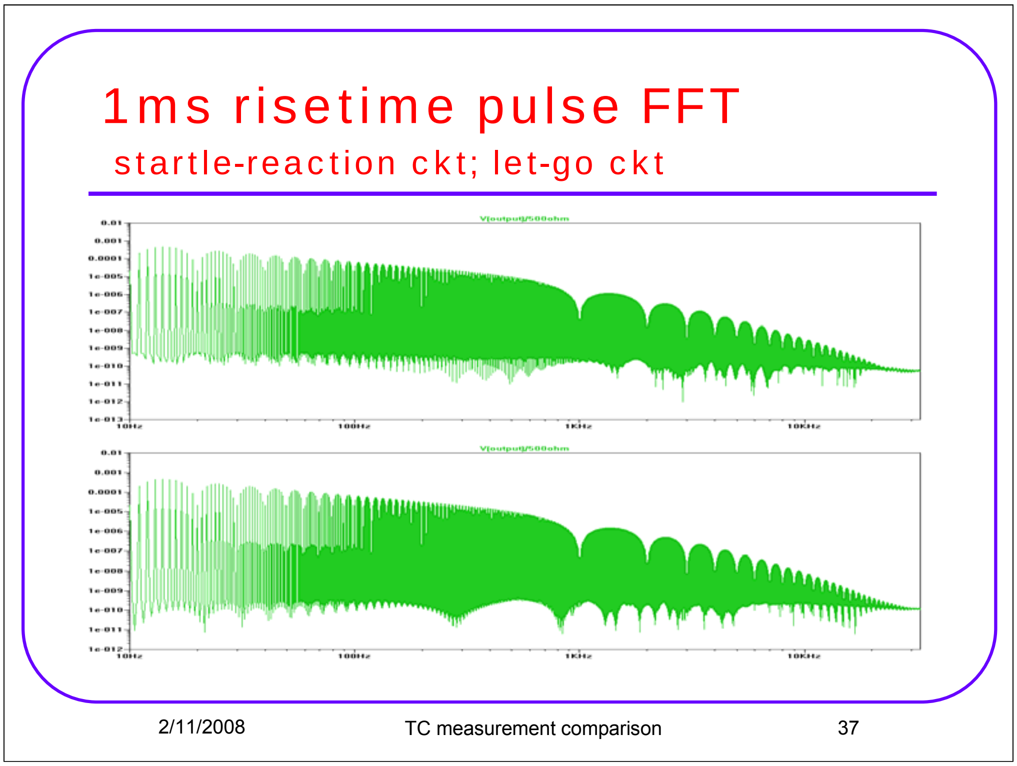
This calculation was looking for a TC below 14mApk to prevent VF for the particulars of this case.

1ms risetime pulse TC

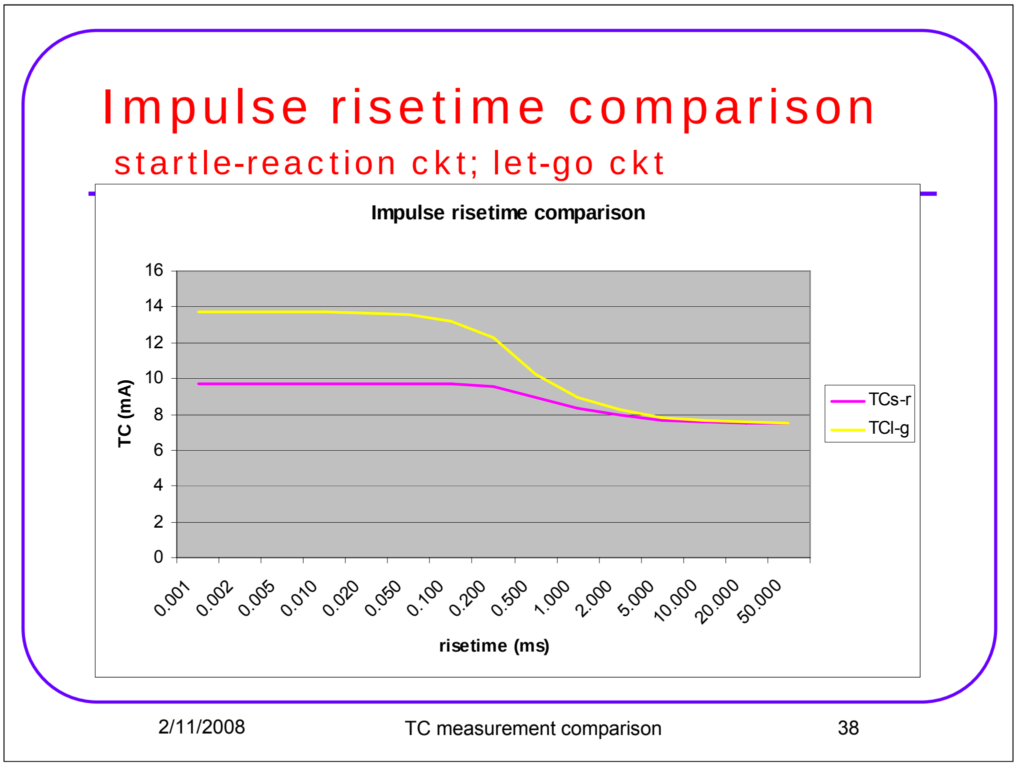
Current	Peak	RMS	Pk/rms ratio
s-r cktTC = I(V(output)/ 500ohm)	8.319 mA	4.761 mA	1.747
l-g cktTC = I(V(output)/ 500ohm)	8.917 mA	4.762 mA	1.873

With this risetime there is only a slight difference in the circuit responses.

The pk/rms ratio is not sqrt 2, however.



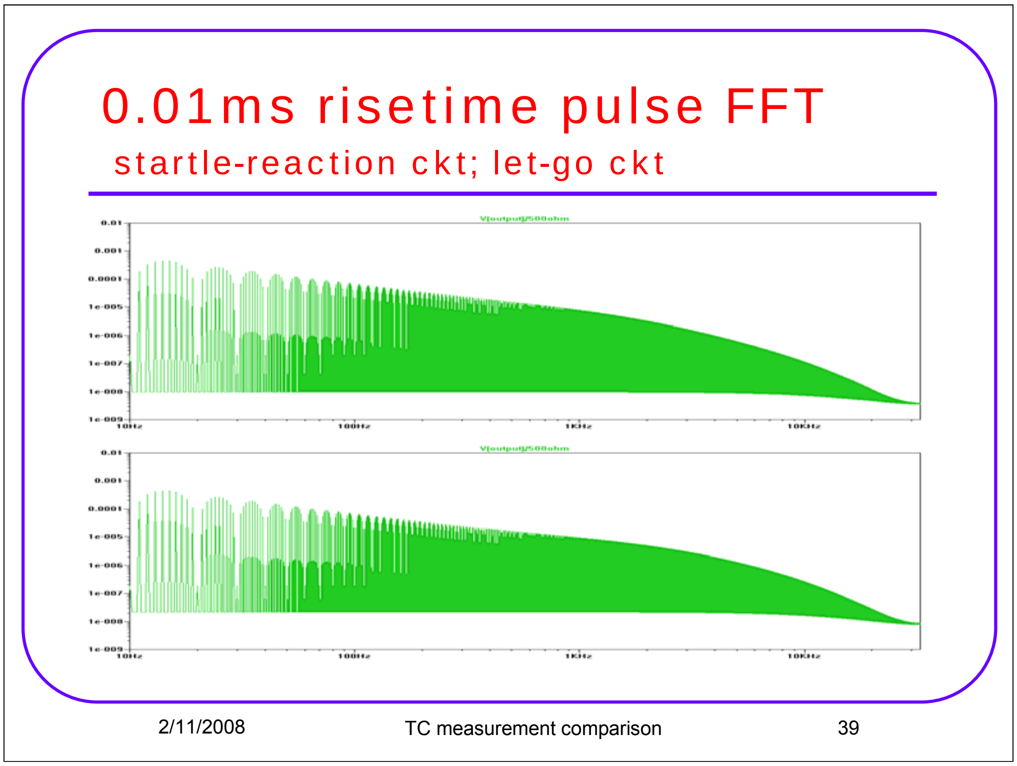
The higher frequency components show as slight differences here.



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, the TC magnitude differs as we saw in the last slide.

0.01ms rep pulse TC

startle-reaction ckt; let-go ckt

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

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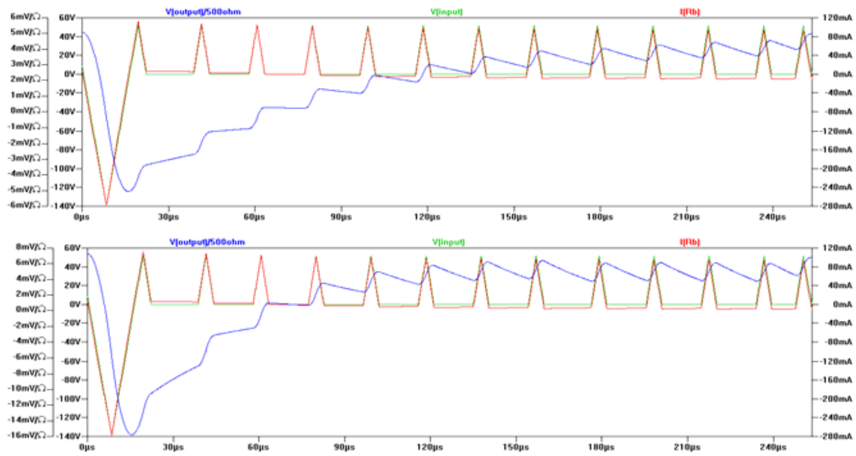
Both the magnitude and the pk/rms ratio are different when filtered by each TC circuit.

LCC circuit

startle-reaction ckt; let-go ckt



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Limited Current Circuit evaluation

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.

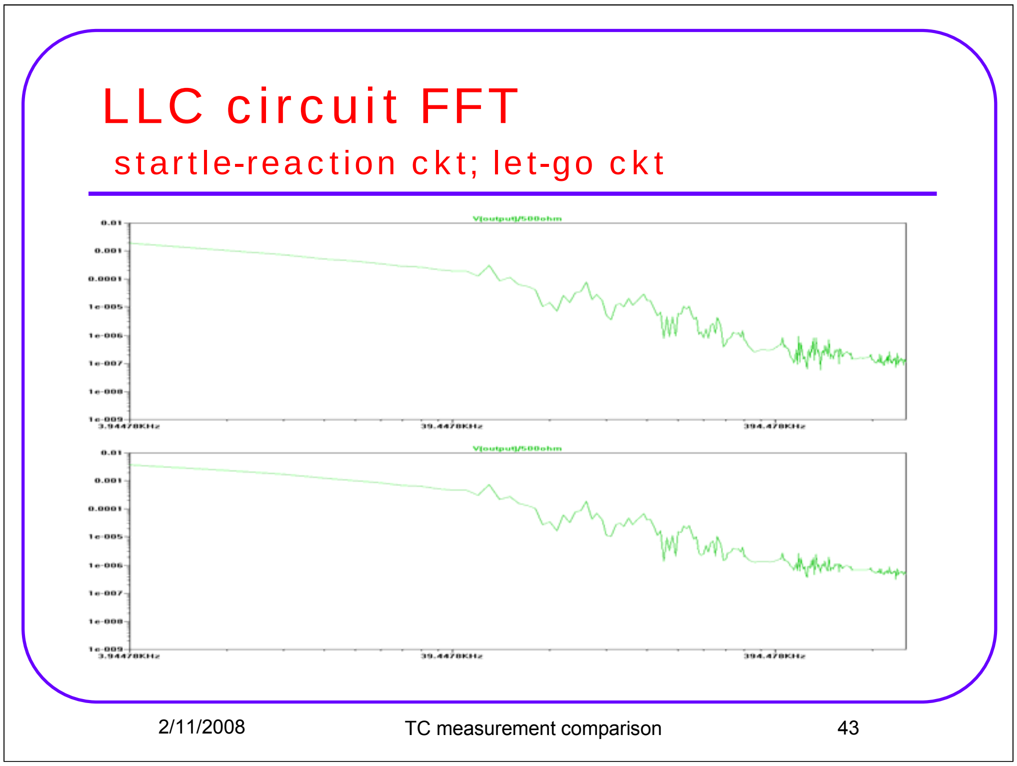
LCC TC comparison

startle-reaction ckt; let-go ckt

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

When reviewing the LCC waveform using the s-r circuit it shows the peculiar characteristic of being less than 3.5 mArms but more than 5 mApk.

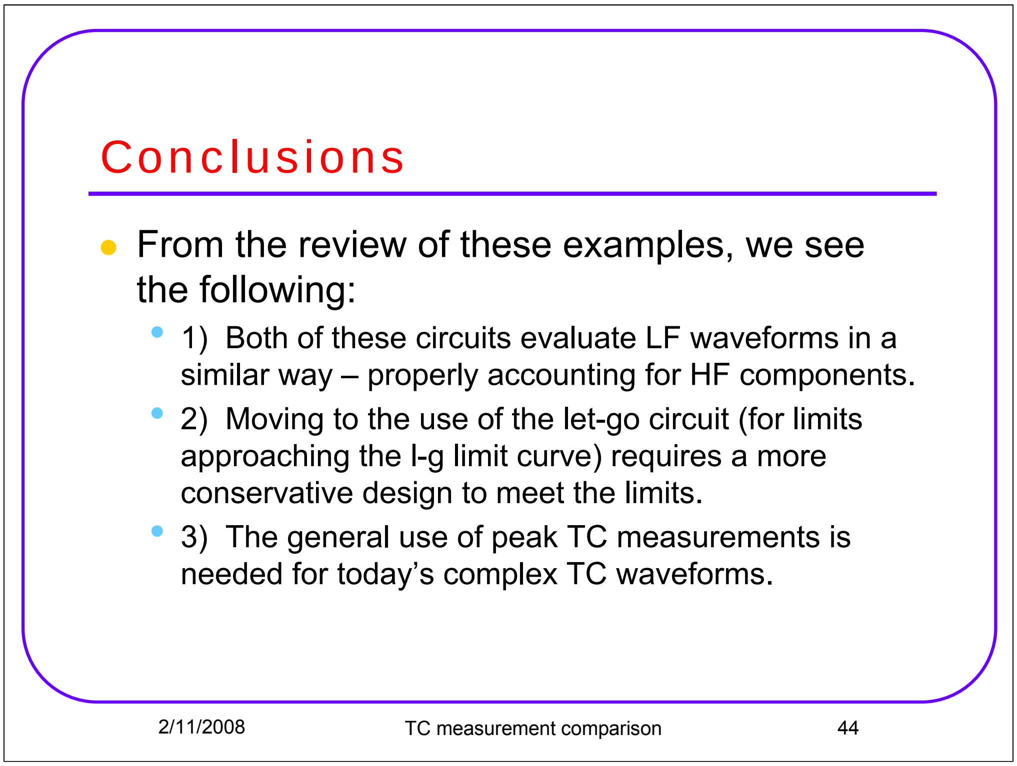
Again, reviewing this LCC waveform using the l-g circuit the values are substantially larger and the pk/rms ratio is also larger.



Comparing these FFT's (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.



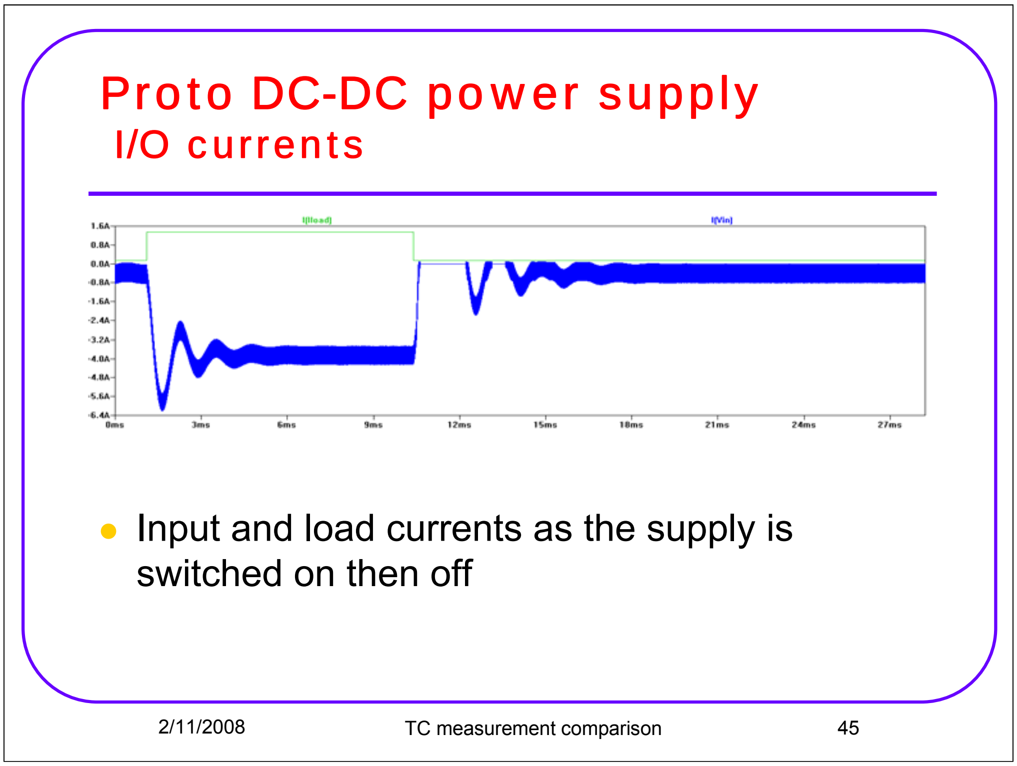
This paper compares the performance of the IEC 60990 eBurn, startle-reaction and let-go circuits against basic waveforms.

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

The 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 standards but not uniformly applied today.



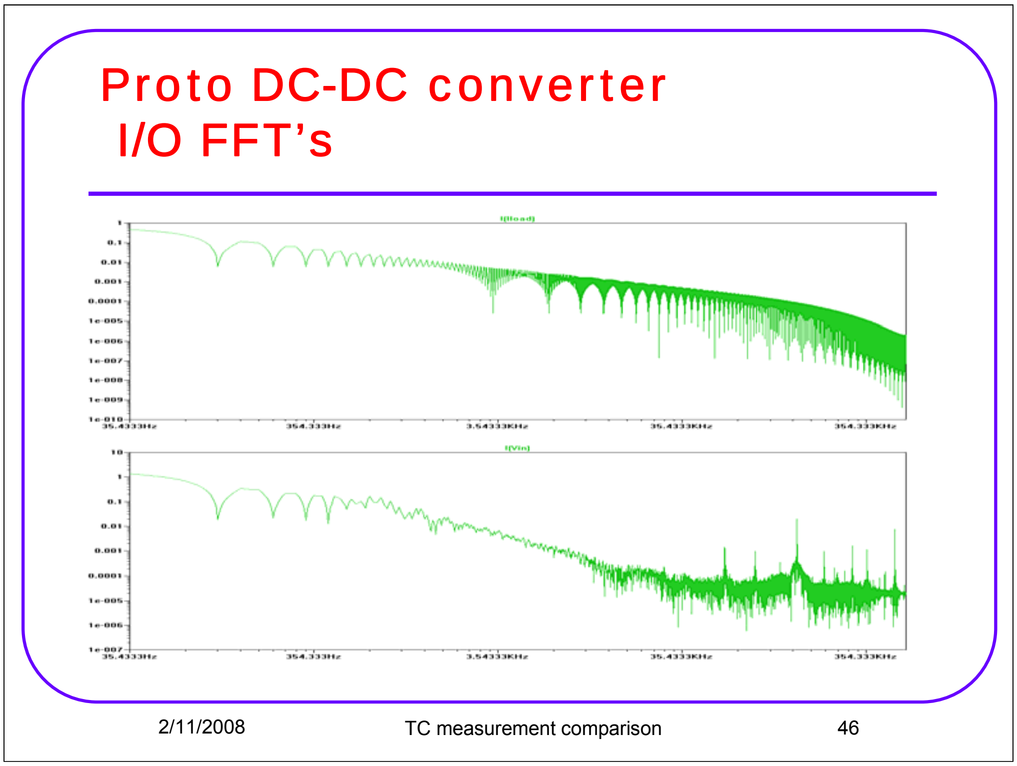
How did we get there and what can we say about real SMPS?

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

Note, however, that the input 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.

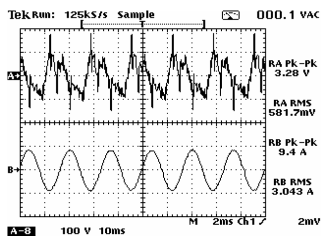
This current oscillation is capacitively coupled to earth and contributes to the TC for the product.

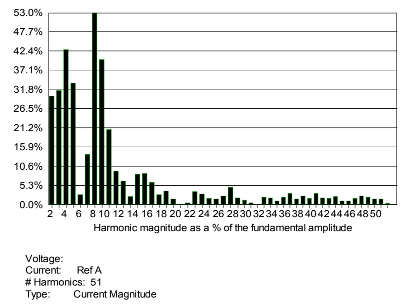
Many products use a multiplicity of these DC-DC converters for the distribution of power in the product; each of these will contribute to the TC for the product in their own way. The measured TC will, of course, sum these sources.



Note that both the output and the input show a continuous harmonic spectrum for this power supply.

Measured Frequency Spectrum for pfcSMPS TC





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The measured harmonics for a Touch Current waveform are shown here.

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.

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Curriculum Vitae, Peter E. Perkins

Mr. Peter E. Perkins, PE has more than 40 years of technical and practical experience. He was, for 17 years, manager in charge of Corporate Product Safety and Regulatory Affairs for an American MNC, a Fortune 500 electronics company. He has also worked in several engineering and managerial capacities within the Display Components Engineering Division of that company.

Mr. Perkins holds a MSEE degree and is a registered Professional Engineer, Electrical and a registered Professional Engineer, Quality in the USA. He is a NARTE certified Product Safety Engineer and also a Certified Product Safety Manager.

Mr. Perkins is a holder of a display patent and the author of numerous papers. He has given numerous talks and training programs for companies all over the world plus the Univ of Wisconsin Extension course ‘Getting your CE marking’.

Mr. Perkins has an ongoing involvement in the development of technical safety standards. He currently sits on the following committees:

IEC/TC108(74) - developer of IEC 60950, Safety Standard for IT Equipment; developing the new HBstd (pr IEC 62368) to replace IEC 60950 and IEC 60065. .

IEC/TC108/WG5 - Convenor of this working group that has developed IEC 60990, Methods of Measurement of Touch Current and Protective Conductor Current, a Pilot Safety committee within the IEC.

IEC/TC64/MT4 – developer of IEC 60479, Effects of electric current on the human body …

IEC/TC64/PT61201 – developer of IEC 61201, Touch Voltage threshold values

US/TAG-TC109 - the US Technical Advisory Group developing American input to IEC 60664, Insulation coordination for low voltage equipment

US/TAG-TC64 - the US Technical Advisory Group developing American input to IEC 60479, Effects of electric shock on the human body.

US/TAG-TC66 - the US Technical Advisory Group developing American input to IEC 61010, Safety requirements for electrical equipment for measurement, control and laboratory use.

US/TAG-TC108 - the US Technical Advisory Group developing American input to IEC 60950, Safety of Information Technology Equipment.

Mr. Perkins is currently working as an independent product safety and regulatory consultant for business in addition to offering seminars and training in the product safety and regulatory area.