

ON Semiconductor

Is Now

onsemi™

To learn more about onsemi™, please visit our website at
www.onsemi.com

onsemi and **onsemi** and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "**onsemi**" or its affiliates and/or subsidiaries in the United States and/or other countries. **onsemi** owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of **onsemi** product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent-Marking.pdf. **onsemi** reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and **onsemi** makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does **onsemi** assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using **onsemi** products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by **onsemi**. "Typical" parameters which may be provided in **onsemi** data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. **onsemi** does not convey any license under any of its intellectual property rights nor the rights of others. **onsemi** products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use **onsemi** products for any such unintended or unauthorized application, Buyer shall indemnify and hold **onsemi** and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that **onsemi** was negligent regarding the design or manufacture of the part. **onsemi** is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner. Other names and brands may be claimed as the property of others.



Is Now Part of



ON Semiconductor®

To learn more about ON Semiconductor, please visit our website at
www.onsemi.com

ON Semiconductor and the ON Semiconductor logo are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent-Marking.pdf. ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

Application Note AN-9052

Design Guide for Selection of Bootstrap Components

1. Bootstrap Circuit

1.1 Bootstrap Floating Supply

Using a N channel MOSFET as a high side switch requires a voltage supply referenced at the source of the MOSFET. One of the most widely used method in supplying power to the high-side circuitry is the use of the bootstrap floating supply due to its inherent simplicity and inexpensive features. This kind of floating supply is suitable for providing a gate drive circuitry to directly drive high side switches that operate up to rail voltages. The basic circuit of the bootstrap supply, shown in Figure 1, is formed by a diode (Dbs) and a capacitor (Cbs). But, this type of floating supply has limitations on refreshment of Cbs when duty cycle is very high or turn-on time is very long. In the case where the gate voltage is not enough to fully turn-on the MOSFET (Q1), the output of gate drive IC (HO) should be turned-off to prevent the Q1 from operating in high dissipation mode. The optional gate resistor (Rg) is used for the purpose of controlling the turn-on/turn-off time of the Q1, and the bootstrap resistor (Rbs) is used to limit the current and prevent the bootstrap capacitor (Cbs) from overcharging.

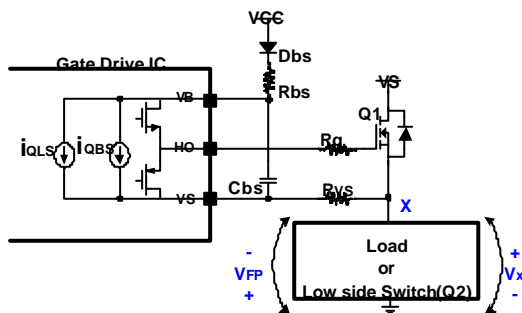


figure 1. Bootstrap Circuit

1.2 Operation of Bootstrap Circuit

The charged capacitor (Cbs) supplies the voltage to the transistors of the gate drive IC, which is used to turn ON and OFF the external high side switch (Q1). The bootstrap capacitor (Cbs) gets charged from the voltage supply (VCC), through the bootstrap diode (Dbs), when the voltage at node X (Vx) is pulled down to ground or even below ground level. The bootstrap capacitor needs to be sized properly to

account for the case when Vx is pulled down to ground, which Vbs is at its lowest level, and cause under voltage lockout (UVLO) malfunction. Most gate drive ICs have undervoltage detection circuit that prevents from driving an external switch when Vbs drops below a certain level (specified in datasheets as VBSUV level). The VBSUV level depends on the external switch that it is driving. The undervoltage level for IGBTs are in the 9V~10V range, and for MOSFETs in the 4V~5V range. In the case where the node X goes below the ground level, Cbs will be overcharged by the level in which it goes negative. There are negative transients at node X caused by the parasitic inductances and peak forward voltage drop (Vfp) of the body diode at the low side switch that needs to be considered also. All of the overcharging affect mentioned above needs to be taken into account in determining the size of Cbs. Adding resistors Rbs, Rvs, and using a diode with a low Vfp value are other possible solutions to limit the overcharge effect on Cbs. Let us now look at the case that causes the Cbs to discharge. Cbs discharges when Q1 turns-on or node X is floating. The associated discharging factors are gate drive power, leakage current in each component, and current consumption in the gate drive IC. From an application point of view, specific conditions such as the duty cycle of PWM that causes ripple voltages on Cbs, operation frequency, and the type of modulation at which Q1 operates needs to be examined to make sure that Cbs can handle.

1.3 Initial Charging and Refreshment of Bootstrap Capacitor

Another key parameter in selecting bootstrap components is initial start-up time. The initial charging time (t_{ch}) can be calculated from the following equation:

$$t_{ch} \geq C_{bs} \times R_T \times \frac{1}{D} \times \ln \left(\frac{V_{cc}}{V_{cc} - V_{bs,Min} - V_f - V_x} \right) \quad (1)$$

Where,

$R_T = R_{bs} + R_{vs}$ (with low side switch and no load)

$R_T = R_{bs} + R_{vs} + R_L$ (with loads including equivalent impedance at node X)

D = duty cycle

In the case where PWM is not used, the load not connected, and the low side switch turned on the charging time at the

start-up phase can be defined by the time constants R_{bs} , R_{vs} , and C_{bs} . When the load is connected and forms the charge path in the bootstrap circuit, the initial charging time is defined by C_{bs} and the relationship between R_{bs} , R_{vs} , and the load impedance R_L . Most designs, the value of C_{bs} is picked with some margins, which leads to longer start-up time. If node X is left floating for a long time, V_{bs} will decrease due to leakage current, and consequently the gate drive IC will go into UVLO condition. Controlling the low side switch properly, the bootstrap capacitor can be recharged and maintain the voltage level needed by the gate drive IC. The gate drive IC FAN7085 (block diagram shown in Fig.2) has a built-in recharge switch that will charge the bootstrap capacitor regardless of the application. If Q1 is turned off and FAN7085 is used as a gate drive IC in the bootstrap circuit shown in Figure 1, the internal recharge switch of the FAN7085 will activate to provide the path to charge the bootstrap capacitor (C_{bs}) fully. Let's look at a specific application of the FAN7085, which is shown in Figure 3. In the event that both of the switch (S1 and S2) are turned off, the internal recharge switch of the FAN7085 will provide the path to charge the bootstrap capacitor. If the current level passing through the recharge switch is higher than the leakage current, bootstrap capacitor will charge through the recharge path. The voltage level on the VS pin of the FAN7085 at a given current level when the recharge switch is turned on is defined on the datasheet.

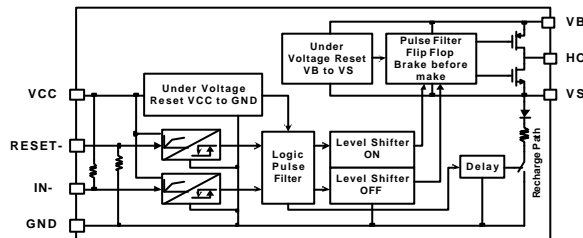


Figure 2. Internal block diagram of FAN7085

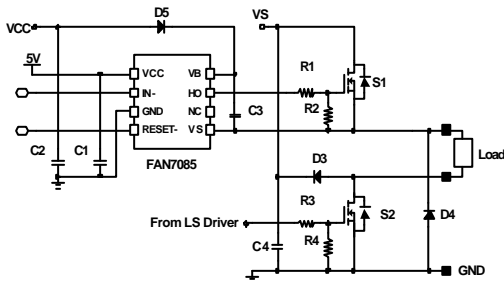


Figure 3. Application example of FAN7085

2. Selection of Bootstrap Components

2.1 Selection of Bootstrap Capacitor

The maximum allowable voltage drop across the bootstrap capacitor to ensure enough gate-source voltage is highly dependent to the internal undervoltage shutdown level of the gate drive IC, and the voltage level at the source connection of Q1 (node X)

$$V_{BS,Drop} = V_{CC} - V_f - V_{OP} - V_X \quad (2)$$

Where:

V_{CC} = gate drive IC supply voltage

V_f = static forward voltage drop of D_{bs}

V_{op} = minimum gate-source voltage level required that will prevent Q1 to go into a high dissipation mode

X = MOSFET source connection

If the minimum operating voltage (V_{OP}) requires to be greater than UVLO voltage level, then equation 2 can be denoted as follows

$$V_{BS,Drop} = V_{CC} - V_f - V_{BSUV,Max} - V_X \quad (3)$$

Where, $V_{BSUV,Max}$ is the maximum UVLO voltage level of gate drive IC.

The total charge (Q_{bs}) required by the bootstrap capacitor can be calculated by summing the Q1 gate charge, charge required for the level shifter in the gate drive IC, and leakage charges resulting from leakage current.

$$Q_{BS} = Q_g + (I_{LK} + I_{QBS}) \times T_{ON} + Q_{LS} \quad (4)$$

Where:

Q_{BS} = total charge from C_{bs}

Q_g = gate charge of Q1

I_{LK} = total leakage current

I_{QBS} = operating current in gate drive IC

T_{ON} = Turning-on interval of Q1

Q_{LS} = level shift charge required per cycle.

The total leakage current is the summation of all of the individual component's leakage currents

$$I_{LK} = I_{LK,GS} + I_{LK,HS} + I_{LK,D} + I_{LK,C} \quad (5)$$

Where,

$I_{LK,GS}$ = gate leakage current of the MOSFET

$I_{LK,HS}$ = high side floating supply leakage current

$I_{LK,D}$ = bootstrap diode leakage current

$I_{LK,C}$ = capacitor leakage current, which can be ignored if it is not an electrolytic capacitor

The guiding criteria for calculating the minimum required bootstrap capacitance can be obtained through the following equation:

$$C_{bs,Min} \geq \frac{Q_{BS}}{V_{BS,Drop}} \quad (6)$$

Equation 6 is a basic equation for calculating the minimum value for the bootstrap capacitor. It uses the value of $V_{bs,Drop}$, which is the minimum operating voltage required and does not account for the any margins. The margin that is needed is to compensate for the ripple voltage on V_{bs} by the PWM, and the overcharging due to negative transients at node X. It implies that $V_{bs,Drop}$, should be changed to a smaller value, $V_{bs,Min}$. In regards to the ripple voltage compensation, the value of V_{BSUVH} is assigned to $V_{bs,Min}$, in calculating the bootstrap capacitor.

$$C_{bs,Min} \geq \frac{Q_{BS}}{V_{BS,Min}} = \frac{Q_{BS}}{V_{BSUVH}} \quad (7)$$

Where V_{BSUVH} is hysteresis voltage of UVLO in gate drive IC. The minimum bootstrap capacitance calculated in Equation 7 might need to account for additional margin depending on the specific application conditions. Conditions at node X, such as long floating state and negative transients with deep and long duration needs to be accounted for. Using the FAN7085, unlike other gate drive ICs, the long floating state of node X does not need to be accounted for when calculating the minimum bootstrap capacitor value ($C_{bs,Min}$). The internal recharge switch of the FAN7085 (pin VS) provides a path to charge the bootstrap capacitor when S1 and S2 are turned off.

2.2 Selection of Bootstrap Diode

The maximum voltage rating should be higher than power rail (VS) and current rating can be multiplication of total charge and switching frequency. A diode with a fast reverse recovery time is beneficial to minimize the leakage current.

3. Examples of Bootstrap Capacitor Selection

3.1 Example 1

The basic operation conditions are:

- Gate drive IC: FAN7080
- Switching device: FDB8442
- Bootstrap diode: MMBD1405
- Switching frequency: 20KHz
- System operating voltage: $V_{cc}(9 \sim 16V)$, $V_S(38V)$

The known values from the datasheets are:

- $I_{QBS} = 150\mu A$
- $Q_{LS} = 3nC$ (assumed in fairchild 600V Gate drive IC)
- $I_{LK_GS} = 100nA$
- $I_{LK_HS} = 50\mu A$
- $I_{LK_D} = 100nA$
- $V_F = 1.1V$
- $I_{LK_C} = 0$
- $V_{OP} = 5.5V$ (is equal to V_{BSUV+})
- $Q_g = 235nC@80A, V_{gs} = 10V$
- $R_{DS,ON(Max)} = 5m\Omega$
- R_{bs} and R_{vs} are not used.

The voltage drop is calculated as:

$$\begin{aligned} V_{BS,Drop} &= V_{CC} - V_f - V_{OP} - V_X \\ &= V_{CC,Min} - 1.1V - V_{BSUV,Max} - R_{DS,ONmax} \times I_{OUT} \\ &= 9 - 1 - 5.5 - 0.4 = 2.0V \end{aligned}$$

The leakage current is calculated as:

$$\begin{aligned} I_{LK} &= I_{LK,GS} + I_{LK,HS} + I_{LK,D} + I_{LK,C} \\ &= 100nA + 50\mu A + 100nA + 0 \\ &= 50.2\mu A \end{aligned}$$

The total charged required is calculated as:

$$\begin{aligned} Q_{BS} &= Q_g + (I_{LK} + I_{QBS}) \times T_{ON} + Q_{LS} \\ &= 235nC + (50.2\mu A + 150\mu A) \times 50\mu Sec + 3nC \\ &= 235nC + 10nC + 3nC = 248nC \end{aligned}$$

The minimum capacitor value needed to prevent UVLO condition is calculated as

$$C_{BS,Min} = \frac{Q_{BS}}{V_{BS,Drop}} = \frac{248nC}{2.0V} = 124nF$$

The minimum capacitor value with a margin taken into account (explained in sec 2.1) is calculated as:

$$C_{BS} \geq \frac{Q_{BS}}{V_{BSUVH}} = \frac{248nC}{0.2V} = 1.2\mu F$$

Depending on the specific operating conditions additional margins needs to be accounted for in calculating the minimum required capacitor value.

3.2 Example 2

The basic operating conditions are:

- Gate drive IC: FAN7085
- Switching device: FDB42AN15A0
- Bootstrap diode: MMBD1405
- Switching frequency: 50KHz
- System operating voltage: $V_{cc}(7 \sim 16V)$, $V_S(130V)$

The known values from the datasheets are:

- . IQBS = 200uA
- . QLS = 3nC
- . ILK_GS= 100nA
- . ILK_HS=200uA
- . ILK_D = 100nA
- . VF = 1.1V
- . ILK_C = 0
- . VOP = 4.3V(is equal to VBSUV+)
- . Qg. = 39nC@12A, Vgs=10V
- . RDS,ON(Max) = 107mohm
- . Rbs and Rvs are not used.

The voltage drop is calculated as:

$$\begin{aligned} V_{BS,Drop} &= V_{CC} - V_f - V_{OP} - V_X \\ &= V_{CC,Min} - 1.1V - V_{BSUV,Max} - R_{DS,ONmax} \times I_{OUT} \\ &= 7 - 1.1 - 4.3 - 1.3 = 0.3V \end{aligned}$$

The leakage current is calculated as:

$$\begin{aligned} I_{LK} &= I_{LK,GS} + I_{LK,HS} + I_{LK,D} + I_{LK,C} \\ &= 100nA + 200uA + 100nA + 0 \\ &= 200.2uA \end{aligned}$$

The total charged required is calculated as:

$$\begin{aligned} Q_{BS} &= Q_g + (I_{LK} + I_{QBS}) \times T_{ON} + Q_{LS} \\ &= 39nC + (200.2uA + 200uA) \times 50uSec + 3nC \\ &= 39nC + 20nC + 3nC = 62nC \end{aligned}$$

The minimum capacitor value needed to prevent UVLO condition is calculated as:

$$C_{BS,Min} = \frac{Q_{BS}}{V_{BS,Drop}} = \frac{62nC}{0.3V} = 200nF$$

The minimum capacitor value with a margin taken into account (when allowable voltage drop is set to VUVBSH, explained in sec 2.1) is calculated as:

$$C_{BS} \geq \frac{Q_{BS}}{V_{BSUVH}} = \frac{62nC}{0.02V} = 3.1uF$$

The initial charging time when S1 and S2 are turned off is calculated as:

$$\begin{aligned} t_{CH} &\geq 5 \times (R_{Recharge} \times C_{BS}) \\ &= 5 \times (500ohm \times 3.1uF) \\ &= 7.75mSec \end{aligned}$$

Where, Recharge is the equivalent series resistance of the switch when the switch is turned on.

DISCLAIMER

FAIRCHILD SEMICONDUCTOR RESERVES THE RIGHT TO MAKE CHANGES WITHOUT FURTHER NOTICE TO ANY PRODUCTS HEREIN TO IMPROVE RELIABILITY, FUNCTION, OR DESIGN. FAIRCHILD DOES NOT ASSUME ANY LIABILITY ARISING OUT OF THE APPLICATION OR USE OF ANY PRODUCT OR CIRCUIT DESCRIBED HEREIN; NEITHER DOES IT CONVEY ANY LICENSE UNDER ITS PATENT RIGHTS, NOR THE RIGHTS OF OTHERS.

LIFE SUPPORT POLICY

FAIRCHILD' S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF FAIRCHILD SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which,
 - (a) are intended for surgical implant into the body, or
 - (b) support or sustain life, or
 - (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

ON Semiconductor and  are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent-Marking.pdf. ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:

Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303-675-2175 or 800-344-3860 Toll Free USA/Canada
Fax: 303-675-2176 or 800-344-3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800-282-9855 Toll Free
USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81-3-5817-1050

ON Semiconductor Website: www.onsemi.com
Order Literature: <http://www.onsemi.com/orderlit>
For additional information, please contact your local
Sales Representative