AN3215
Application note

Boost for solar applications with 3 kW fixed off time (FOT)

Introduction

The following application note describes the modifications implemented on the STEVAL-ISF001V1 demonstration board, originally designed to work as a PFC rated for a power of 3 kW, to be used as a front-end boost stage for photovoltaic applications.

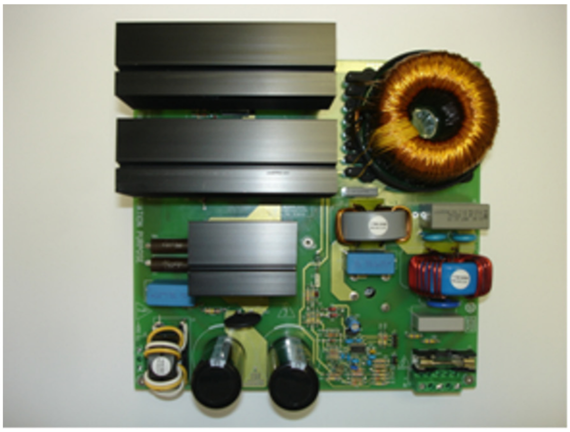
In recent years the field of solar energy, the production of electric power using solar cells, is requiring power electronic solutions to manage the power delivered by the panels.

The DC voltage provided by the photovoltaic field needs, in many cases, to be boosted before supplying a second electronic power stage needed to convert the DC source into AC voltage, required by domestic appliances or for grid connection.

The power conversion must be done with a solution capable of working at high efficiency in order to avoid energy waste. Each and every watt is important!

The availability of new power devices with lower voltage drop and higher switching capability allows a very efficient solution to be obtained, wasting only a few watts while managing power in the range of thousands of watts.

Figure 1. 3 kW boost power board



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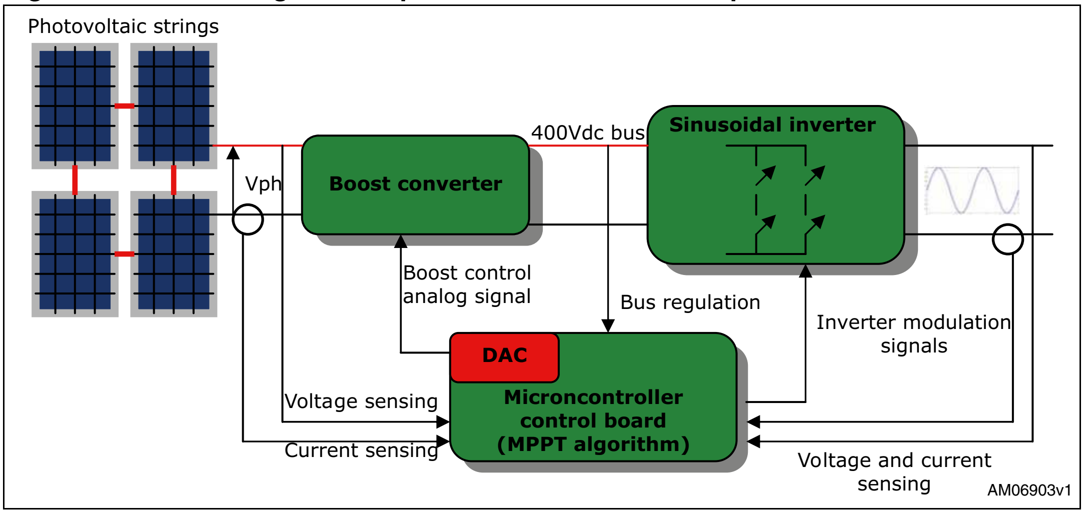
1 FOT boost for solar front-end applications

The front-end power boost can be found in most solar inverter solutions.

The functions of this stage are two. The first is to boost the voltage coming from the solar string, in many cases it is mandatory to have a DC bus with a value sufficient to supply a sinusoidal inverter which is able to give 220 Vac at its output, or to be connected on the mains. The second function is to adapt the impedance of the solar string with the impedance of the inverter. This concept can be better understood when remembering that the power delivered by the solar strings is variable according to a wide range of factors, first of all the solar power incidence on the photovoltaic field. For these reasons the front-end power stage connected to the solar strings must give the possibility of modulating the power drained from the string according to a well known algorithm called MPPT (maximum power point tracking). The MPPT calculates run time, the power delivered by the panels under different voltages, and current conditions. The power boost stage is able to modulate the power absorbed from the strings according to the MPPT algorithm. The MPPT algorithm is implemented via firmware in the microcontroller involved in managing the whole solar inverter.

The boost stage receives an analog voltage in the range of 0-2.5 V from the microcontroller, the boost drains power according to this control voltage from the solar string. *Figure 2* below shows this concept with a block diagram:

Figure 2. Block diagram of a photovoltaic inverter with power boost front-end



The boost converter acts as a current generator.

The output voltage of the boost stage is not controlled, so it can be connected in parallel with another boost board in order to increase the power range.

The voltage at the output is regulated by the load (the inverter) that, connected to the mains line, supplies the right power amount in order to maintain the output boost voltage to a fixed value of 400 V.

2 Fixed off time boost

Using the hardware demonstration board, designed for the fixed off time 3 kW PFC ISF001V1 (see AN2951; *3 kW fixed-off-time (FOT) power factor correction*), and implementing some simple modifications to the control part, it is possible to realize a boost converter working in the same power range. The idea is to maintain the fixed off time modulation strategy and to modify the control part in order to eliminate the output control voltage loop, maintaining overvoltage protection, and to give the possibility of controlling, through an analog voltage, the power delivered by the boost on the DC bus.

The T_{off} constant strategy gives a variable frequency control according to the input voltage. In fact, fixing the input voltage, as the output is fixed by the inverter, the duty cycle is dictated by the relationship:

Equation 1

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-\delta} \quad \text{where } \delta \text{ is duty cycle}$$

Variation against the power delivered is really small. Only the peak current on the boost inductor, dictated by the power requested by the inverter, is variable.

As the T_{off} is fixed at a low input voltage, when the T_{on} is higher with respect to the continuous mode voltage relation, between input and output, the switching frequency is reduced. At high input voltage the T_{on} is reduced to respect the same input/output voltage ratio, so the frequency is increased. This gives a reduction in the working frequency when the switched current is higher, reducing switching losses (lower input voltage at maximum power delivered), and an increased frequency when the current is reduced, reducing voltage ripple on the boost inductor.

3 Technical specifications and design rules

In *Table 1* the technical specifications of the system are shown.

Table 1. Main board characteristics

Parameter	Value
Input voltage	190 to 350 Vdc
Output working voltage	400 Vdc
Maximum output power	3000 W
Vout ripple (%) (50 Hz inverter load)	5 %
Maximum switching frequency	65 kHz
Inductor current ripple (Kr)	0.25

Starting from the definition of K_r (current ripple coefficient on the inductor), as:

Equation 2

$$K_r = \frac{\Delta I_{ripple}}{I_{LPeak}} = \frac{\Delta I_{ripple}}{IL_m + \frac{\Delta I_{ripple}}{2}}$$

It is possible to calculate the maximum current ripple on the boost inductor as:

Equation 3

$$\Delta I_{ripple} = \frac{2K_r I_{L\,max}}{2 - Kr}$$

Remembering that for a boost converter the maximum current ripple on the boost inductor is at δ=0.5, and that from *Equation 1* this condition is at $V_{in}=V_{out}/2$, we can write:

Equation 4

$$\Delta I_{Lripple_{max}} = \frac{\frac{V_{out}}{2} * T_{on(\delta=0.5)}}{L_{min}}$$

Equation 5

$$T_{on(\delta=0.5)} = T_{off}$$

Equation 6

$$L_{min} \geq \frac{\frac{V_{out}}{2} * T_{off}}{I_{Lripple_{max}}}$$

Some consideration on the switching frequency gives the right value of T_{off}.

As mentioned above, the switching frequency of the T_{off} constant boost is variable according to the input voltage and so to the duty cycle to maintain the output voltage fixed. There is a minimum frequency at minimum input voltage and a maximum frequency on the maximum input voltage.

Therefore one of the two extremes can be fixed according to the power switches limit or preference; this gives the next two relationships:

Equation 7

$$\frac{\delta_{max}}{F_{sw_{min}}} + t_{off} = \frac{1}{F_{sw_{min}}}$$

Equation 8

$$\frac{\delta_{min}}{F_{sw_{max}}} + t_{off} = \frac{1}{Fsw_{max}}$$

It is possible to fix a maximum or a minimum switching frequency for the system and calculate the required T_{off}.

As the T_{off} is calculated using *Equation 6* the minimum required value for the boost inductor can be evaluated.

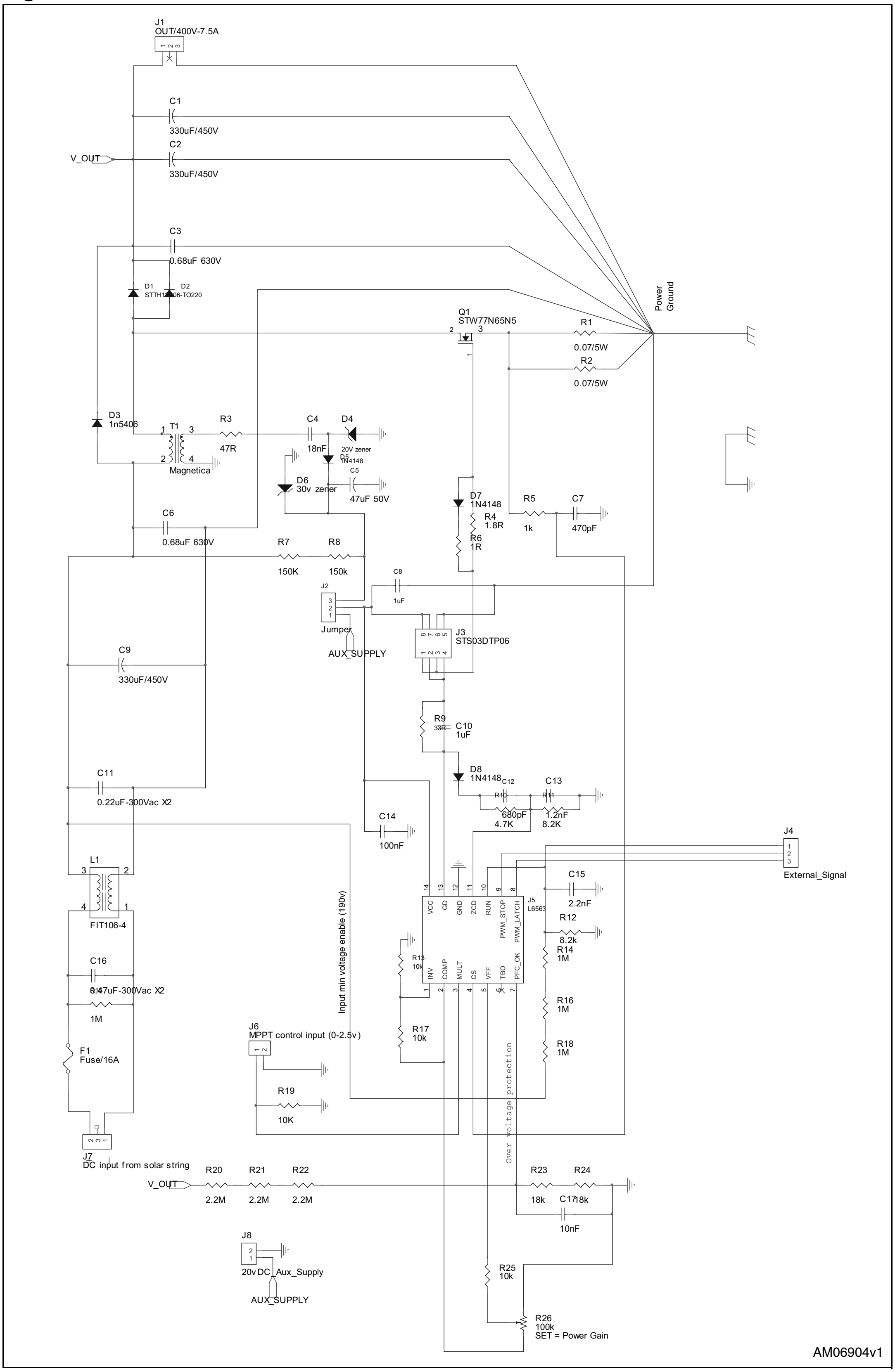
The following relationship can be used to calculate the right value for the RC net to be connected on the ZCD pin of the L6563, to have the required T_{off} (for further information refer to AN2951).

Equation 9

$$Toff = RC \ln \frac{V_{ZCDclamp}}{V_{ZCDtrigger}} \approx 2.09 * RC.$$

(Refer to the L6563; *Advanced transition-mode PFC controller* datasheet for the two voltage thresholds).

Figure 3. Circuit board schematic



4 Circuital modifications and schematic

The schematic of the modified ISF001.v1 follows.

All the power passive components, including magnetic filters, are essentially maintained and not modified. In order to have the maximum efficiency it is mandatory to remove the diode bridge, necessary on a standard PFC circuitry, which in this case is not useful because the input voltage is a DC from a solar panel string.

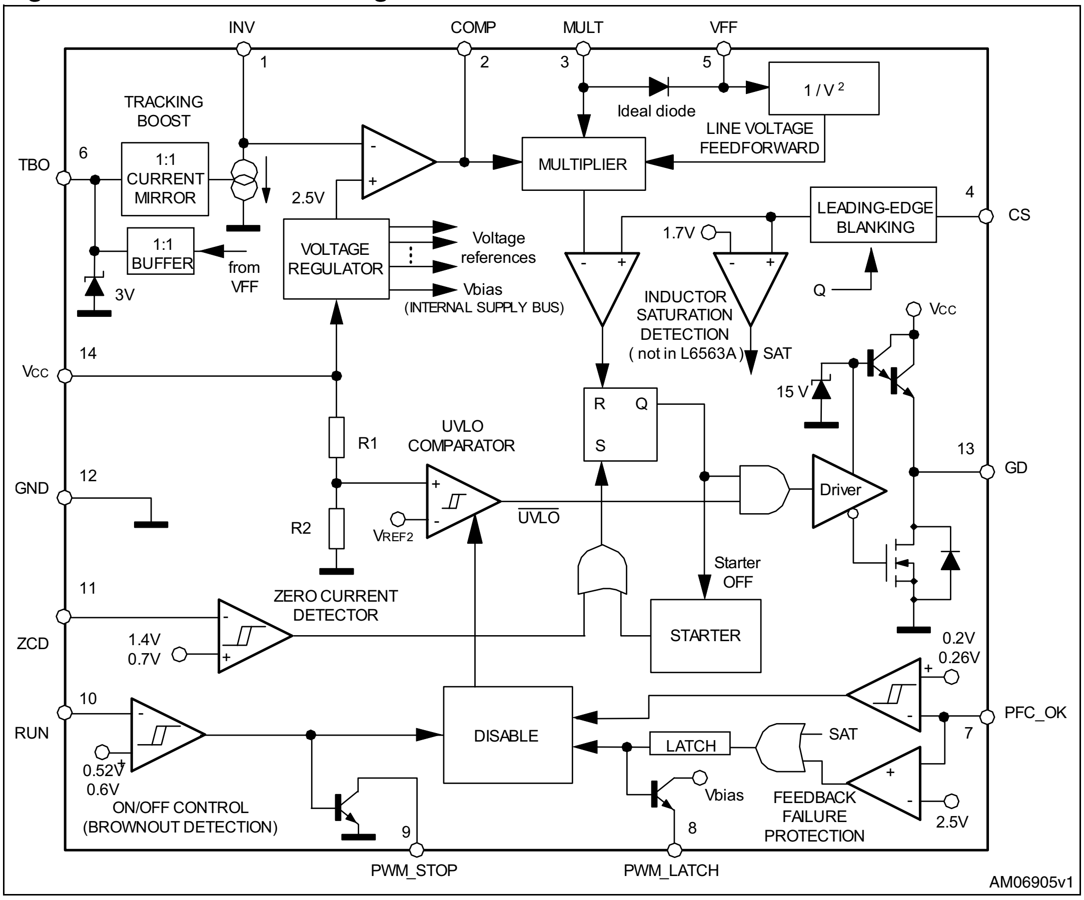
Putting an electrolytic capacitor on the input to reduce voltage ripple is suggested.

For the power active part, the new MDmesh™ V family power MOSFET is recommended for this particular application. The STW77N65M5 is a new device capable of very low RDSon, and an increased breakdown voltage from 600 to 650 V. This last aspect gives a better safety margin for an application that may work under low temperature conditions at startup. In fact, the solar converters are usually installed outdoors and the low temperature at sunrise, especially during winter, could require an increase in the breakdown voltage of the devices involved, which are guaranteed at 25 degrees.

Using only one STW77N65M5 device, it is possible to remove one of the original installed MDmesh™ II devices, reducing the cost of the application at the same output power range.

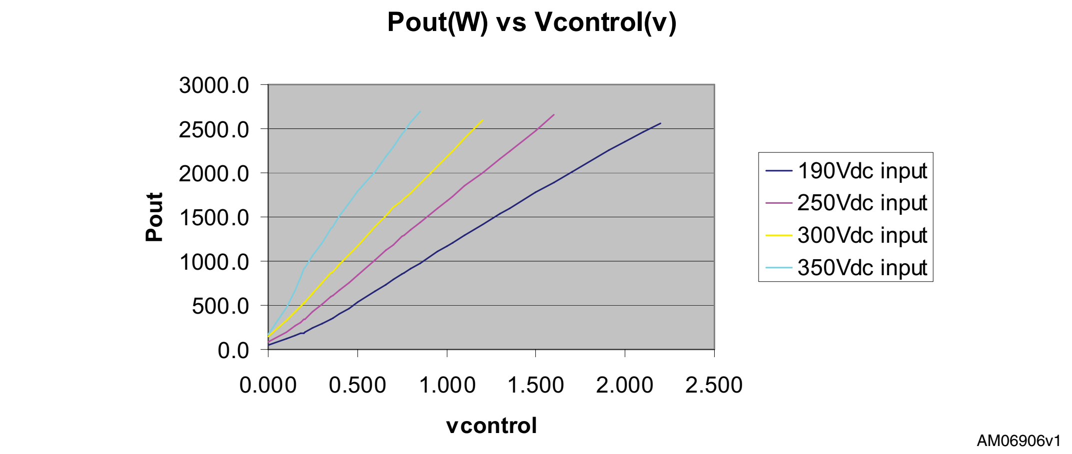
The internal block diagram of an L6563 can help in understanding how the external control voltage drives the power delivered by the system.

Figure 4. Internal block diagram of L6563



The INV and COMP pins, connected to the internal comparator, are used to fix the voltage on its output. The output of the comparator is one of the inputs of the internal multiplier that gives the current peak reference. The input used to change the current reference, according to the power delivered by the boost converter, is the multiplier input connected to the MULT pin. The VFF pin, originally used to implement a voltage feed forward function, is connected to an external trimmer, useful for setting the gain of the system. In other words, by moving the external trimmer it is possible to fix a value of power delivered according to an input reference voltage applied on the MULT pin. The power delivered also depends on the input DC voltage from the solar string. For this reason it is better to tune the trimmer R26 to deliver, at the output, the maximum power at the minimum input voltage, giving the maximum input control voltage. The system has been characterized, the curves depicted in *Figure 5* show the output power according to the input voltage.

Figure 5. Output power vs. V control at different input DC voltages



As can be seen, by increasing the input voltage the range of the input reference control voltage, to have the maximum power delivered to the output, is reduced.

5 Lab test and measurements

Following is a collection of measurements carried out on a modified ISF001V1 board, working as boost.

The measurement sets are arranged on four different input voltages: 190, 250, 300, and 350 Vdc.

With the value of the passive component used for the RC net, used to fix T_{off}, the switching frequency is 19 kHz for 190 Vdc input and 37 kHz for 350 Vdc input.

Table 2. Power measurement at different input voltages

Vcontr	Pout@190 Vdc	Pout@250 Vdc	Pout@300 Vdc	Pout@350 Vdc
0.000	44.0	81.2	143.6	176.0
0.100	118.0	194.4	330	478.0
0.150	155.0	262.7	426.2	676.0
0.180	177.2	303.2	483.9	815.9
0.200	188.0	337.2	522.4	909.2
0.205	193.2	345.7	532.0	924.7
0.250	239.8	422.1	636.2	1064.0
0.300	291.5	507.1	752.0	1210.4
0.350	343.3	592.0	860.0	1360.2
0.360	353.6	608.7	881.6	1390.2
0.400	404.2	675.4	968.0	1510.0
0.450	467.5	758.8	1069.2	1652.8
0.500	530.7	844.4	1170.4	1795.6
0.550	594.0	930.0	1278.8	1905.0
0.600	659.0	1015.6	1387.2	2014.4
0.660	736.9	1119.1	1517.3	2180.0
0.700	788.9	1188.1	1604.0	2293.8
0.750	853.8	1274.4	1687.0	2436.0
0.760	866.8	1290.4	1703.6	2462.4
0.800	916.8	1354.4	1770.0	2568.0
0.850	979.2	1434.4	1872.4	2700.0
0.950	1104.1	1596.3	2077.2	
1.000	1166.5	1677.2	2185.2	
1.030	1204.0	1730.6	2246.0	
1.100	1290.1	1855.2	2388.0	
1.200	1413.0	2000.0	2594.0	

Table 2. Power measurement at different input voltages (continued)

Vcontr	Pout@190 Vdc	Pout@250 Vdc	Pout@300 Vdc	Pout@350 Vdc
1.300	1536.0	2164.0		
1.350	1597.0	2246.0		
1.500	1780.0	2480.0		
1.600	1895.2	2658.0		
1.700	2010.4			
1.910	2252.0			
2.000	2351.2			
2.100	2458.0			
2.200	2564.0			

5.1 Efficiency curves at different input voltages

Figure 6. Boost efficiency at 190 Vdc input

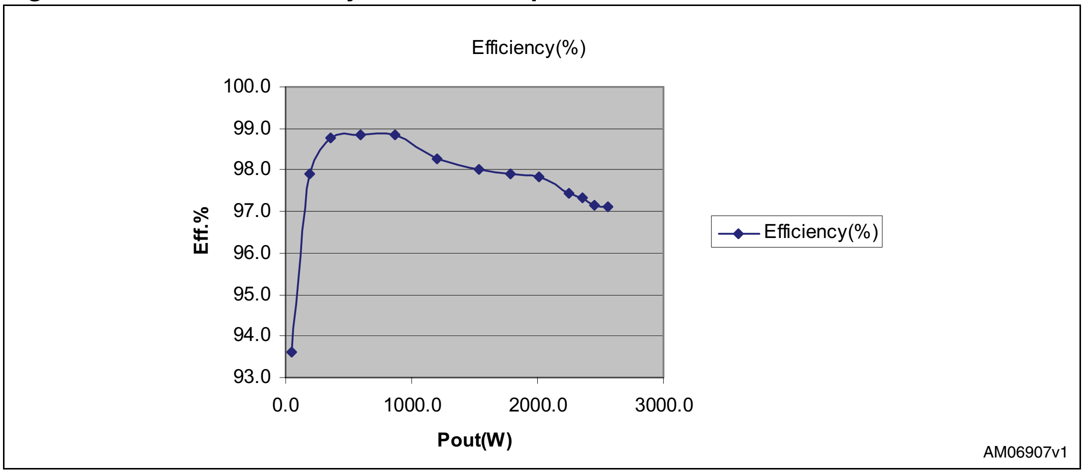


Figure 7. Boost efficiency at 250 Vdc

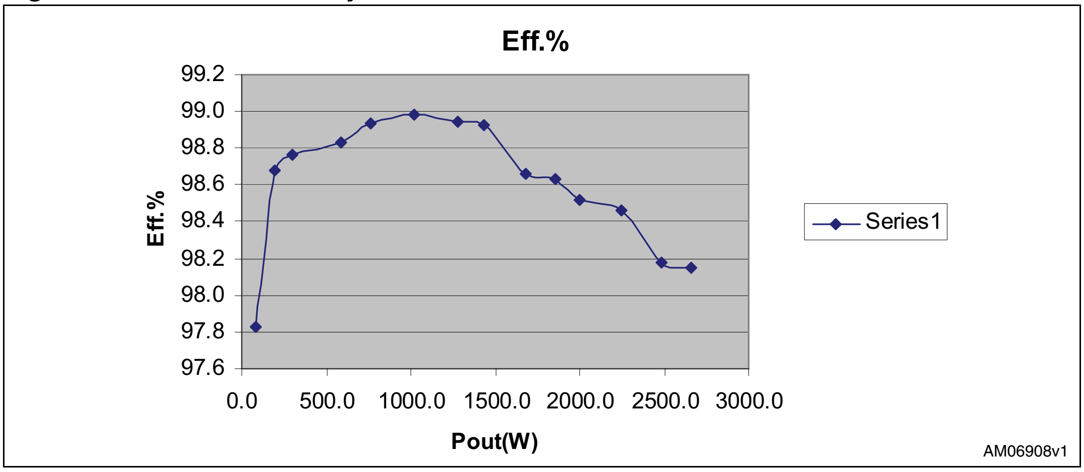


Figure 8. Boost efficiency at 300 Vdc

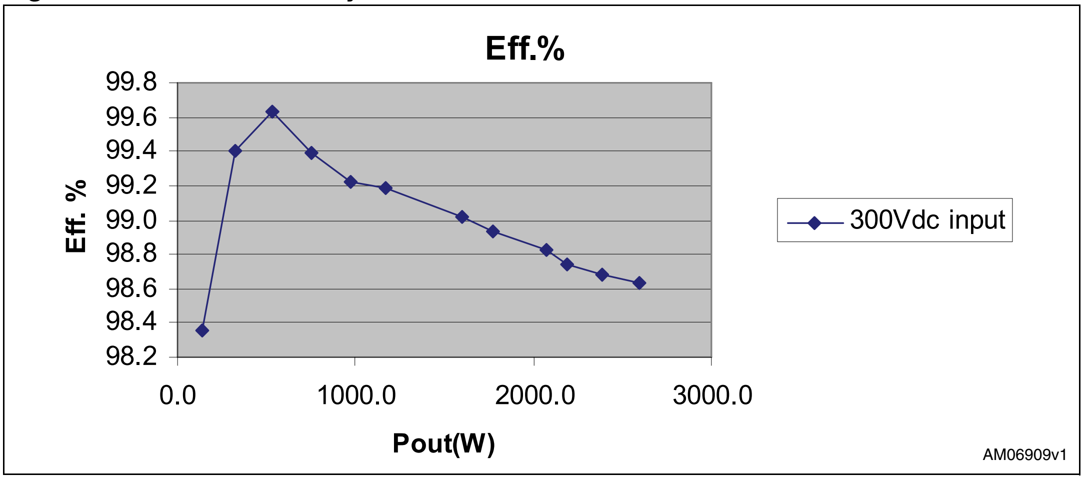
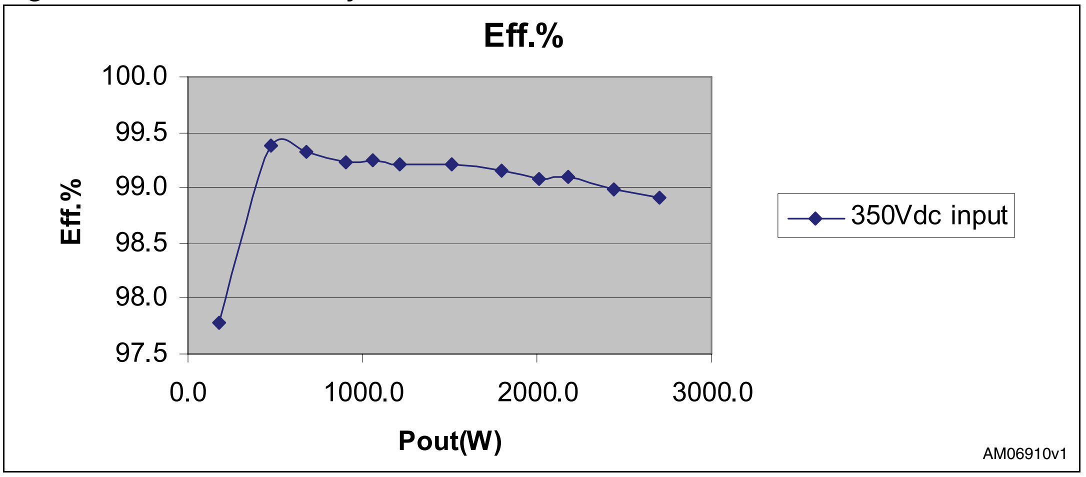


Figure 9. Boost efficiency at 350 Vdc



6 Revision history

Table 3. Document revision history

Date	Revision	Changes
30-Aug-2010	1	Initial release