STDES-BCBIDIR test report

Introduction

The STDES-BCBIDIR is an 11 kW bidirectional battery charger that provides a comprehensive solution for high-voltage charging applications in both industrial and automotive fields.

It features two power stages: a power factor correction (PFC) stage and an isolated DC-DC stage.

The PFC stage employs a three-phase full-bridge topology, while the DC-DC stage can be configured with two topologies by externally connecting the resonant cell. Both stages utilize ACEPACK DMT-32 SiC power modules.

The system is controlled by two dedicated control boards, one for the PFC stage and another for the DC-DC stage, each based on the STM32G4 microcontroller.

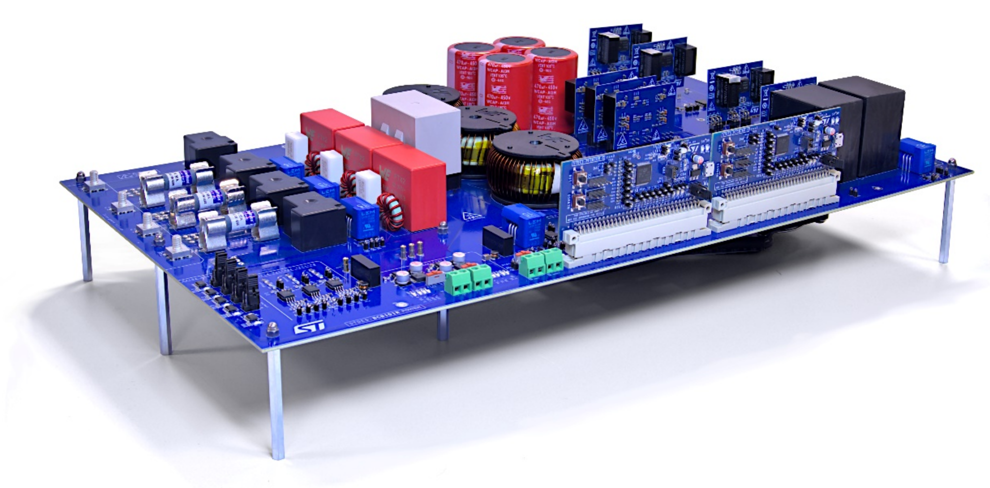
The PFC stage operates at a switching frequency of 70 kHz. The DC-DC stage operates at a fixed switching frequency of 100 kHz in dual active bridge (DAB) topology or a variable switching frequency ranging from 82 to 235 kHz in CLLC topology. This design achieves a peak system efficiency exceeding 96%.

The STDES-BCBIDIR has a single 11 kW magnetic component, which includes the high-frequency isolation transformer and resonant elements for the CLLC tank, or the isolation transformer and leakage inductance for the DAB topology.

The modular hardware architecture consists of the following components:

- Main power board equipped with: ACEPACK DMT-32 SiC power modules, featuring a sixpack topology (M1P45M12W2-1LA) for the PFC stage, and two full-bridge modules (M1F45M12W2-1LA) for the DC-DC stage. The board also includes bulk capacitors, sensing circuits, and an auxiliary power supply.
- Driver board: designed for the full-bridge and sixpack ACEPACK DMT-32 SiC power modules, it incorporates the STGAP2SiCD galvanically isolated 4 A dual gate driver optimized for SiC MOSFETs.
- Control board: based on the STM32G4 microcontroller series, this board features connectors for communication and programming, test points, and status indicators to facilitate testing and monitoring.

Figure 1. STDES-BCBIDIR reference design



1 Overview

1.1 Features

- Reference design modular kit consisting of:
  - Main power board - STDES-BCBIDIRP
  - Driver board (three for PFC stage, four for DC-DC stage) - STDES-GAP2SICD
  - STM32G474RET3 control board (one for PFC stage, one for DC-DC stage) - STDES-BCBIDIRC
- PFC stage: 3-phase, 2-level bidirectional AC-DC power converter
  - Rated nominal AC voltage: 400 V_{AC} at 50 Hz
  - Rated nominal DC voltage: 800 V_{DC}
  - Nominal power: 11 kW
  - Switching frequency: 70 kHz
  - Rectifier mode:
    - Power factor: PF >0.99
    - Total harmonic distortion: THDi <5%
    - Inrush current control and soft startup
  - Inverter mode:
    - Active and reactive power control
    - Integrated grid connection solution
- DC-DC stage: dual active bridge (DAB)/CLLC power converter
  - Nominal input voltage 800 V
  - Nominal output voltage 550 V to 800 V
  - Nominal power 11 kW
  - DAB: switching frequency 100 kHz
  - CLLC: switching frequency range 82 to 235 kHz
- System key features
  - ACEPACK DMT-32 power module for high integration level
  - High frequency operation for weight and size reduction
  - Bidirectional capabilities
  - DAB soft switching behavior enabled by enhanced modulation management techniques.
  - Peak efficiency: greater than 96%

2 Specifications

Table 1. Main characteristics

Description	Symbol	Min.	Typ.	Max.	Unit	Comment
Three-phase input voltage	V_{AC}	208		400	*V*	Line to line voltage
Output voltage	V_{DC}	550	800	850	*V*	
Maximum output power	P_{OUTmax}		11		*kW*	At nominal voltages
AC line frequency	f_g		50		*Hz*	
Power factor	*PF*		0.9	0.996	-	
Total harmonic distortion	THD_i		<5		*%*	At overall conditions
Switching frequency PFC stage	f_{sw}		70		*kHz*	
Switching frequency DAB	f_{sw}		100		*kHz*	
Switching frequency CLLC	f_{sw}	82		235	*kHz*	

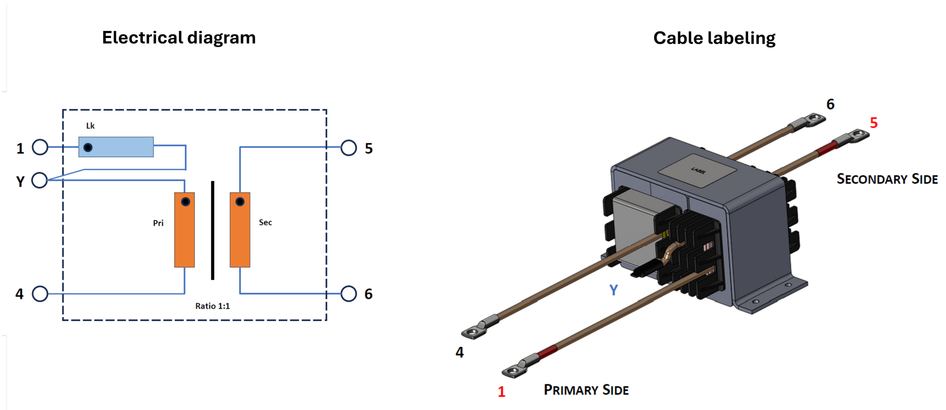
3 HFT connection to STDES-BCBIDIR

The high-frequency transformer (HFT) plus leakage inductor is crucial for the dual active bridge (DAB) topology as it enables efficient energy transfer with reduced losses and compact size.

The correct connection of the primary and secondary windings of the transformer to the power board is essential to ensure the optimal functioning of the board.

The connection of the transformer to the board is made through the connectors: J21, J22, J23, J24. Figure 2 shows the electrical diagram of the transformer, and the various cables of the transformer are also shown. Figure 3 shows the connection of the transformer to the power board.

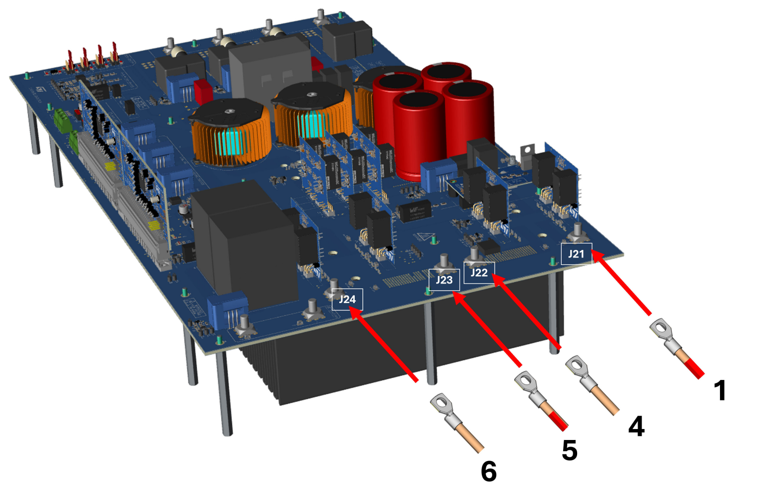
Figure 2. HFT - 2446.0001 AQ magnetic cable labeling



The correct connection of the transformer cables to the power board is as follows:

- **1** (red-marked cable) must be connected to the J21 connector of the STDES-BCBIDIRP
- **4** must be connected to the J22 connector of the STDES-BCBIDIRP
- **5** (red-marked cable) must be connected to the J23 connector of the STDES-BCBIDIRP
- **6** must be connected to the J24 connector of the STDES-BCBIDIRP

Figure 3. HFT - 2446.0001 AQ magnetic connection to the board



4 Test setup

4.1 Safety precautions

Attention: *The STDES-BCBIDIR is designed for demonstration purposes only and is not intended for domestic or industrial installations.*

Danger: *The high voltage levels used to operate the STDES-BCBIDIR could provoke a serious electrical shock. This reference design must be used in a suitable laboratory by qualified personnel only, familiar with the installation, use, and maintenance of power electrical systems. During operation, do not touch the board as some of its components could reach a very high temperature.*

4.2 Preliminary test procedure

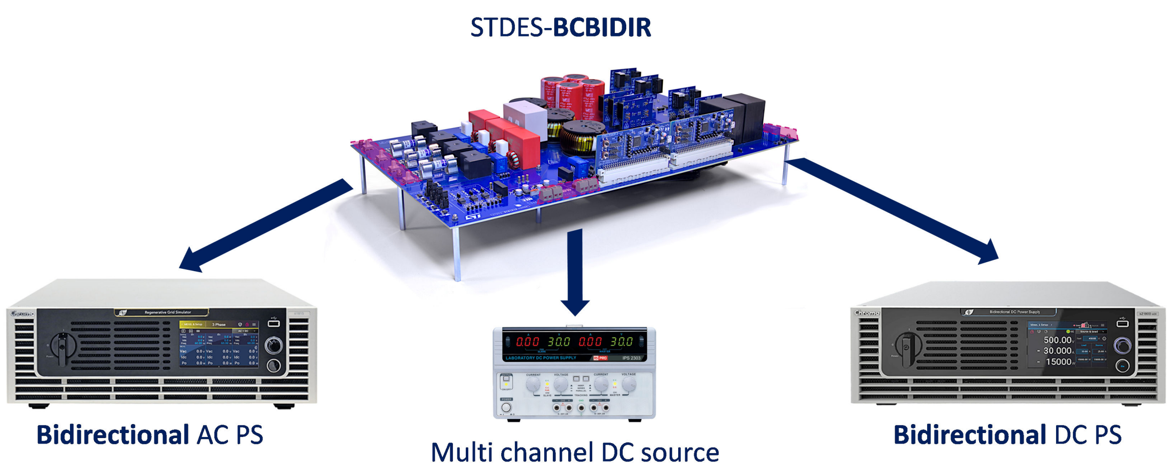
The preliminary test procedure includes a set of checks needed to verify the proper functionality of key sections: grid relays, sensing section on AC side and DC side, PLL routine, gate-source voltages, PFC (start-up), DAB (start-up). Successfully passing the aforementioned tests allows the board to operate at full load.

By powering the board with the auxiliary voltages (12 V, 7 V) the sensing sections and the relays can be checked

Equipment needed:

- Programmable bidirectional AC source
- Bidirectional DC electronic load
- Low-power multichannel DC source
- High-definition multichannel oscilloscope + probes
- High precision power analyzer

Figure 4. Typical test bench

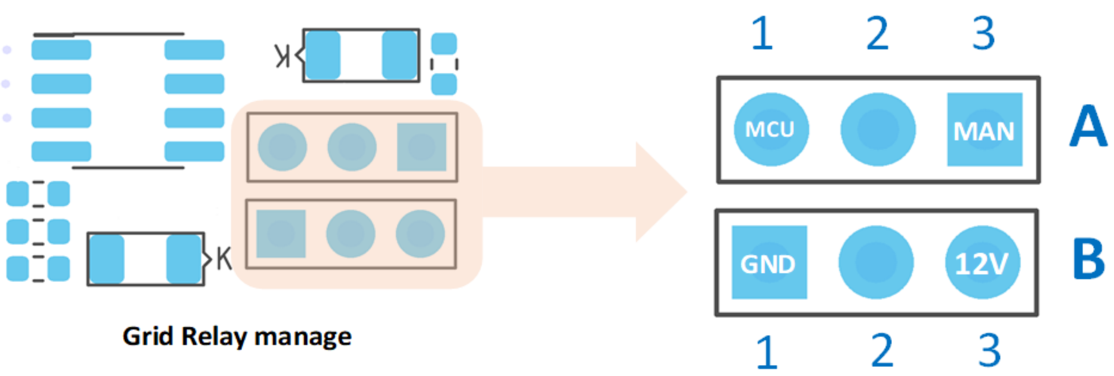


4.2.1 Grid relay

Grid relays test

To manage the grid connection the STDES-BCBIDIR presents four relays: three of them used for the three-phase connection and one for the neutral. Figure 5 show the section related to the command of the grid relays with a focus on the selectors.

Figure 5. Grid relays management



The selector highlighted allows the user the possibility of managing the control of the relays using the MCU or manually. The two configurations of the relays are allowed by the following jumpers connections:

Figure 6. Grid relay jumper configuration

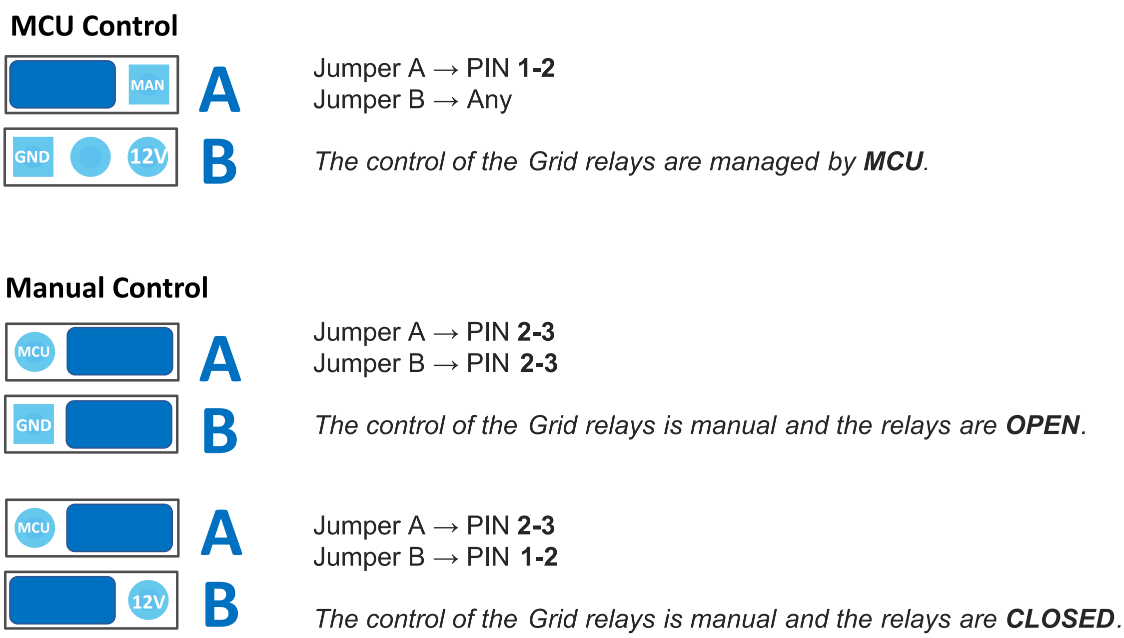


Table 2. Hardware and software requirements

Hardware	Software
STDES-BCBIDIRP	/
Multichannel DC power supply (12 V, 7 V)	

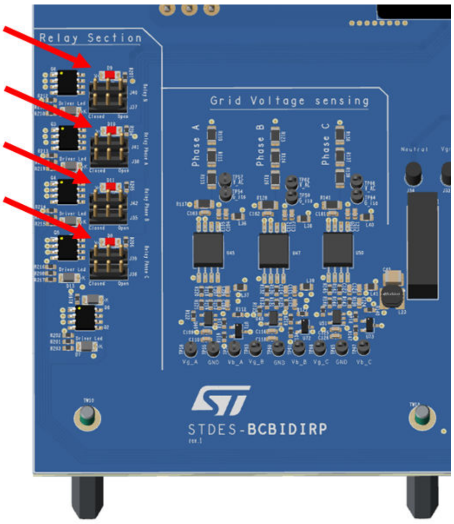
4.2.2 Procedure to perform test

Step 1. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 2. Connect the jumpers to enable manual control of the relays in the CLOSED position (J39-J40-J41-J42 position 2-3, J35-J36-J37-J38 position 1-2). (Grid relays test, third configuration)

Step 3. Enable the auxiliary power supply output. Once the auxiliary system is powered with the indicated jumper configuration, the LEDs D8, D9, D10, and D11 will light up (Figure 23)

Figure 7. **Grid relay check**



The test allows verifying that the network relays are properly powered.

4.2.3 Sensing section test

To verify correct operation of the voltage and current sensing, the voltage values on the test points shown in the following figures can be verified. The expected voltage values in specific test conditions are shown in the following figures.

Table 3. **Hardware and software requirements**

Hardware	Software
STDES-BCBIDIRP	-
Multichannel DC power supply	-
Multimeter	-
Oscilloscope	-
AC power supply	-
DC power supply	-

Table 4. **Hardware and software configurations**

Hardware	Status
DC auxiliary power supply (12 V, 7 V)	Connected

At each sensor, there are three test points: GND, the sensor BIAS, and the conditioned voltage that is sent to the MCU. The voltage values read at these test points, when the system is not powered (with only the auxiliary power enabled), must match the values indicated in Figure 8, Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13.

4.2.4 AC sensing

Figure 8. PFC section - Grid voltage sensing

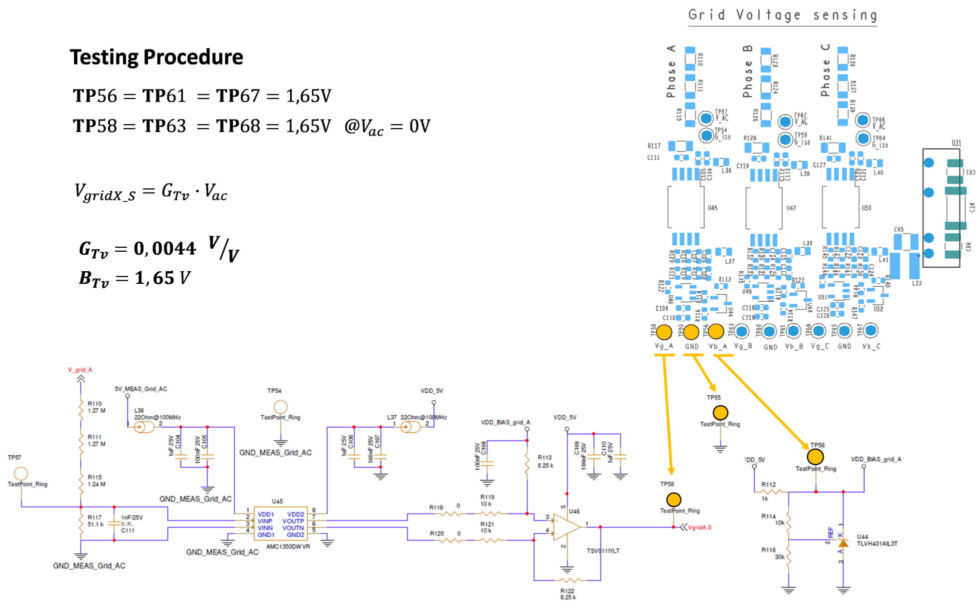


Figure 9. PFC section - Grid current sensing

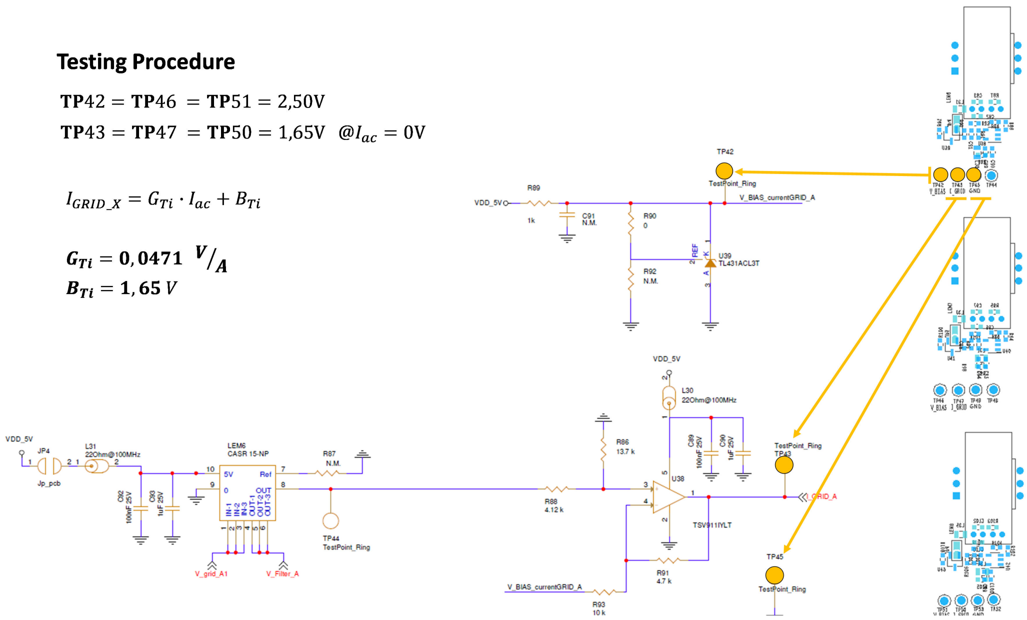


Figure 10. PFC section - Line voltage sensing

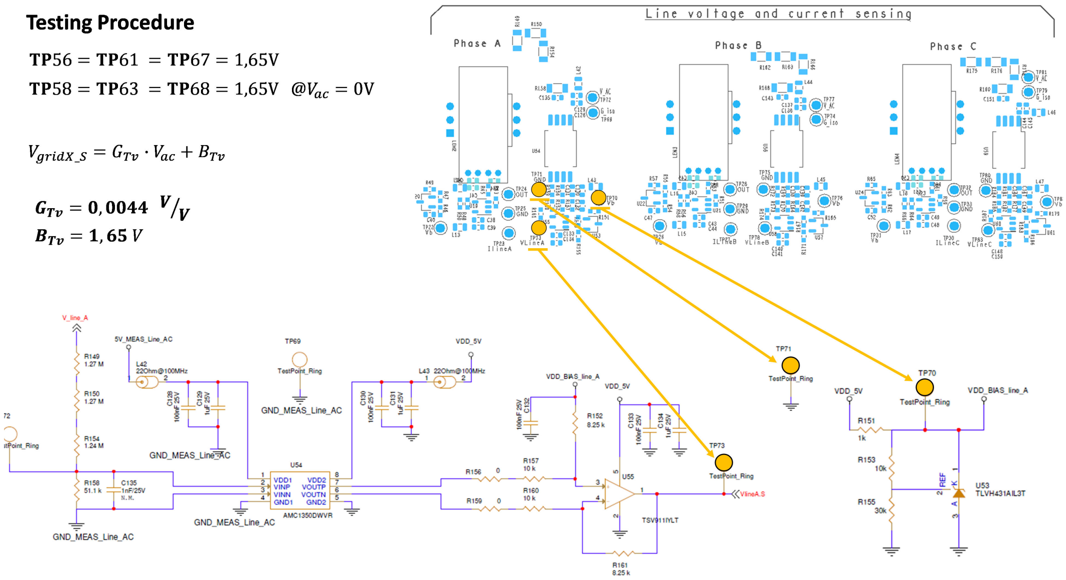
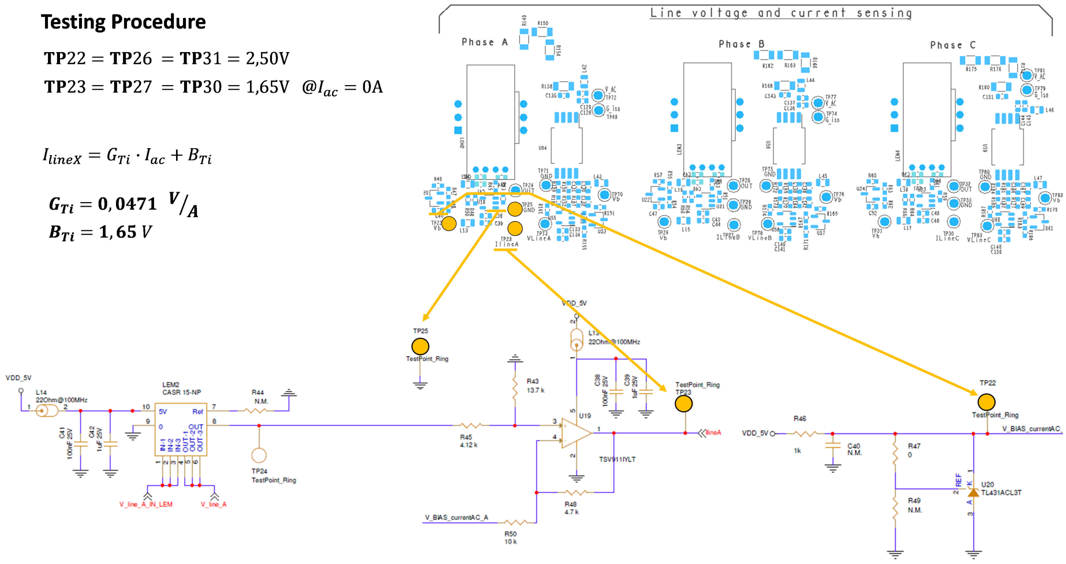


Figure 11. PFC section - Line current sensing



4.2.5 DC sensing

Figure 12. DC-DC section - DC voltage sensing

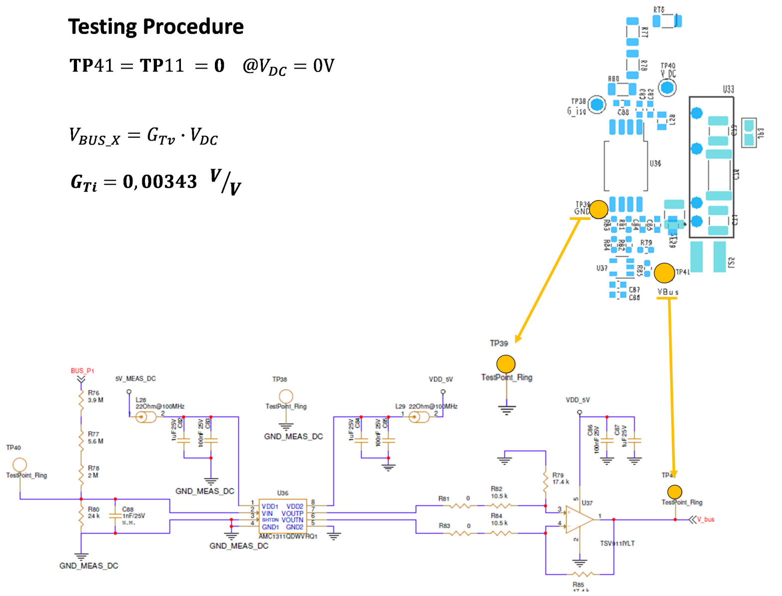
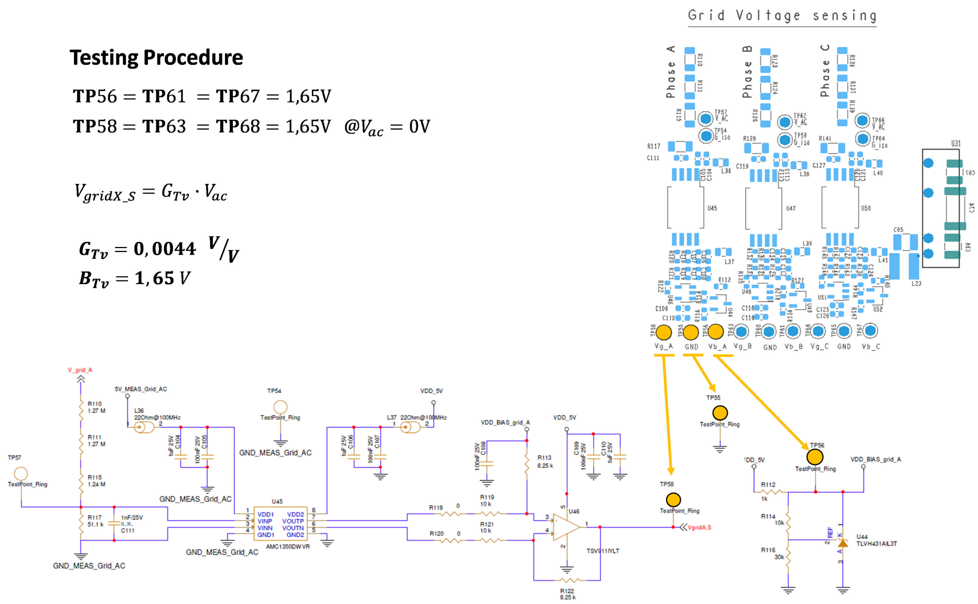


Figure 13. DC-DC section - DC current sensing



4.2.6 Procedure to perform test

Step 1. Connect the jumpers to enable manual control of the relays in the OPEN position (J39-J40-J41-J42 position 2-3, J35-J36-J37-J38 position 2-3) (Fig.6, second configuration)

Step 2. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 3. Enable the auxiliary power supply output

Step 4. Check that the voltages read on the test points match the values indicated in Figures 8 to 13 under the conditions respectively @V_ac=0V, @I_ac=0A, @V_dc=0V, and @I_dc=0A

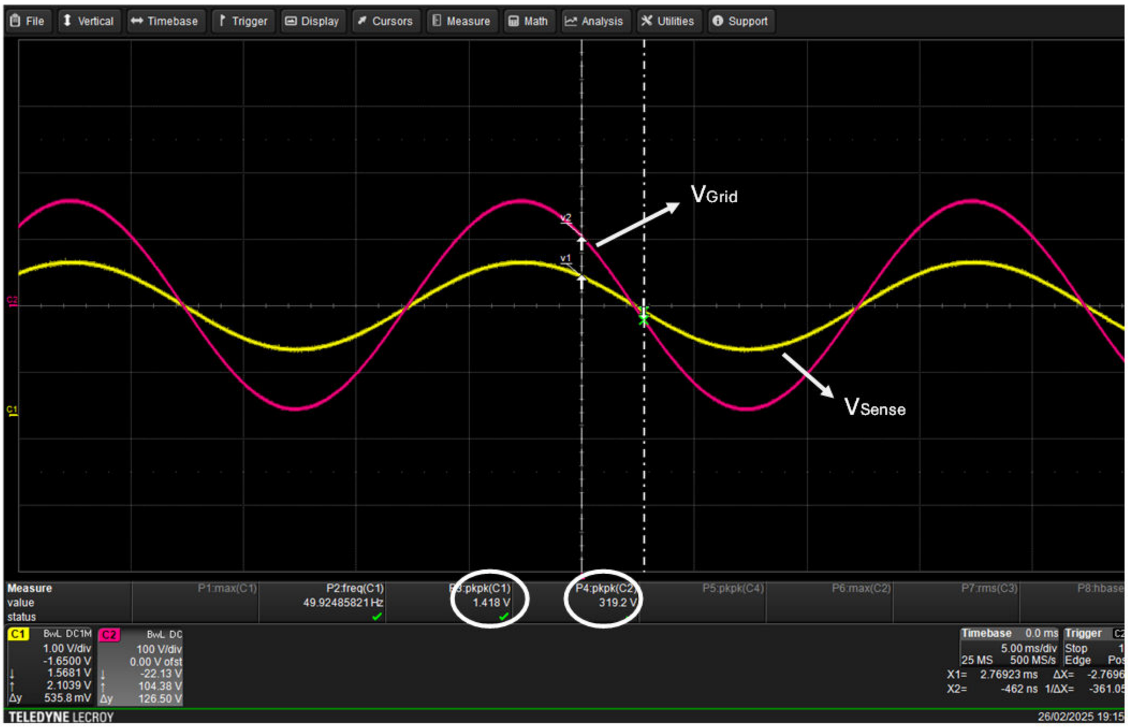
Step 5. Connect the AC power supply (J15 → PHA, J17 → PHB, J18 → PHC, J27 → N)

Step 6. Connect a differential probe between J15 (PHA) and J27 (N) and a passive probe between TP58 (Vg_A) and TP55 (GND)

Step 7. Set an AC voltage of 110 Vrms and enable an AC power supply

Step 8. Check that the V_(s pk-pk)=G· V_(g pk-pk) =0,0044·319,2=1,40 V (Figure 14)

Figure 14. Measurement of the mains voltage and reading of the corresponding sensor



Step 9. Disconnect the AC power supply

Step 10. Connect of the DC power supply (J20 → +, J25 → -)

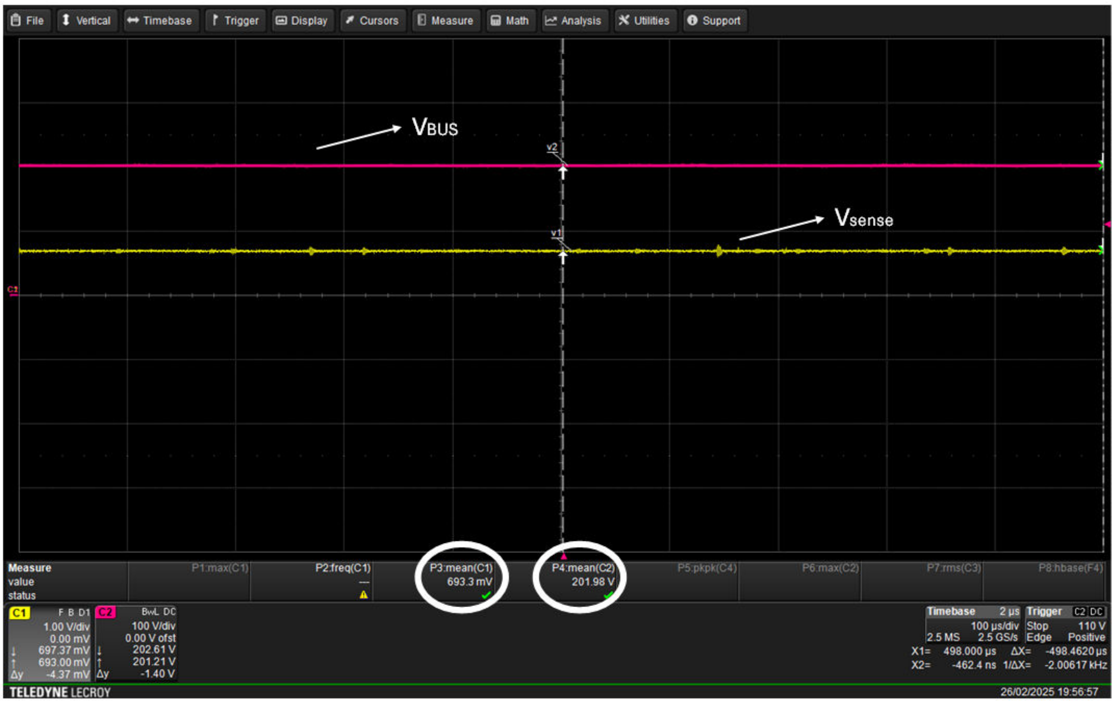
Step 11. Connect a differential probe between J20 (+) and J25 (-) and a passive probe between TP41 (Vbus) and TP39 (GND)

Step 12. Set a DC voltage of 200 Vdc and enable a DC power supply

Step 13. Check that the $V_{s\,DC} = G \cdot V_{BUS} = 0,00343 \cdot 201,98 = 0,692$ V (Figure 15)

Danger: *Ensure that the voltage present on connectors J20 and J25 has dropped to zero before touching the connectors*

Figure 15. Measurement of the BUS voltage and reading of the corresponding sensor



4.2.7 PLL testing procedure

To test the proper functionality of the phase-locked loop (PLL), a comprehensive test environment and a series of steps must be followed.

The following outlines the necessary environment setup and the detailed steps for conducting the PLL test.

Table 5. Hardware and software requirements

Hardware	Software
STDES-BCBIDIR	STM32CubeIDE
STDES-PFCBIDIRC x3	STSW-BCBIDIR
STDES-PFCBIDIRC	
Multichannel DC power supply	
8 channel oscilloscope	
AC power supply	
ST-LINK/V2-ISOL + JTAG	

Table 6. Hardware configurations

Hardware	Status
AC input voltage	Connected
DC load	Disconnected
DC auxiliary power supply (12 V, 7 V)	Connected

Table 7. Software configurations

Software	Status
DPC_PWM_INIT	PWM_Safe
DPC_TTC_MODE_INIT	AC2DC_PFC_OPERATION
DAC_CH1_INIT	13
DAC_CH2_INIT	7
DAC_CH3_INIT	8
DAC_G_CH1_INIT	2048
DAC_G_CH2_INIT	2048
DAC_G_CH3_INIT	2048
DAC_B_CH1_INIT	2048
DAC_B_CH2_INIT	2048
DAC_B_CH3_INIT	2048

4.2.8 Procedure to perform test

Step 1. Connect the jumpers to enable manual control of the relays in the OPEN position (J39-J40-J41-J42 position 2-3, J35-J36-J37-J38 position 2-3). (Fig.6, second configuration)

Step 2. Connect the STDES-PFCBIDIRC at the connector J1

Step 3. Connect the AC power supply (J15 → PHA, J17 → PHB, J18 → PHC, J27 → N). Connection of the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards Vext to configure the external auxiliary power supply mode

Step 4. Connect the three differential probes (PHA-N/PHB-N/PHC-N) and three non isolated probes in the control board (DAC1-GND, DAC2-GND, DAC3-GND)(T29–TP31, T32–TP31, T33–TP31)

Step 5. Enable auxiliary power supply

Step 6. Open the firmware: STSW-BCBIDIR_PFC inside the STSW-BCBIDIR and, in the file project *DPC_Application_Conf.h* set:

```
#define DPC_TTC_MODE_INIT AC2DC_PFC_OPERATION
#define DPC_PWM_INIT PWM_Safe
#define DAC_CH1_INIT 13
#define DAC_CH2_INIT 7
#define DAC_CH3_INIT 8
#define DAC_G_CH1_INIT 2048
#define DAC_G_CH2_INIT 2048
#define DAC_G_CH3_INIT 2048
#define DAC_B_CH1_INIT 2048
#define DAC_B_CH2_INIT 2048
#define DAC_B_CH3_INIT 2048
```

Step 7. Connect the STLINK to the control board of PFC (STDES-PFCBIDIRC on connector J1) section as is shown in Figure 16 and flash the code

Step 8. Power the board by supplying three-phase voltages (for instance 30 Vrms)

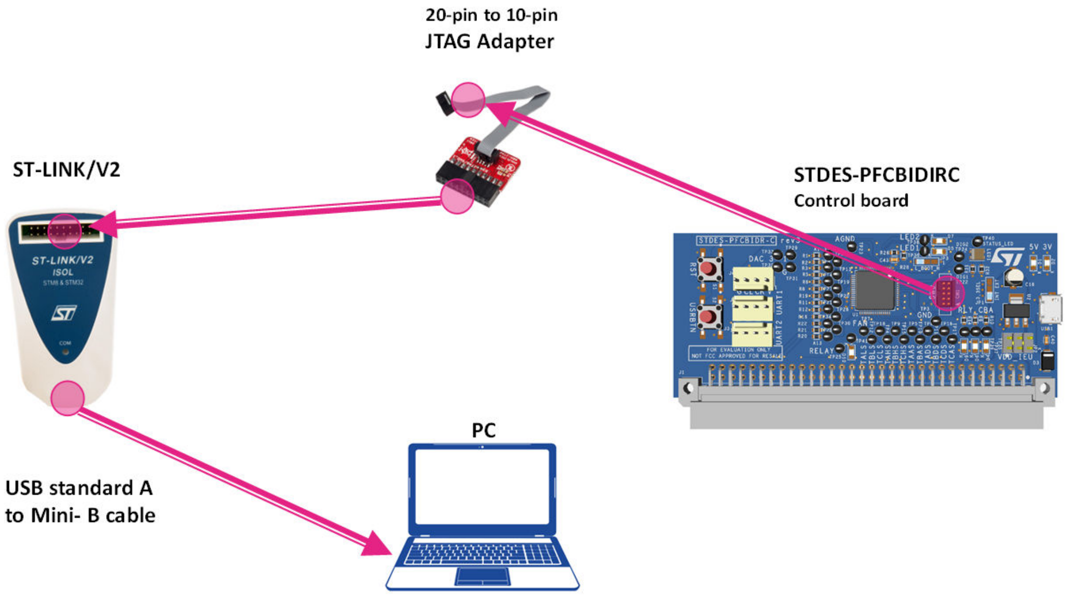


Figure 16. ST-LINK/V2 connected to the control board

The oscilloscope displays the three sinusoidal grid voltages and the theta angle which will appear as a sawtooth synchronized with the sinusoid relating to phase A. Furthermore, it is possible to see the d and q axis components of the voltage. When the steady state condition is reached, the d axis has a positive value while the q axis will be zero how is is shown in Figure 17.

Figure 17. PLL test waveforms

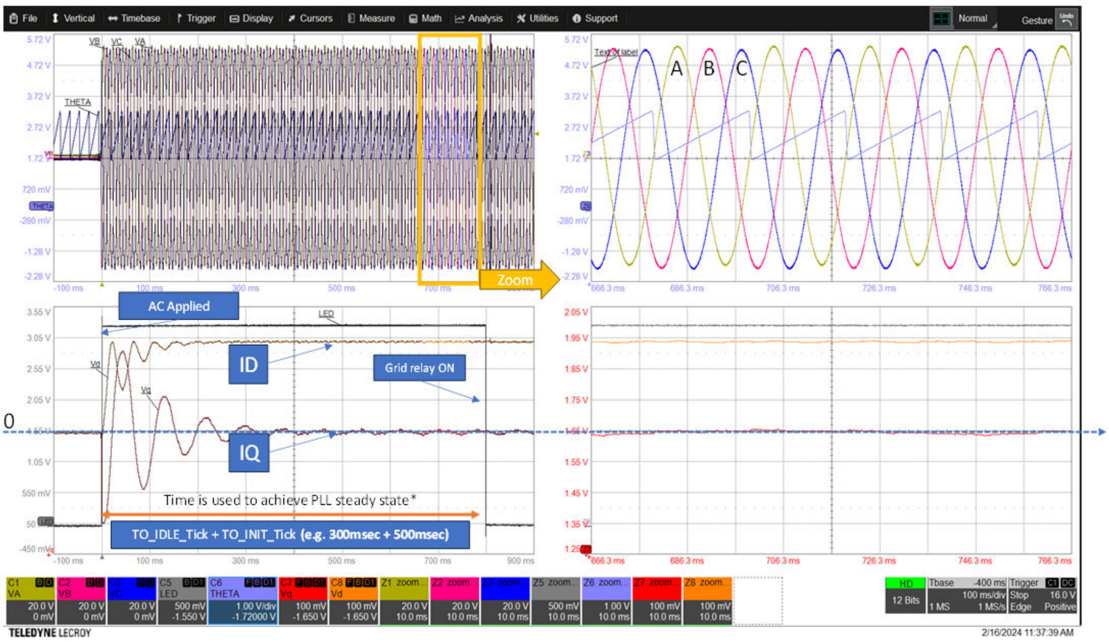
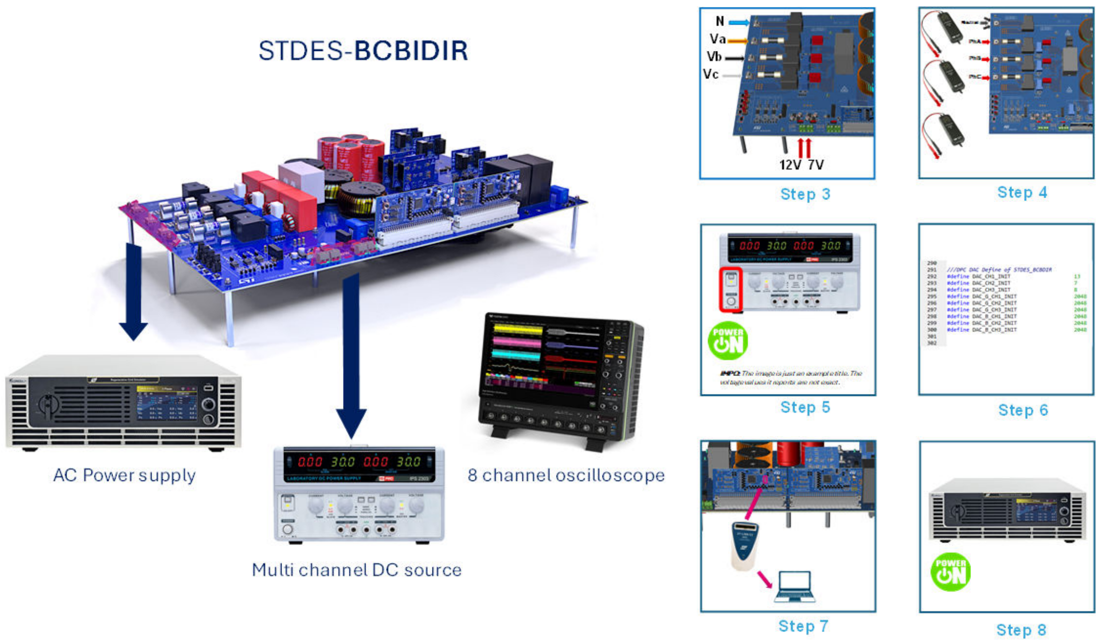


Figure 18. **PLL test environment and procedure**



4.2.9 Gate-source voltages testing

This test allows to check if the driving signals of the switches are correct sent from the MCU to the driver board. At the same time, it is possible to verify the correct behavior of the gate driver, and the driver boards in general. To perform this test a multichannel DC source is needed to provide the auxiliary power supply to the power board

Table 8. **Hardware and software requirements**

Hardware	Software
STDES-BCBIDIRP	STM32 CUBE IDE
STDES-GAP2SICD x3	FW: STSW-BCBIDIR
STDES-PFCBIDIRC	
Multi-channel DC Power supply (12 V, 7 V)	
8 channel oscilloscope	
ST-linkV2 isol + JTAG	

4.2.10 Procedure to perform test (PFC side)

Step 1. Connect the jumpers to enable manual control of the relays in the OPEN position (J39-J40-J41-J42 position 2-3, J35-J36-J37-J38 position 2-3). (Fig.6, second configuration)

Step 2. Connect the isolated voltage probes to the VGS of the devices

Step 3. Connect the STDES-PFCBIDIRC at the connector J1

Step 4. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 5. Power the auxiliary section of the board by providing both 12 V and 7 V

Step 6. Open the FW: STSW_BCBIDIR_PFC inside the STSW-BCBIDIR and verify that in the file project *DPC_Application.c* when *PC_State==FSM_Debug* only the following functions must be present:

DPC_MISC_Relay_Cntl(RELAY_GRID_ABC, RELAY_OFF);
DPC_ACT_OutEnable(&tDPC_PWM);
DPC_ACT_Send_Duty_SPWM(&tDPC_PWM,0.0f, 0.0f, 0.0f);
In the file project *DPC_Application_Conf.h:*
macroDPC_PC_State_Initmust be set to FSM_Debug.
macro DPC_PWM_INIT must be set to PWM_Armed.

Step 7. Connect the ST-link to the control board of the PFC (STDES-PFCBIDIRC on connector J1) stage as is shown in Figure 16 and flash the code.

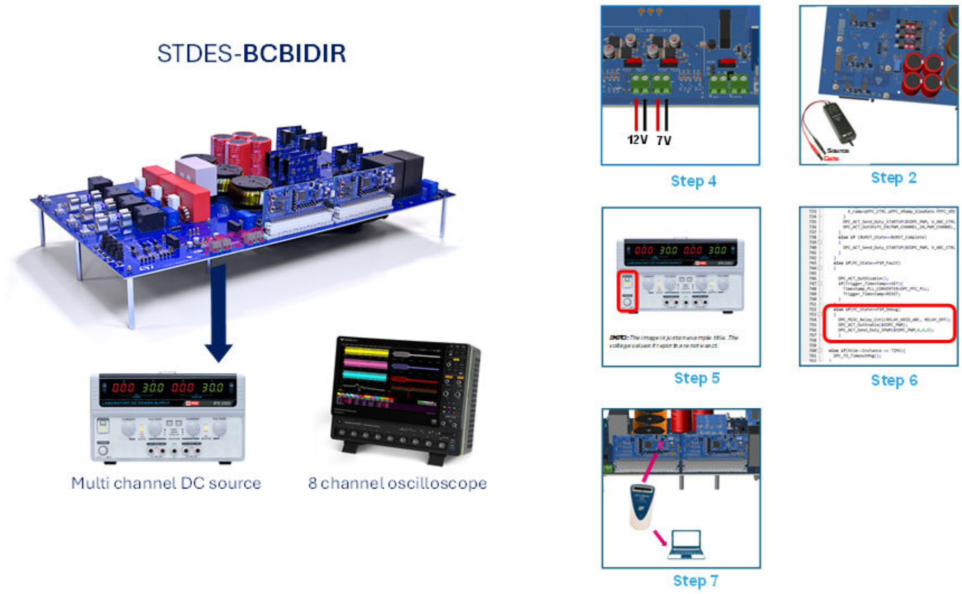


Figure 19. Testing procedure of gate to source voltages

By setting an appropriate time base on the oscilloscope, considering a switching frequency of 70 kHz, square waves with a voltage range of +20 to -5 V and a duty cycle of 50% will be displayed, as shown in fig 20.

Figure 20. Gate to source voltage PFC stage

4.2.11 Procedure to perform test (DC-DC side)

Step 1. Connect the isolated voltage probes to the VGS of the devices.

Step 2. Connect the STDES-PFCBIDIRC at the connector P1

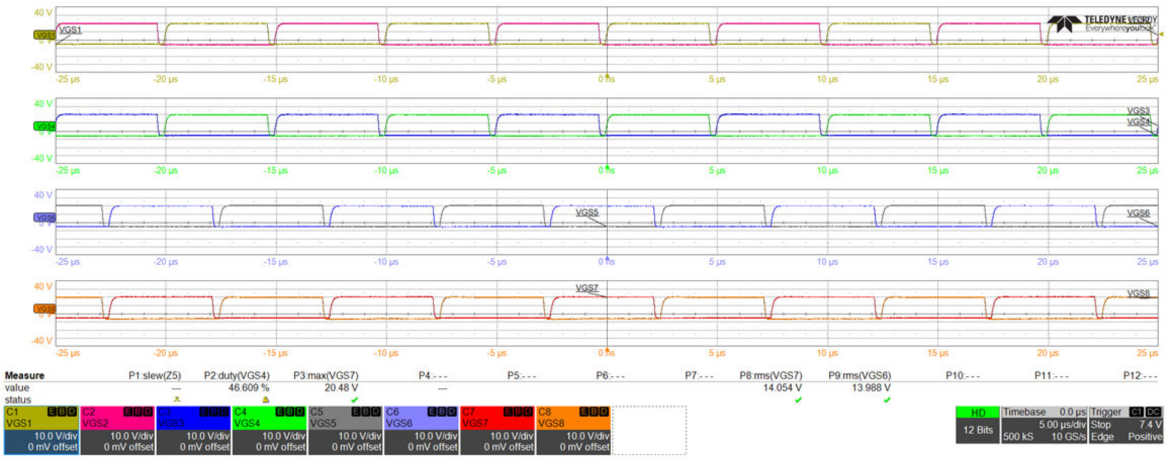
Step 3. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 4. Power the auxiliary section of the board by providing both 12 V and 7 V

Step 5. Open FW: STSW_BCBIDIR_DAB inside the STSW-BCBIDIR, and verify that in the file project *DPC_Application.c* in case PC_State==FSM_Debug only the following functions must be present:
DPC_ACT_OutEnable(&DAB.tDPC_PWM);
In the file project *DPC_Application_Conf.h:*
#defineDPC_PC_State_Init FSM_Debug
#define DPC_DAB_PWM_INIT PWM_Armed

Step 6. Connect the ST-link to the control board of the DAB (STDES-PFCBIDIRC on connector P1) stage as is shown in Figure 16 and flash the code
By setting an appropriate time base on the oscilloscope, considering a switching frequency of 100 kHz, square waves with a voltage range of +20V to -5V and a duty cycle of 50% will be displayed, as shown in Figure 21.

Figure 21. Gate to source voltage DC-DC stage



4.2.12 PFC startup

This test is used to verify the design functionalities up to full load. By following the procedure outlined below, the converter executes the startup phase, bringing both stages to nominal voltage conditions.

Subsequently, the load can be increased until the target conditions of the converter are reached.

Table 9. Hardware and software requirements

Hardware	Software
STDES-BCBIDIRP	STM32 CUBE IDE
STDES-GAP2SICD x 3	FW: STSW-BCBIDIR
STDES-PFCBIDIRC x 1	
Multichannel DC power supply (12 V, 7 V)	
8 channel oscilloscope	
ST-LINK/V2-ISOL + JTAG	
AC power supply	

Hardware	Software
DC load	

4.2.13 Procedure to perform test

Step 1. Connect the jumpers to enable MCU control of the relays (J39-J40-J41-J42 position 1-2, J35-J36-J37-J38 not connected). (Fig.6, first configuration)

Step 2. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 3. Connect the AC power supply (J15 → PHA, J17 → PHB, J18 → PHC, J27 → N) without activation "output disabled"

Step 4. Connect the three differential voltage probes (PHA-N/PHB-N/PHC-N) and three current probes on the PHA, PHB, and PHC. Connect an additional isolated voltage probe on the DC bus J20-J25

Step 5. Connect the fan cables to U11 respecting the correct polarity. Connect a 12V power supply to the U10 and provide the power. Move selector J8 in position 2-3 (PFC_FAN)

Step 6. Connect the DC-Load taking care of the correct polarity at the connector. Positive cable to J20, negative cable to J25, the load must be set to Constant Current mode (CC) and must be disabled

Step 7. Open the firmware: STSW_BCBIDIR_PFC inside the STSW-BCBIDIR, and verify that in the file project *DPC_Application_Conf.h:*

```
///DPC finite state machine DEFINE of STDES-BCBIDIR
#define DPC_PC_State_Init FSM_Idle
#define DPC_PWM_INIT PWM_Armed
#define DPC_TTC_MODE_INIT AC2DC_PFC_OPERATION
#define DPC_CTRL_INIT VOLTAGE_LOOP
///AC MAIN DEFINE of STDES-BCBIDIR
#define DPC_TTC_VAC_EU
///AC MAIN connection DEFINE of STDES-BCBIDIR
#define DPC_AC_3W
///DC OUTPUT DEFINE of STDES-BCBIDIR
#define DPC_PFC_VDC_OUT 800
#define DPC_PFC_VDC_rampstart 760
///PROTECTION
//AC-DC
#define DPC_PFC_VAC_RMS_OVP 250
#define DPC_PFC_VAC_RMS_UVLOP 10
#define DPC_PFC_VAC_RMS_UVP 7
#define DPC_PFC_IAC_OCP 7
#define DPC_PFC_VDC_OVP 850
#define DPC_PFC_IDC_OCP 7
```

Step 8. Connect the STLINK to the control board of the PFC (STDES-PFCBIDIRC on connector J1) stage as is shown in Figure 16 and flash the code

Step 9. Enable three-phase power supply (230 Vrms)

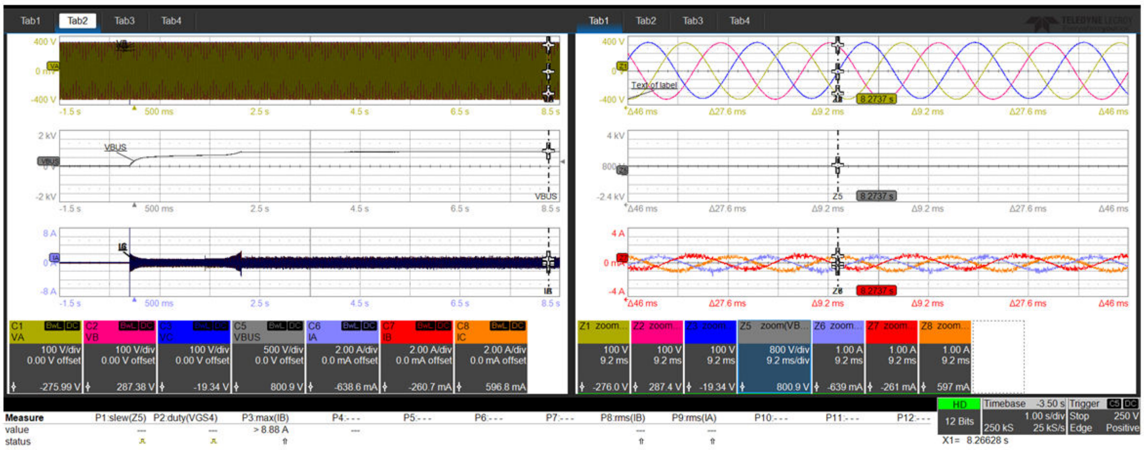
After powering the board (230 Vrms), setting a time base of 1 second, and appropriately adjusting the zoom, waveforms like those in figure 22 will be displayed on the oscilloscope

Shutdown:

– Gradually reduce the load to zero
– Disconnect the AC power supply
– Enable the load to discharge the capacitors of the BUS

Danger: *After performing the test and disconnecting the AC power supply, it is necessary to re-enable the load to discharge the output BUS capacitors. Furthermore, before touching connectors J20, J25 ensure with a multimeter that there is no residual charge on the DC BUS capacitors.*

Figure 22. Start-up waveforms of the PFC



4.2.14 DAB startup

This test is used to verify the DAB functionalities up to full load. By following the procedure outlined below, the converter executes the startup phase, bringing the DAB stage to nominal voltage conditions.

Subsequently, the load can be increased until the target conditions of the converter are reached.

Table 10. Hardware and software requirements

Hardware	Software
STDES-BCBIDIRP	STM32CubeIDE
STDES-GAP2SICD x 4	FW: STSW-BCBIDIR
STDES-PFCBIDIRC x 1	
Multichannel DC power supply	
8 channel oscilloscope	
ST-LINK/V2-ISOL + JTAG	

Table 11. Hardware configurations

Hardware	Status
AC input voltage	Connected
DC load	Connected
DC auxiliary power supply (12 V, 7 V)	Connected

Table 12. Software configurations

Software	Status
DPC_PWM_INIT	PWM_Armed

4.2.15 Procedure to perform test

Step 1. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J19, J10) towards Vext to configure the external auxiliary power supply mode

Step 2. Connect the transformer according to the instruction in chapter 3

Step 3. Connect the DC-Source taking care of the correct polarity at the connector. Positive cable to J20, negative cable to J25

Step 4. Connect the DC-Load taking care of the correct polarity at the connector. Positive cable to J28, negative cable to J29, the load must be set to Constant Current mode (CC) and must be disabled

Step 5. Connect the fan cables to U11 respecting the correct polarity. Connect a 12 V power supply to the U10 and provide the power. Move selector J8 in position 1-2 (DCDC_FAN)

Step 6. Connect the four differential voltage probs: OUTA_DAB1- OUTB_DAB1 (TP94-TP95), OUTA_DAB2-OUTB_DAB2 (TP96-TP97) VBUS (TP92-TP84), VLOAD (TP126-TP127). Connect three hall-effect current probe on IBUS (cable connected to J59), ILOAD (cable connected to J20), IDAB1(cable connected to J28)

Step 7. Open the firmware: STSW_BCBIDIR_DAB inside the STSW-BCBIDIR, and verify that in the file project *DPC_Application_Conf.h*::

```
/// DPC finite state machine DEFINE of STDES_DABBIDIR
#define DPC_DAB_ADPPWM
#define DPC_PC_State_Init FSM_Idle
#define DPC_FSM_RUN_INIT Run_Idle
#define DPC_FSM_STATE_INIT DPC_FSM_WAIT
#define DPC_CTRL_INIT DAB_VOLTAGE_LOOP
#define DPC_DAB_PWM_INIT PWM_Armed
#define DPC_DAB_MODE_INIT HV2LV
///DC OUTPUT DEFINE of STDES-DCDC_DAB
#define DPC_DAB_VDC_OUT 800
#define DPC_DAB_IDC_OUT 5
///PROTECTION HV2LV
#define DPC_DAB_VDCHV_OVP 850
#define DPC_DAB_VDCHV_UV 650
#define DPC_DAB_VDCHV_UVLO 30
#define DPC_DAB_VDCHV_MIN 20
#define DPC_DAB_IDCHV_OCP 5
#define DPC_DAB_IDCLV_OCP 5
#define DPC_DAB_VDCLV_OVP 900
```

Step 8. Connect the ST-LINK to the control board of the DAB (STDES-BCBIDIRC on connector P1) stage as is shown in Figure 16 and flash the code

Step 9. Enable DC power supply (800 VDC)

Results

After powering the board (800 VDC), setting a time base of 1 second, and appropriately adjusting the zoom, waveforms like those in figure 23 will be displayed on the oscilloscope

Shutdown:

– Gradually reduce the load to zero
– Disconnect the DC power supply
– Re-enable the load to discharge the capacitors of the output BUS
– Discharge the DC BUS if there is a residual voltage, with a suitable discharge circuit

Danger: *After performing the test and disconnecting the DC power supply, it is necessary to re-enable the load to discharge the output BUS capacitors. Furthermore, before touching connectors J20, J25, and J28, J29 ensure with a multimeter that there is no residual charge on the DC BUS capacitors.*

Figure 23. Startup waveforms of the DAB

4.2.16 Full-load test

This test is used to verify the design functionalities up to full load. By following the procedure outlined below, the converter executes the startup phase, bringing both stages to nominal voltage conditions. Subsequently, the load can be increased until the target conditions of the converter are reached.

Table 13. Hardware and software requirements

Hardware	Software
STDES-BCBIDIRP	STM32 CUBE IDE
STDES-GAP2SICD x7	FW: STSW-BCBIDIR
STDES-PFCBIDIRC x2	
Multi-channel DC Power supply	
8 channel oscilloscope	
ST-linkV2 isol + JTAG	

Table 14. Hardware configurations

Hardware	Status
AC input voltage	Connected
DC load	Connected
DC auxiliary power supply (12 V, 7 V)	Connected

Table 15. Software configurations

Software	Status
DPC_PWM_INIT	PWM_Armed

4.2.17 Procedure to perform test

Step 1. Connect the jumpers to enable MCU control of the relays (J39-J40-J41-J42 position 1-2, J35-J36-J37-J38 not connected). (Fig.6, first configuration)

Step 2. Connect the transformer according to the instruction in chapter 3

Step 3. Connect the low voltage auxiliary power supply (12 V, 7 V) respectively in U28 and U26 moving the selectors (J2, J3, J9, J10) towards V_{ext} to configure the external auxiliary power supply mode

Step 4. Connect the AC power supply (J15 → PHA, J17 → PHB, J18 → PHC, J27 → N) without activation “output disabled”

Step 5. Connect the five differential voltage probes: OUTA_DAB1- OUTB_DAB1 (TP94-TP95), OUTA_DAB2-OUTB_DAB2 (TP96-TP97) VBUS (TP92-TP84), VLOAD (TP126-TP127) PHA-N (J15-J27). Connect two hall-effect current probe on ILOAD, IA and a Rogowski probe on IDAB1

Step 6. Connect the fan cables to U11 respecting the correct polarity. Connect a 12 V power supply to the U10 and provide the power. Move selector J8 in position 2-3 (PFC_FAN)

Step 7. Connect the DC-Load taking care of the correct polarity at the connector. Positive cable to J28, negative cable to J29, the load must be set to Constant Current mode (CC) and must be disabled

Step 8. Open the firmware: STSW_BCBIDIR_PFC inside the STSW-BCBIDIR, and verify that in the file project *DPC_Application_Conf.h:*

```
///DPC Finite State Machine DEFINE of STDES-BCBIDIR
#define DPC_PC_State_Init FSM_Idle
#define DPC_PWM_INIT PWM_Armed
#define DPC_TTC_MODE_INIT AC2DC_PFC_OPERATION
#define DPC_CTRL_INIT VOLTAGE_LOOP
///AC MAIN DEFINE of STDES-BCBIDIR
#define DPC_TTC_VAC_EU
///AC MAIN Connection DEFINE of STDES-BCBIDIR
#define DPC_AC_3W
///DC OUTPUT DEFINE of STDES-BCBIDIR
#define DPC_PFC_VDC_OUT 800
#define DPC_PFC_VDC_rampstart 760
///PROTECTION
//AC-DC
#define DPC_PFC_VAC_RMS_OVP 250
#define DPC_PFC_VAC_RMS_UVLOP 10
#define DPC_PFC_VAC_RMS_UVP 7
#define DPC_PFC_IAC_OCP 27
#define DPC_PFC_VDC_OVP 850
#define DPC_PFC_IDC_OCP 17
```

Step 9. Connect the STLINK to the control board of the PFC (STDES-PFCBIDIRC on connector J1) stage as is shown in Figure 16 and flash the code

Step 10. Open the firmware: STSW_BCBIDIR_DAB inside the STSW-BCBIDIR, and verify that in the file project *DPC_Application_Conf.h:*

```
/// DPC Finite State Machine DEFINE of STDES-DABBIDIR
#define DPC_DAB_ADPPWM
#define DPC_PC_State_Init FSM_Idle
#define DPC_FSM_RUN_INIT Run_Idle
#define DPC_FSM_STATE_INIT DPC_FSM_WAIT
#define DPC_CTRL_INIT DAB_VOLTAGE_LOOP
#define DPC_DAB_PWM_INIT PWM_Armed
#define DPC_DAB_MODE_INIT HV2LV
///DC OUTPUT DEFINE of STDES-DCDC_DAB
#define DPC_DAB_VDC_OUT 800
#define DPC_DAB_IDC_OUT 6
///PROTECTION HV2LV
#define DPC_DAB_VDCHV_OVP 850
#define DPC_DAB_VDCHV_UV 650
#define DPC_DAB_VDCHV_UVLO 30
#define DPC_DAB_VDCHV_MIN 750
#define DPC_DAB_IDCHV_OCP 17
#define DPC_DAB_IDCLV_OCP 17
#define DPC_DAB_VDCLV_OVP 850
```

Step 11. Connect the STLINK to the control board of the DAB (STDES-PFCBIDIRC on connector P1) stage as is shown in Figure 16 and flash the code

Step 12. Enable three-phase power supply (230 Vrms)

After powering the board (230 Vrms), setting a proper time base, and appropriately adjusting the zoom, waveforms like those in Figure 24 will be displayed on the oscilloscope

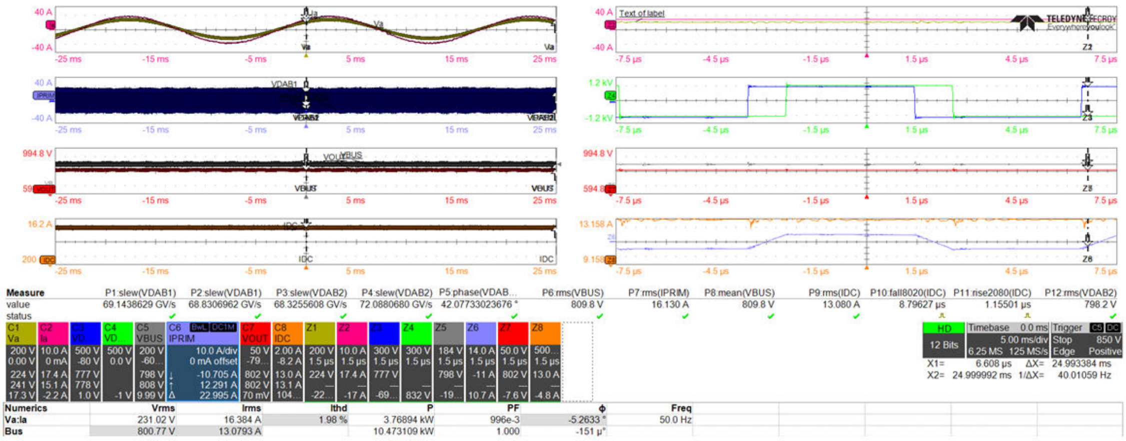
Step 13. Once the output voltage reaches the reference value (approximately 800 VDC), it will be possible to enable the load starting from 0 current up to full load

Shutdown:

– Gradually reduce the load to zero
– Disconnect the AC power supply
– Re-enable the load to discharge the capacitors of the output BUS
– Discharge the DC BUS with a suitable discharge circuit

Danger: *After performing the test and disconnecting the AC power supply, it is necessary to re-enable the load to discharge the output BUS capacitors. Furthermore, before touching connectors J20, J25, and J28, J29 ensure with a multimeter that there is no residual charge on the DC BUS capacitors*

Figure 24. Full power test–double conversion



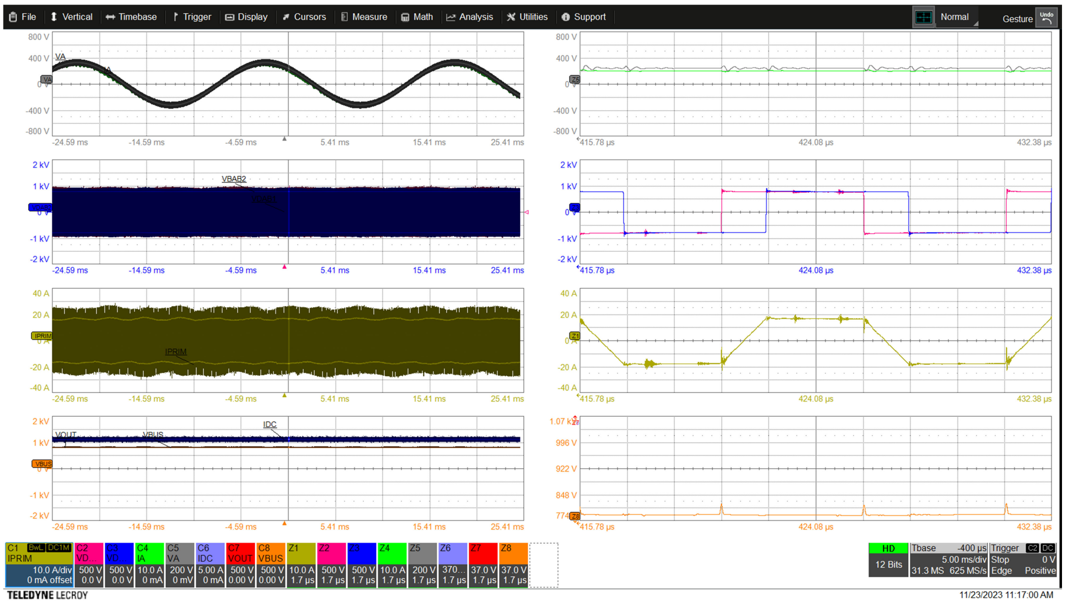
5 Measurements/waveforms/test data

5.1 Waveform

Waveforms analysis at:

- V_{IN} = 230 Vrms
- V_{OUT} = 800 V
- $f_{SW\ (PFC)}$ = 70 kHz
- $f_{SW\ (DC\text{-}DC)}$ = 100 kHz
- PF = 0.996
- Voltage regulation operating mode

Figure 25. Steady-state operations



Channel labels:

C1 = I_{PRIM}

C2 = V_{DAB1}

C3 = V_{DAB2}

C4 = I_A

C5 = V_A

C6 = I_{DC}

C7 = V_{OUT}

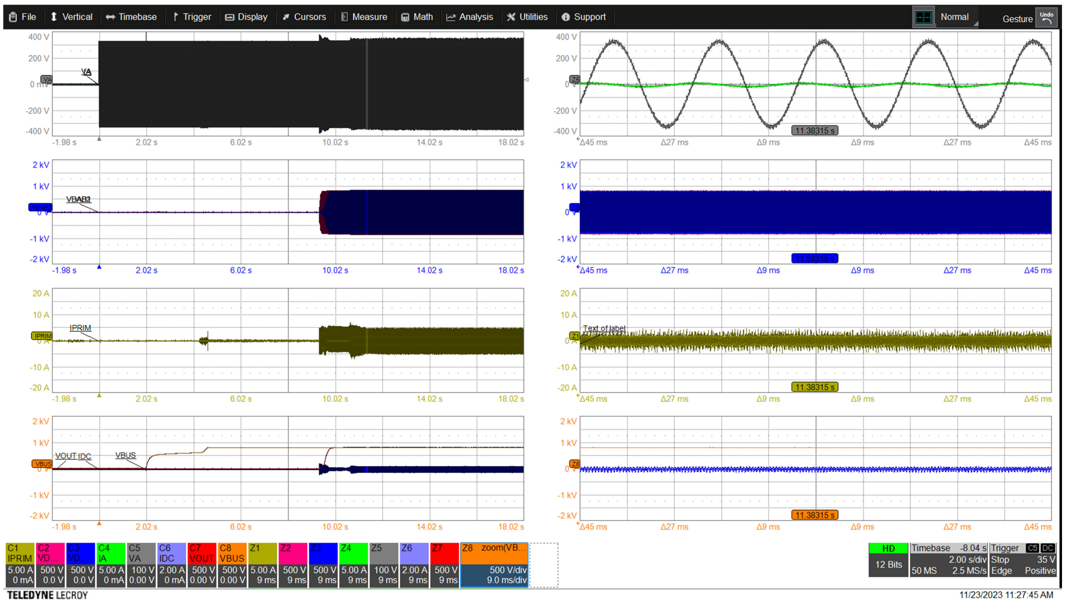
C8 = V_{BUS}

As can be seen from the first plot in Figure 25, the phase voltage and the relative current are perfectly aligned due to the high power factor (0.996). It is also possible to observe, from plots 6 and 7 respectively, the voltages at the ends of the HFT and the primary current of the Dual Active Bridge.

Waveforms analysis at:

- V_{IN} = 230 Vrms
- V_{OUT} = 800 V
- $f_{SW\ (PFC)}$ = 70 kHz
- $f_{SW\ (DC\text{-}DC)}$ = 100 kHz

Figure 26. **Soft start-up**



Channel labels:

C1 = I_{PRIM}

C2 = V_{DAB1}

C3 = V_{DAB2}

C4 = I_A

C5 = V_A

C6 = I_{DC}

C7 = V_{OUT}

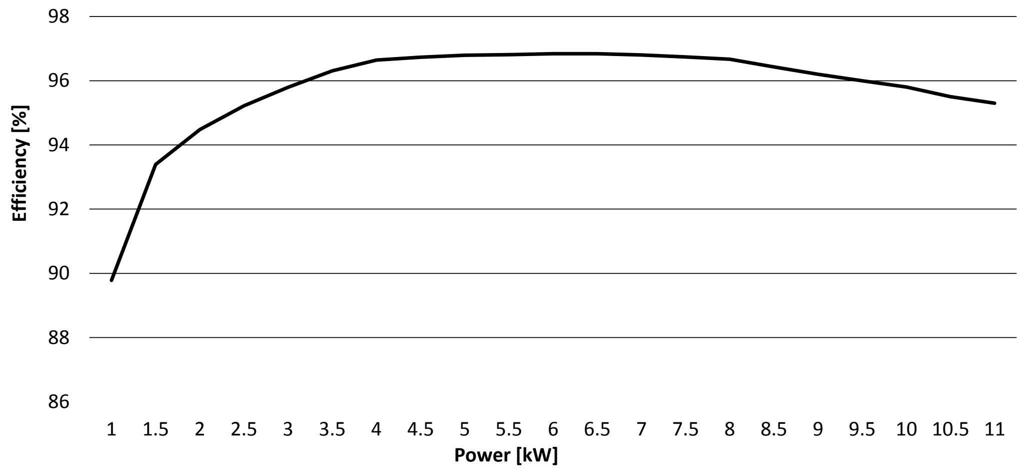
C8 = V_{BUS}

Figure 26, shows the soft startup procedure implemented in the STDES-BCBIDIR. As can be seen from the fourth plot, the DC-BUS voltage (C8) is raised to the reference value following a controlled trend. After a configurable delay, the output voltage V_{OUT} (C7) is raised to the reference value also in a controlled manner.

Efficiency characterizations at:

- V_{IN} = 230 Vrms
- V_{OUT} = 800 V
- $f_{SW\ (PFC)}$ = 70 kHz
- $f_{SW\ (DC\text{-}DC)}$ = 100 kHz

Figure 27. Overall Efficiency



6 Schematic diagrams

Figure 28. STDES-BCBIDIR circuit schematic - Power board (1 of 18)

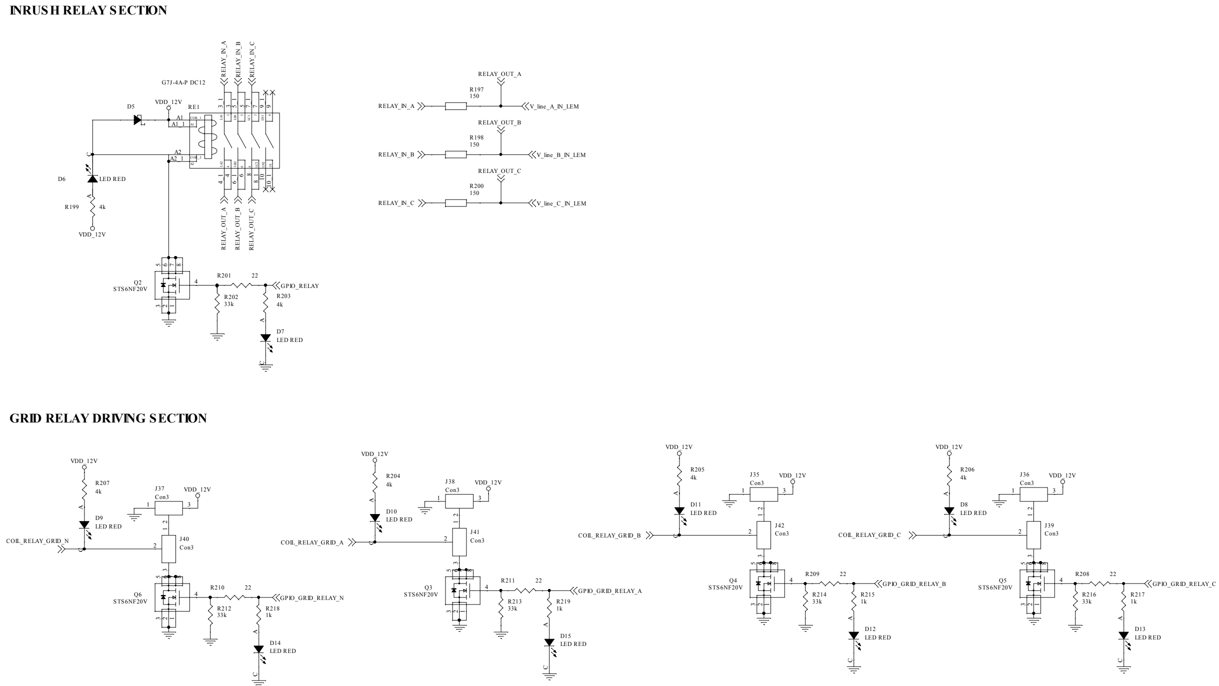


Figure 29. STDES-BCBIDIR circuit schematic - Power board (2 of 18)

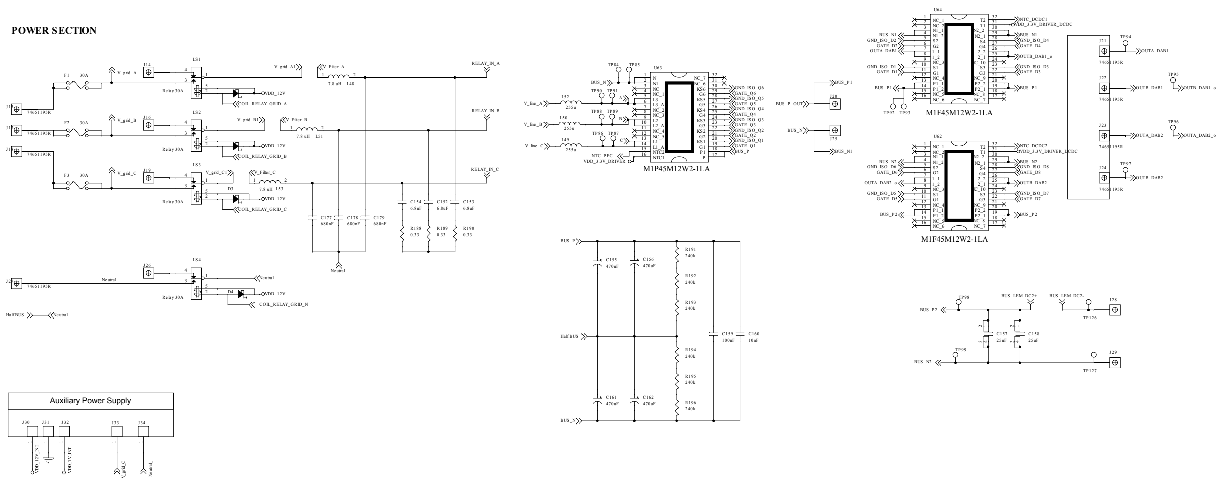


Figure 30. STDES-BCBIDIR circuit schematic - Power board (3 of 18)

LINE VOLTAGE SENSING

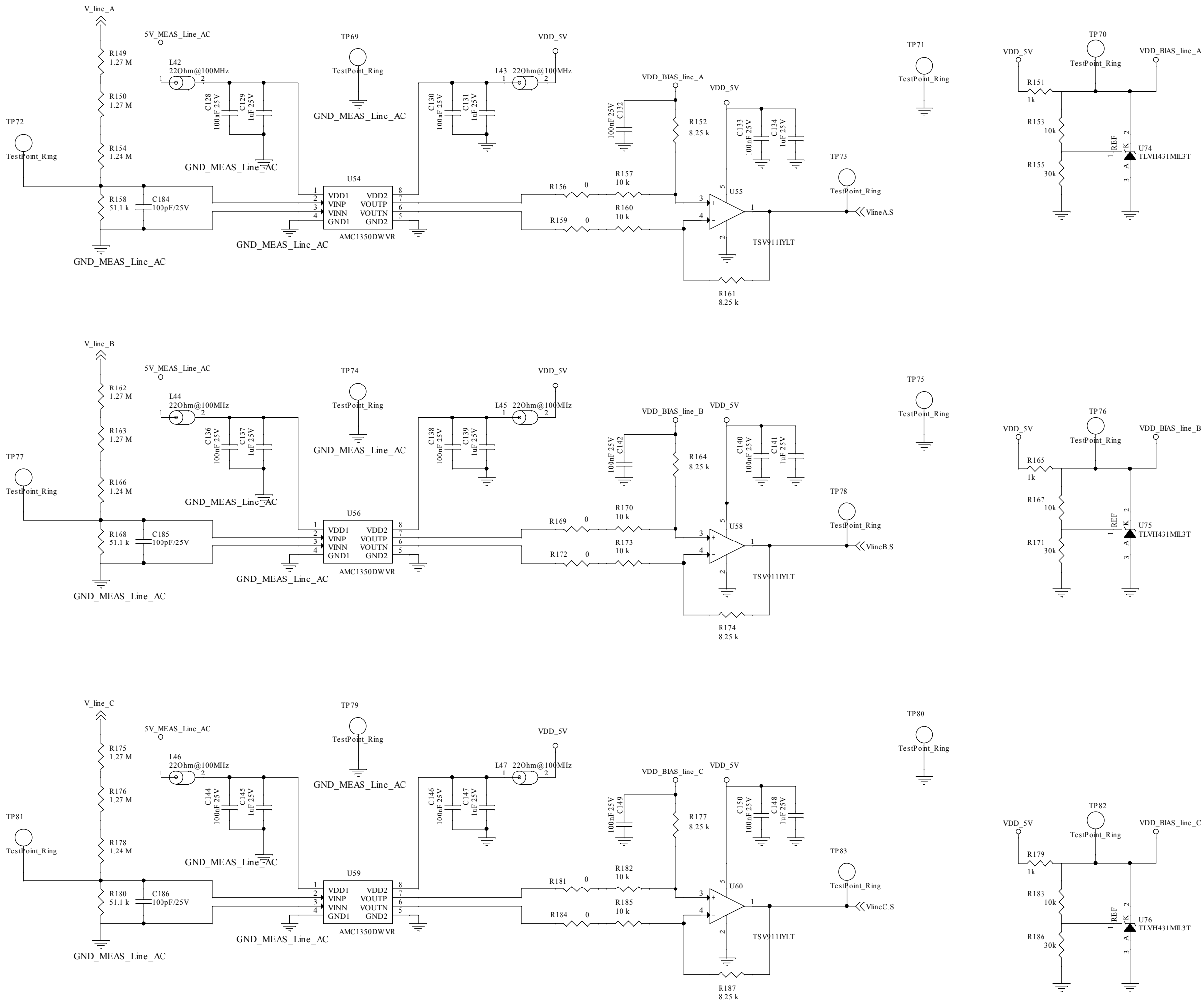


Figure 31. STDES-BCBIDIR circuit schematic - Power board (4 of 18)

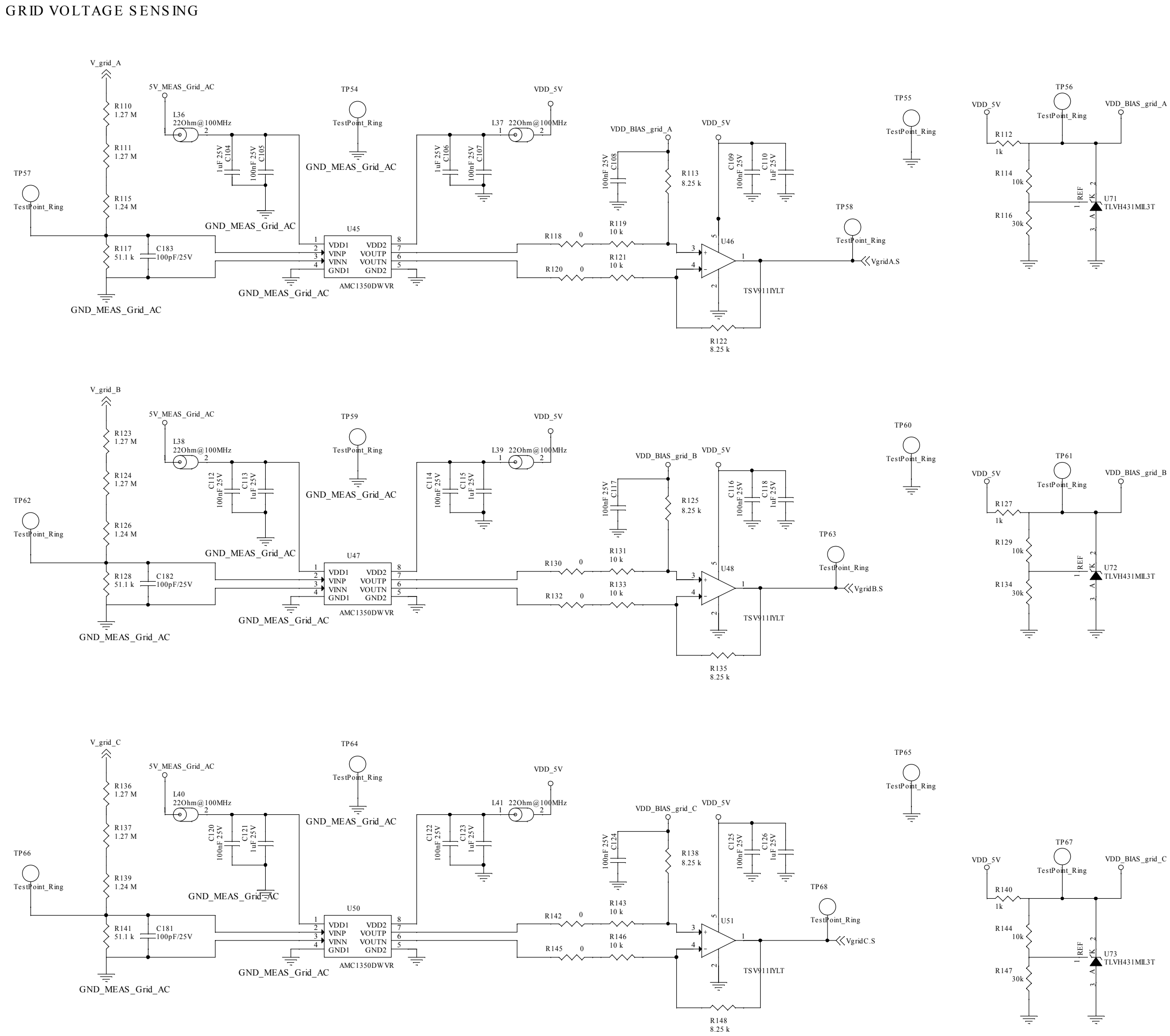


Figure 32. STDES-BCBIDIR circuit schematic - Power board (5 of 18)

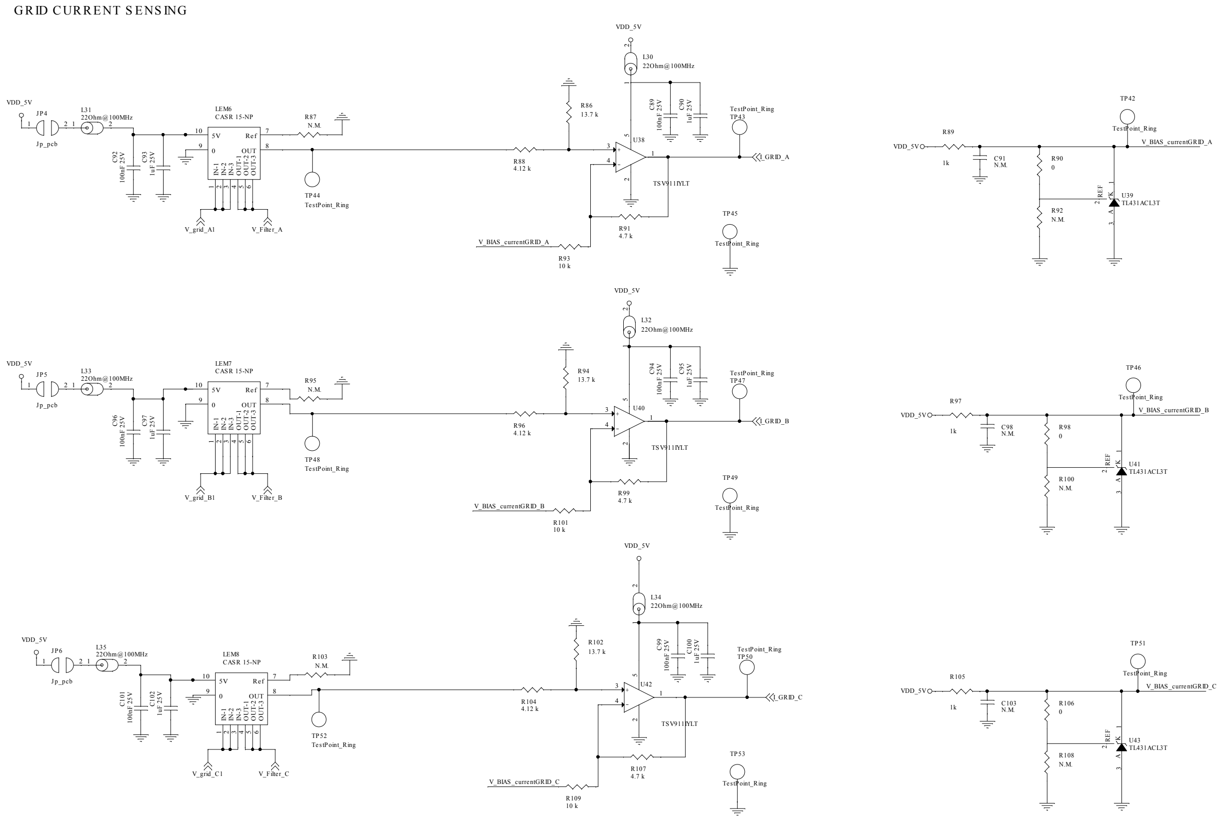


Figure 33. STDES-BCBIDIR circuit schematic - Power board (6 of 18)

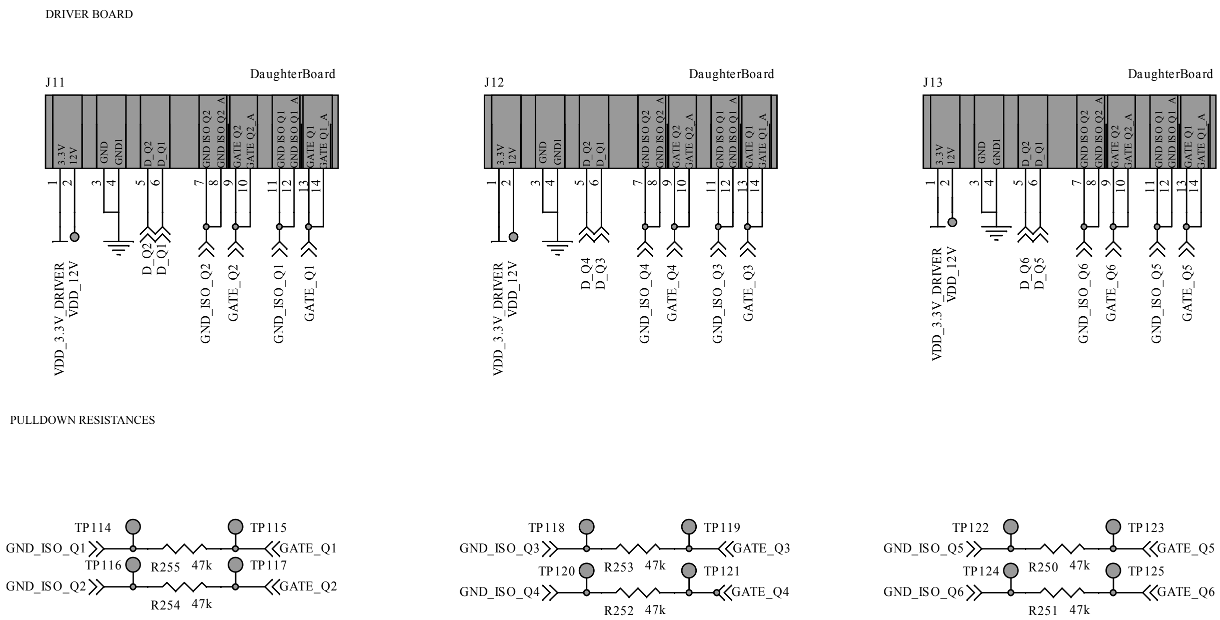


Figure 34. STDES-BCBIDIR circuit schematic - Power board (7 of 18)

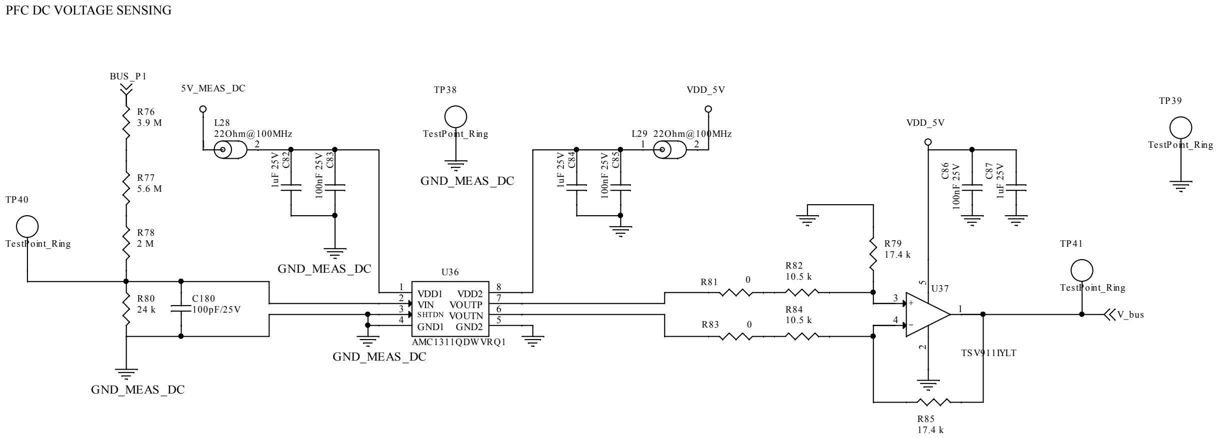


Figure 35. STDES-BCBIDIR circuit schematic - Power board (8 of 18)

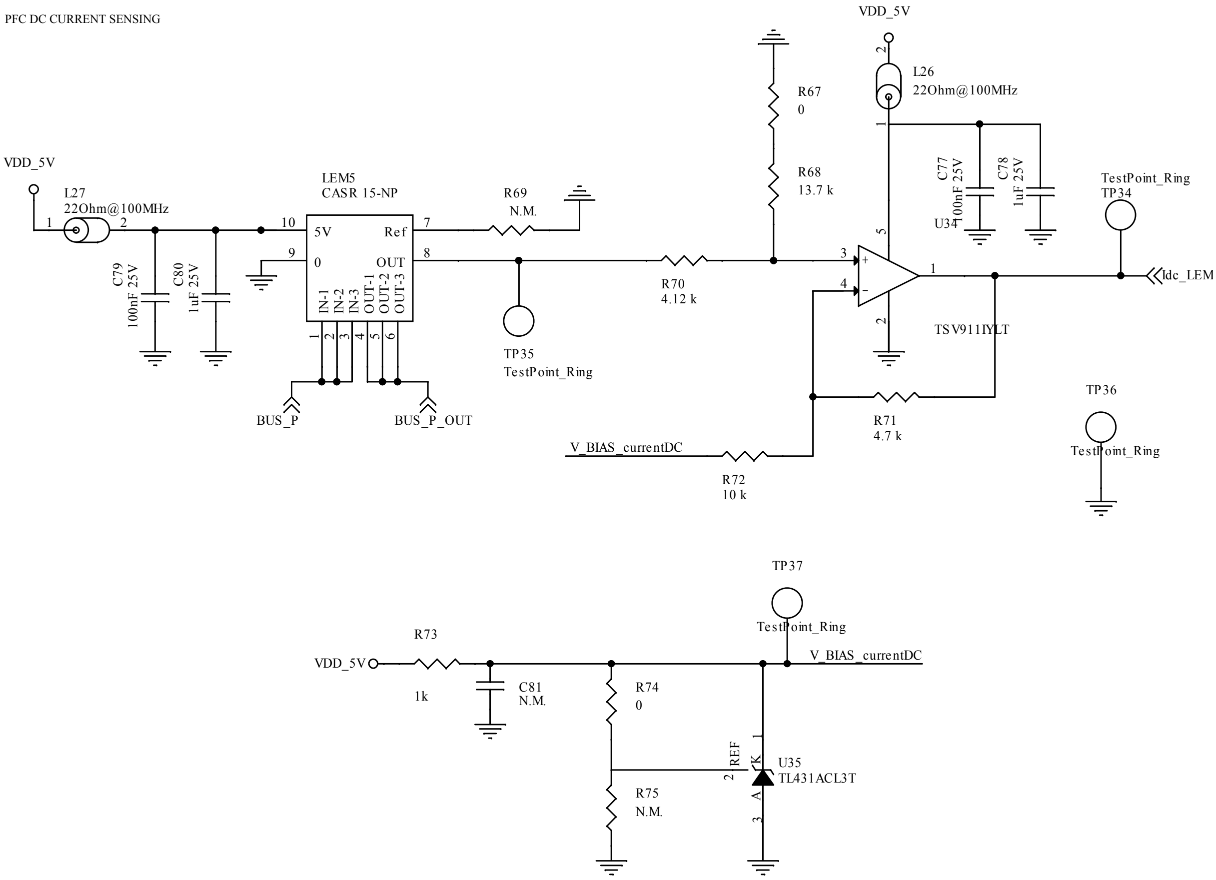


Figure 36. STDES-BCBIDIR circuit schematic - Power board (9 of 18)

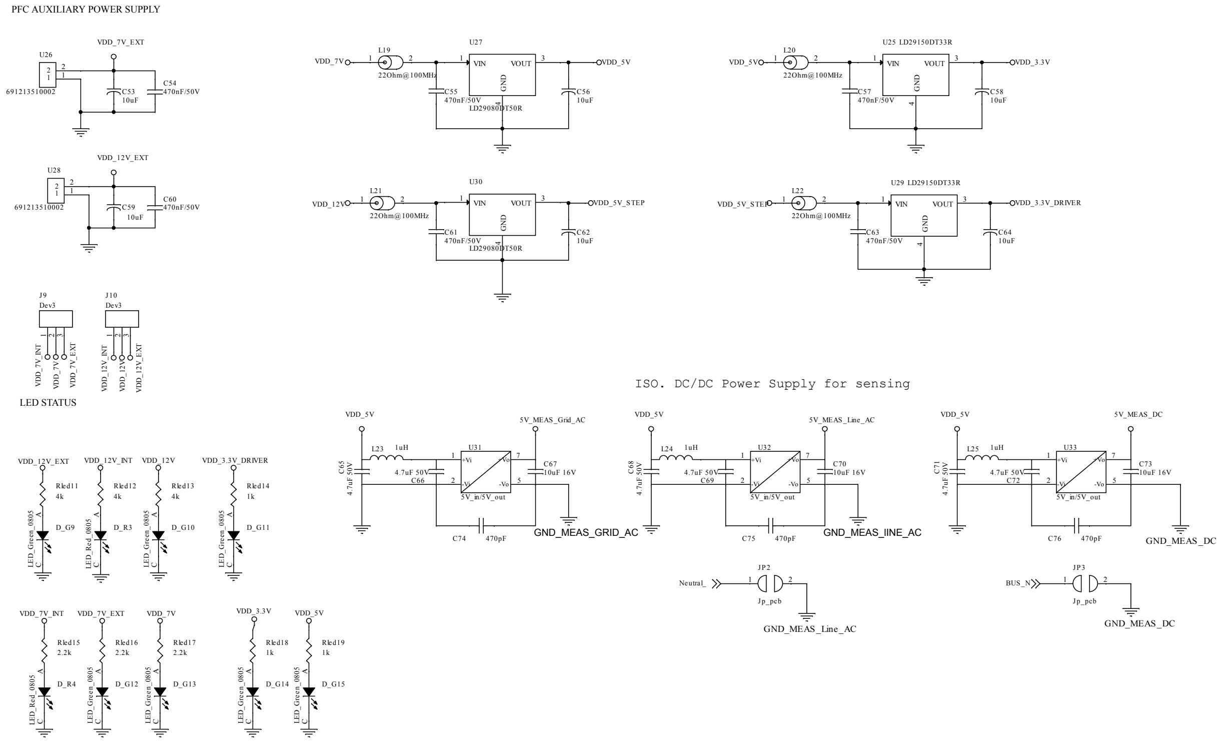


Figure 37. STDES-BCBIDIR circuit schematic - Power board (10 of 18)

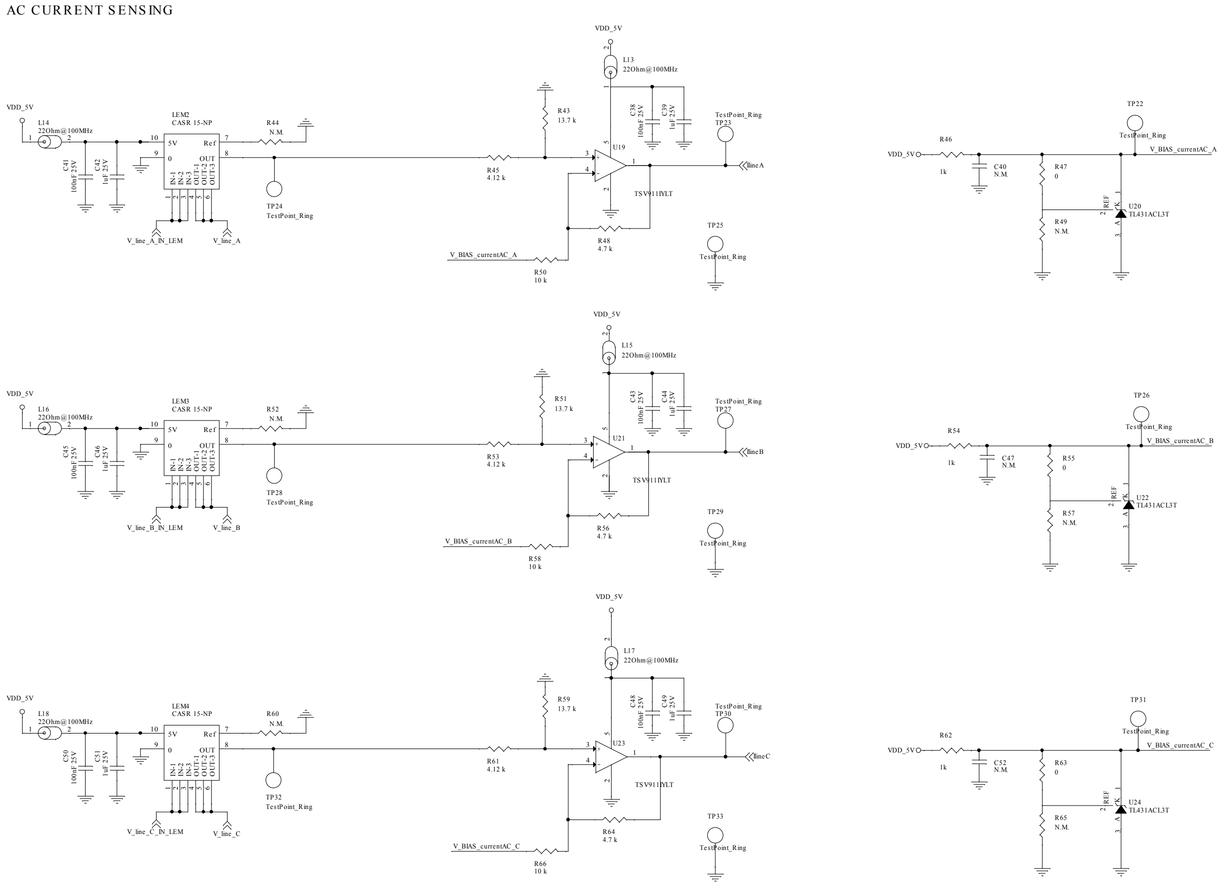


Figure 38. STDES-BCBIDIR circuit schematic - Power board (11 of 18)

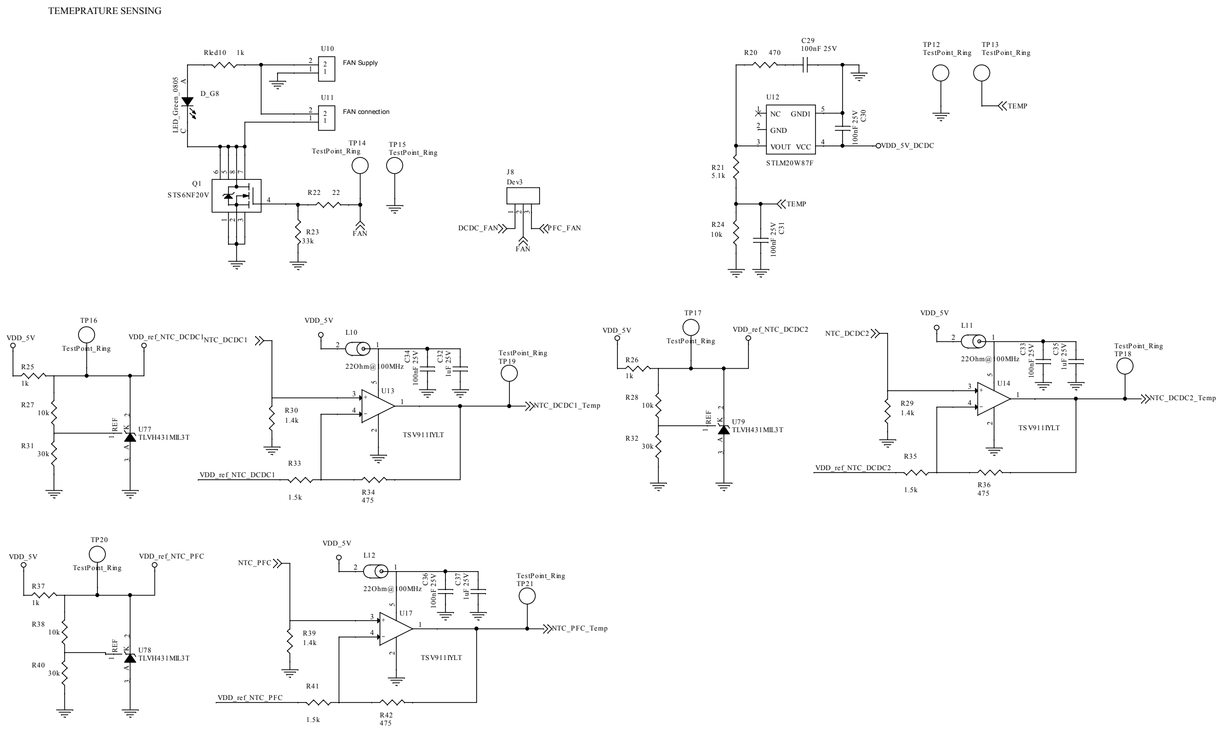


Figure 39. STDES-BCBIDIR circuit schematic - Power board (12 of 18)

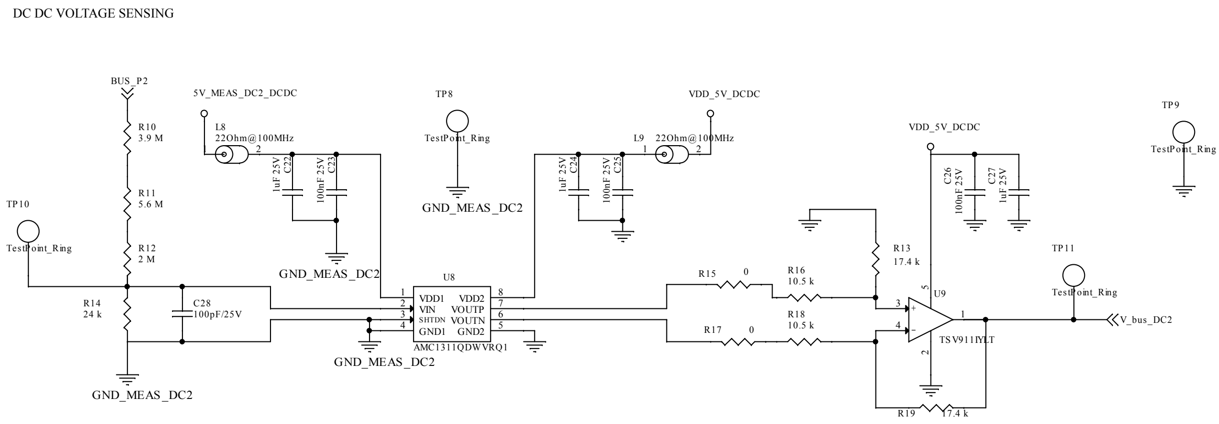


Figure 40. STDES-BCBIDIR circuit schematic - Power board (13 of 18)

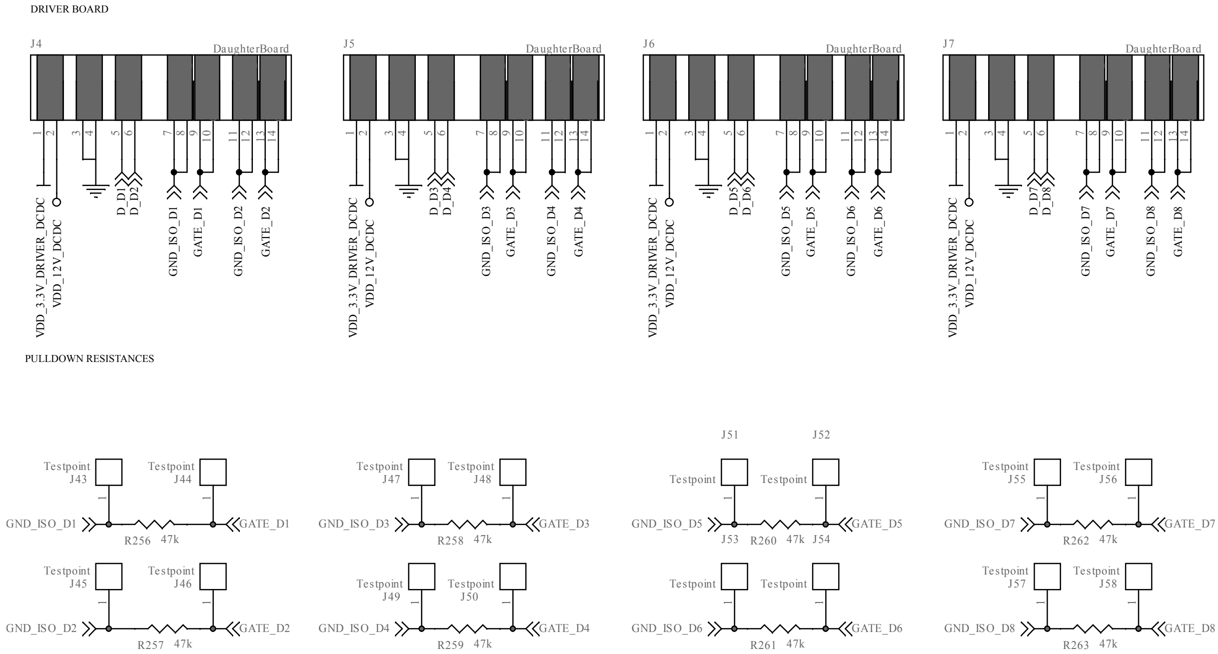


Figure 41. STDES-BCBIDIR circuit schematic - Power board (14 of 18)

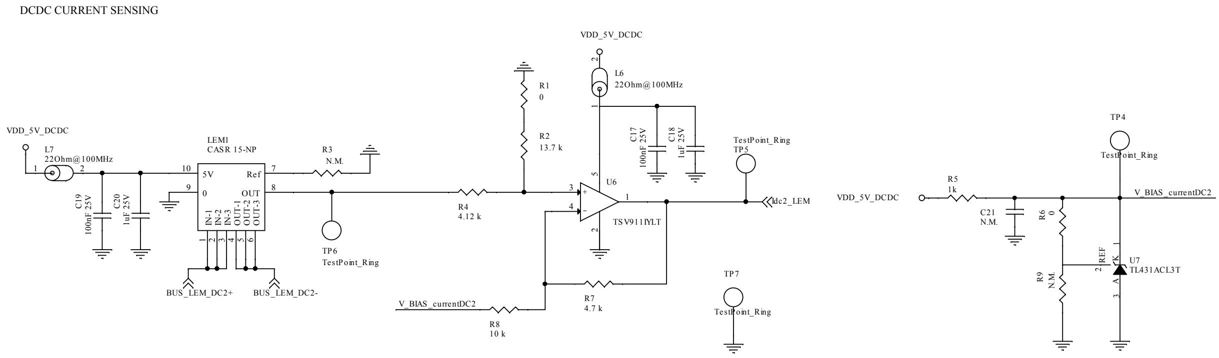


Figure 42. STDES-BCBIDIR circuit schematic - Power board (15 of 18)

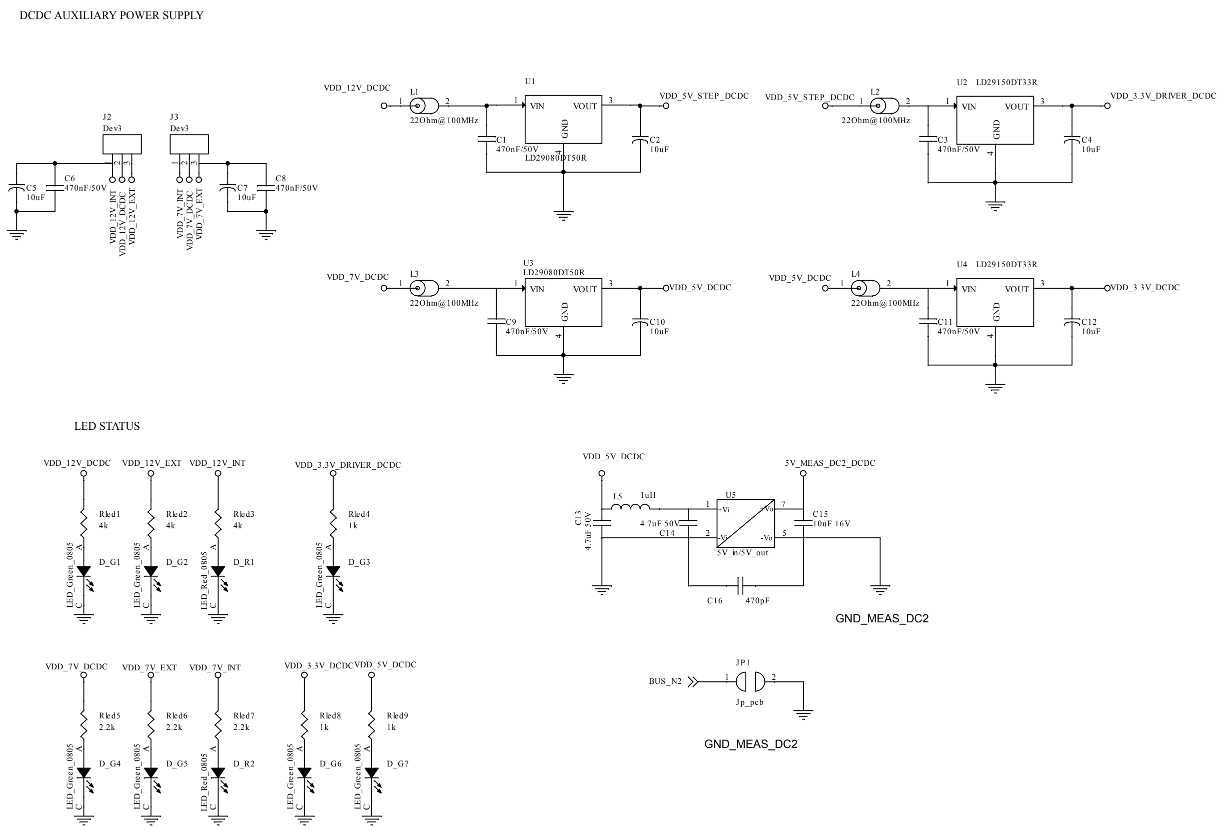


Figure 43. STDES-BCBIDIR circuit schematic - Power board (16 of 18)

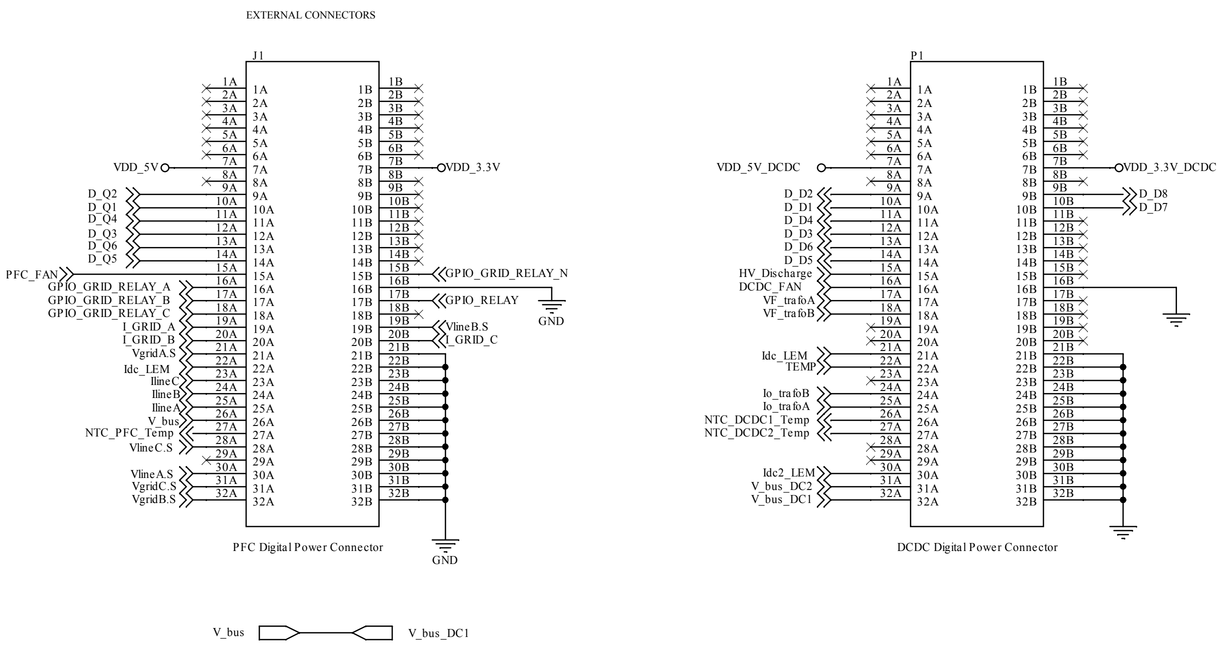


Figure 44. STDES-BCBIDIR circuit schematic - Power board (17 of 18)

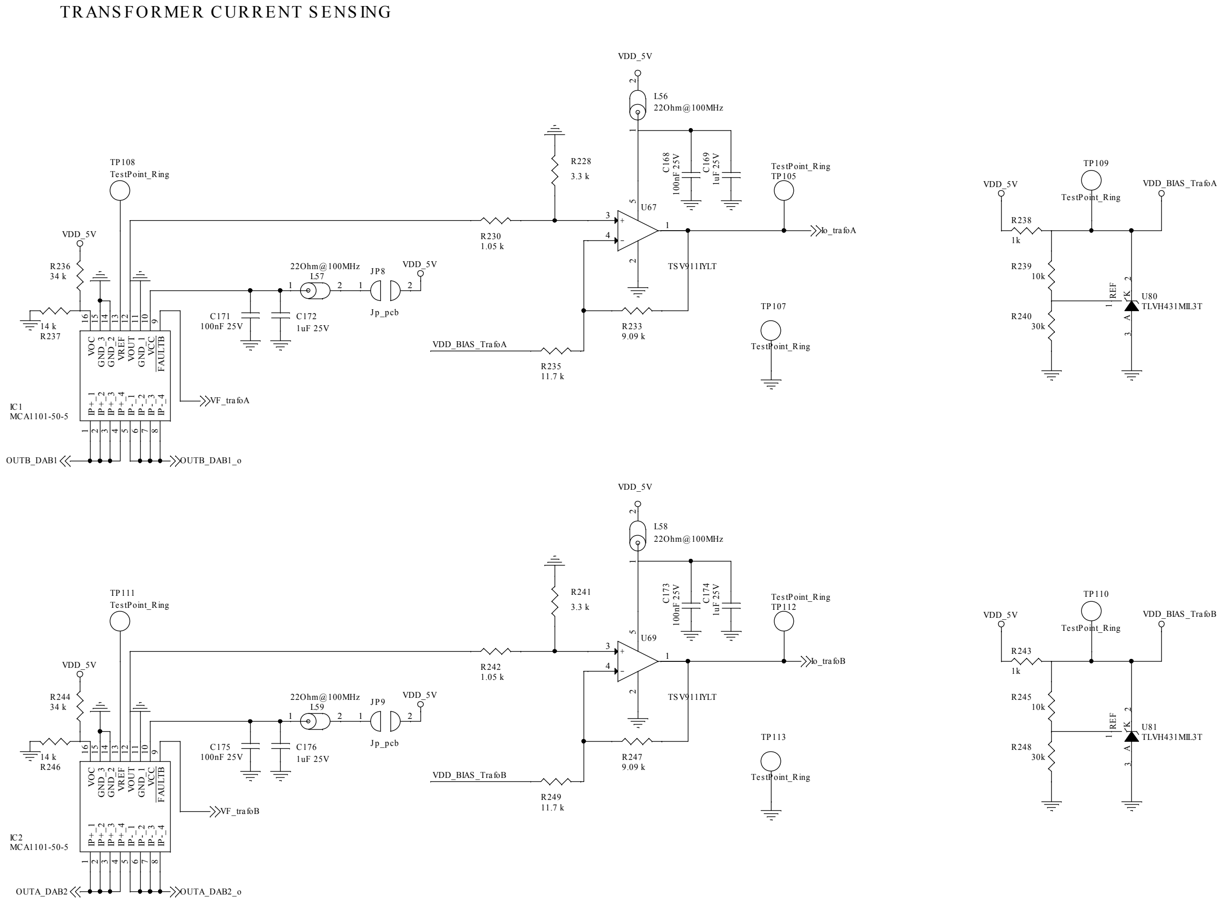


Figure 45. STDES-BCBIDIR circuit schematic (18 of 18) - Power board

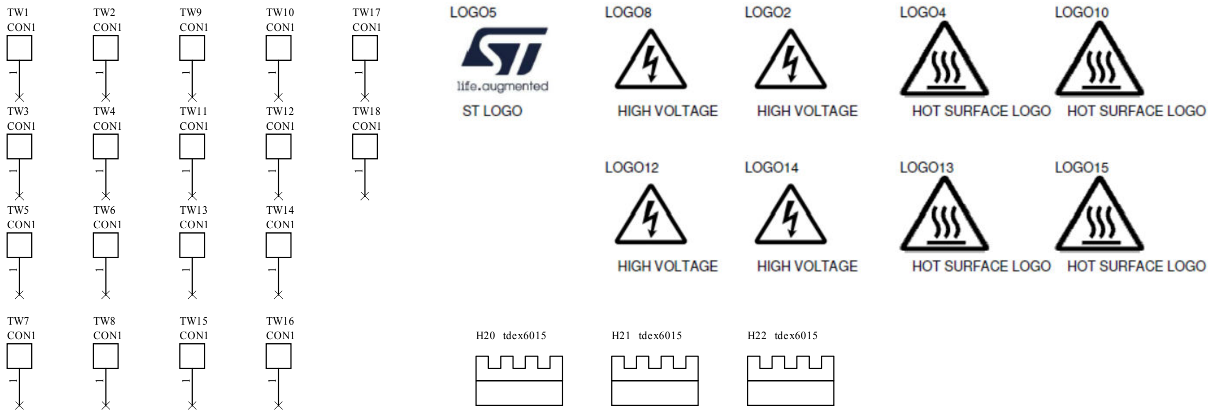


Figure 46. STDES-BCBIDIR circuit schematic - Control board

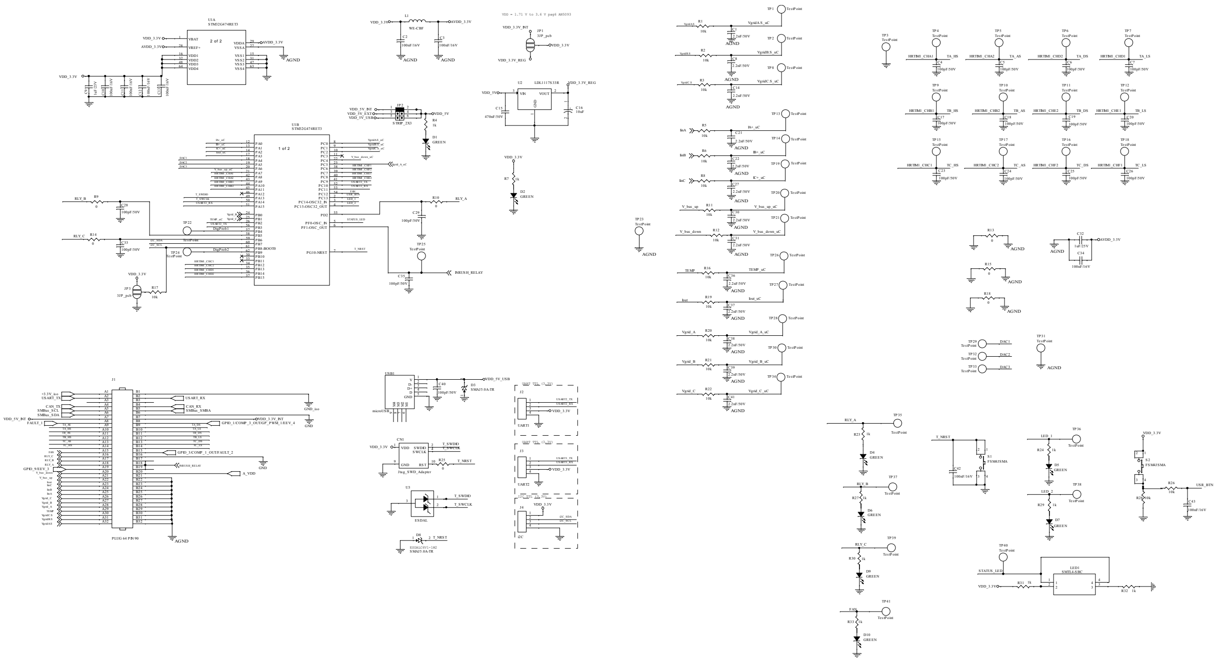
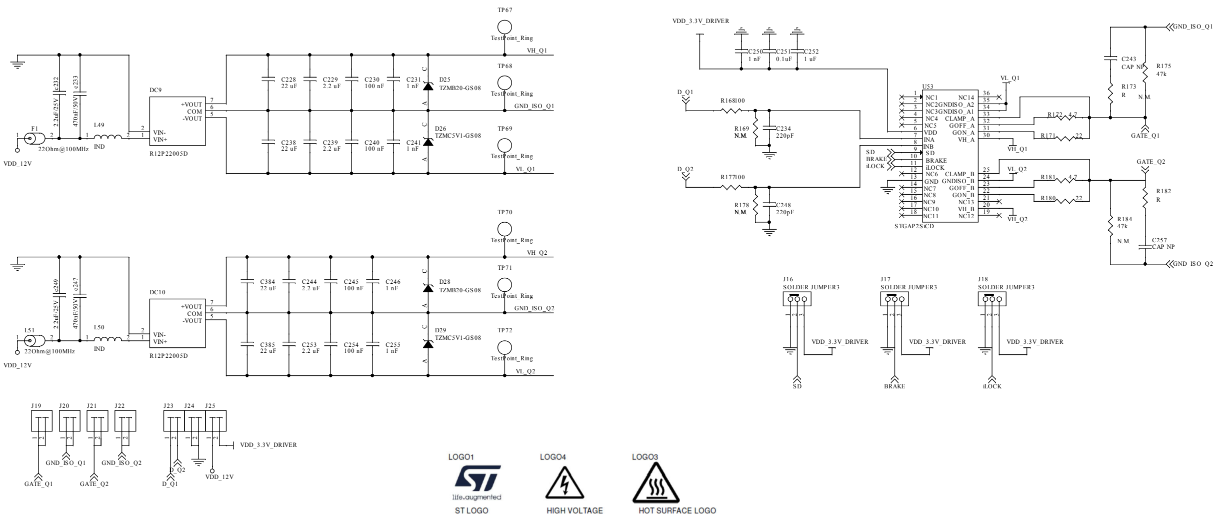


Figure 47. STDES-BCBIDIR circuit schematic - Driver board



7 Bill of materials

Table 16. STDES-BCBIDIR bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	1	-	Table 17. STDES-BCBIDIR	Main power board	ST	Not available for separate sale
2	2	-	Table 18. STDES-PFCBIDIR	Control board	ST	Not available for separate sale
3	2	-	Table 19. STDES-GAP2SICD	Driver board	ST	Not available for separate sale

Table 17. STDES-BCBIDIR - main power board

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	12	C1 C3 C6 C8 C9 C11 C54 C55 C57 C60 C61 C63	470nF/50V	Condensatore ceramico multistrato (MLCC) WURTH 470nF, ±10%, 50 V c.c., SMD	Wurth Electronics Inc.	885012207102
2	12	C2 C4 C5 C7 C10 C12 C53 C56 C58 C59 C62 C64	10uF	Aluminum Electrolytic Capacitors	Wurth Electronics Inc.	865250643009
3	8	C13 C14 C65 C66 C68 C69 C71 C72	4.7uF 50V	CAPACITOR CERAMIC SMD 1210	Wurth Electronics Inc.	885012209048
4	4	C15 C67 C70 C73	10uF 16V	CAPACITOR CERAMIC SMD 1210	Wurth Electronics Inc.	885012109009
5	4	C16 C74 C75 C76	470pF	CAPACITOR CERAMIC SMD 2211	Murata	GA352QR7GF471KW01L
6	56	C17 C19 C23 C25 C26 C29 C30 C31 C33 C34 C36 C38 C41 C43 C45 C48 C50 C77 C79 C83 C85 C86 C89 C92 C94 C96 C99 C101 C105 C107 C108 C109 C112 C114 C116 C117 C120 C122 C124 C125 C128 C130 C132 C133 C136 C138 C140 C142 C144 C146 C149 C150 C168 C171 C173 C175	100nF 25V	CAPACITOR CERAMIC SMD 0603	Wurth Electronics Inc.	885012206071R

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
7	47	C18 C20 C22 C24 C27 C32 C35 C37 C39 C42 C44 C46 C49 C51 C78 C80 C82 C84 C87 C90 C93 C95 C97 C100 C102 C104 C106 C110 C113 C115 C118 C121 C123 C126 C129 C131 C134 C137 C139 C141 C145 C147 C148 C169 C172 C174 C176	1uF 25V	CAPACITOR CERAMIC SMD 0603	Wurth Electronics Inc.	885012206076
8	8	C21 C40 C47 C52 C81 C91 C98 C103	N.M.	CAPACITOR CERAMIC SMD 0603	ANY	ANY
9	8	C28 C180 C181 C182 C183 C184 C185 C186	100pF/25V	Condensatore ceramico multistrato (MLCC) 100pF, ±5%, 25V cc, SMD	ANY	
10	3	C152 C153 C154	6.8uF	X2-Safety Class Capacitor; MKP - Metallized Polypropylene	Wurth Electronics Inc.	890324028008
11	4	C155 C156 C161 C162	470uF	Aluminium Electrolytic Capacitors	Wurth Electronics Inc.	861141486024
12	2	C157 C158	25uF	WCAP-FTDB DC-Link Capacitor,32.5mm,25uF	Wurth Electronics Inc.	890494428004CS
13	1	C159	100nF	MKT-Metallized polyester	Wurth Electronics Inc.	890493425009CS
14	1	C160	10nF	MKT-Metallized polyester	Wurth Electronics Inc.	890493422002CS
15	3	C177 C178 C179	680nF	WCAP-FTBE Film Capacitors,C2,PITCH:15,LxWxH:18x8.5x15		890283425008CS
16	5	D1 D2 D3 D4 D5	STPS360AFY	DIODE SCHOTTKY 60V 3A SOD128	STMicroelectronics	STPS360AFY
17	10	D6 D7 D8 D9 D10 D11 D12 D13 D14 D15	LED RED	LED RED CLEAR 1206 SMD	Wurth Electronics Inc.	150120RS75000

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
18	15	D_G1 D_G2 D_G3 D_G4 D_G5 D_G6 D_G7 D_G8 D_G9 D_G10 D_G11 D_G12 D_G13 D_G14 D_G15	LED_Green_0805		Wurth Electronics Inc.	150080GS75000
19	4	D_R1 D_R2 D_R3 D_R4	LED_Red_0805		Wurth Electronics Inc.	150080RS75000
20	3	F1 F2 F3	30A	Industrial & Electrical Fuses 30A 250VAC Midget	Littelfuse	0BLN030.T
21	3	H20 H21 H22	tdex6015	t high-performance extruded fan heat sink	Thermo Electric Devices	TDEX6015/TH12G
22	2	IC1 IC2	MCA1101-50-5	Board Mount Current Sensors High Accuracy +/-50A Current Sensor, 3.3V, Fixed gain, 1.5MHz 3dB BW, OCD, Galvanic Isolation. UL/IEC/ EN60950-1 and UL1577 certified. SOIC-16		
23	2	J1 P1	Digital Power Connector	Connector Erni 284166 32X2 female	ERNI	284166
24	5	J2 J3 J8 J9 J10	Dev3	SWITCH SLIDE SPDT 500MA 12V	Wurth Electronics Inc.	450301014042
25	4	J4 J5 J6 J7	DaughterBoard	Each DaughterBoard consists of 7 connectors of the indicated part number	Preci-Dip	801-87-002-10-001101
26	3	J11 J12 J13	DaughterBoard	Each DaughterBoard consists of 7 connectors of the indicated part number	Mill-Max Mfg Corp.	834-43-002-10-001000
27	16	J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26 J27 J28 J29	74651195R	Screw erminal with External Thread	Wurth Electronics Inc.	74651195R
28	5	J30 J31 J32 J33 J34	9324-0-15-15-23-27-04-0	Circuit Board Hardware - PCB RECPT. GOLD/ NICKEL .106 IN. PRESSFIT	Mill-Max Mfg Corp.	9324-0-15-15-23-27-04-0
29	8	J35 J36 J37 J38 J39 J40 J41 J42	Con3	SIL VERTICAL PC TAIL PIN HEADER	Harwin Inc.	M20-9990345

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
30	28	J43 J44 J45 J46 J47 J48 J49 J50 J51 J52 J53 J54 J55 J56 J57 J58 TP114 TP115 TP116 TP117 TP118 TP119 TP120 TP121 TP122 TP123 TP124 TP125	Testpoint	PC TEST POINT NATURAL	Harwin Inc.	S2751-46R
31	8	JP1 JP2 JP3 JP4 JP5 JP6 JP8 JP9	Jp_pcb		ANY	
32	47	L1 L2 L3 L4 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 L21 L22 L26 L27 L28 L29 L30 L31 L32 L33 L34 L35 L36 L37 L38 L39 L40 L41 L42 L43 L44 L45 L46 L47 L56 L57 L58 L59	22Ohm@100MHz		Wurth Electronics Inc.	742792021
33	4	L5 L23 L24 L25	1uH	SMT Power Inductor	Wurth Electronics Inc.	7447730
34	3	L48 L51 L53	7.8 uH	Power Inductor 7.8 uH 20.5A	Wurth Electronics Inc.	750344312
35	3	L49 L50 L52	255u	Power Inductor 255uH 23 A	Wurth Electronics Inc.	760801101
36	8	LEM1 LEM2 LEM3 LEM4 LEM5 LEM6 LEM7 LEM8	CASR 15-NP	SENSOR CURRENT HALL 15A AC/DC	LEM USA Inc.	CASR 15-NP
37	4	LS1 LS2 LS3 LS4	Relay 30A	General Purpose Relays Industrial Relays (General Purpose)	TE Connectivity / P&B	T9AV5L12-12
38	6	Q1 Q2 Q3 Q4 Q5 Q6	STS6NF20V, SO-8	MOSFET N-CH 20V 6A 8SOIC	ST	STS6NF20V
39	10	R1 R6 R47 R55 R63 R67 R74 R90 R98 R106	0	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
40	8	R2 R43 R51 R59 R68 R86 R94 R102	13.7 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
41	8	R3 R44 R52 R60 R69 R87 R95 R103	N.M.	N.M.	N.M.	N.M.
42	8	R4 R45 R53 R61 R70 R88 R96 R104	4.12 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
43	19	R5 R25 R26 R37 R46 R54 R62 R73 R89 R97 R105 R112 R127 R140 R151 R165 R179 R238 R243	1k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
44	8	R7 R48 R56 R64 R71 R91 R99 R107	4.7 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
45	20	R8 R50 R58 R66 R72 R93 R101 R109 R119 R121 R131 R133 R143 R146 R157 R160 R170 R173 R182 R185	10 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
46	8	R9 R49 R57 R65 R75 R92 R100 R108	N.M.	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
47	1	R10	3.9 M	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
48	1	R11	5.6 M	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
49	1	R12	2 M	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
50	1	R13	17.4 k	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
51	1	R14	24 k	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
52	2	R15 R17	0	CHIP RESISTOR SMD 0.1% 1/4W 0603	ANY	
53	2	R16 R18	10.5 k	CHIP RESISTOR SMD 0.1% 1/4W 0603	ANY	
54	1	R19	17.4 k	CHIP RESISTOR SMD 0.1% 1/4W 0603	ANY	
55	1	R20	470	Resistore per montaggio superficiale a film spesso Vishay 470O ±1%, 0,1W, 0603, serie CRCW	ANY	

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
56	1	R21	5.1k	Resistore per montaggio superficiale a film spesso Panasonic 5,1kO ±1%, 0,25W, 0603, serie ERJPA3	ANY	
57	1	R22	22	Resistore per montaggio superficiale a film spesso Vishay 22O ±1%, 0,25W, 1206, serie CRCW	ANY	
58	1	R23	33k	Resistore per montaggio superficiale a film spesso Vishay 33kO ±1%, 0,1W, 0603, serie CRCW	ANY	
59	1	R24	10k	Resistore SMD Bourns 10kO ±1%, 0,1W, 0603, serie CR0603-FX	ANY	
60	11	R27 R28 R38 R114 R129 R144 R153 R167 R183 R239 R245	10k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
61	3	R29 R30 R39	1.4k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
62	11	R31 R32 R40 R116 R134 R147 R155 R171 R186 R240 R248	30k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
63	3	R33 R35 R41	1.5k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
64	3	R34 R36 R42	475	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
65	1	R76	3.9 M	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
66	1	R77	5.6 M	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
67	1	R78	2 M	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
68	2	R79 R85	17.4 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
69	1	R80	24 k	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
70	14	R81 R83 R118 R120 R130 R132 R142 R145 R156 R159 R169 R172 R181 R184	0	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
71	2	R82 R84	10.5 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
72	6	R110 R111 R123 R124 R136 R137	1.27 M	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
73	12	R113 R122 R125 R135 R138 R148 R152 R161 R164 R174 R177 R187	8.25 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
74	3	R115 R126 R139	1.24 M	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
75	3	R117 R128 R141	51.1 k	CHIP RESISTOR SMD 0.1% 1/10W 1206	ANY	
76	6	R149 R150 R162 R163 R175 R176	1.27 M	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
77	3	R154 R166 R178	1.24 M	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
78	3	R158 R168 R180	51.1 k	CHIP RESISTOR SMD 0.1% 1/4W 1206	ANY	
79	3	R188 R189 R190	0.33	RES 0.33 OHM 5W 5% RADIAL	TE Connectivity Passive Product	SQMW5R33J
80	6	R191 R192 R193 R194 R195 R196	240k	Resistenza fissa per montaggio superficiale di precisione a film spesso Panasonic 240kO ±1%, 0,25W, 1206, serie ERJ	ANY	
81	3	R197 R198 R200	150	Wirewound Resistors - Through Hole 150 Ohms 5W 300PPM	TE Connectivity	SQMW5150RJ
82	12	R199 R203 R204 R205 R206 R207 RLED1 RLED2 RLED3 RLED11 RLED12 RLED13	4k	Resistore per montaggio superficiale a film spesso TE Connectivity 1kO ±1%, 0,1W, 0603, serie CRG0603	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
83	5	R201 R208 R209 R210 R211	22	CHIP RESISTOR SMD 1% 1/10W 0603	ANY	
84	5	R202 R212 R213 R214 R216	33k	CHIP RESISTOR SMD 1% 1/10W 0603	ANY	
85	11	R215 R217 R218 R219 RLED4 RLED8 RLED9 RLED10 RLED14 RLED18 RLED19	1k	Resistore per montaggio superficiale a film spesso TE Connectivity 1kO ±1%, 0,1W, 0603, serie CRG0603	ANY	ANY
86	2	R228 R241	3.3 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
87	2	R230 R242	1.05 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
88	2	R233 R247	9.09 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
89	2	R235 R249	11.7 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
90	2	R236 R244	34 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
91	2	R237 R246	14 k	CHIP RESISTOR SMD 0.1% 1/10W 0603	ANY	
92	14	R250 R251 R252 R253 R254 R255 R256 R257 R258 R259 R260 R261 R262 R263	47k	CHIP RESISTOR SMD 1% 1/8W 0805	ANY	
93	1	RE1	G7J-4A-P DC12		ANY	G7J-4A-P DC12
94	6	RLED5 RLED6 RLED7 RLED15 RLED16 RLED17	2.2k	Resistore per montaggio superficiale a film spesso TE Connectivity 1kO ±1%, 0,1W, 0603, serie CRG0603	ANY	ANY
95	88	TP4 TP5 TP6 TP7 TP8 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP19 TP20 TP21 TP22 TP23 TP24 TP25 TP26 TP27 TP28 TP29 TP30 TP31	TestPoint_Ring	Polo terminale RS Pro, diam. foro 1mm, Bronzo fosforoso	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
		TP32 TP33 TP34 TP35 TP36 TP37 TP38 TP39 TP40 TP41 TP42 TP43 TP44 TP45 TP46 TP47 TP48 TP49 TP50 TP51 TP52 TP53 TP54 TP55 TP56 TP57 TP58 TP59 TP60 TP61 TP62 TP63 TP64 TP65 TP66 TP67 TP68 TP69 TP70 TP71 TP72 TP73 TP74 TP75 TP76 TP77 TP78 TP79 TP80 TP81 TP82 TP83 TP105 TP107 TP108 TP109 TP110 TP111 TP112 TP113				
96	18	TP84 TP85 TP86 TP87 TP88 TP89 TP90 TP91 TP92 TP93 TP94 TP95 TP96 TP97 TP98 TP99 TP126 TP127	TEST POINT	PC TEST POINT NATURAL	Harwin Inc.	S1751-46R
97	18	TW1 TW2 TW3 TW4 TW5 TW6 TW7 TW8 TW9 TW10 TW11 TW12 TW13 TW14 TW15 TW16 TW17 TW18	CON1	Standoffs & Spacers WA-SBRIE M3x60mm	Wurth Electronics Inc.	971600324
98	4	U1 U3 U27 U30	LD29080DT50R , DPAK	IC REG LINEAR 5V 800MA DPAK	ST	LD29080DT50R
99	4	U2 U4 U25 U29	LD29150DT33R , DPAK	Regolatori di tensione LDO 1.5A VLD 400mV 3.3V Fixed	ST	LD29150DT33R
100	4	U5 U31 U32 U33	5V_in/5V_out	Modulo di alimentazione c.c.-c.c. DCH010505SN7, Modulo SIP, 4-Pin	Wurth Electronics Inc.	1779205141

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
101	21	U6 U9 U13 U14 U17 U19 U21 U23 U34 U37 U38 U40 U42 U46 U48 U51 U55 U58 U60 U67 U69	TSV911IYLT, SOT23-5L	IC OPAMP GP 8MHZ RRO SOT23-5	ST	TSV911IYLT
102	8	U7 U20 U22 U24 U35 U39 U41 U43	TL431ACL3T, SOT23	IC VREF SHUNT ADJ SOT23-3	ST	TL431ACL3T
103	2	U8 U36	AMC1311QDWVRQ1	IC ISOLATION 8SOIC	Texas Instruments	AMC1311QDWVRQ1
104	4	U10 U11 U26 U28	691213510002	Fixed Terminal Blocks WR-TBL 5.08mm THT 2Pin 14A 300V 20mOhm	Wurth Electronics Inc.	691213510002
105	1	U12	STLM20W87F, SOT323-5L	SENS TEMP ANLG VOLT SOT-323-5	ST	STLM20W87F
106	6	U45 U47 U50 U54 U56 U59	AMC1350DWVR	Amplificatore Di isolamento 1 Circuito 8-SOIC	TexasInstrument	AMC1350DWVR
107	2	U62 U64	M1F45M12W2-1LA, ACEPACK DMT-32	Power module fourpack topology 45 m? typ. SiC Power MOSFET with NTC	ST	M1F45M12W2-1LA
108	1	U63	M1P45M12W2-1LA	Power module sixpack topology 27.5 m? typ. SiC Power MOSFET with NTC	ST	M1P45M12W2-1LA
109	11	U71 U72 U73 U74 U75 U76 U77 U78 U79 U80 U81	TLVH431MIL3T, SOT23	IC VREF SHUNT ADJ SOT23-3	STMicroelectronics	TLVH431AIL3T

Table 18. **STDES-PFCBIDIR - control board**

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	13	C1 C8 C14 C21 C22 C27 C30 C31 C36 C37 C38 C39 C41	2.2nF/50V	Wurth Elektronik, 0603 (1608M) 2.2nF Multilayer Ceramic Capacitor MLCC 50V dc ±10% , SMD 885012206085	Wurth Elektronik	885012206085
2	9	C2 C3 C10 C11 C12 C13 C34 C42 C43	100nF/16V	Wurth Elektronik, 0603 (1608M) 100nF Multilayer Ceramic Capacitor MLCC 16V dc ±10% , SMD 885012206046	Wurth Elektronik	885012206046
3	16	C4 C5 C6 C7 C18 C19 C20 C23 C24 C25 C26 C28 C29 C33 C35 C40	100pF/50V	Wurth Elektronik, 0603 (1608M) MLCC 885012006057	Wurth Elektronik	885012006057

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
4	2	C9 C32	1uF/25V	Wurth Elektronik, 0603 (1608M) 1µF Multilayer Ceramic Capacitor MLCC 25V dc ±10% , SMD 885012206076	Wurth Elektronik	885012206076
5	1	C15	470nF/50V	Wurth Elektronik, 0805 (2012M) 470nF Multilayer Ceramic Capacitor MLCC 50V dc, SMD 885012207102	Wurth Elektronik	885012207102
6	1	C16	10uF	Wurth Elektronik 10µF Electrolytic Capacitor 16V dc, Surface Mount - 865230340001	Wurth Elektronik	865230340001
7	1	C17	100pF/50V	Wurth Elektronik, 0603 (1608M) MLCC 885012006057	Wurth Elektronik	885012006057
8	1	CN1	Jtag_SWD_Adapter	Samtec, FTSH, 10 Way, 2 Row, Straight Pin Header	Samtec	FTSH-105-01-F-D-K
9	8	D1 D2 D4 D5 D6 D7 D9 D10	GREEN	3.2 V Green LED 2012 (0805) SMD, Wurth Elektronik WL-SMCW 150080GS75000	Wurth Elektronik	150080GS75000
10	2	D3 D8	SMAJ5.0A-TR, SMA	STMicroelectronics SMAJ5.0A-TR, Uni-Directional TVS Diode, 400W, 2-Pin DO-214AC	ST	SMAJ5.0A-TR
11	1	J1	PLUG 64 PIN 90	Connector Erni 90° 384241 32X2 male	ERNI	384241
12	1	J2	UART1	Wurth Elektronik, WR-PHD, 6130, 4 Way, 1 Row, Straight Pin Header	Wurth Elektronik	61300411121
13	1	J3	UART2	Wurth Elektronik, WR-PHD, 6130, 4 Way, 1 Row, Straight Pin Header	Wurth Elektronik	61300411121
14	1	J4	i2C	Wurth Elektronik, WR-PHD, 6130, 4 Way, 1 Row, Straight Pin Header	Wurth Elektronik	61300411121
15	2	JP1 JP3	3JP_pcb		N.M.	N.M.
16	1	JP2	STRIP_2X3		N.M.	N.M.
17	1	L1	WE-CBF	Wurth Elektronik Ferrite Bead (EMI Suppression), 1.6 x 0.8 x 0.8mm (0603 (1608M)), 120O impedance at 100 MHz	Wurth Elektronik	74279262

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
18	1	LED1	PLCC4_3P2X2P8	LED Bivar, Verde, rosso, SMD, 2,4 V, 2 Led, PLCC 4	Bivar	SMTL4-SBC
19	16	R1 R2 R3 R5 R6 R8 R11 R12 R16 R17 R19 R20 R21 R22 R26 R28	10k	Bourns 10kO, 0603 (1608M) Thick Film SMD Resistor ±1% 0.1W - CR0603-FX-1002ELF	ANY	ANY
20	10	R4 R7 R23 R24 R27 R29 R30 R31 R32 R33	1k	TE Connectivity 1kO, 0603 Thick Film SMD Resistor ±1% 0.1W - CRG0603F1K0	ANY	ANY
21	7	R9 R10 R13 R14 R15 R18 R25	0	TE Connectivity 0O, 0603 (1608M) Thick Film SMD Resistor ±0% 0.1W - CRG0603ZR	ANY	ANY
22	2	S1 S2	FSM4JSMA	Black Button Tactile Switch, Single Pole Single Throw (SPST) 50 mA @ 24 V dc 1.4mm Surface Mount	TE Connectivity ALCOSWITCH Switches	FSM4JSMA
23	41	TP1 TP2 TP3 TP4 TP5 TP6 TP7 TP8 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP19 TP20 TP21 TP22 TP23 TP24 TP25 TP26 TP27 TP28 TP29 TP30 TP31 TP32 TP33 TP34 TP35 TP36 TP37 TP38 TP39 TP40 TP41	TestPoint	RS PRO 1mm Black Terminal Post	ANY	ANY
24	1	U1	STM32G474RET3, LQFP 64 10x10x1.4 mm	Arm® Cortex®-M4 32b MCU+FPU, 512KB Flash, 150 MHz, 128KB SRAM	ST	STM32G474RET3
25	1	U2	LDL1117S33R, SOT-223	STMicroelectronics LDL1117S33R, 1 Low Dropout Voltage, Voltage Regulator 1.2A, 3.3 V 4-Pin, SOT-223	ST	LDL1117S33R
26	1	U3	ESDAL, SOT23-3L	STMicroelectronics ESDA6V1L, Dual-Element Uni-Directional TVS Diode, 300W, 3-Pin SOT-23	ST	ESDA6V1L

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
27	1	USB1	microUSB	Molex Right Angle, SMT, Socket Type Micro-B 2.0 USB Connector	MOLEX	47346-0001

Table 19. STDES-GAP2SICD - driver board

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	4	C228 C238 C384 C385	22 uF	CAPACITOR CERAMIC SMD 0805		
2	4	C229 C239 C244 C253	2.2 uF	CAPACITOR CERAMIC SMD 0805		
3	4	C230 C240 C245 C254	100 nF	CAPACITOR CERAMIC SMD 0603		
4	4	C231 C241 C246 C255	1 nF	CAPACITOR CERAMIC SMD 0603		
5	2	C234 C248	220pF	CAPACITOR CERAMIC SMD 0603	Würth Elektronik	885012206079
6	2	C243 C257	CAP NP		ANY	
7	1	C250	1 nF	CAP CER 1 nF 25V 0603	Würth Elektronik	885012006044
8	1	C251	0.1uF	CAP CER 0.1UF 50V X7R 0603	Würth Elektronik	885012206095
9	1	C252	1 uF	CAP CER 1UF 6.3V X5R 0603	Yageo	CC0603KRX5R5BB105
10	2	D25 D28	TZMB20-GS08	DIODE ZENER 20V 500MW SOD80	Vishay Semiconductor Diodes Division	TZMB20-GS08
11	2	D26 D29	TZMC5V1-GS08	DIODE ZENER 5.1V 500MW SOD80	Vishay Semiconductor Diodes Division	TZMC5V1-GS08
12	2	DC9 DC10	R12P22005D	CONV DC/DC 2W 12VIN +20/-5VOUT T	Recom Power	R12P22005D
13	2	F1 L51	22Ohm@100MHz		Würth Elektronik	742792021
14	3	J16 J17 J18	SOLDER JUMPER3	TIN DROP JUMPER 0603 3pin		
15	7	J19 J20 J21 J22 J23 J24 J25	CONN_002P_000C_1			802-10-002-20-001000
16	2	L49 L50	IND	Fixed Inductor 22uH SMD 0805	Taiyo Yuden	LBC2012T220M
17	2	R168 R177	100	CHIP RESISTOR SMD 1% 1/10W 0603		

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
18	2	R169 R178	N.M	CHIP RESISTOR SMD 1% 1/10W 0603		
19	2	R171 R180	22	CHIP RESISTOR SMD 5% 1/4W 1206	any	
20	2	R172 R181	4.7	CHIP RESISTOR SMD 5% 1/4W 1206	any	
21	2	R173 R182	R			
22	2	R175 R184	47k	CHIP RESISTOR SMD 1% 1/8W 0805		
23	6	TP67 TP68 TP69 TP70 TP71 TP72	TestPoint_Ring	Polo terminale RS Pro, diam. foro 1mm, Bronzo fosforoso	ANY	ANY
24	1	U53	STGAP2SiCD, SSOP 32 LEAD 300 MIL PKG .0315 P	STGAP2SiCD	ST	STGAP2SiCD
25	2	C232 C249	2.2uF/25V	Condensatore ceramico multistrato (MLCC) WE 2,2µF, ±10%, 25 V c.c., SMD	Würth Elektronik	885012108019
26	2	C233 C247	470nF/50V	Condensatore ceramico multistrato (MLCC) 470nF, ±10%, 50 V c.c., SMD	Würth Elektronik	885012207102

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Revision history

Table 20. **Document revision history**

Date	Revision	Changes
19-Dec-2023	1	Initial release.
20-Aug-2025	2	Updated Introduction, Section 1.1: Features, Section 4.2: Preliminary test procedure. Added Section 3: HFT connection to STDES-BCBIDIR and Section 4: Test setup.

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