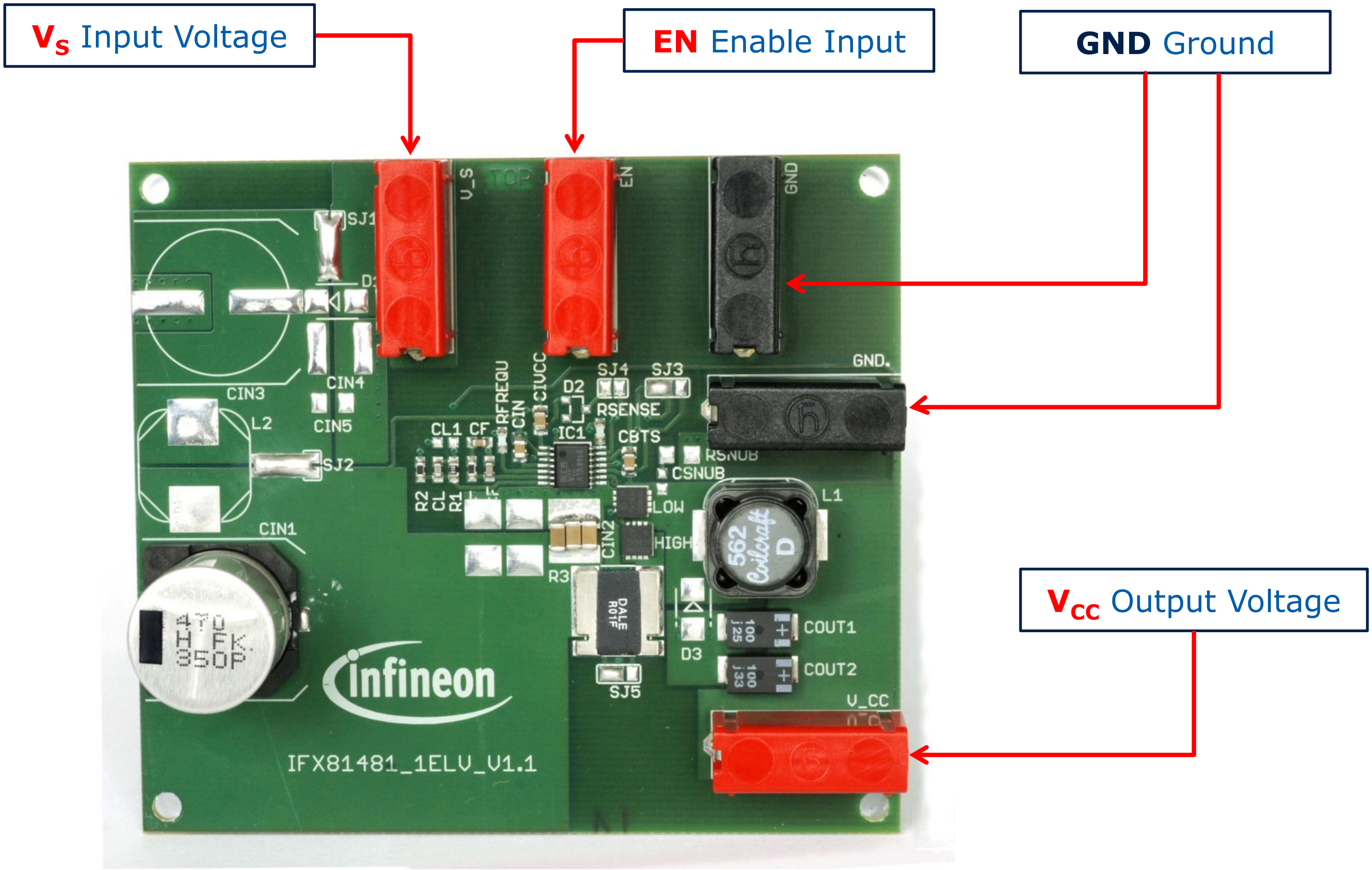
IFX81481 DEMO Board

DC/DC Step Down Controller User Guide

Board Overview and Quick Start

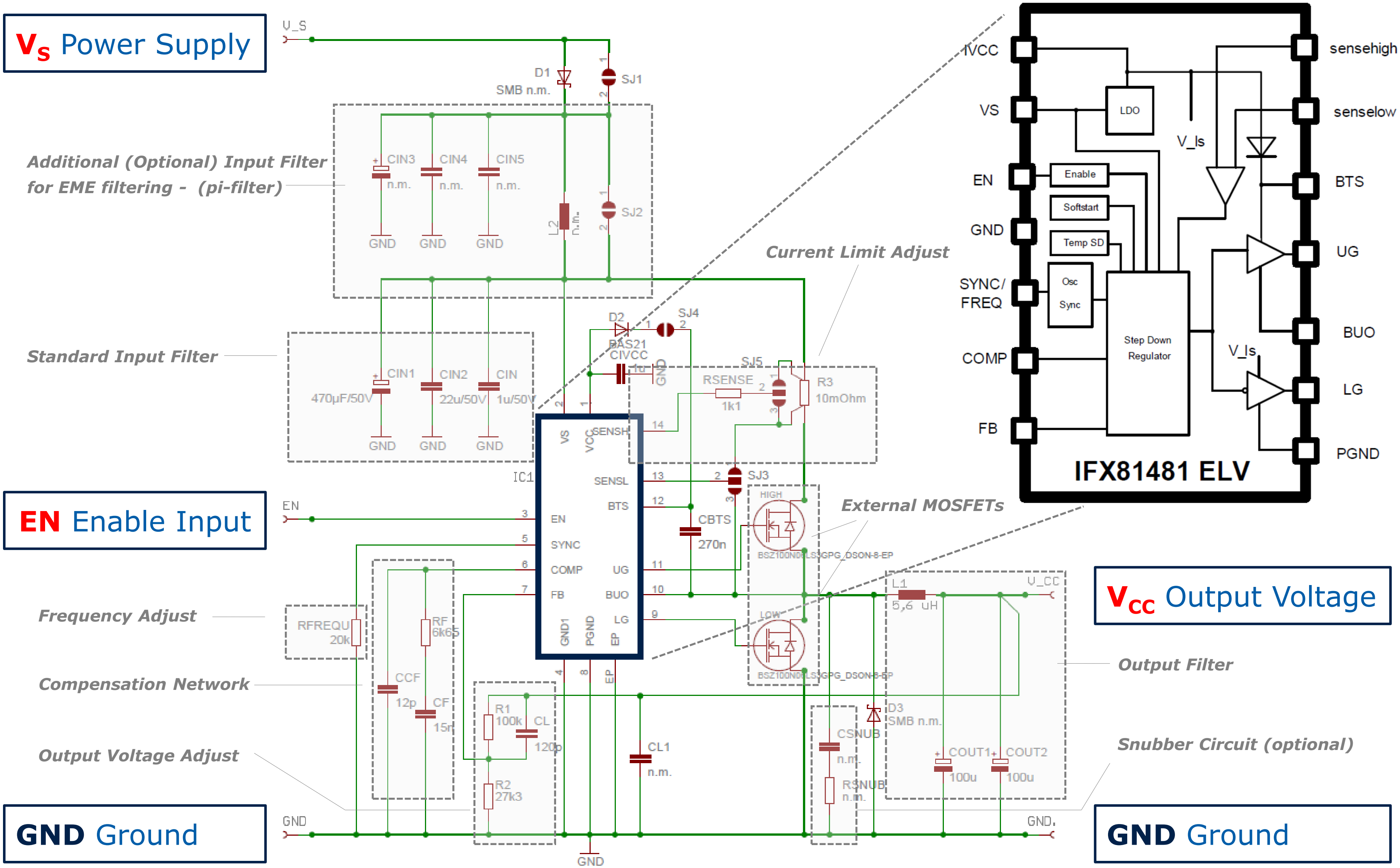


Quick Start

- Connect **GND** to Ground
- Connect **V_S** to the Voltage Supply
  - Functional Range V_S : 4.75V to 45V
  - Absolute Maximum Rating V_S: -0.3V to 45V
- Connect **V_{CC}** to the load
  - The IFX81481ELV is an adjustable output voltage device
  - Functional Output Voltage Adjust Range: $1.2V \leq V_{CC} \leq V_S$
  - On this evaluation board the output voltage is pre-adjusted to ~5.6V.
  - For other output voltages the resistor values R_1 and R_2 of the voltage devider on the board need to be adapted correspondingly.
  - Absolute Maximum Rating for the BUO pin of the controller: -2V to 45V
  - Note that the maximum rating for V_{CC} on the evaluation board will be limited in addition by voltage rating of the chosen output capacitor(s). In the assembled BOM this is 6.3V. For higher output voltages output capacitors with higher voltage rating have to be used!
- Set **EN** to high level or connect to **V_S** **to start the board**
  - Absolute Maximum Rating EN: -20V to 45V

Note: Do NOT exceed the Absolute Maximum Ratings!

Board Schematics and Controller Block Diagram

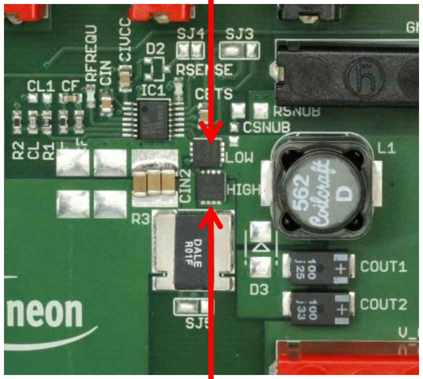


Main Building Blocks of the Demo Board

- External MOSFET Power Stage
  - The selection of optimum MOSFET switches is key for efficiency and performance of the DC/DC converter.
  - The ideal choice may depend on the operation conditions of the converter, like switching frequency f_{SW}, load current, V_{IN}–to–V_{OUT} ratio, etc
  - Main target of MOSFET choice is to keep power losses at the lowest level. The main contributors are :
    - Switching Losses: $P_{DIS,SW} \sim C_{GS}\, f_{SW}\, V_{GS}^2$ (C_{GS}: Gate-Source capacitance, f_{SW}: switching frequency)
    - Conduction losses: $P_{DIS,Cond} \sim R_{DSON}\, I^2$ (R_{DSON}: Drain-Source resistance in ON-state)
  - **Hints:**
    - Choose low R_{DSON} MOSFETs.
    - Look for Gate Charge Characteristics (Q_{gs},Q_{gd}) to obtain low capacitance of MOSFET and thus optimized switching losses.
    - Keep in mind to balance switching vs conduction losses according to the application conditions (e.g. load current, switching frequency):
      - Oversizing MOSFET lowers R_{DSON} but might add switching loss penalties at higher frequencies.
      - Switching Losses are independent of load current and thus may dominate under light load conditions.
    - Use MOSFETs with low parasitic inductance for enhanced efficiency.
    - Logic Level MOSFETs are required for usage with the IFX81481.

Infineon MOSFET's provide ideal solutions to ensure high efficient DC/DC conversion!

Low-Side MOSFET



High-Side MOSFET

Main Building Blocks of the Demo Board

- Bootstrap Components
  - Bootstrap Capacitor
    - The bootstrap capacitor C_{BTS} is mandatory and needs to be placed between the pins BTS and BUO.
    - The bootstrap capacitor is charging the gate of the High-Side MOSFET for switching it properly.
    - C_{BTS} must be sufficiently dimensioned – if C_{BTS} is dimensioned too small bootstrap undervoltage lockouts may occur. Such events may increase unwanted output voltage ripple.

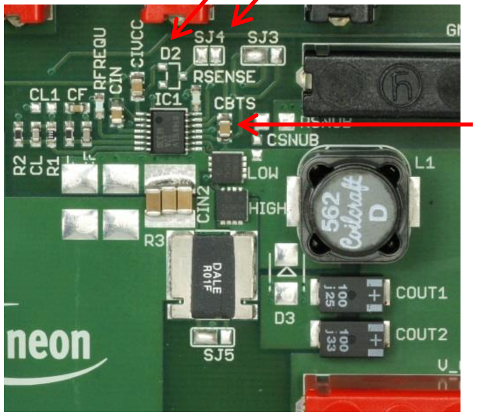
Note:

In case of operating the device at very high dutycycles (e.g. very small V_{IN}-to-V_{OUT} ratio) also a maximum limit of C_{BTS} may apply: For operation close to 100% dutycycle the off-time of the High-Side MOSFET might not be big enough to fully charge the capacitor C_{BTS} and thus causing increased output voltage ripple. If such operation conditions need to be covered the usage of a bootstrap diode (see below) is recommended.

  - Bootstrap Diode
    - The usage of a bootstrap diode (D2) is optional.
    - The bootstrap diode supports the internal diode that recharges the bootstrap capacitor C_{BTS}.
    - It is only needed for very high dutycycle operation to avoid an increase of output voltage ripple if C_{BTS} is not sufficiently charged anymore by the internal diode under such extreme conditions.
    - The usage of bootstrap D2 is foreseen on this Demo Board but D2 is not assembled.
    - If the bootstrap diode is used (soldered) also the jumper SJ4 must be set accordingly (closed) on the board.

Footprint for bootstrap diode D2

Jumper SJ4 to activate D2

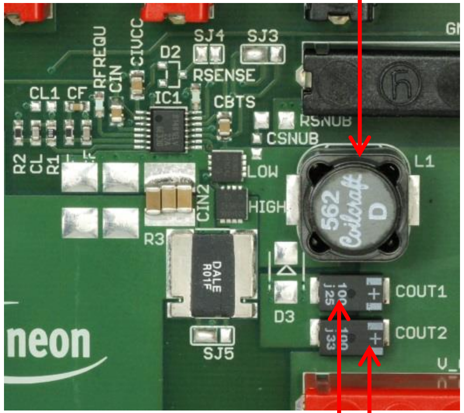


Bootstrap Capacitor C_{BTS}

Main Building Blocks of the Demo Board

- **Output Filter Inductor L_{OUT}**
  - The inductor L_{OUT} is driving the current during the Off-Time of the High-Side MOSFET.
  - Thus L_{OUT} determines the Output Current Ripple ΔI_{ripple} according to the equation (1)
  - It is key that the inductor does never get into saturation under any operation condition!
    - The saturation value of the inductor needs to be safely above the nominal load current.
    - 50% of $I_{OUT,ripple}$ adds up to the nominal (average) output current when considering saturation current.
    - The selected current limit of the controller must be lower than the saturation current of the inductor!
  - The magnitude of the inductor correlates with the switching frequency that is required to ensure a desired current ripple. A higher frequency can allow a smaller inductor and vice versa.
  - When choosing L_{OUT} and C_{OUT} it needs to be taken care that the resonant frequency of the filter f_{RES} - as given in equation (2) - stays well below the applied switching frequency f_{SW}. As a rule of thumb the resonant frequency should fall between 1 and 10kHz (lower is better, ideally ~ 2kHz)

Output Filter Inductor L_{OUT}



Output Filter Capacitors C_{OUT}

$$(1) \qquad \Delta I_{ripple} = \frac{(V_{IN} - V_{OUT})V_{OUT}}{L_{OUT}\, f_{SW}\, V_{IN}}$$

$$(2) \qquad f_{RES} = \frac{1}{2\pi\sqrt{L_{OUT}\; C_{OUT}}}$$

Main Building Blocks of the Demo Board

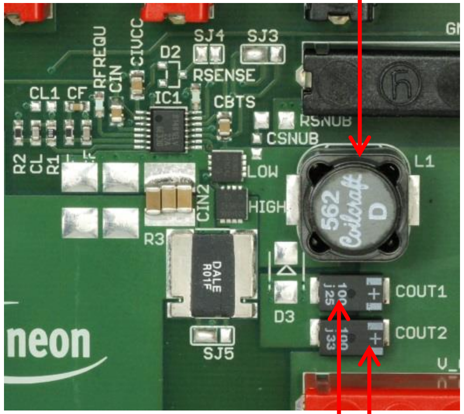
Output Filter Capacitor C_{OUT}

- The capacitor C_{OUT} buffers the output voltage at V_{CC}.
- Thus C_{OUT} determines the Output Voltage Ripple ΔV_{ripple} according to the equation (3)

$$(3) \qquad \Delta V_{ripple} = \Delta I_{ripple}\left(\frac{1}{8\, C_{OUT}\, f_{sw}} + R_{ESR}\right)$$

- To optimize Output Voltage Ripple and as well transient response behaviour C_{OUT} should be low-ESR:
  - ESR (C_{OUT}) ideally should be < 50mΩ
  - ESR (C_{OUT}) should NEVER exeed 300mΩ
  - An additional low ESR ceramic capacitor can be placed in parallel to C_{OUT}.
  - Output Capacitance of 33µF to 120µF will be sufficient for many applications. Bigger values improve ripple and transient response behaviour.
  - On the present board C_{OUT} is split to two individual capacitors of each 100µF in parallel. This additionally lowers the effective ESR.

Output Filter Inductor L_{OUT}

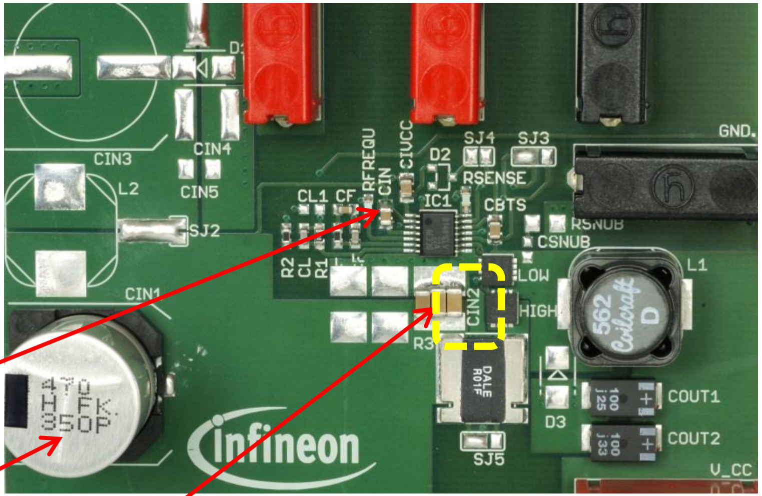


Output Filter Capacitor C_{OUT}

Main Building Blocks of the Demo Board

Input Filter Capacitor (C_{IN})

- The usage of an Input Capacitor is mandatory!
- C_{IN} however may be split into multiple individual capacitors.
- On this demo board many individual capacitors are applied at 3 locatations:
  - C_{IN}: 1µF ceramic cap – needs to be placed directly at pin V_S!
  - C_{IN1}: 470µF buffer cap: buffers voltage ripple on the input line – can be electrolytic type.
  - C_{IN2}: **low ESR ceramic capacitor(s)** blocking drain of H-Side MOSFET to GND. The location of this capacitor(s) of this needs to be chosen with care in order to keep the current path as short as possible (indicated by yellow dashed loop)! On this board 3 individual capacitors of 10µF each are applied in parallel.
- Optional a pi-filter can be placed at the input (see later) to improve EMC performance. Not assembled in standard configuration.



Note1:
C_{IN2} can also be realized by two or three smaller capacitors placed in parallel to optimize ESR.

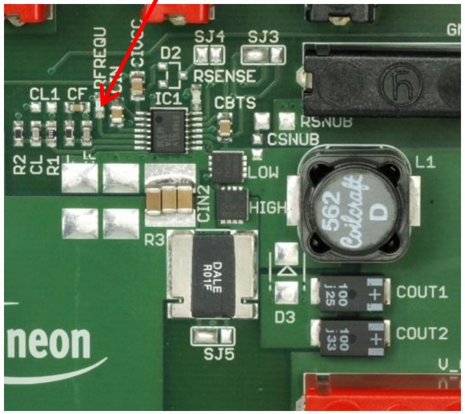
Note2:
In conjunction with C_{IN} at pin V_S also an additional small ceramic capacitor (10-220nF) to supress high frequency conducted disturbances can be placed in parallel. On the present board a 10nF capacitor in additionis stacked above the 1µF C_{IN}.

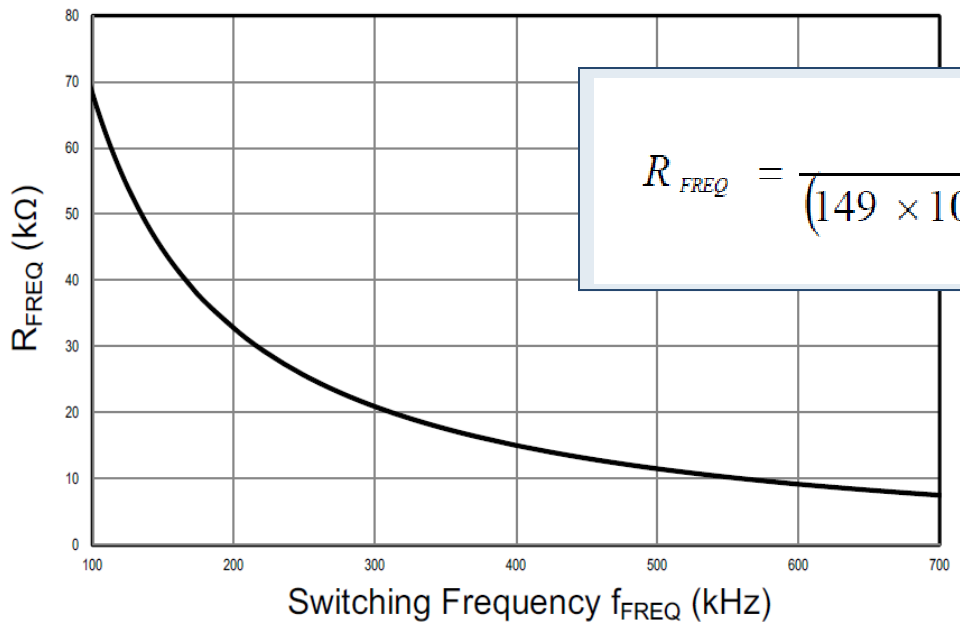
Main Building Blocks of the Demo Board

Frequency Adjust

- The switching frequency of the IFX81481 can be adjusted by the external resistor R_{freq} connected to the SYNC/FREQ pin.
- The adjustable frequency of the internal oscillator ranges from 100kHz to 700kHz.
- The Demo Board is pre-adjusted to ~ 305kHz (R_{freq}= 20kΩ). The calculation formula is given below.

Frequency Adjust Resistor R_{freq}

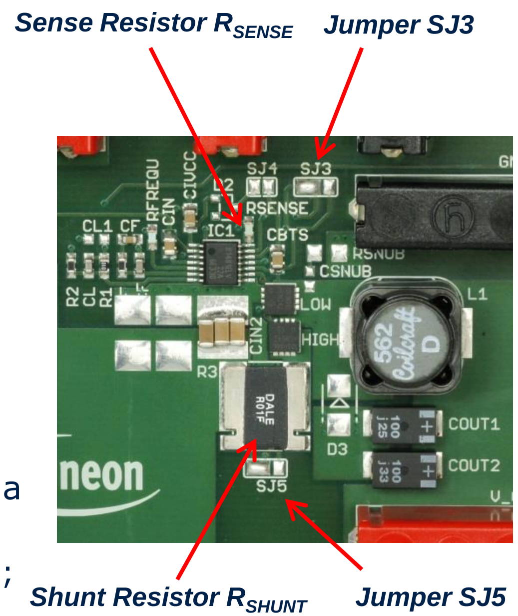




$$R_{FREQ} = \frac{1}{\left(149 \times 10^{-12}\left[\frac{s}{\Omega}\right]\right) \times \left(f_{FREQ}\left[\frac{1}{s}\right]\right)} - \left(2.0 \times 10^{3}[\Omega]\right)[\Omega]$$

Note:
Alternatively to adjusting the switching frequency with an external resistor between SYNC/FREQ pin and ground an external clock signal can be directly fed to this pin. In this way the Controller will be synchronized to the external clock signal. This option can be used for frequency sources from 350kHz up to 700kHz.

Main Building Blocks of the Demo Board



Current Limit

- The IFX81481 ensures overcurrent limit by sensing the current in the high-side path.
- The overcurrent limit can be adjusted by varying the sense resistor R_{SENSE} (on the board 1.1kΩ).
- two alternative sense configurations are available to the user: **Shunt-** and **RDSON** configuration.
- In a overcurrent situation the IFX81481 will cut the „On"-pulses of HS-Switch from the nominal dutycycle to reduce the operation current.
- **Shunt-Configuration**: the sense resistor forms a voltage divider with a shunt resistor in the high-side current path.
  - This is the pre-adjusted configuration of the demo board (SJ5: 1-2 closed; SJ3: 1-2 closed)
  - A resistor R_{SHUNT} needs to be placed at the drain of the HS-MOSFET. (On the board 10mΩ are used → I_{limit} ~ 10.5A)
  - The Shunt Configuration is recommended if a precise current limit is required over temperature.
- **R_{DSON}-Configuration**: here the shunt resistor is „replaced" by the resistance of the MOSFET in „on"-state R_{DSON}. (SJ5: 2-3 closed, SJ3: 2-3 closed)
  - Naturally in this configuration the current limit is less precise and dependent on the choice of the MOSFET (note that R_{DSON} is a function of temperature!)
  - RDSON configuration is recommended for trading off highest efficiency against a more accurate and temperature independent current limit. In this configuration no additional resistance needs to be placed in the current path.
  - Less cost of BOM as R_{SHUNT} is not required.

$$I_{limit,\,SHUNT} = \frac{I_{OC\,lim\,ref} \cdot R_{SENSE}}{R_{SHUNT}}$$

$$I_{limit,\,RDSON} = \frac{I_{OC\,lim\,ref} \cdot R_{SENSE}}{R_{DSON}}$$

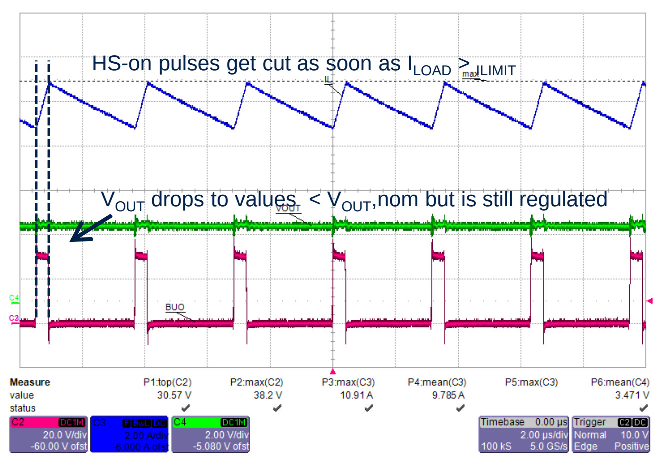
Main Building Blocks of the Demo Board

Current Limit (cont‘d, cases)

- **IFX81481 in *normal* operation under overload** : if under normal operation (no short circuit) a load requests higher current than the adjusted current limit.
  - the nominal „ON"-pulses of HS-Switch will be cut to lower the effective dutycycle and limit the current to lower values.
  - As a consequence next to the load current also the output voltage will be lower than the nominal V_{OUT}.
  - Picture below shows the IFX81481 in current limitation: periodically the High-Side-On pulses get cut when $I_{load} > I_{limit}$; under these conditions will be lower than the nominal value ($V_{OUT} < V_{OUT,nom}$) but still V_{OUT} is regulated.
- **IFX81481 in *current limitation* under short-circuit condition**: if short circuit to GND at output is present.
  - Again HS-MOSFET is switched of after current limit is exceeded
  - Due to the short circuit to GND at the output V_{OUT} drops to values below the undervoltage lockout of the controller (V_{OUT} < 60% of $V_{OUT,nom}$) and the controller is switches off the current to protect the load.
  - After being switched of the controller tries to restart with its softstart functionality. The softstart is performed during 512 clockcycles (f_{SW}).
  - After 25% of the softstart clocks have elapsed a new undervoltage condition can be detected and if short to GND persists the controller is switching off the current again. After the full 512 clock cycles elapsed a new softstart is triggered.
  - The sequence explained above is periodically repeated as long as the short circuit condition is present at the output.

Example:

Current limitation in overload condition

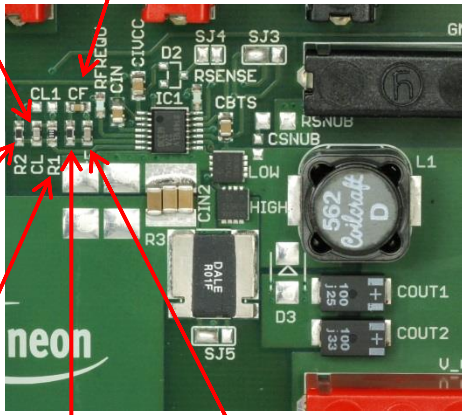


Main Building Blocks of the Demo Board

- **Compensation Network**
  - The compensation network consists of two capacitors (C_{CF} & C_F) and one resistor (R_F).
  - The compensation network is connected to the COMP pin and is mandatory for regulation loop stability.
  - The compensation network is required to compensate the switching ripple on the feeback line.
  - The compensation network needs to be adapted to the specific application. The values used on the board are chosen to to provide phase margin over a wide operation range.

Capacitor C_L (120nF)

Capacitor C_F (15nF)



Resistor R_2

Resistor R_1

Resistor R_F **(6.65kΩ)**

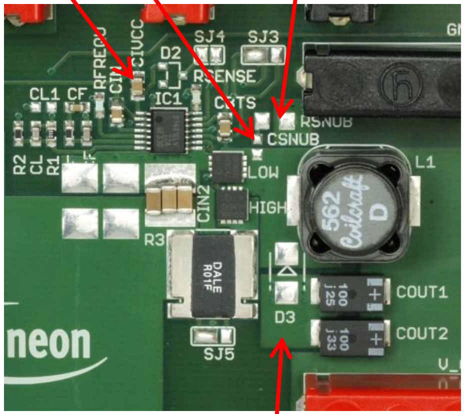
Capacitor C_{CF} (12pF)

- **Feedback Voltage Divider**
  - A voltage divider from V_{OUT} to GND is used to adjust the desired output voltage. The middle of the devider is connected to the FB pin of the IFX81481.
  - The calculation of V_{OUT} as a function of R1 and R2 of the voltage divider given in equation on the right.
  - For very high input voltages and high I_{OUT} a small ceramic capacitor C_L (120nF) can be placed between V_{OUT} and FB inparallel to R1 in order to improve noise rejection as well as line- and load regulation. In the present standard configuration this part is not assembled.

$$V_{OUT} = V_{FB}\,(1 + \frac{R1}{R2})$$

$$V_{FB} = 1.2V$$

Main Building Blocks of the Demo Board



Snubber Circuit

- The possibilty to place a snubber circuit is foreseen on the board. For normal operation the snubber is not required – it is not assembled in standard configuration
- The Snubber R-C-filter can help to damp oscillations at the switching node if this should be needed
- The snubber circuit is optional and in order to optimize efficiency should be only used if it is required by the application

Freewheeling Diode

- The possibilty to place a freewheeling diode is foreseen on the board. For normal operation a freewheeling diode is not required and it is not assembled in standard configuration
- A freewheeling diode can be a beneficial option for very high currents and high input voltage to optimize efficiency – the freewheeling diode will assist the body diode of the low side MOSFET during any dead-time of the MOSFET switching.

Internal voltage regulator

- The IFX81481 has an internal linear regulator that supplies the low-side gate drives (typ 5.4V) and via a diode the high side driver as well.
- An external output capacitor C_{IVCC} (1µF, ceramic) is required at the IVCC pin for the loop stability of the internal voltage regulator.
- The current capability of the internal regulator is 50mA. For very high input voltages of the IFX81481 also the power dissipation of the internal regulator needs to be taken into account and a sufficient cooling via PCB ensured for the IC.

Main Building Blocks of the Demo Board

- Pi-Filter (optional):
  - In addition to the input capacitors described earlier also an Input Filter Inductor L_{IN} can be mounted. This is recommended whenever a low pass filter at the input is advisable.
  - In addition to L_{IN} also additional footprints for further input filter capacitors C_{IN3}, C_{IN4}, C_{IN5} are provided. In conjunction with C_{IN}, C_{IN1}, C_{IN2} as well as L_{IN} they form a pi-filter for enhanced EME and EMI performance.
  - In standard configuration the input filter inductor L_{IN} as well as the pi-filter is not assembled.
  - a recommendation for these filter elements is listed on the right.
  - In addition the footprint for a diode protecting from reverse current is available – a diode can be mounted if it should be required.
  - For the usage of additional filter elements as well as of the reverse polarity diode the Jumpers SJ1 and SJ2 need to be set accordingly (both: open; standard configuration both closed: diode and pi-filter bypassed).

Footprints for further input filter elements

L_{IN}, C_{IN3}, SJ_2 ,C_{IN5}, C_{IN4}, SJ_1

Recommendation:

For a very bassic pi-filter the following values can be used

- $L_{IN} = L_{OUT}$
- $C_{IN3} = C_{IN1}$
- $C_{IN4} = C_{IN2}$
- $C_{IN5} = C_{IN}$

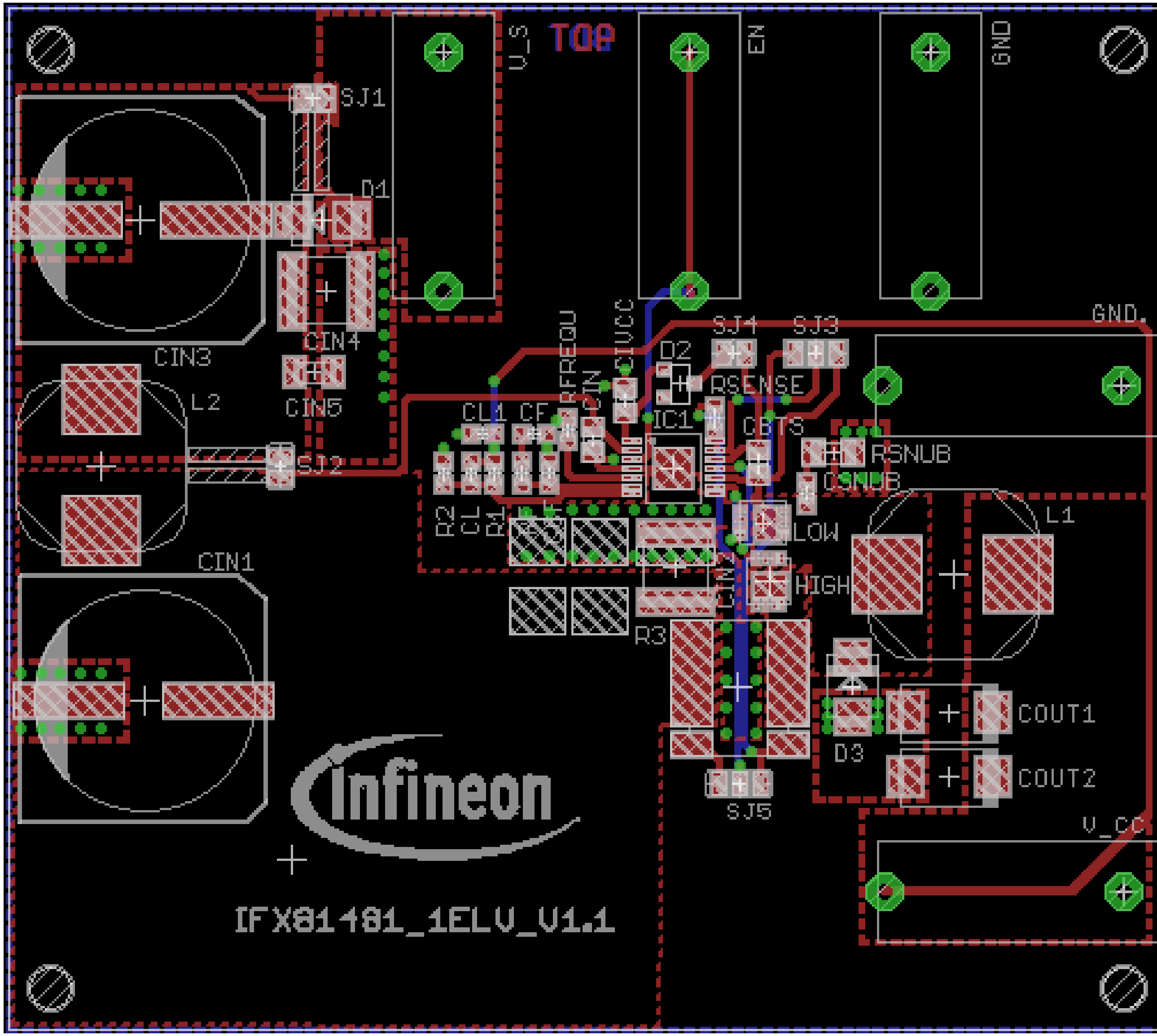
Bill of Material

- BOM

Part	Description	Value	Type	Manufacturer	Quantity
IC1	Buck Controller	10A synchronous	TLF51801ELV	Infineon	1
L1	Inductor	5.6µH	MSS1278-562ML	COILCRAFT	1
HIGH, LOW	N-MOSFET	N-CH, 60V, 10mΩ	BSZ100N06LS3GP G	Infineon	2
COUT1, COUT2	Capacitor, Poly Al, 6.3V, low ESR	100µF	6SW100M	Rubycon	2
CIN	Capacitor, X7R	1µF/50V	C0805C105K5RACTU	Kemet	1
CIN (stacked)	capacitor, X7R	100nF/50V	C0805C104K5RACTU	Kemet	1
CIN1	Capacitor, Al, 50V	470µF/50V	EEVFKH471M	Panansonic	1
CIN2 (parallel)	Capcitor, X5R	10µF/50V	GRM31CR61H106KA12L	Murata	3
RFREQU	Resistor, +/- 1%, 0.1W	20kΩ	ERJ3EKF2002V	Panasonic	1
R1	Resistor, +/- 1%, 0.1W	100kΩ	ERJ3EKF1003V	Panasonic	1
R2	Resistor, +/- 1%, 0.1W	27.3kΩ	ERJ3EKF2742V	Panasonic	1
RF	Resistor, +/- 1%, 0.1W	6.65kΩ	ERJ3EKF6651V	Panasonic	1
RSENSE	Resistor, +/- 1%, 0.1W	1.1kΩ	ERJ3EKF1101V	Panasonic	1
RSHUNT	Resistor, +/1.1%, 3W	10mΩ	VISHAYWSL363	Vishay Dale	1
CCF	Capacitor, COG	12pF	C0603C120J5GACTU	Kemet	1
CL	Capacitor, COG	120pF	C0603C121J5GACTU	Kemet	1
CF	Capacitor, X7R, 50V	15nF	C0603C153J5GACTU	Kemet	1
CIVCC	Capacitor, X7R, 16V	1µF	C1206C105K4RACTU	Kemet	1
CBTS	Capacitor, X7R, 50V	330nF	C0805C334K5RACTU	Kemet	1

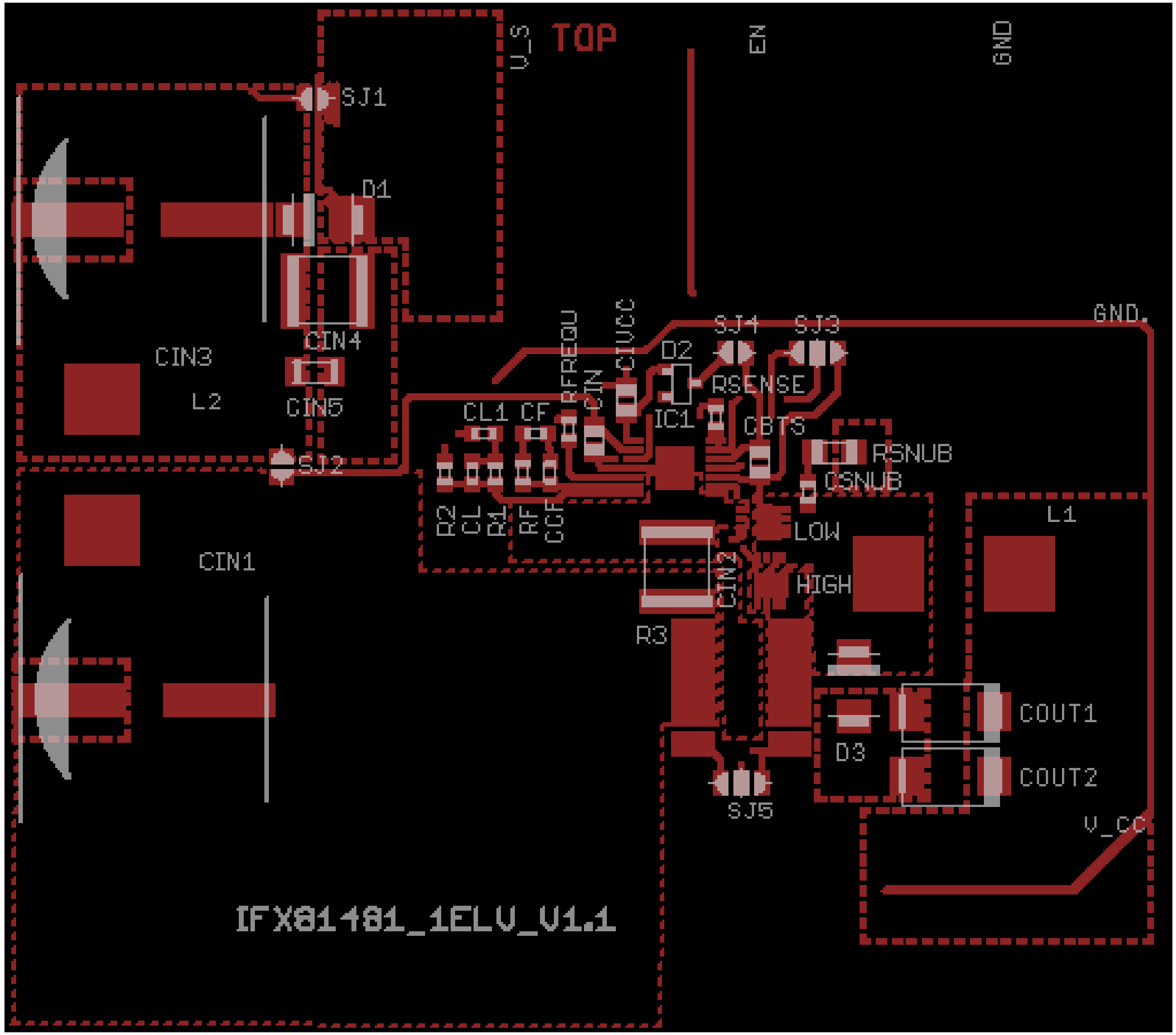
Appendix - Layout

- AllLayer



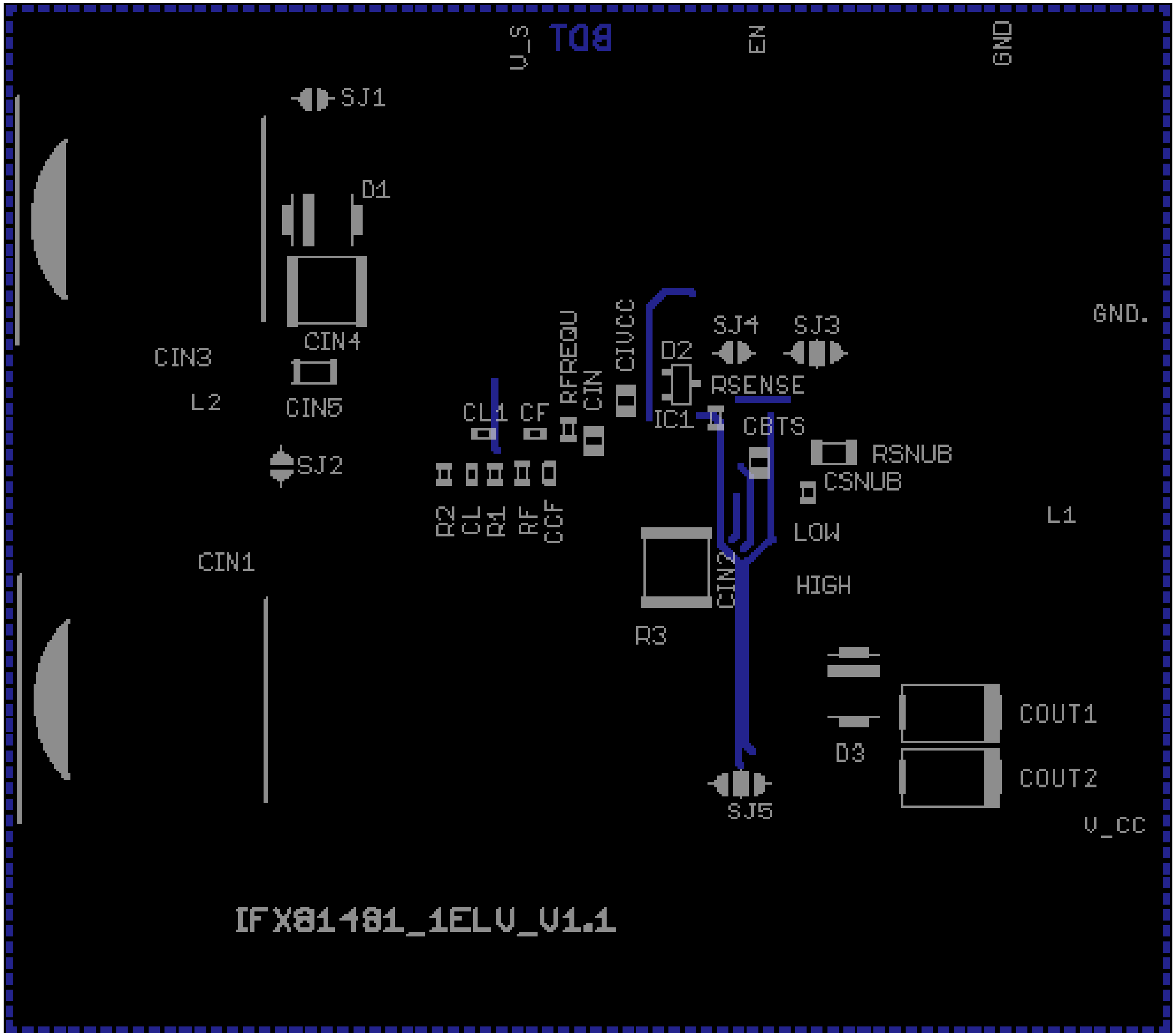
Appendix - Layout

- Top Layer



Appendix - Layout

- Bottom Layer



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Edition 2014-05-05
Published by
Infineon Technologies AG
81726 Munich, Germany

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