


PQ2625-R Forward Converter UC3845

Transformer Design Calculations 150W,
48V, 1 Switch Forward

Magnetics Physical Properties


PQ2625-R Core

MFG: Mag Inc

Ht := 2.475	cm Core Height
Wth := 2.95	cm Core Width
Lt := 2.65	cm Core Length
 G := 1.61	cm Core Window Length
MPL := 5.6	cm Mean Magnetic Path Length
Wtfe := 36	grams Weight
Wtcu := 16.8	grams Copper weight using a 40% fill
MLT := 5.6	cm Mean Length Per Turn
Ac := 1.19	cm ² Iron Area
Wa := 0.845	cm ² Window Area
Ap := 0.997	cm ⁴ Area Product Wa*Ac
Kg := 0.084418	cm ⁵ Core Geometry
At := 32.6	cm ² Surface Area
μ := 2300	Permeability
AL := 5250	Core mH/1000 turns
Volfe := 6.53	Ferrite core Volume
Ki := 0.0388	Gap Loss Coefficient
Ku := 0.32	Window utilization factor use 40% for most cases
Kf := 4	Waveform coefficient use 4 for a square wave or 4.4 for a sinewave
Kj := 4	Use 403 for powder core

Forward Converter Design Calculations

Vmin := 67 Vmax := 264

 in := Vmin .. Vmax

 V_{in} := $\sqrt{2} \cdot \text{in}$ **The x2 is for a voltage doubler Add if needed**

η := 0.9 Expected Efficiency

Facmains := 60 Minimum Line Frequency

thold := $\frac{1}{\text{Facmains}}$ Single Cycle holdup time

r := 0.3

Vfdr := 0.8 **Average forward voltage drop for the input bridge rectifier. Adjust this for current**

$D_{max} := 0.63$ Max Duty Cycle
 $V_{o1} := 24$ Output Voltage 1
 $V_{o2} := 5$ Output 2 Voltage
 $I_{o1} := 5.2$ Amps Current for the 36V winding
 $I_{o2} := 3.2$ Output 2 Current
 $V_{diode} := 1.2$ Forward Drop of the Diode $V_{drr} := 250$ Diode Reverse Recovery Rating
 $\Delta\beta_m := 0.20$ Tesla (1000 gauss) Operating Flux density
 $\alpha := 2$ Load Regulation in %
 $P_{o1} := V_{o1} \cdot I_{o1}$
 $P_{o1} = 124.8$ Watts Output power for the +5V Rail
 $P_{o2} := V_{o2} \cdot I_{o2}$
 $P_{o2} = 16$ Watts Power Output
 $P_o := P_{o1} + P_{o2}$
 $P_{in} := \frac{P_o}{\eta}$ assume n% efficiency in the transformer
 $P_{in} = 156.444$ Estimated Power useage
 $f_s := 100000$ Switching frequency
 $T := \frac{1}{f_s}$
 $t_{on} := D_{max} \cdot T$
 $t_{on} = 6.3 \times 10^{-6}$ FET On Time
 $K_e := 0.145 \cdot f_s^2 \cdot 4^2 \cdot 10^{-4}$ electrical condidtions for a saturation flux density of 3000
 $K_e = 2.32 \times 10^4$
 $K_{gx} := \frac{1.1 \cdot P_{in} \cdot D_{max}}{K_e \cdot \alpha}$ Core geometry
 $K_{gx} = 2.337 \times 10^{-3}$ Choose a transformer that is greater than this number
 $I_{dc} := \frac{P_{in}}{V_{Vmin} \cdot D_{max}}$ Amps Primary current $\Delta I := 0.1 \cdot I_{dc}$
 $I_p := I_{dc} + \frac{\Delta I}{2}$ $I_p = 2.752$
 $L_m := V_{Vmin} \frac{t_{on}}{\Delta I}$ $L_m = 2.278 \times 10^{-3}$ Required Inductance
 $Energy := L_m \cdot \frac{I_p^2}{2}$
 $D_{min} := \frac{V_{o1}}{V_{Vmax}}$ $D_{min} = 0.064$

$$N_p := \frac{V_{Vmin} \cdot t_{on}}{(\Delta \beta_m \cdot 10^4) \cdot A_c \cdot 10^{-8}} \quad \text{This equation is compensated for Dmax}$$

$$N_p = 25.081 \quad \text{Number of turns on the primary side}$$

$$N_p := 25 \quad \text{Take it down a couple turns to compensate for capacitor ripple}$$

$$J := \frac{2 \cdot \sqrt{D_{max}} \cdot P_{in} \cdot 10^4}{K_u \cdot \Delta \beta_m \cdot f_s \cdot A_p}$$

$$J = 389.211 \quad \text{Amps/cm}^2 \quad \text{Current Density Use slightly hied current density}$$

$$I_{prms} := \sqrt{\left[I_p^2 + I_p \cdot (I_p - \Delta I) + \Delta I^2 \right] \cdot \frac{D_{max}}{3}} \quad \text{RMSCurrent in the wire on the primary side}$$

$$I_{prms} = 1.745$$

$$A_w := \frac{I_{prms}}{J}$$

$$A_w = 4.482 \times 10^{-3} \quad \text{cm}^2 \quad \text{Bare Copper cross sectional Area}$$

From the magnetwire table select 20AWG

$$N_{ps} := 1 \quad \text{Number of strands primary side}$$

$$A_{wb} := 0.005188$$

$$R_{cu} := .0003323 \quad \text{ohms/cm Cu resistance}$$

$$R_p := MLT \cdot N_p \cdot R_{cu}$$

$$\text{WireLenp} := N_p \cdot MLT \quad \frac{\text{WireLenp}}{2.54} = 55.118 \quad \text{in}$$

$$R_p = 0.047 \quad \text{Ohms Primary side winding resistance}$$

$$P_p := I_{prms}^2 \cdot R_p$$

$$P_p = 0.142 \quad \text{W copper loss on the primary side}$$

$$V_{s1} := \frac{V_{o1} + V_{diode}}{D_{max}}$$

$$V_{s1} = 40 \quad \text{Voltage stress on the reverse recovery diodes at min line condition}$$

$$N_{s1} := \frac{N_p \cdot V_{s1}}{V_{Vmin}} \quad V_{s1max} := V_{Vmax} \cdot \frac{N_{s1}}{N_p} \quad V_{s1max} = 157.612$$

$$N_{s1} = 10.554 \quad N_{s1} := 10$$

$$\text{Headroom\%} := \left(1 - \frac{V_{s1max} - V_{o2}}{V_{drr}} \right) \cdot 100$$

$$V_{s2} := \frac{V_{o2} + V_{diode}}{D_{max}} \quad \text{Voltage Stress on the Vs2 diode}$$

$$\text{Headroom\%} = 38.955$$

$$V_{s2} = 9.841$$

$$N_{s2} := \frac{N_p \cdot V_{s2}}{V_{Vmin}} \quad V_{s2max} := V_{Vmax} \cdot \frac{N_{s2}}{N_p} \quad V_{s2max} = 38.778$$

$$N_{s2} = 2.597$$

$$N_{s2} := 3$$

Copper Losses

$$I_{s1} := I_{o1} \cdot \sqrt{D_{\max}}$$

Secondary output current on the +24V/5V Rail

$$I_{s2} := I_{o2} \cdot \sqrt{D_{\max}}$$

$$I_{s1} = 4.127$$

$$I_{s2} = 2.54$$

$$A_{ws1} := \frac{I_{s1}}{J}$$

$$A_{ws2} := \frac{I_{s2}}{J}$$

$$A_{ws1} = 0.011$$

$$A_{ws2} = 6.526 \times 10^{-3}$$

$$N_{strs_s1} := 2 \quad \text{Number of strands}$$

$$N_{strs_s2} := 2$$

Selecting 19 AWG

This is a stacked Winding

$$A_{ws1} := 0.006531 \quad R_{cuaws} := 263.9 \cdot 10^{-6}$$

$$A_{ws2} := A_{ws1}$$

$$R_{cus1} := \frac{R_{cuaws}}{N_{strs_s1}}$$

$$R_{cus2} := \frac{R_{cuaws}}{N_{strs_s2}}$$

$$R_{s1} := R_{cus1} \cdot MLT \cdot N_{s1}$$

$$R_{s2} := R_{cus2} \cdot MLT \cdot N_{s2}$$

$$P_{cus1} := R_{s1} \cdot I_{o1}^2$$

$$P_{cus2} := R_{s2} \cdot I_{o2}^2$$

$$P_{cus1} = 0.2$$

$$P_{cus2} = 0.023$$

$$\varepsilon := \frac{6.61}{\sqrt{f_s}}$$

Verify that we don't have a skin effect problem

$$\varepsilon = 0.021$$

Skin depth choose the $D > 2 \cdot \varepsilon$
In this case choose an AWG > than 23

$$l_g := 0.002$$

Bias Winding

$$V_b := 10 \quad \text{Minimum turn on voltage}$$

$$V_{s3} := \frac{V_b + V_{diode}}{D_{\max}}$$

$$V_{s3} = 17.778 \quad \text{Stress voltage on the reverse recovery diode}$$

$$N_{sb} := \frac{N_p \cdot V_{s3}}{V_{V_{\min}}} \cdot \left(1 + \frac{\alpha}{100} \right)$$

$$N_{sb} = 4.784 \quad \text{Number of turns for the bias winding}$$

$$N_{sb} := 4 \quad \text{Empirically determined}$$

Core Losses

$$P_{fe} := \frac{0.074 \cdot \left(\frac{f_s}{1000}\right)^{1.43} \cdot (\Delta\beta_m \cdot 10)^{2.85}}{1000} \cdot Vol; P_{fe} = 2.524$$

From core loss curves Mag Inc "R" material

$$P_g := K_i \cdot \frac{A_c}{\pi} \cdot l_g \cdot f_s \cdot \Delta\beta_m^2$$

Assumes a 0.002" gap

$$P_g = 0.118$$

$$P_{xfmr} := P_p + P_{cus1} + P_{fe} + P_g + P_{cus2}$$

$$P_{xfmr} = 3.006$$

App 7W power dissipation on this device

$$\Delta T := \left(\frac{P_{xfmr} \cdot 10^3}{A_t} \right)^{0.833}$$

General equation for predicting Temperature rise from Pd and Surface area

$$\Delta T = 43.312$$

Output Rectifier Ns1

$$P_{d1} := I_{s1} \cdot V_{diode} \cdot D_{max}$$

Power dissipation in the diode from conduction losses

$$P_{d1} = 3.12$$

Output Rectifier Ns2

$$P_{d2} := I_{s2} \cdot V_{diode} \cdot D_{max}$$

$$P_{d2} = 1.92$$

Based on Infineon SPB8N50C3

$Q_{gate} := 32 \cdot 10^{-9}$ Coulombs Total Gate Charge

$R_{dson} := 0.5$ Ohms R_{dson} of the FET

$C_{oss} := 350 \cdot 10^{-12}$ Farads Output Capacitance

$V_{gate} := 12$ Gate Drive voltage

$t_r := 5 \cdot 10^{-9}$ rise time

$t_f := 7 \cdot 10^{-9}$ fall time

$P_{gate} := Q_{gate} \cdot V_{gate} \cdot f_s$ Watts Power Loss to the Gate

$P_{gate} = 0.038$

$P_{coss} := \frac{C_{oss}}{2} \cdot (V_{85})^2 \cdot f_s$ Watts Power Loss to FET output capacitance

$P_{coss} = 0.253$

$I_{rms} := I_p \cdot \sqrt{D_{max}}$

$P_{cond} := R_{dson} \cdot I_{rms}^2$ Watts conducted Power Loss from R_{dson}

$P_{fettr} := \frac{V_{85}}{2} \cdot I_{rms} \cdot 0.9 \cdot (t_r + t_f) \cdot f_s$ Watts Power Loss during transition

$P_{cond} = 2.385$ $P_{fettr} = 0.142$ V300 changes to include leakage spike and reset clamp voltage

$P_{q1} := (P_{gate} + P_{coss} + P_{cond} + P_{fettr})$ if 2 transistor forward not used
Use 2X when 2 transistor forward used Watts
Power loss in main FET

$P_{q1} = 2.818$

Current Sense Resistor

$R_s := \frac{1}{I_p}$

$R_s = 0.363$ Use 4-10hm ohm 1/2W resistors

$P_{rs} := (I_p \cdot \sqrt{D_{max}})^2 \cdot R_s$

$P_{rs} = 1.734$

Output Filter Design

Start with NS2 the main output
voltage

$$\begin{aligned} V_{L1on} &:= V_{s1} - V_{diode} - V_{o1} & V_{L1on} &= 14.8 \\ V_{L2on} &:= V_{s2} - V_{diode} - V_{o2} & V_{L2on} &= 3.641 \\ V_{L1off} &:= -V_{diode} - V_{o1} & V_{L1off} &= -25.2 \\ V_{L2off} &:= -V_{diode} - V_{o2} & V_{L2off} &= -6.2 \end{aligned}$$

$$n := \frac{N_{s2}}{N_{s1}}$$

$$n = 0.3 \quad \text{3:1 turns ratio between } N_{s1} \text{ and } N_{s2}$$

$$N_{2p} := N_{s1} \quad \text{Normalize the secondary to match impedances}$$

$$V_{s2p} := \frac{V_{s2}}{n}$$

$$V_{d2p} := V_{diode} \cdot n$$

$$V_{o2p} := \frac{V_{o2}}{n}$$

$$I_{o2p} := I_{o2} \cdot n$$

$$I_{o1} = 5.2 \quad V_{o1} = 24 \quad V_{o1} \cdot I_{o1} = 124.8$$

$$I_{o2p} = 0.96 \quad V_{o2p} = 16.667 \quad V_{o2p} \cdot I_{o2p} = 16 \quad \text{Normalized Values}$$

$$I_{Lm} := I_{o1} + I_{o2p}$$

$$\Delta I_{dc} := I_{Lm} \cdot 0.1 \quad \text{Set the ripple current to 10% of total power to each normalized inductor}$$

$$\Delta I_{dc} = 0.616$$

$$L_{mutual} := \frac{(V_{s1} - V_{o1} - V_{diode}) \cdot t_{on}}{\Delta I_{dc} \cdot 2} \quad \text{The } 2X\Delta I_{dc} \text{ provides the peak current calculation. This is also the amount of p-p ripple current in the inductor}$$

$$L_{mutual} = 7.568 \times 10^{-5} \quad \text{100uH needed}$$

$$L_{mutual} := 0.0001$$

Make winding 1 the inner Layer the +24V (Highest continuous current in the center)
And winding 2 the outer +5V layer

Toroid Core Selection
T106-52 Micrometals Core

OD := 2.69 Outside Diameter in cm

ID := 1.45 Inside Diameter in cm

Ht := 1.11 Thickness of the Toroid

Ac := 0.659

AL := 95

MPL := 6.49

MLT := 3.9

Ap := 1.088

Kg := .07299

At := 38

μ := 75

Vol := 2.283

ILpk := $ILm + \frac{\Delta Idc}{2}$ ILpk = 6.468 ILripple := ΔId ILripple = 0.616 Pk-Pk ripple current

Energy := $\frac{L_{mutual} \cdot ILpk^2}{2}$ Required Energy Storage

Energy = 2.092×10^{-3}

ApL := $\left(\frac{2 \cdot \text{Energy} \cdot 10^4}{1.4 \cdot K_u \cdot K_j} \right)^{1.14}$ Required Ap. Assumes a Saturation Flux density of 1.4 Tesla

ApL = 36.287

N := $\sqrt{\frac{L_{mutual} \cdot MPL \cdot 10^8}{0.4 \cdot \pi \cdot \mu \cdot Ac}}$

N = 32.325 Unloaded Number of turns

N := 54 Permeability Changes Due to loading
 From Curve Fitting Formula for 52 Material
 Increment N until LmutualLoaded=Lmutual

H := $\frac{0.4 \cdot \pi \cdot N \cdot (Io1 + Io2p)}{MPL}$ H = 64.408 magnetization in oersteds

a := 10090 b := $5.05 \cdot 10^{-3}$ c := 13.1 d := $1.17 \cdot 10^{-3}$ e := .0212 Put in -70 curve fit here

%μLdc := $\sqrt{\frac{(a + c \cdot H + e \cdot H^2)}{(1 + b \cdot H + d \cdot H^2)}}$

$$\% \mu_{Ldc} = 42.235$$

$$\mu_r := \mu \cdot \frac{\% \mu_{Ldc}}{100} \quad \mu_r = 31.676$$

$$L_{Loaded} := \frac{0.4 \cdot \pi \cdot N^2 \cdot A_c \cdot \mu_r}{MPL \cdot 10^8}$$

$$L_{Loaded} = 1.179 \times 10^{-4}$$

$$L_{nls1} := \frac{0.4 \cdot \pi \cdot N^2 \cdot A_c \cdot \mu}{MPL \cdot 10^8}$$

$$L_{nls1} = 2.791 \times 10^{-4} \quad \text{Unloaded Inductance}$$

$$B_{mac} := \frac{0.4 \cdot \pi \cdot N \cdot \left(\frac{\Delta I_{dc}}{2} \right) \cdot 10^{-4} \cdot \mu_r}{MPL} \quad \text{Permeability changes due to } B_{ac}$$

$$B_{mac} = 0.01$$

$$B_m := \frac{0.4 \cdot \pi \cdot N \cdot (I_{Lpk}) \cdot 10^{-4} \cdot \mu_r}{MPL}$$

$$B_m = 0.214 \quad \text{Total flux density}$$

$$B_{mdc} := B_m - B_{mac} \quad \text{Dc Component of the flux density}$$

$$B_{mdc} = 0.204$$

$$P_{Lcore} := 1.2 \quad \text{From The Micrometals Software}$$

$$N_{Ls1} := N$$

$$J := \frac{2 \cdot \sqrt{D_{max}} \cdot (P_{o1} + P_{o2}) \cdot 10^4}{K_u \cdot B_{mac} \cdot f_s \cdot A_p}$$

$$J = 6.293 \times 10^3 \quad \text{Too high use } J=500 \quad J := 500$$

$$A_{wb} := \frac{I_{o1} + \Delta I_{dc}}{J}$$

$$A_{wb} = 0.012 \quad \text{Suggested wire is 18 AWG}$$

18 AWG Wire

$$A_{wL1} := 0.008228 \quad \text{cm}^2 \text{ 20 AWG bare wire cross sectional area}$$

$$R_{cuL1} := 0.0002095 \quad \text{Ohms Cu Resistance}$$

$$R_{L1} := R_{cuL1} \cdot M_{LT} \cdot N_{Ls1} \quad \text{Ohms resistance in the length of the wire}$$

$$P_{cuL1} := R_{L1} \cdot (I_{o1} + \Delta I_{dc})^2 \quad \text{Copper losses in that winding}$$

$$P_{cuL1} = 1.492$$

$$N_{Ls2} := N \cdot n$$

$$N_{Ls2} = 16.2$$

$$A_{wb} := \frac{I_{o2} + \Delta I_{dc}}{J}$$

$$A_{wb} = 7.632 \times 10^{-3}$$

Suggested wire is 24 AWG

24 AWG Wire

$$A_{wL2} := 0.002047 \quad \text{cm 24 AWG bare wire cross sectional area}$$

$$R_{cuL2} := 0.0008521 \quad \text{Ohms Cu Resistance}$$

$$R_{L2} := R_{cuL2} \cdot M_{LT} \cdot N_{Ls2} \quad \text{Ohms resistance in the length of the wire}$$

$$P_{cuL2} := R_{L2} \cdot (I_{o2} + \Delta I_{dc})^2 \quad \text{Copper losses in that winding}$$

$$P_{cuL2} = 0.784$$

$$P_{L1} := P_{Lcore} + P_{cuL1} + P_{cuL2}$$

$$P_{L1} = 3.476$$

$$\Delta T_{L1} := \left(\frac{P_{L1} \cdot 10^3}{A_t} \right)^{0.833} \quad \text{General equation for predicting Temperature rise from Pd and Surface area}$$

$$\Delta T_{L1} = 43.033$$

Bridge Diode Power Calculation

$$V_{acmin} := 85 \quad \text{Minimum AC input voltage}$$

$$I_{acrms} := \frac{P_{in}}{V_{acmin}} \quad \text{AC RMS Current}$$

$$I_{acrms} = 1.841$$

$$R_{load} := \left(\frac{P_{in}}{I_{acrms}^2} \right) \quad \text{Load Resistance}$$

$$R_{load} = 46.183$$

$$I_m := I_{acrms} \cdot \sqrt{2} \quad \text{Use 0.5 instead of 1.414 for a half bridge}$$

$$I_m = 2.603 \quad \text{Peak Current in the Bridge}$$

$$I_{av} := \frac{1}{\pi} \cdot \int_0^{\pi} I_m \cdot \sin(\omega) d\omega \quad \text{use } 1/2 \cdot \pi \text{ for half bridge}$$

$$I_{av} = 1.657$$

$$P_{rect} := V_{fdr} \cdot I_{av}$$

Prect = 1.326 Average Power Dissipation of Bridge

Input Capacitor Selection

$$C_{in} := \frac{2 \cdot P_o \cdot \text{thold}}{(V_{in}^2 - (V_{in})_{min})^2}$$

$$C_{in} = 5.801 \times 10^{-5}$$

Use a 220uF 450Vdc Al Elec. Capacitor
United Chemicon 25x25 snap mount

$$C_{in} := 220 \cdot 10^{-6}$$

Set to 220uf

$$\text{Resrco} := 0.753$$

120Hz ESR at 20C

$$\Delta V_{in} := \frac{P_o}{V_{Vmin}} \cdot \sqrt{\frac{1}{(2 \cdot \pi \cdot 2 \cdot \text{Facmains} \cdot C_{in})^2} + \text{Resrco}^2}$$

$$\Delta V_{in} = 9.028 \quad 1/2 \text{ peak to peak value}$$

$$P_{cin} := \left[\left(\frac{32 \cdot \sqrt{2}}{9 \cdot \pi} \cdot I_{acrms}^2 \cdot \frac{V_{85}}{V_{115}} \right) - \left(\frac{P_o}{V_{Vmin}} \right)^2 \right] \cdot \text{Resrco}$$

$$P_{cin} = 1.355$$

Capacitor Power Dissipation

Total Losses

$$P_{tot} := P_{q1} + P_{xfmr} + P_{d1} + P_{d2} + P_{rs} + P_{L1} + P_{rect} + P_{cin}$$

$$P_{tot} = 18.755$$

$$\eta_{projected} := \frac{P_{o1} + P_{o2}}{(P_{o1} + P_{o2} + P_{tot})}$$

$$\eta_{projected} = 0.882$$

Start Resistor

$$I_{start} := 0.0015 \quad \text{Startup current}$$

$$R_{start} := \frac{V_{Vmin} - V_b}{I_{start}} \quad \text{Start Resistor Valus}$$

$$R_{start} = 5.65 \times 10^4 \quad \text{Use an 8K 1/2W Resistor}$$

$$P_{rstart} := I_{start}^2 \cdot R_{start}$$

$$Pr_{start} = 0.127$$

$$Pr_{startmax} := \left[\frac{(V_{140})^2}{R_{start}} \right]$$

$$Pr_{startmax} = 0.694$$

Use a 0.5W resistor

TL431 Reference Calculation

$$V_{ref} := 2.5$$

$$R1 := 1000$$

$$R2 := \frac{V_{o1}}{V_{ref}} \cdot R1 - R1$$

$$R2 = 8.6 \times 10^3$$

