Introductory discussion of PSE- PD Power issues.
Focusing on Startup and Normal powering modes.
Part –A: Normal Powering Mode

In order to close a number of parameters, it is necessary to discuss two of the operating modes in the PSE-PD system, Start-Up Mode and the Normal Powering Mode.

- Start up mode, is the mode in which the PSE applies power to the MDI connected to a PD, and the PD power supply input capacitor is charged.
  During this time the PSE output current is decreasing over time from its initial peak current (limited by cable resistance and/or PSE or PD inrush current limit circuitry).

- Normal powering mode is the mode in which the PD power supply is operating and continuously receiving power from the PSE.

IEEE802.3af has established a range for the PSE output voltage (44 VDC to 57 VDC) and PSE maximum current (350mA). However, many other parameters are required to ensure reliable and robust operation of PSE-PD that have to be defined and we need to work through these points.

It is suggested that we discuss first the normal powering mode and conclude with the startup mode. The reason for it is that fundamental parameters are as yet unclear or are not fully specified and if we specify them at the normal powering mode first, it will be easier to follow with the startup mode.

The following discussion assumes that our objective is to specify the power supply requirements required to ensure system operation and reliability with reasonable cost, by using proven techniques and/or definitions from the power conversion field without re-inventing it for the purpose of Power Over MDI technology.

Normal Powering Mode

List of technical questions plus possible answers. Readers are invited to add their thoughts.

1. Is the "350mA maximum continuous current" requirement well defined? Should we specify for 350mA_peak or 350mA_avg or 350mA_rms?

2. What is the power limitation from the PSE side? (44V x 350mA) or (57Vx350mA) or other number within this range?

3. What is the max. current at 57V? (Equivalent to question 2)

4. What is the minimum power that is guaranteed to PD designer?

Is the "350mA maximum continuous current" requirement well defined?
Should we specify for 350mA_peak or 350mA_avg or 350mA_rms?

According to 802.3af requirements list:
"The <u>maximum continuous current</u> drawn at the PD end be <u>no more than 350mA</u>.-July 2000 Plenary"
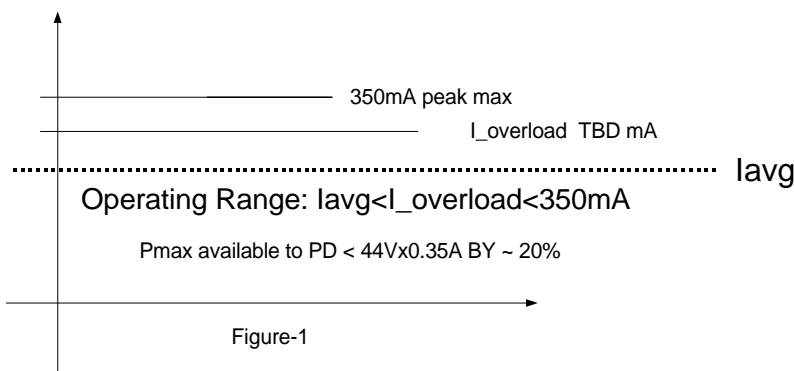
Let us discuss each option

Case 1- 350mA peak.

In the above case the PD designer needs to set the design not to exceed 350mA.
Therefore, the over-current protection of the PD power supply should be set to Ip < 350mA.
By doing the above settings, the actual average current will be lower and we will not be able to utilize the full power available from PSE.
44Vx Ip < 44vx350mA, Ip<350mA. 350mA-Ip = circuit tolerance + safety margin. (~20%)

350mA peak max
I_overload TBD mA

Iavg

Operating Range: Iavg<I_overload<350mA

Pmax available to PD < 44Vx0.35A BY ~ 20%

Figure-1

Drawbacks of 350mA_peak definition:
1. PSE full power can't fully be utilized. (We are paying for unused Watts)!
2. Reducing the number of possible applications supported by the Power Over MDI technology.
3. The problem will increase, in respect to low power applications, in which the power is limited due to utilization of classification feature.

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Note for reference: When we use standard power supply specified for 150W, 50V, this refers to the nominal continuous average current being 3A. The over current threshold point is set at 20% to 50% above the nominal number to guarantee meeting 3Adc nominal current.

Why in the above example (standard power supply), can't we set the current limit to 3.01 ADC or 3.11 ADC?

Answer:
It is not practical since the load type is unknown, and it is a general-purpose power source.
It should support constant load and dynamic loads both repetitive and non-repetitive types.
It should support loads at noisy environment

Typical standard power supply will exhibit the following parameters: (See Annex A for lab tests)
Pout_avg=153.6W
3.2A average continuous. The current limit threshold is set to 4A. The current limit circuit will be activated at 4 Apeak if the pulse width is longer than 500uSec.
For pulse widths shorter than 500uSec, the peak current can be higher than 4Apeak.
Meaning that at D=10%, and Frequency=7KHz, Ip=34Apeak! and the average is 3.2A. Negligible effects on power loss!

The reason for these results is that at pulse width < 500uSec, the power supply output filter, is reducing the ac components and reflects DC current to the power supply internal circuits.
For pulse width > 500uSec, the power supply output filter reflects the peak current without attenuation.
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Case 2- 350mAavg or Case 3 – 350mArms?

- The average or RMS value of the current drawn from power source, is specified according to its source voltage type i.e. DC source or AC source.
- If the source voltage is a DC source, than the current is specified as the average current.

Average current: $Iavg = \dfrac{1}{T}\displaystyle\int_0^T I(t)dt$ Eq-1

- If the source voltage is specified as AC source, then the current is specified as the RMS current.

RMS current: $Irms = \sqrt{\left(\dfrac{1}{T}\displaystyle\int_0^T \big(I(t)\big)^2 dt\right)}$ Eq-2

In both cases we are referring to a continuous current. However the "units" used to describe it are different.

The reason for the above definitions is to ensure always the correct power delivery in Watts.

For AC source: $P[Wrms] = Vrms \cdot Irms$ Eq-3
For DC source: $P[Wavg] = Vdc \cdot Idc$ Eq-4

When DC current contains an AC current component than $Irms^2 = Idc^2 + Iac^2$ Eq-5
If $Iac \langle\langle Idc$ than Irms=Idc.

Power defined by: (Vdc x Ip) or (Vac_avg x Idc) or (Vdc x Irms) is meaningless.

RMS value is used to calculate the power loss across the component. The resulting RMS power is equivalent to the average power across the component.

- Since our source is a DC voltage source, the current must be specified as continuous average or in short: an average current.

Note for reference: In many applications, the current drawn from the source, contains an ac component.
In order to further smooth it, a larger filter (Inductor and/or capacitor) is required at the load side,
which is not a cost-effective solution and requires larger footprint, volume etc especially if the ac component is at low frequency.

In this case the practical solution is to utilize the power source output filter capabilities to allow such an ac component, without additional cost due to the fact that the filter required is already in place.
(It is part of the power supply topology)

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Note for reference: If we allow an AC component to be superimposed on the DC current, it will not infer that we increase the power delivered from the source. The average power can still be limited to the value we choose. See figure-2.

Always: P_avg [Watts]$= \dfrac{1}{T}\int_0^T V(t)\cdot I(t)\,dt$ Eq-6.   Since V(t)=Vdc, then P_avg [Watts]$= \dfrac{Vdc}{T}\int_0^T I(t)\,dt$

Vsource=Constant

Ppeak, Ipeak

Pavg, Iavg

Figure-2
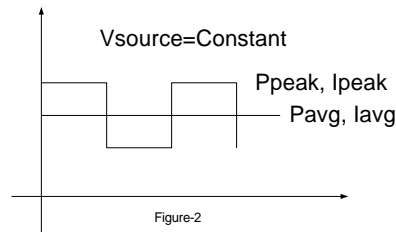
        Eq-7

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Note for reference: Although the average power that is taken from the power source can be kept within a specified value for I(t)=Idc+Iac(t), the ratio between Iac/Idc affects power dissipation across system segments (cable etc.) and power supply internal components.
The reason being that the Iac(t) increases the RMS value in comparison the DC value. RMS value determines the power loss across component.

Source Voltage & Current

Vsource=Constant

Irms

Ppeak, Ipeak

Pavg, Iavg

Figure-3

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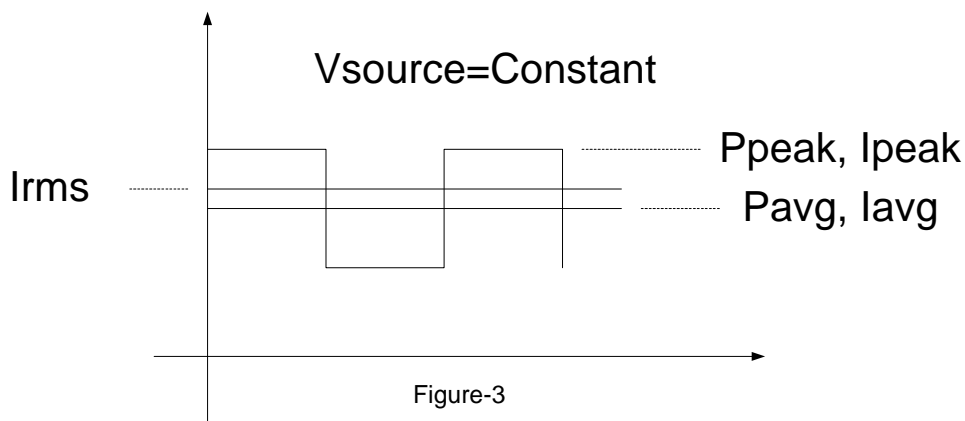
Summary:

- We need to decide:
  Case 1- 350mApeak maximum or Case 2 - 350mA _avg maximum.

- Case 3 - 350 mArms is not relevant to our system as a definition to the current drawn from the PSE.
  The RMS value will be used to limit power loss and yet maintain max. average current.

- If we agree that we should specify for 350mA maximum average current, *we need to specify the waveform parameters. (Ip, Duty Cycle, pulse width etc.)*

Specifying the waveform parameters if case 2 is selected.

Note: In the following paragraphs the following numbers and definitions will be used for illustration only.

Nominal voltage: 50.5VDC
Max. Continuous average current: 350mA
Peak current 500mA for 100mSec
Multi-Port system with M ports simultanuously. M=12.

In order to specify wave shape parameters we need to be aware of the following scenarios:

- In the multi-port system, do the loads change simultaneously? and/or do they synchronize with each other?

Example -   All the loads are phones and a message needs to be send via the speaker system.
                    This is an example for synchronized loads and non-repetitive operation.
                     (It is also relevant for low power applications, in which the power is limited due to
                      the utilization of a classification feature).

- Do the loads change repetitively? or is it a non-repetitive phenomena?

Example- In wireless access points, transmitting causes a low frequency ripple at the current,
which can be considered as repetitive operation.

Considering all options, we have 4 of them:

6-A.   Non-Repetitive, Not Synchronized
6-B.   Non-Repetitive, Synchronized
6-C   Repetitive, Not Synchronized
6-D.   Repetitive, Synchronized

6-A   Non-repetitive, Not Synchronized.
If the loads are changed in non-repetitive fashion and the ports are not synchronized to each other, this becomes the simplest case.
In this case, we need few spare Watts, limited in time, which have no effect on cost.

Example: If we allow peak current of 0.5A for 100mSec, we will require 50.5V x (0.5A-0.35A) = 7.6Watts, or twice this number to retain a safety margin i.e. 15W more, limited for 100mSec.
This requirement will not increase power supply cost since standard off the shelf power supply
can deliver 20-50% more current until the overload protection is activated. Meaning that for 150W, 50V power supply, we have an extra 30W (20%) until it reaches the over-current threshold, which is 30W/50V=0.6A additional current, supporting 0.6A/(0.5-0.35) = 4 ports simultaneously.

Conclusion: Case 6-A can be supported with the numbers suggested above.

6-B Non-repetitive, Synchronized.

The nominal average power requirement is: 12x0.35Adcx50.5V=212W
In this case the power supply needs to supply 12 x 50.5V x (0.5A-0.35A)=91W extra power for 100mSec.

Although the average power is still the nominal value (212W), the peak value relatively to the switching frequency lasts for a long period (100mSec) continuously, and it is seen by the power supply components as 91W continuous power in addition to the nominal value which is 212W+91W=303W.
Due to the fact that it is a non-repetitive condition we can ignore the power loss effects.

Data received from power supply vendors:

6-B1: Additional 15% power for 100mSec has no effect on the power supply cost.   Ip<0.4A
6-B2: Additional 30% power for 100mSec has no effect on the power supply cost.   Ip<0.455A
6-B3: Additional 43% power for 100mSec has less than 3% effects on cost.   Ip<0.5A

Conclusion: With out additional cost Case 6-B can be supported if the additional peak power will be between 30% to 43% max. above nominal power, limited to 100mSec max.
In this case, Ip can be set to 0.45Ap to 0.5Ap

6-C Repetitive Not Synchronized.

This case is similar to 6-A in which the additional spare power required does not increase power supply cost.
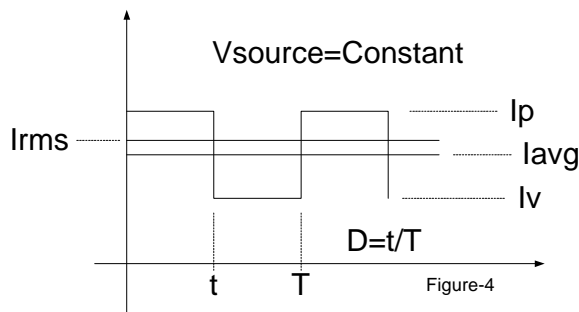
Power loss is increased due to the periodic operation.
The average power is still within spec.

Example: Calculating current shape parameters, representing possible repetitive load changes.

Given: Ip=0.5A, Idc =0.35, Duty cycle=0.5
Calculated: Iv=0.2A to keep Idc=0.35A. Using: Iv=(Iavg-Ip*D)/(1-D)
            Irms=(0.5x0.5^2+0.5x0.2^2)^0.5=0.38Arms.

Figure-4

The increase in power loss can be estimated by the change in the RMS current compared to the AVG value.
In this case, the power loss on single port will increase by approximately (Irms/Idc)^2=(0.38/0.35)^2➔ 17.8%
Assuming power loss for each port is 25mW max. than the new number will be 30mW max, which is acceptable. (for Rdson=0.2 ohm).

The effect of the power loss on the power supply internal components is similar. 17.8% increment in power loss will reduce the power supply efficiency by 2.8% for a power supply with 80% initial efficiency.

New efficiency given by: $\eta\_new = \dfrac{\eta}{1+k-k\cdot\eta}$ Eq-8, k= power loss increment = 1-(Irms/Idc)^2,

η = Initial power supply efficiency

If we reduce the Duty Cycle to 0.33 max. the results will be:
Ipeak=0.5A. Ivaley=0.276A, Irms=0.365A. (Irms/Idc)^2=(0.365/0.35)^2➔ 8.75% power loss increment.
New efficiency = 78.6%. ➔ 1.4% reduction from initial efficiency (80%), which is better.

Conclusion: With no additional cost Case 6-C can be supported. Due to the fact that the loads are not synchronized, the additional power loss due to Irms/Idc>1 as demonstrated above, is negligible if the Duty Cycle is limited to the desired number.

6-D Repetitive, Synchronized.

6-D is the worst case.
Synchronization of the loads will increase the total peak power required for all active ports.
The repetitive behavior will increase the additional power loss.

The additional power required due to the synchronization of loads is identical to that of 6-B.

The repetitive behavior may increase the power loss if the current shape parameters are not well defined.

In order to explain how this can be achieved, let's review a number of examples that cover the following 3 alternatives:

6-D-1: Irms=0.35Amax.
6-D-2: Iavg=350mA max.
6-D-3: Allowing much shorter pulse width only for the repetitive case.

6-D-1, 6-D-2: Derivation of pulse shape parameters(figure 4):

    Assuming pulse with Ip, Iv, D, T parameters
    Idc_max=0.35A: Required to keep max. average power
    Irms_max=0.35A   Required to keep initial efficiency.
    Ip=0.5A
    D=(Irms^2-Iv^2)/(Ip^2-Iv^2)
    Dmax=(Irms^2-Iv^2)/(Ip^2-Iv^2) @ Iv=0
    Dmax=Irms^2/0.5^2 = 4 x Irms^2 = 4 x 0.35^2 = 0.49
    Dmax=0.49
    For 100mSec-pulse width, the period must be 100mSec/0.49 = 204mSec.

    What will be the average current?

    Iavg=0.5Ap x 0.49 = 0.245A
    The average power will be less than can be utilized!
    50.5Vx0.245A=12.37W.
    We could have had: 50.5Vx0.35Adc = 17.67W

    Solution: We need to lock the average current to 0.35ADC max. and allow a bit higher RMS value as shown in Case 6-C discussion.

    How much higher? The limit will be max. reduction of 1% at the main power supply initial efficiency.
    The assumption is that reduction of 1% in efficiency is tolerable by the system.

    For a typical power supply with 80% efficiency, k=1- (Irms/Idc)^2 ratio required to have 1% reduction in initial efficiency is: 0.063, received from Eq-9.

$$k = \frac{\eta - \eta\_new}{\eta\_new - \eta\_new \cdot \eta} \qquad \text{Eq-9}$$

    Irms=Iavg(1+k)^0.5=0.35x(1+1.063)^0.5=0.35x1.031 = 0.36A.
    Now we will use Eq-10,11 to derive the other parameters.

$$Ip^2 \cdot D + Iv^2 \cdot (1-D) = Irms^2 \qquad \text{Eq-10}$$
$$Ip \cdot D + Iv \cdot (1-D) = Iavg \qquad \text{Eq-11}$$

Solving Eq-10, Eq-11 yeilds: $D\max = \dfrac{Irms^2 - Iavg^2}{Ip^2 - 2 \cdot Iavg \cdot Ip + Irms^2} = 0.24 \qquad$ Eq-12

For 100mSec-pulse width, Tmin should be: 100mSec/0.24=417mSec. (See figure 4)
- If we require less than 0.1% efficiency loss, than k=0.00626, Irms=0.351A, Dmax=0.033 (3.3%), Ip=0.5A, Iavg=0.35A and for 100mSec pulse width, Tmin=3.03sec. (See figure 4)

<u>6-D-3: Allowing much shorter pulse width only for the repetitive case.</u>

We can utilize the fact that the main PSE power supply output contains large filter at its output.
This filter, attenuates ripple current drawn by the load changes, and reflects higher DC current contents to the PSE power supply internal circuits.

From lab tests on typical power supply (See Annex A), we have observed that current that has an ac components with a frequency above 2KHZ, was well filtered already at power supply output filter and posses Irms/Idc close to 1 at the input to this filter.
It means that we can specify that for repetitive ac current we allow, a pulse width of less than 500uSec with Ip=0.5A and Dmax=0.7, in order to keep Iavg=0.35A max. and with out efficiency reduction.

Summary:
If we integrate all scenarios we can conclude the following:
- For <u>non-repetitive</u> operation and synchronized loads:
  - Power supply: Power supply can support 30% - 43% more power for 100mSec Without additional cost.
  - Port switch: Will not be affected by the above since we are at normal powering mode, in which the switch is ON. The PD power supply should be designed to draw less than Ip, at <u>normal powering mode</u>.
    Actually this is the normal design procedure for power supply – load operation.
    (Inrush current peak at startup mode is not discussed here, we will refer to it at Part B of this document)
    For <u>repetitive</u> operation along with synchronized loads we have 3 options:
  a- Efficiency loss of less than 1% is permitted, pulse width is up to 100mSec
  b- Efficiency loss of less than 0.1% is permitted, pulse width is up to 100mSec.
  c- No efficiency losses in power supply. Pulse width is less than 500uSec.

Parameters (Figure 4)	Option A	Option B	Option C
Ip max.	**0.5A**	**0.5A**	**0.5A**
Iavg max.	**0.35A**	**0.35A**	**0.35A**
Irms max.	0.36A	0.351A	0.36A
Pulse width max.	**100mSec**	**100mSec**	0.205mSec
Tmin	417mSec	3.03sec	NA
Tmax	NA	NA	**0.5mSec**
Dmax	0.24	0.033	0.24
Efficiency loss			
Power supply	**1% max.**	**0.1%max**	**0%**
Port switch, RJ45, Cable	**1% max**	**0.1%max**	**1%**
Additional power loss			
Power supply	5.8%	0.5%	0%
Port switch, RJ45, Cable	5.8%	0.5%	5.8%

Table –1

Suggested solution to questions 2,3,4:

2. What is the power limitation from the PSE side? (44V x 350mA) or (57Vx350mA) or other number within this range?
3. What is the max. current at 57V? (Equivalent to question 2)
5. What is the minimum power that is guaranteed to PD designer?

In order to cover the implications of any suggestion, it is necessary to discuss first our possible options. For now, lets ignore the min/max window for each parameter to simplify the discussion.

PSE voltage: 44V-57V.
PSE current: 350mA at any voltage between 44V to 57V.

Implications:

The PSE designer will select power supply according to the PSE output voltage x 0.35A.
Example: Nominal PSE voltage=50.5V, 24 port system ➔ P_port=50.5Vx0.35=17.67W
For 24 port system: Ptotal=50.5Vx0.35x24=424Watts.

The PD designer, doesn't know what will be the PSE output voltage, however he knows that it is 44V min. Thus, he will design his PD according to max. power of (44V-0.35Ax20 Ohms)*0.35A=12.95W at PD side, Which is 44Vx0.35A=15.4W at PSE side.

The result is that 17.67W-15.4W=2.27W average power per port is unused, 54.5W for the whole system.

If the PSE output voltage was 57V, than the unused power would be 4.55W/Port, 109W for the whole system.

Conclusion: It is up to the PSE designer to select the nominal PSE output voltage and control the power supply unused power.

Possible suggestion to the above questions:

PSE out voltage range: 44V to 57V
PSE output current, Iavg=350mA min @ 44V – 57V

PSE average output current cutoff range, Iavg=355mA to 375mA. No requirements on PSE output voltage (We need to discuss if it is 350mA+5% or 350mA-5%, or other numbers)

PSE output power min. = Specified by PSE voltage and currents (15.4W min., TBD max. or live it open?)
PSE output power peak min. for 100mSec = Specified by PSE voltage and currents
PSE Peak output current, Ip=500mA for 100mSec max. for non-repetitive operation.
                                  One of options A, B or C for repetitive operation.
PSE RMS output current: One of options A,B or C for repetitive operation.

Under the above specifications, the PD power input parameters will be:

PD input voltage range: (44V-0.5Ax20)=34V min. 57V max. after startup.
PD input current max.: 0.35A avg.

PD input power max.: (44-0.35x20)*0.35= 12.95W
PD Peak input current, Ip=500mA max. for 100mSec max. for non-repetitive operation.
                                  One of options A or B or C for repetitive operation.
PD RMS input current: One of options A,B or C for repetitive operation.

Turn On voltage: 38V – 44V
Turn Off voltage range: 30V-33V

Allowing flexibility of managing the power in the PSE.

In addition to the discussion in the previous paragraphs, we have additional flexibility in selection the PSE power supply size pending on the following requirements suggested to be included in the 802.3af specification:

1. The PSE output requirements that are suggested above are related to a single port.
   It means that each port should be design to deliver the max current/power as specified.

2. It is up to the system designer if to support all ports simultaneously with the max current/power as specified for each port, or to specify total output power available for this system. The user will decide according the total output power specified how to distribute the power to the ports according to the application.

The above definitions allow using smaller power supplies for multi-port systems.

Example:

Assuming that each port should supply 15.4W min, a system with 24 ports will need a 370W power supply to simultaneously support 24 ports delivering the max. power available.

According the suggestion above, the system designer can specify that his 24 port system is limited to total 200W. In this case the user will decide which ports will be connected to applications that needs the max. power and which ports will be connected to low power applications, keeping that
$200W >= n1 \times p1 + n2 \times p2 + n3 \times p3 + \ldots\ldots$, $M = N1 + N2 + N3 + \ldots$

- See part B of this document for discussion on Startup mode

Annex A:
Test results of standard 150W power supply, demonstarting its ability to supply 25% more peak power and yet not exceeding nominal average power.

Vin=150Vdc   Vout=48   Ioutavg=3.2A

Frequency 10 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	Irms/Iavg
100	3.2	3.20	3.2	1.254	1.25	1.312	1.0000
80	4.016	3.21	3.573	1.263	1.38	1.901	1.0903

Frequency 20 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.25	1.25	1.312	1.0000
80	4.031	3.22	3.59	1.278	1.36	1.734	1.0618

Frequency 50 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.264	1.26	1.328	1.0000
80	4.031	3.22	3.573	1.269	1.28	1.578	1.0118

Frequency 100 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.26	1.26	1.328	1.0000
80	4.037	3.23	3.575	1.266	1.27	1.422	1.0016

Frequency 500 Hz   Irms/Iavg

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.254	1.25	1.312	1.0000
80	4	3.20	3.559	1.268	1.27	1.328	1.0000

Frequency 2000 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.25	1.25	1.3	1.0000
90	3.588	3.23	3.377	1.27	1.27	1.328	1.0000
80	4.031	3.22	3.591	1.29	1.29	1.344	1.0000
70	4.547	3.18	3.796	1.291	1.29	1.359	1.0000
60	5.341	3.20	4.089	1.282	1.28	1.359	1.0000

Frequency 5000 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.25	1.25	1.312	1.0000
80	4	3.20	3.549	1.276	1.28	1.344	1.0000
70	4.516	3.16	3.76	1.278	1.28	1.344	1.0008
60	5.325	3.20	4.105	1.298	1.3	1.344	1.0008
50	6.312	3.16	4.396	1.296	1.3	1.344	1.0008
40	7.863	3.15	4.926	1.27	1.27	1.328	1.0000

Frequency 6000 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	Irms/Iavg
100	3.2	3.20	3.2	1.259	1.26	1.328	1.0008
80	4.022	3.22	3.553	1.275	1.275	1.344	1.0000
60	5.384	3.23	4.071	1.283	1.284	1.344	1.0008
40	8.025	3.21	4.962	1.263	1.264	1.328	1.0008

Frequency 7000 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.264	1.265	1.312	1.0008
80	4	3.20	3.557	1.275	1.275	1.344	1.0000
60	5.334	3.20	4.093	1.294	1.295	1.344	1.0008
40	8.062	3.22	4.991	1.289	1.289	1.344	1.0000
30	10.82	3.25	5.755	1.307	1.307	1.359	1.0000
20	16.36	3.27	6.982	1.272	1.273	1.344	1.0008
10	34	3.40	9.952	1.29	1.291	1.344	1.0008

Frequency 8000 Hz   Irms/Iavg

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.251	1.251	1.312	1.0000
80	4.013	3.21	3.543	1.269	1.269	1.328	1.0000
60	5.312	3.19	4.081	1.293	1.294	1.359	1.0008
40	7.97	3.19	4.952	1.282	1.283	1.344	1.0008
30	10.81	3.24	5.726	1.281	1.282	1.359	1.0008
20	16.88	3.38	7.068	1.294	1.294	1.359	1.0000
10	34.88	3.49	9.866	1.265	1.265	1.734	1.0000

Frequency 10000 Hz

Duty(%)	Iout(A) Ipeak	Iavg	Irms	Iin(A) Iavg	Irms	Ipeak	
100	3.2	3.20	3.2	1.251	1.251	1.312	1.0000
90	3.606	3.25	3.356	1.255	1.255	1.326	1.0000
80	4.019	3.22	3.55	1.26	1.26	1.344	1.0000
70	4.625	3.24	3.782	1.28	1.28	1.359	1.0000
60	5.344	3.21	4.069	1.278	1.278	1.359	1.0000
50	6.438	3.22	4.434	1.284	1.284	1.359	1.0000
40	8.094	3.24	4.965	1.284	1.284	1.344	1.0000
30	10.81	3.24	5.672	1.265	1.265	1.328	1.0000
20	16.8	3.36	6.999	1.272	1.272	1.328	1.0000
10	34	3.40	9.634	1.248	1.248	1.312	1.0000