

# HIGH VOLTAGE RESONANT CONTROLLER

## 1 FEATURES

- HIGH VOLTAGE RAIL UP TO 600V
- $dV/dt$  IMMUNITY  $\pm 50V/ns$  IN FULL TEMPERATURE RANGE
- DRIVER CURRENT CAPABILITY:  
250mA SOURCE  
450mA SINK
- SWITCHING TIMES 80/40ns RISE/FALL WITH 1nF LOAD
- CMOS SHUT DOWN INPUT
- UNDER VOLTAGE LOCK OUT
- SOFT START FREQUENCY SHIFTING TIMING
- SENSE OP AMP FOR CLOSED LOOP CONTROL OR PROTECTION FEATURES
- HIGH ACCURACY CURRENT CONTROLLED OSCILLATOR
- INTEGRATED BOOTSTRAP DIODE
- CLAMPING ON  $V_s$
- SO16, DIP16 PACKAGES

## 2 DESCRIPTION

The device is manufactured with the BCD OFF LINE

Figure 1. Packages



Table 1. Order Codes

Part Number	Package
L6598	DIP-16
L6598D	SO-16N
L6598D013TR	Tape & Reel

technology, able to ensure voltage ratings up to 600V, making it perfectly suited for AC/DC Adapters and wherever a Resonant Topology can be beneficial. The device is intended to drive two Power MOS, in the classical Half Bridge Topology. A dedicated Timing Section allows the designer to set Soft Start Time, Soft Start and Minimum Frequency. An Error Amplifier, together with the two Enable inputs, are made available. In addition, the integrated Bootstrap Diode and the Zener Clamping on low voltage supply, reduces to a minimum the external parts needed in the applications.

Figure 2. Block Diagram

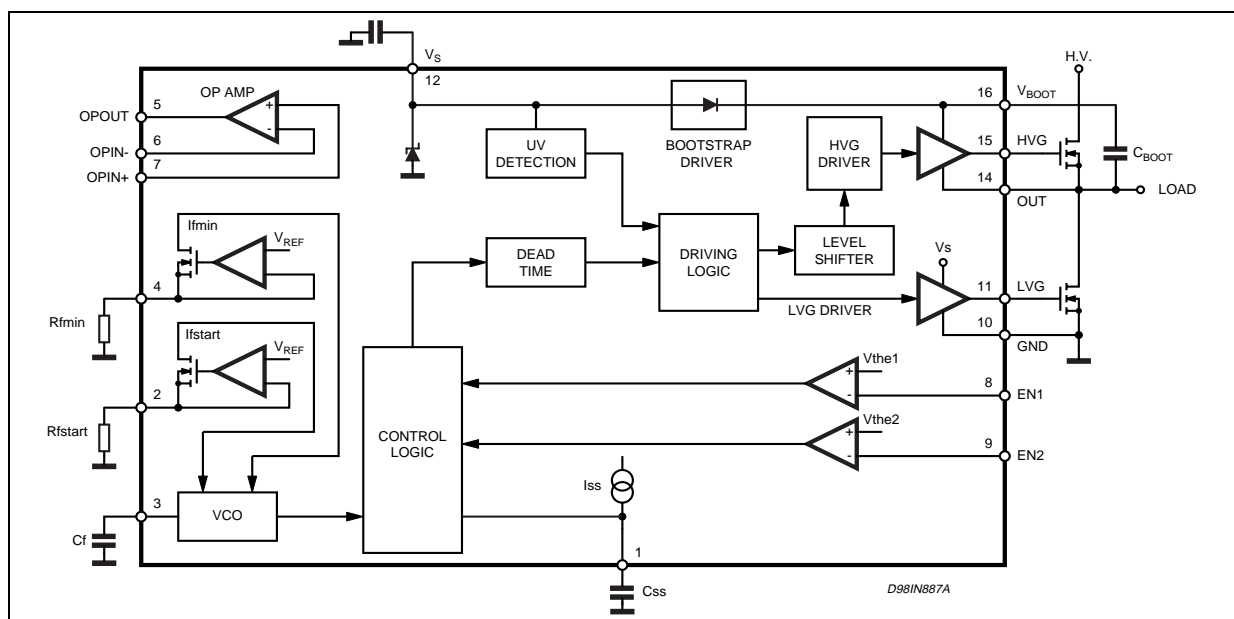


Figure 3. Pin Connection

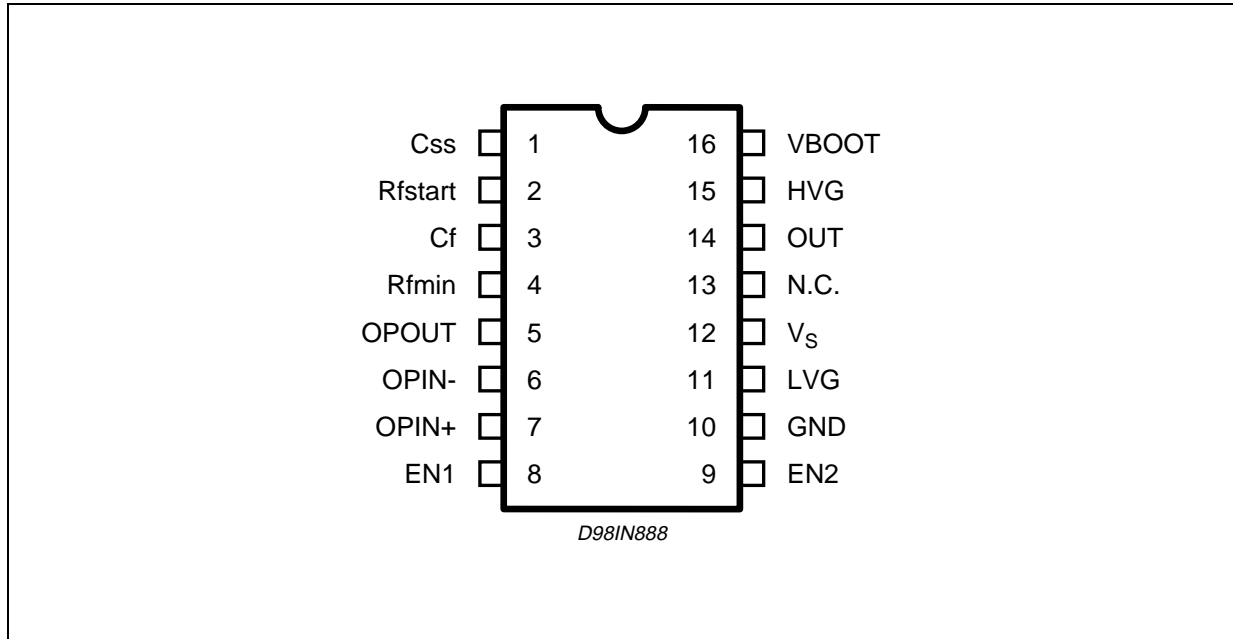


Table 2. Thermal Data

Symbol	Parameter	SO16N	DIP16	Unit
R <sub>th j-amb</sub>	Thermal Resistance Junction to Ambient	120	80	°C/W

Table 3. Pin Function

N.	Name	Function
1	C <sub>SS</sub>	Soft Start Timing Capacitor
2	R <sub>fstart</sub>	Soft Start Frequency Setting - Low Impedance Voltage Source - See also C <sub>f</sub>
3	C <sub>f</sub>	Oscillator Frequency Setting - see also R <sub>fmin</sub> , R <sub>fstart</sub>
4	R <sub>fmin</sub>	Minimum Oscillation Frequency Setting - Low Impedance Voltage Source - See also C <sub>f</sub>
5	OP <sub>out</sub>	Sense OP AMP Output - Low Impedance
6	OP <sub>on-</sub>	Sense Op Amp Inverting Input - High Impedance
7	OP <sub>on+</sub>	Sense Op Amp Non Inverting Input - High Impedance
8	EN1	Half Bridge Latched Enable
9	EN2	Half Bridge Unlatched Enable
10	GND	Ground
11	LVG	Low Side Driver Output
12	V <sub>s</sub>	Supply Voltage with Internal Zener Clamp
13	N.C.	Not Connected
14	OUT	High Side Driver Reference
15	HVG	High Side Driver Output
16	V <sub>boot</sub>	Bootstrapped Supply Voltage

**Table 4. Absolute Maximum Ratings**

Symbol	Parameter	Value	Unit
I <sub>S</sub>	Supply Current at V <sub>cl</sub> (*)	25	mA
V <sub>LVG</sub>	Low Side Output	14.6	V
V <sub>OUT</sub>	High Side Reference	-1 to V <sub>BOOT</sub> -18	V
V <sub>HVG</sub>	High Side Output	-1 to V <sub>BOOT</sub>	V
V <sub>BOOT</sub>	Floating Supply Voltage	618	V
dV <sub>BOOT</sub> /dt	VBOOT pin Slew Rate (repetitive)	±50	V/ns
dV <sub>OUT</sub> /dt	OUT pin Slew Rate (repetitive)	±50	V/ns
V <sub>ir</sub>	Forced Input Voltage (pins Rfmin, Rfstart)	-0.3 to 5	V
V <sub>ic</sub>	Forced Input Voltage (pins C <sub>ss</sub> , C <sub>f</sub> )	-0.3 to 5	V
V <sub>EN1</sub> , V <sub>EN2</sub>	Enable Input Voltage	-0.3 to 5	V
I <sub>EN1</sub> , I <sub>EN2</sub>	Enable Input Current	±3	mA
V <sub>opc</sub>	Sense Op Amp Common Mode Range	-0.3 to 5	V
V <sub>opd</sub>	Sense Op Amp Differential Mode Range	-5 to 5	V
V <sub>opo</sub>	Sense Op Amp Output Voltage (forced)	4.6	V
T <sub>stg</sub>	Storage Temperature	-40 to +150	°C
T <sub>j</sub>	Junction Temperature	-40 to +150	°C
T <sub>amb</sub>	Ambient Temperature	-40 to +125	°C

(\*) The device is provided of an internal Clamping Zener between GND and the Vs pin, It must not be supplied by a low impedance voltage source.

Note : ESD immunity for pins 14, 15 and 16 is guaranteed up to 900 (Human Body Model).

**Table 5. Recommended Operating Conditions**

Symbol	Parameter	Value	Unit
V <sub>S</sub>	Supply Voltage	10 to V <sub>cl</sub>	V
V <sub>out</sub> (*)	High Side Reference	-1 to V <sub>boot</sub> -V <sub>cl</sub>	V
V <sub>boot</sub> (*)	Floating Supply Rail	500	V
f <sub>max</sub>	Maximum Switching Frequency	400	kHz

(\*) If the condition V<sub>boot</sub> - V<sub>out</sub> < 18 is guaranteed, V<sub>out</sub> can range from -3 to 580V.

**Table 6. Electrical Characteristics**(V<sub>S</sub> = 12V; V<sub>BOOT</sub> - V<sub>OUT</sub> = 12V; T<sub>amb</sub> = 25°C)

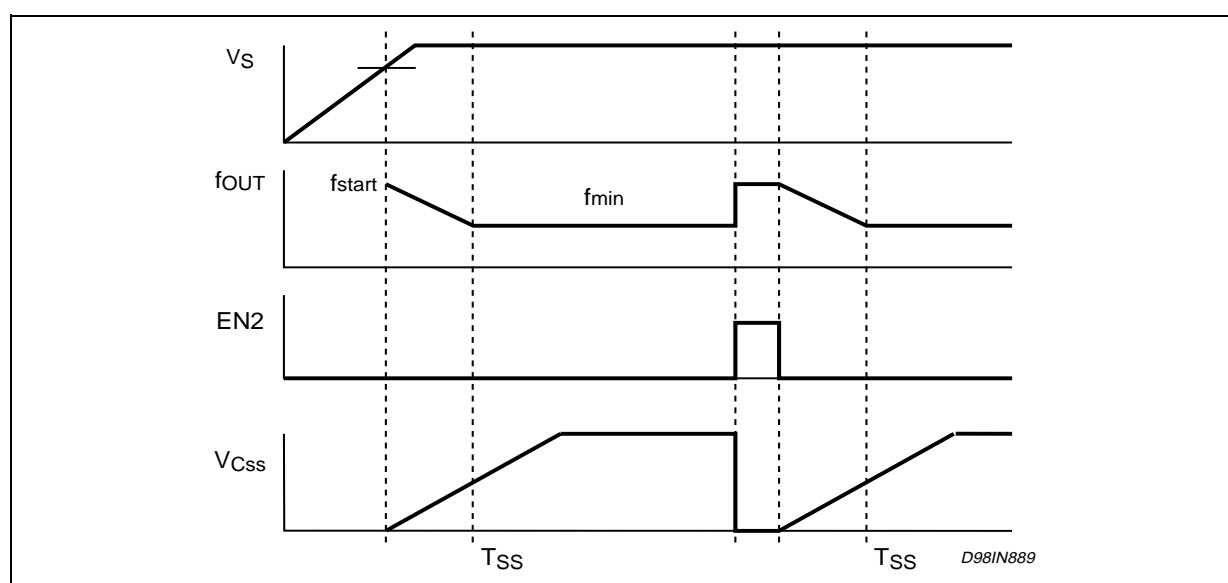
Symbol	Pin	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<b>SUPPLY VOLTAGE</b>							
V <sub>suvp</sub>	12	V <sub>S</sub> Turn On Threshold		10	10.7	11.4	V
V <sub>suvn</sub>		V <sub>S</sub> Turn Off Threshold		7.3	8	8.7	V
V <sub>suvh</sub>		Supply Voltage Under Voltage hysteresis			2.7		V
V <sub>cl</sub>		Supply Voltage Clamping		14.6	15.6	16.6	V
I <sub>su</sub>		Start Up Current	V <sub>S</sub> < V <sub>suvn</sub>			250	μA
I <sub>q</sub>		Quiescent Current, f <sub>out</sub> = 60kHz, no load	V <sub>S</sub> > V <sub>suvp</sub>		2	3	mA
<b>HIGH VOLTAGE SECTION</b>							
I <sub>bootleak</sub>	16	BOOT pin Leakage Current	V <sub>BOOT</sub> = 580V			5	μA
I <sub>outleak</sub>	14	OUT pin Leakage Current	V <sub>OUT</sub> = 562V			5	μA
R <sub>don</sub>	16	Bootstrap Driver On Resistance		100	150	300	Ω
<b>HIGH/LOW SIDE DRIVERS</b>							
I <sub>hvgso</sub>	15	High Side Driver Source Current	V <sub>HVG</sub> -V <sub>OUT</sub> = 0	170	250		mA
I <sub>hvgsi</sub>		High Side Driver Sink Current	V <sub>HVG</sub> -V <sub>BOOT</sub> = 0	300	450		mA
I <sub>lvgsso</sub>	11	Low Side Driver Source Current	V <sub>LVG</sub> -GND = 0	170	250		mA
I <sub>lvgsi</sub>		Low Side Driver Sink Current	V <sub>LVG</sub> - V <sub>S</sub> = 0	300	450		mA
t <sub>rise</sub>	15,11	Low/High Side Output Rise Time	C <sub>load</sub> = 1nF		80	120	ns
t <sub>fall</sub>			C <sub>load</sub> = 1nF		40	80	ns
<b>OSCILLATOR</b>							
DC	14	Output Duty Cycle		48	50	52	%
f <sub>min</sub>		Minimum Output Oscillation Frequency	C <sub>f</sub> = 470pF; R <sub>fmin</sub> = 50k	58.2	60	61.8	kHz
f <sub>start</sub>		Soft Start Output Oscillation Frequency	C <sub>f</sub> = 470pF; R <sub>fmin</sub> = 50k; R <sub>fstart</sub> = 47k	114	120	126	kHz
V <sub>ref</sub>	2, 4	Voltage to Current Converters Threshold		1.9	2	2.1	V
t <sub>d</sub>	14	Dead Time between Low and High Side Conduction		0.2	0.27	0.35	μs
<b>TIMING SECTION</b>							
k <sub>ss</sub>	1	Soft Start Timing constant	C <sub>ss</sub> = 330nF	0.115	0.15	0.185	s/μF
<b>SENSE OP AMP</b>							
I <sub>IB</sub>	6, 7	Input Bias Current				0.1	μA
V <sub>io</sub>		Input Offset Voltage		-10		10	mV
R <sub>out</sub>	5	Output Resistance		200		300	Ω
I <sub>out-</sub>		Source Output Current	V <sub>out</sub> = 4.5V	1			mA
I <sub>out+</sub>		Sink Output Current	V <sub>out</sub> = 0.2V	1			mA
V <sub>ic</sub>	6,7	OP AMP input common mode range		-0.2		3	V

**Table 6. Electrical Characteristics** (continued)  
 ( $V_S = 12V$ ;  $V_{BOOT} - V_{OUT} = 12V$ ;  $T_{amb} = 25^\circ C$ )

Symbol	Pin	Parameter	Test Condition	Min.	Typ.	Max.	Unit
GBW		Sense Op Amp Gain Band Width Product (*)		0.5	1		MHz
$G_{dc}$		DC Open Loop Gain		60	80		dB
<b>COMPARATORS</b>							
$V_{the1}$	8	Enabling Comparator Threshold		0.56	0.6	0.64	V
$V_{the2}$	9	Enabling Comparator Threshold		1.05	1.2	1.35	V
$t_{pulse}$	8,9	Minimum Pulse length				200	ns

(\*) Guaranteed by design

**Figure 4. EN2 Timing Diagrams**



**Figure 5. EN1 Timing Diagrams**

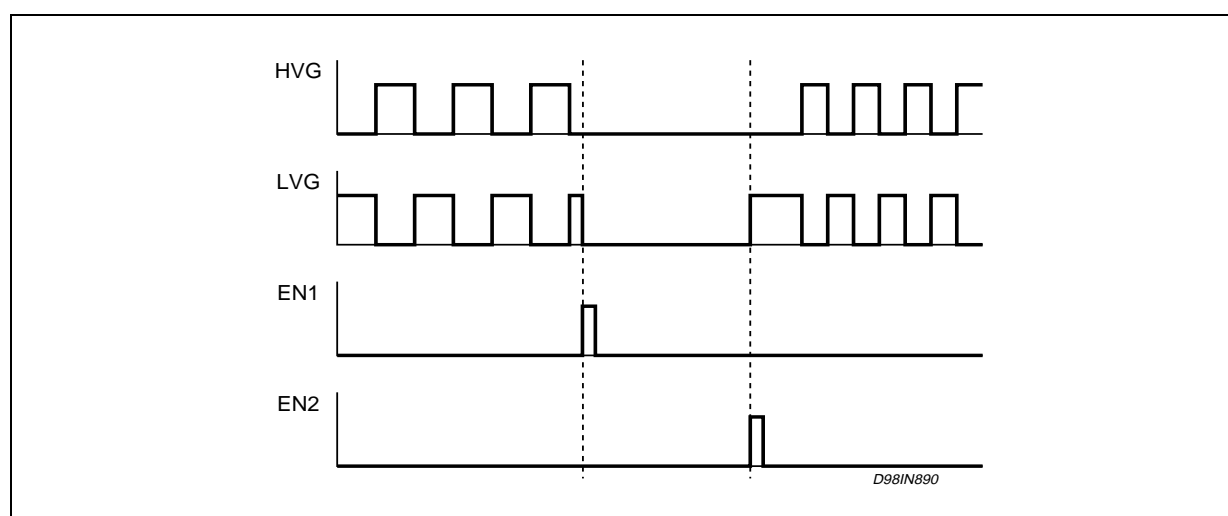
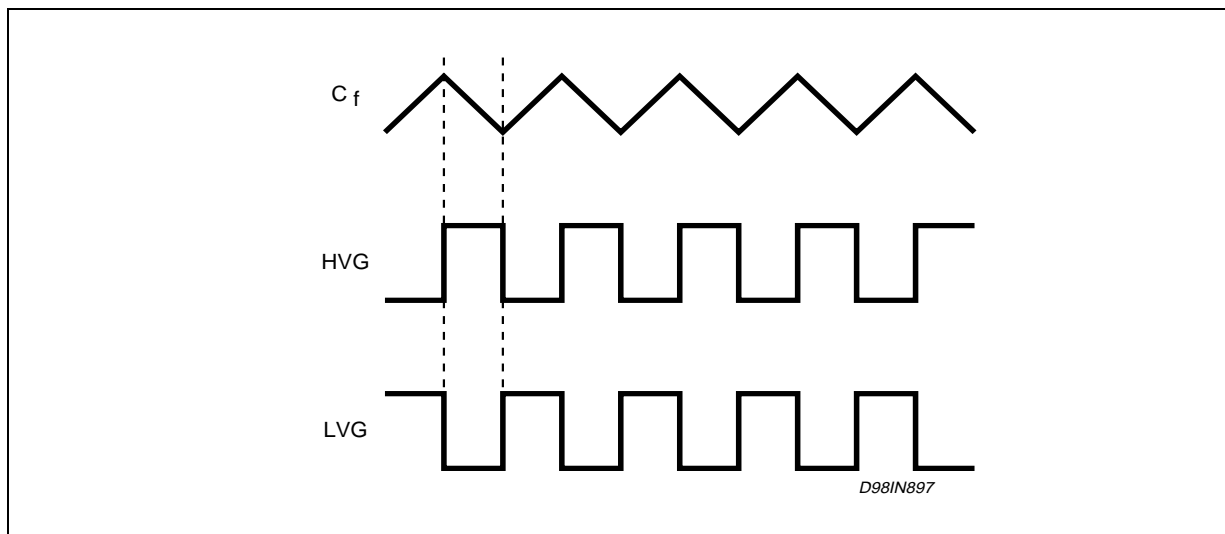


Figure 6. Oscillator/Output Timing Diagram



### 3 BLOCK'S DIAGRAM DESCRIPTION

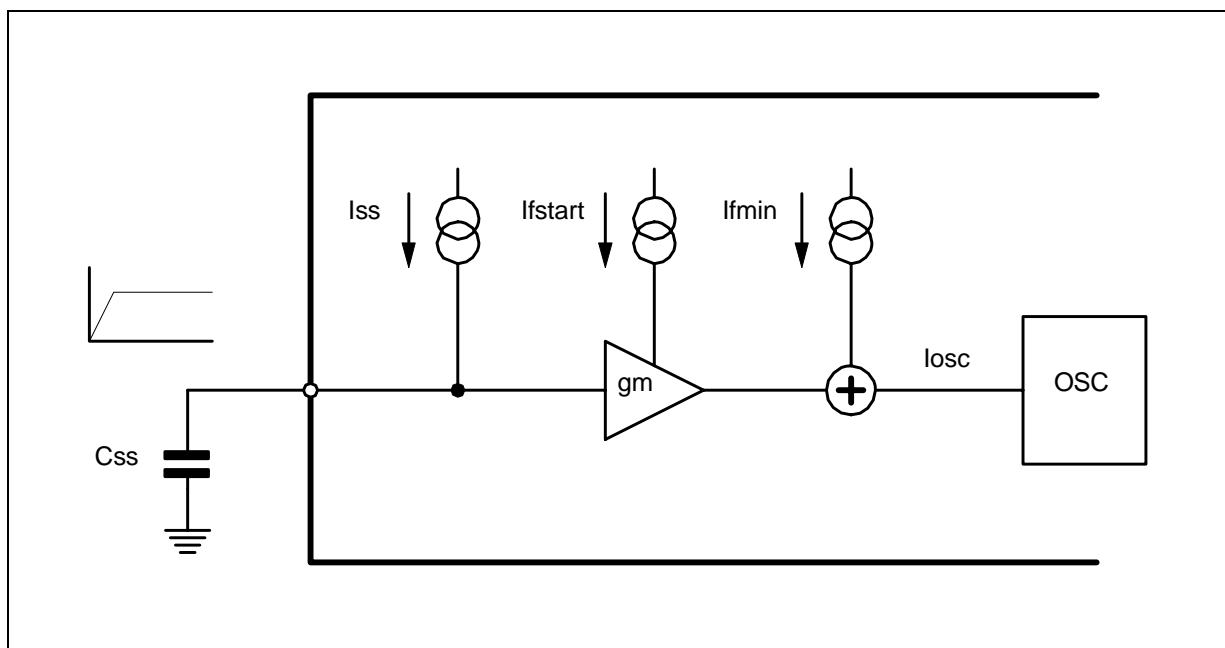
#### 3.1 High/Low Side driving section

An High and Low Side driving Section provide the proper driving to the external Power MOS or IGBT. An high sink/source driving current (450/250 mA typ) ensure fast switching times also when size4 Power MOS are used. The internal logic ensures a minimum dead time to avoid cross-conduction of the power devices.

#### 3.2 Timing and Oscillator Section

The device is provided of a soft start function. It consists in a period of time,  $T_{SS}$ , in which the switching frequency shifts from  $f_{start}$  to  $f_{min}$ . This feature is explained in the following description (ref. fig.7 and fig.8).

Figure 7. Soft Start and frequency shifting block



During the soft start time the current  $I_{SS}$  charges the capacitor  $C_{SS}$ , generating a voltage ramp which is delivered to a transconductance amplifier, as shown in fig. 7. Thus this voltage signal is converted in a growing current which is subtracted to  $I_{fstart}$ . Therefore the current which drives the oscillator to set the frequency during the soft start is equal to:

$$I_{osc} = I_{fmin} + (I_{fstart} - g_m V_{C_{SS}}(t)) = I_{fmin} + \left( I_{fstart} - \frac{g_m I_{SS} t}{C_{SS}} \right) \quad [1]$$

$$\text{where } I_{fmin} = \frac{V_{REF}}{R_{fmin}}, I_{fsart} = \frac{V_{REF}}{R_{fstart}}, V_{REF} = 2V \quad [2]$$

At the start-up ( $t=0$ ) the oscillator frequency is set by:

$$I_{osc}(0) = I_{fmin} + I_{fstart} = V_{REF} \left( \frac{1}{R_{fmin}} + \frac{1}{R_{fstart}} \right) \quad [3]$$

At the end of soft start ( $t = T_{SS}$ ) the second term of eq.1 decreases to zero and the switching frequency is set only by  $I_{min}$  (i.e.  $R_{fmin}$ ):

$$I_{osc}(T_{SS}) = I_{fmin} = \frac{V_{REF}}{R_{fmin}} \quad [4]$$

Since the second term of eq.1 is equal to zero, we have:

$$I_{fstart} - \frac{g_m I_{SS} T_{SS}}{C_{SS}} = 0 \rightarrow T_{SS} = \frac{C_{SS} I_{fstart}}{g_m I_{SS}} \quad [5]$$

Note that there is not a fixed threshold of the voltage across  $C_{SS}$  in which the soft start finishes (i.e. the end of the frequency shifting), and  $T_{SS}$  depends on  $C_{SS}$ ,  $I_{fstart}$ ,  $g_m$ , and  $I_{SS}$  (eq. 5). Making  $T_{SS}$  independent of  $I_{fstart}$ , the  $I_{SS}$  current has been designed to be a fraction of  $I_{fstart}$ , so:

$$I_{SS} = \frac{I_{fstart}}{K} \rightarrow T_{SS} = \frac{C_{SS} I_{fstart}}{g_m I_{fstart} K} \rightarrow T_{SS} = \frac{C_{SS}}{g_m K} \rightarrow T_{SS} = k_{SS} C_{SS} \quad [6]$$

In this way the soft start time depends only on the capacitor  $C_{SS}$ . The typical value of the  $k_{SS}$  constant (Soft Start Timing Constant) is 0.15 s/ $\mu$ F.

The current  $I_{osc}$  is fed to the oscillator as shown in fig. 7. It is twice mirrored (x4 and x8) generating the triangular wave on the oscillator capacitor  $C_f$ . Referring to the internal structure of the oscillator (fig.7), a good relationship to compute an approximate value of the oscillator frequency in normal operation is:

$$f_{min} = \frac{1.41}{R_{fmin} C_f} \quad [7]$$

The degree of approximation depends on the frequency value, but it remains very good in the range from 30kHz to 100kHz (figg.9-13)

Figure 8. Oscillator Block

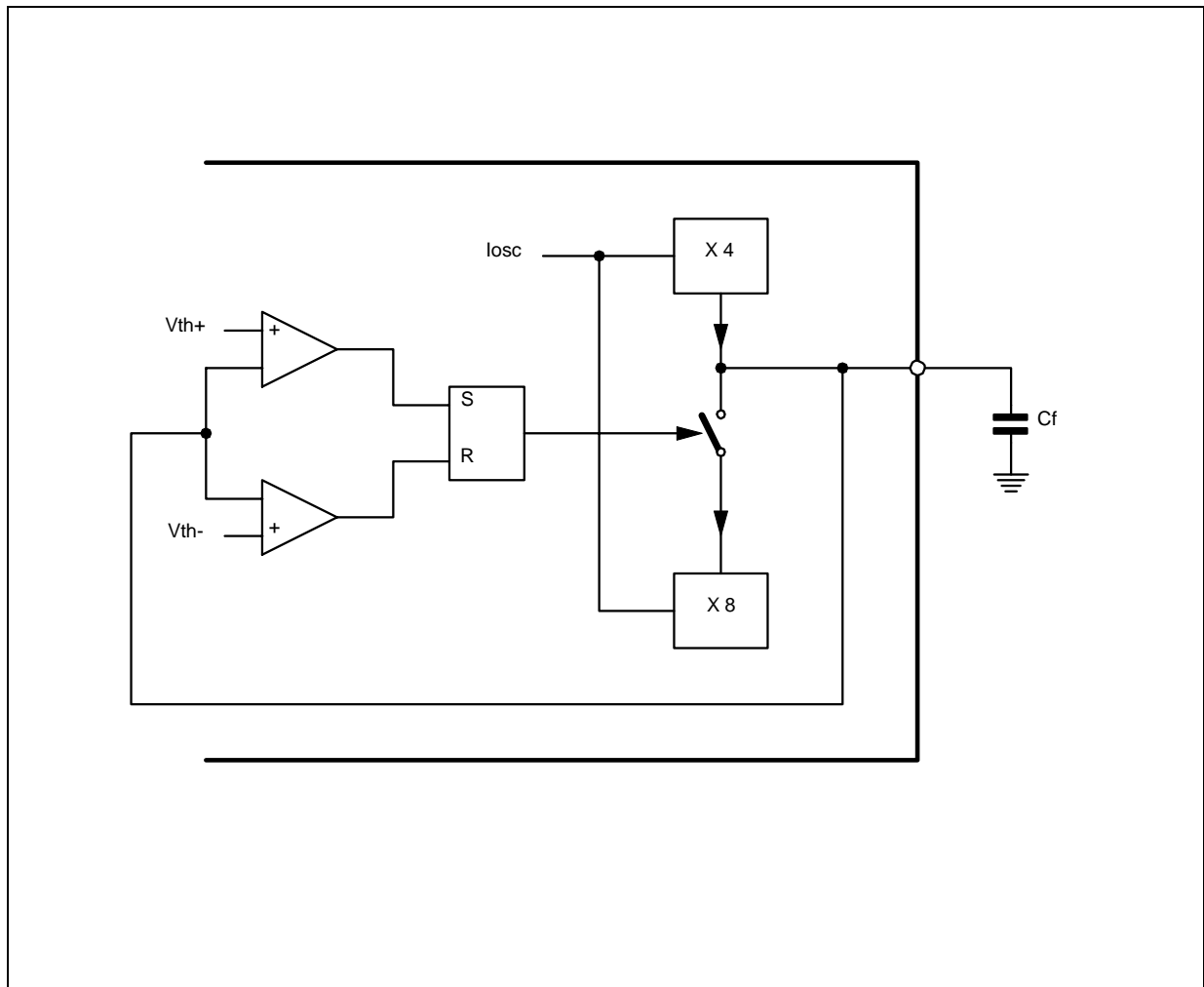




Figure 9. Typ.  $f_{min}$  vs.  $R_{fmin}$  @  $C_f = 470\text{pF}$

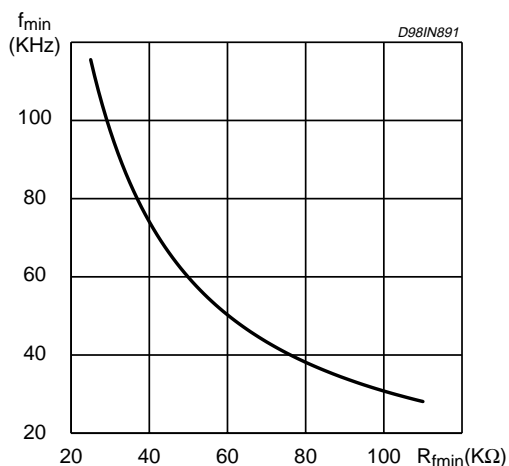


Figure 12. Typ.  $(f_{start}-f_{min})$  vs.  $R_{fstar}$  @  $C_f = 470\text{pF}$

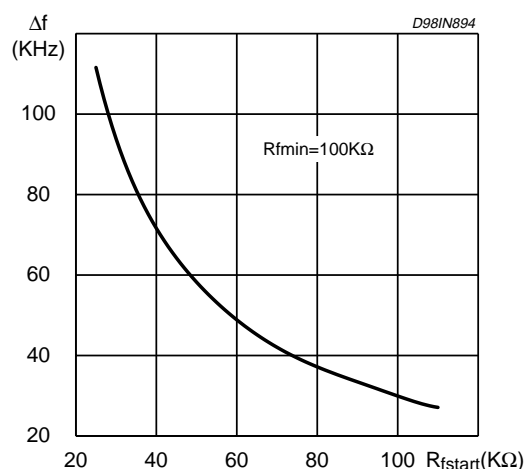


Figure 10. Typ.  $(f_{start}-f_{min})$  vs.  $R_{fstar}$  @  $C_f = 470\text{pF}$

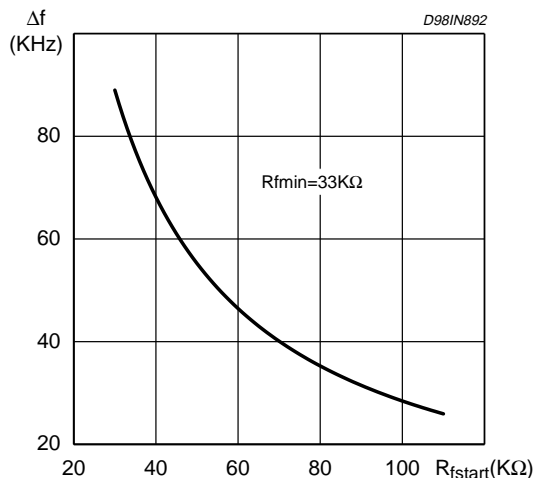


Figure 13.  $f_{min}$  @ different  $R_f$  vs  $C_f$

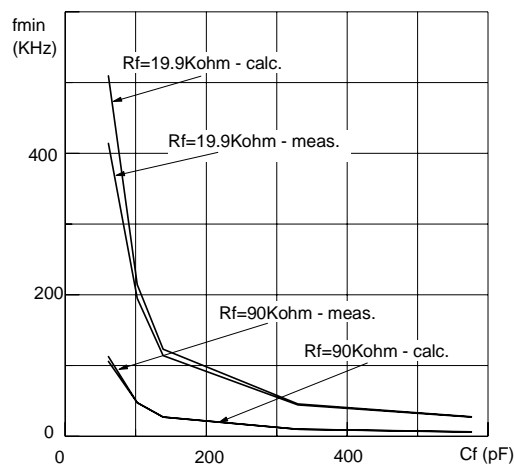
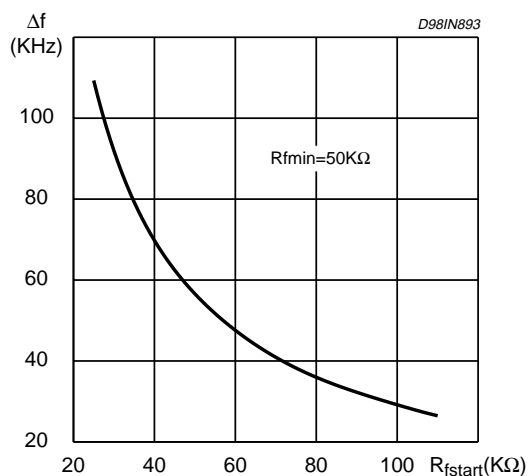


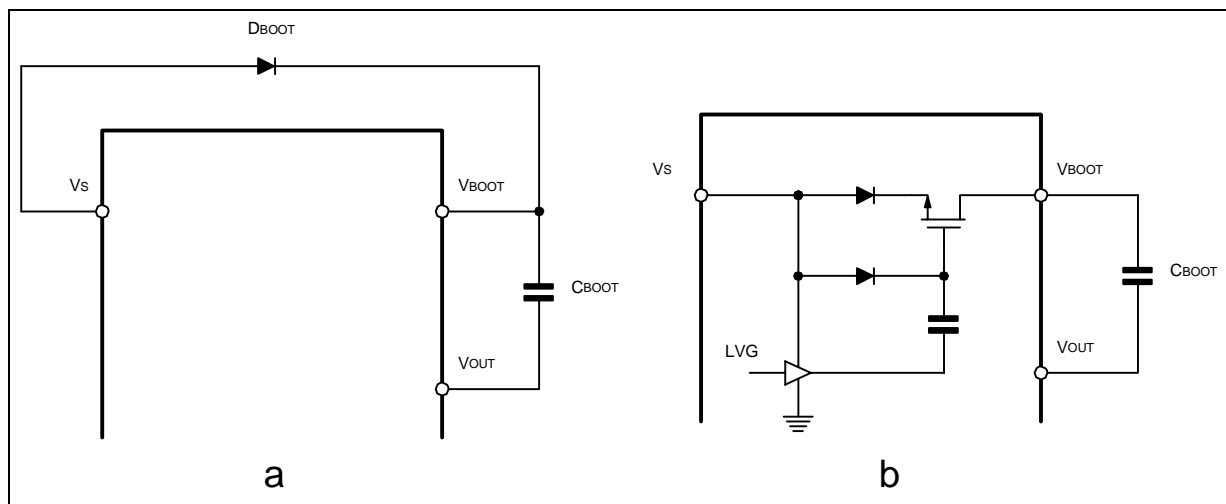
Figure 11. Typ.  $(f_{start}-f_{min})$  vs.  $R_{fstar}$  @  $C_f = 470\text{pF}$



### 3.3 Bootstrap Section

The supply of the high voltage section is obtained by means of a bootstrap circuitry. This solution normally requires a high voltage fast recovery diode for charging the bootstrap capacitor (fig. 14a). In the device a patented integrated structure, replaces this external diode. It is realised by means of a high voltage DMOS, driven synchronously with the low side driver (LVG), with in series a diode, as shown in fig. 14b.

Figure 14. Bootstrap driver



To drive the synchronised DMOS it is necessary a voltage higher than the supply voltage  $V_S$ . This voltage is obtained by means of an internal charge pump (fig. 14b).

The diode connected in series to the DMOS has been added to avoid undesirable turn on of it. The introduction of the diode prevents any current can flow from the  $V_{boot}$  pin to the  $V_S$  one in case that the supply is quickly turned off when the internal capacitor of the pump is not fully discharged.

The bootstrap driver introduces a voltage drop during the recharging of the capacitor  $C_{boot}$  (i.e. when the low side driver is on), which increases with the frequency and with the size of the external power MOS. It is the sum of the drop across the  $R_{DSON}$  and of the diode threshold voltage. At low frequency this drop is very small and can be neglected. Anyway increasing the frequency it must be taken in to account. In fact the drop, reducing the amplitude of the driving signal, can significantly increase the  $R_{DSON}$  of the external power MOS (and so the dissipation).

To be considered that in resonant power supplies the current which flows in the power MOS decreases increasing the switching frequency and generally the increases of  $R_{DSON}$  is not a problem because power dissipation is negligible. The following equation is useful to compute the drop on the bootstrap driver:

$$V_{drop} = I_{charge} R_{dson} + V_{diode} \rightarrow V_{drop} = \frac{Q_g}{T_{charge}} R_{dson} + V_{diode} \quad [8]$$

where  $Q_g$  is the gate charge of the external power MOS,  $R_{dson}$  is the on resistance of the bootstrap DMOS, and  $T_{charge}$  is the time in which the bootstrap driver remains on (about the semiperiod of the switching frequency minus the dead time). The typical resistance value of the bootstrap DMOS is 150 Ohm. For example using a power MOS with a total gate charge of 30nC the drop on the bootstrap driver is about 3V, at a switching frequency of 200kHz. In fact:

$$V_{drop} = \frac{30nC}{2.23\mu s} 150\Omega + 0.6V \sim 2.6V$$

To summarise, if a significant drop on the bootstrap driver (at high switching frequency when large power MOS are used) represents a problem, an external diode can be used, avoiding the drop on the  $R_{DSON}$  of the DMOS.

### 3.4 OP AMP Section

The integrated OP AMP is designed to offer Low Output Impedance, wide band, High input Impedance and wide Common Mode Range. It can be readily used to implement protection features or a closed loop control. For this purpose the OP AMP Output can be properly connected to  $R_{fmin}$  pin to adjust the oscillation frequency.

### 3.5 Comparators

Two CMOS comparators are available to perform protection schemes. Short pulses ( $\geq 200\text{ns}$ ) on Comparators Input are recognised. The EN1 input (active High), has a threshold of 0.6V (typical value) forces the device in a latched shut down state (e.g. LVG Low, HVG low, Oscillator stopped), as in the Under Voltage Conditions. Normal Operating conditions are resumed after a power-off power-on sequence. The EN2 input (active high), with a threshold of 1.2V (typical value) restarts a Soft Start sequence (see Timing Diagrams). In addition the EN2 Comparator, when activated, removes a latched shutdown caused by EN1.

Figure 15. Switching Time Waveform Definitions

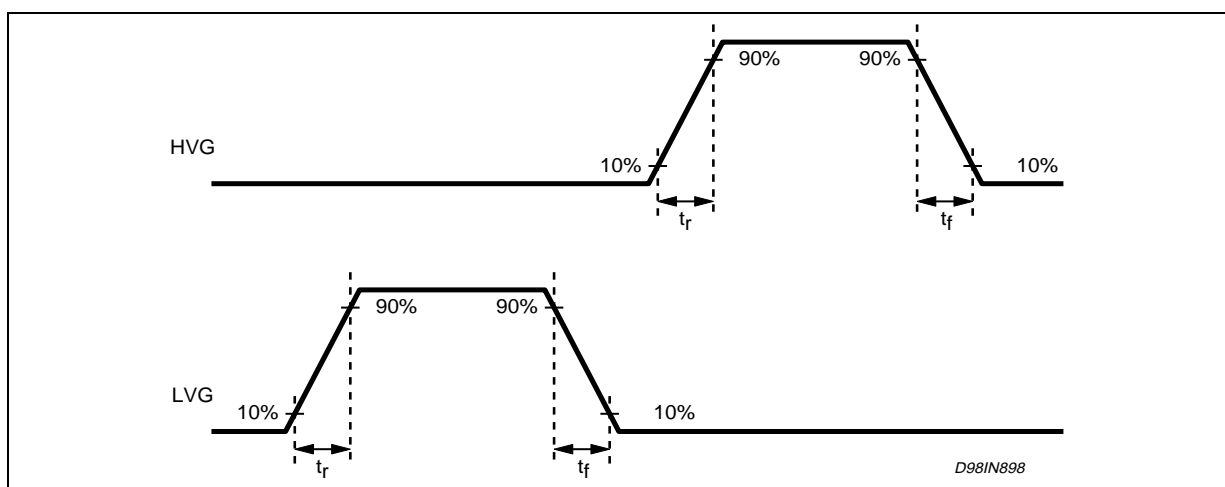


Figure 16. Dead Time and Duty Cycle Waveform Definition

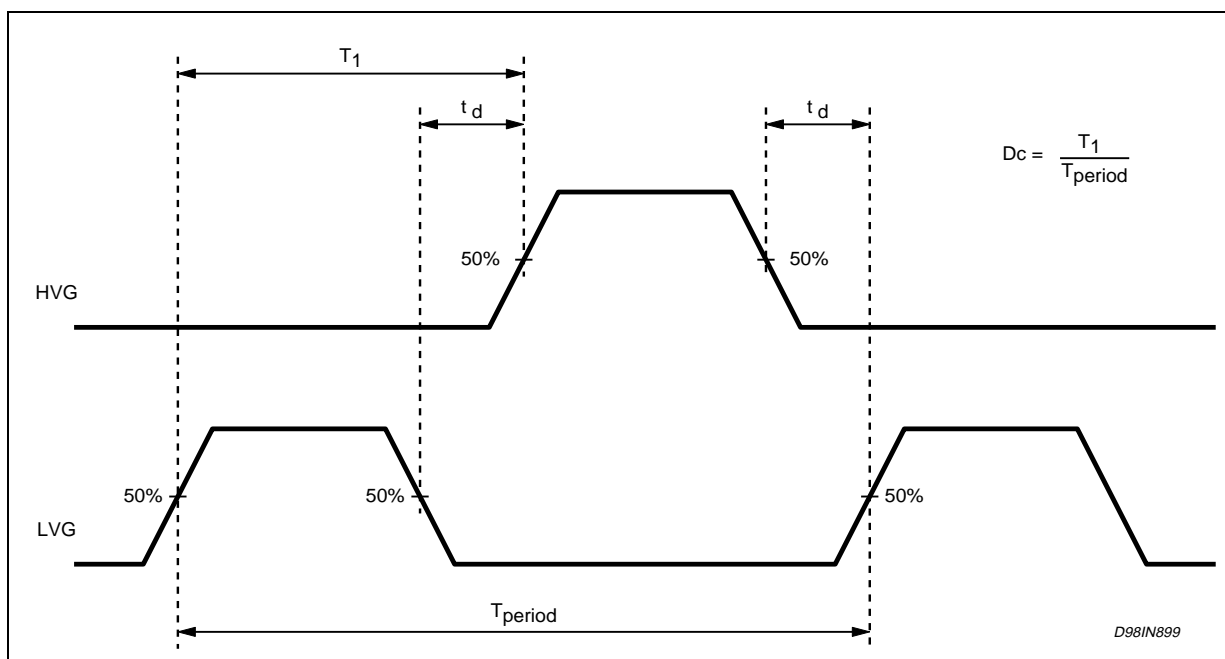


Figure 17. Typ.  $f_{min}$  vs. Temperature

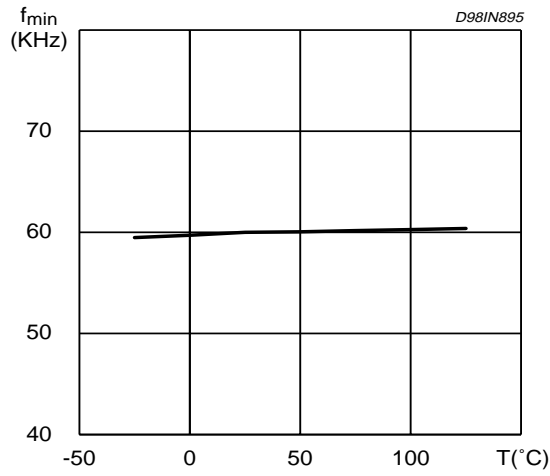


Figure 20. Start Up Current vs Temperature

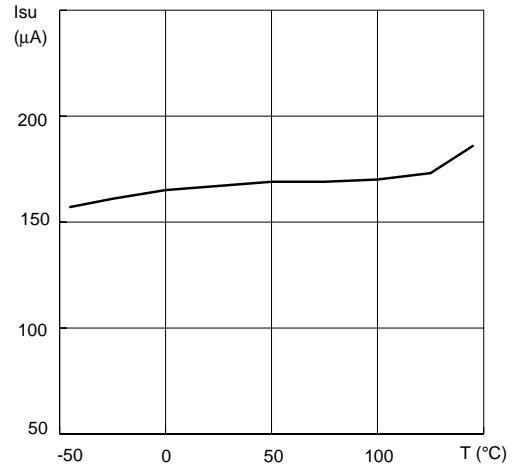


Figure 18. Typ.  $f_{start}$  vs. Temperature

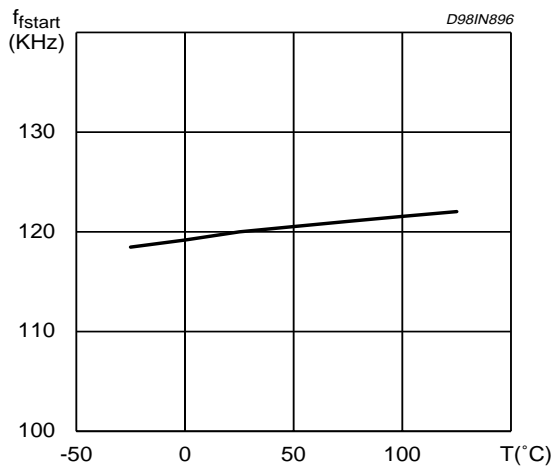


Figure 21. Quiescent Current vs Temperature

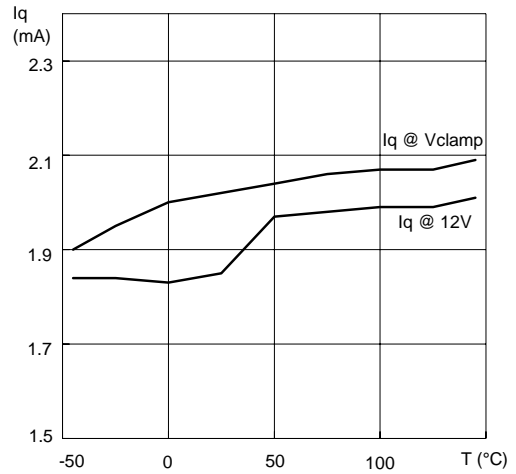


Figure 19.  $V_s$  thresholds and clamp vs temp.

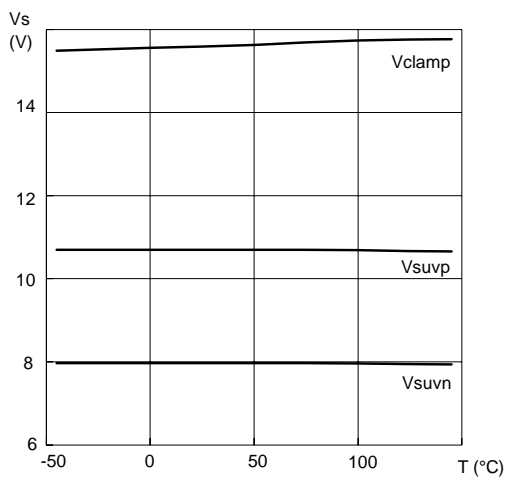
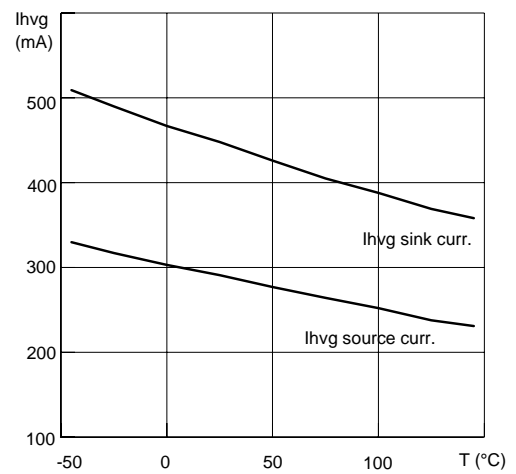
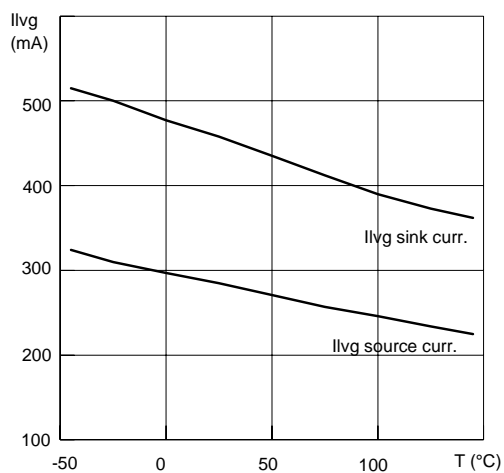


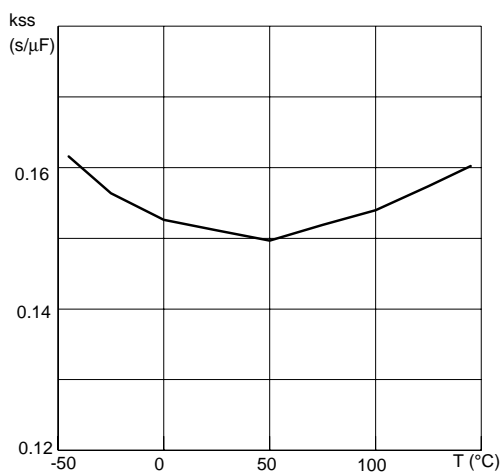
Figure 22. HVG Source and Sink Current vs. Temperature



**Figure 23. LVG Source and Sink Current vs. Temperature**



**Figure 24. Soft Start Timing Constant vs. Temperature**



**Figure 25. Wide Range AC/DC Adapter Application**

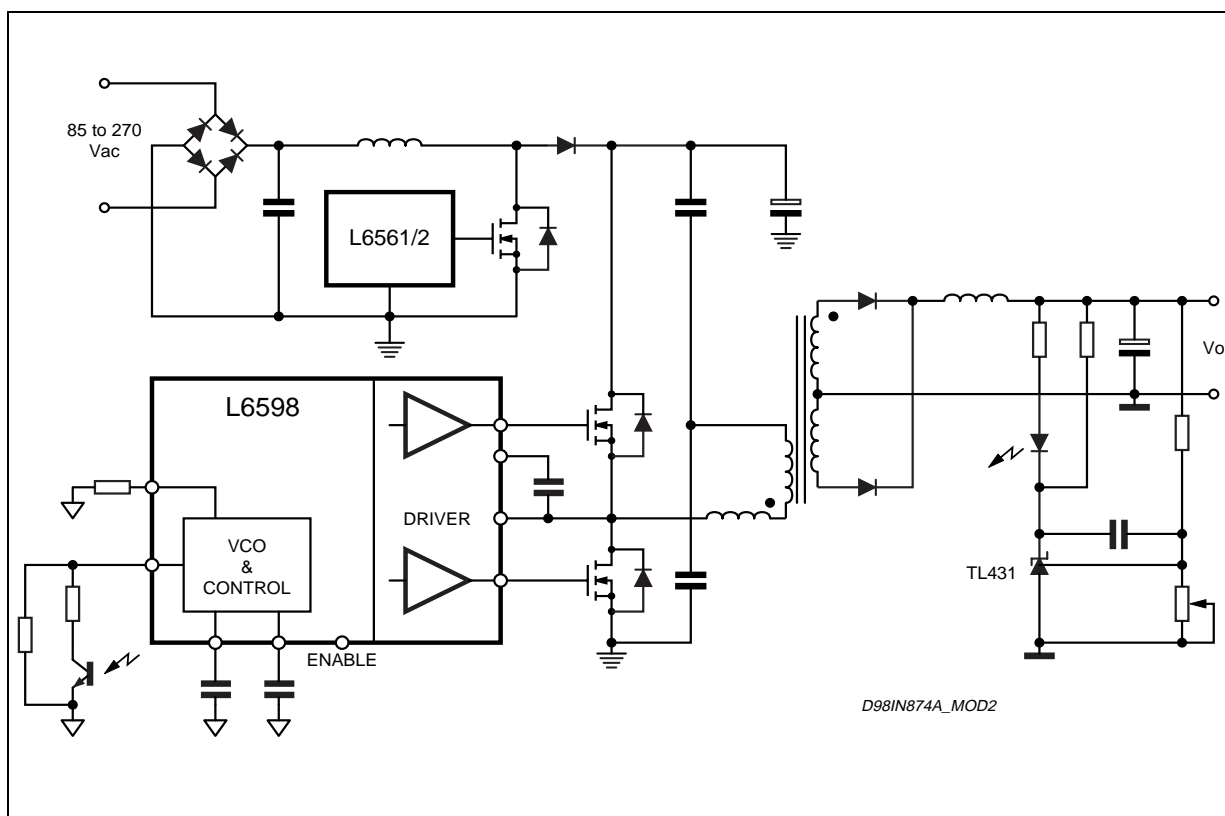
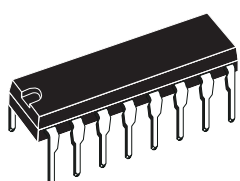


Figure 26. DIP-16 Mechanical Data & Package Dimensions

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	0.77		1.65	0.030		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		17.78			0.700	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z			1.27			0.050

**OUTLINE AND MECHANICAL DATA**



**DIP16**

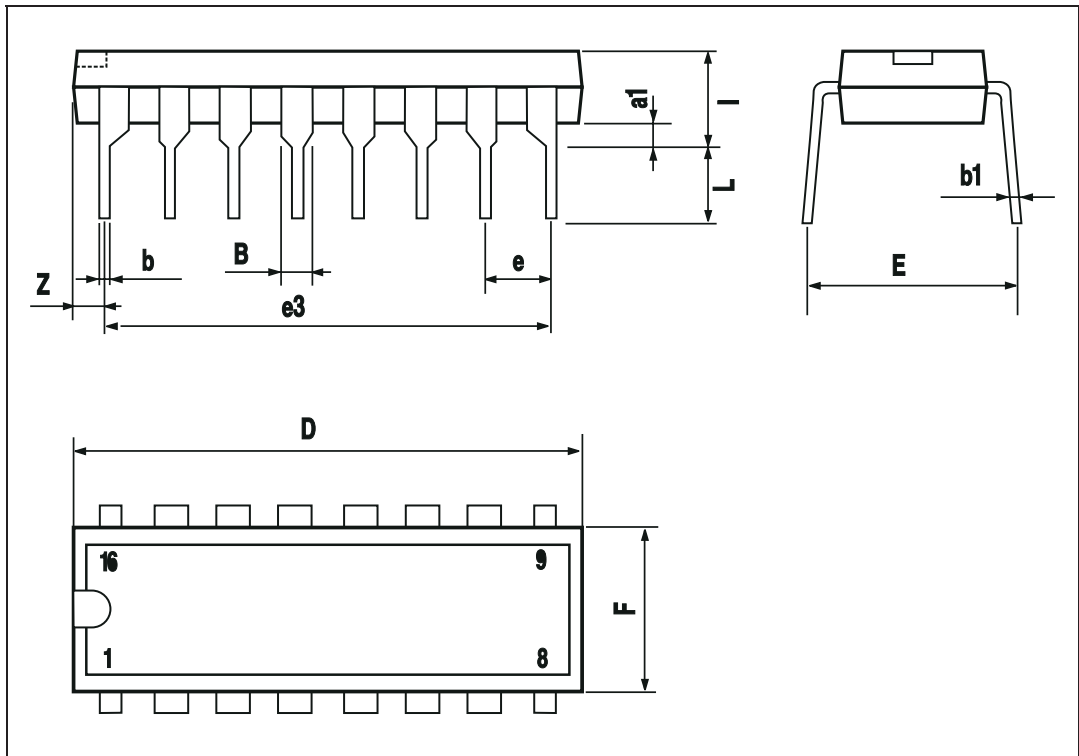
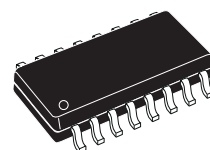


Figure 27. SO-16N Mechanical Data &amp; Package Dimensions

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			1.75			0.069
a1	0.1		0.25	0.004		0.009
a2			1.6			0.063
b	0.35		0.46	0.014		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.020	
c1			45°	(typ.)		
D <sup>(1)</sup>	9.8		10	0.386		0.394
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F <sup>(1)</sup>	3.8		4.0	0.150		0.157
G	4.60		5.30	0.181		0.208
L	0.4		1.27	0.150		0.050
M			0.62			0.024
S	8° (max.)					

(1) "D" and "F" do not include mold flash or protrusions - Mold flash or protrusions shall not exceed 0.15mm (.006inc.)

### OUTLINE AND MECHANICAL DATA



### SO16 (Narrow)

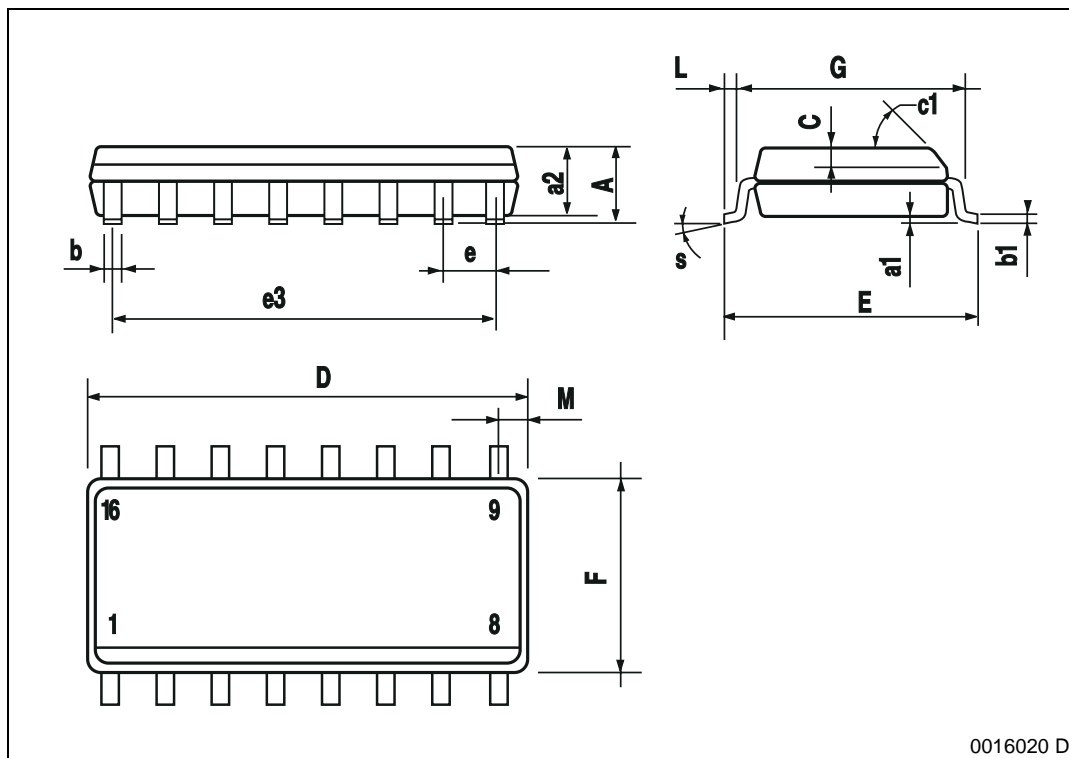


Figure 28. Revision History

Date	Revision	Description of Changes
June 2004	5	Changed the impagination following the new release of "Corporate Technical Pubblication Design Guide". Done a few of corrections in the text.



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