Inverter Assembly

A typical inverter assembly is pictured in Figure 1. The PCB is mounted on an aluminum base plate, to which both the GaN module and heat sink are thermally coupled. Note the microcontroller card in the DIM100 connector.

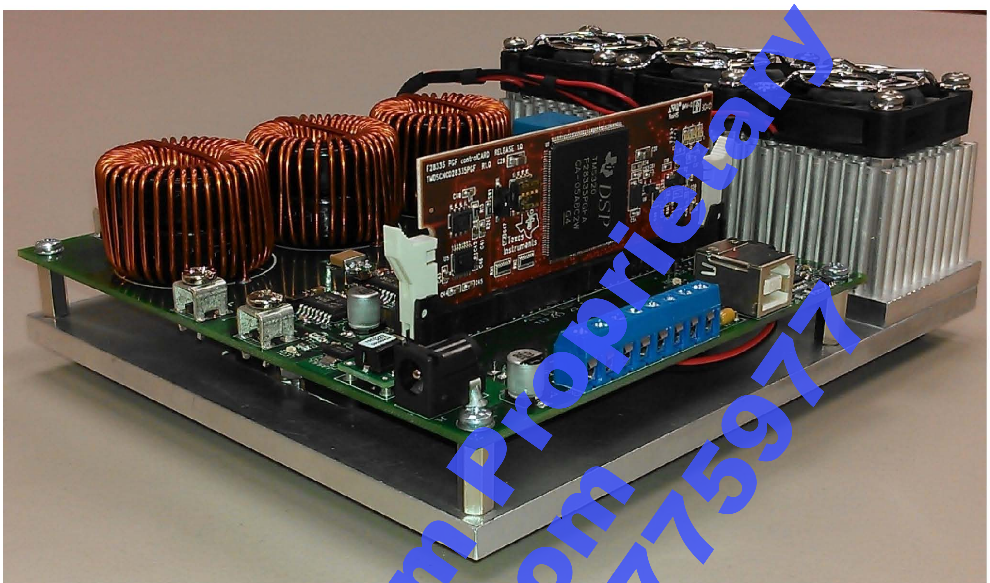


Figure 1. A typical TDMC inverter assembly, including controlCARD

Circuit Overview

Refer to figure 2 for a block diagram of the inverter circuit. A detailed schematic is also provided in pdf format on the USB stick which comes with the kit.

The TDMC motor drive is essentially a simple three-phase voltage-source inverter. Three GaN half bridges, integrated in a single module, are driven with pulse-width modulated command signals to create the three sinusoidally varying outputs. Output filters largely remove the switching frequency, effectively making the drive a three-phase class-D amplifier. The high-frequency (100kHz+) PWM signals are generated by the TI microcontroller and connected directly to three high-speed, high-voltage gate drivers. External connection to the microcontroller is provided by an isolated USB interface. There are also six general-purpose I/O signals, available at screw terminal block CN1. These signals are intended for connection to a shaft-angle encoder, but may be used for any desired purpose with appropriate programming. Except for the high-voltage supply for the power stage, all required voltages for the control circuitry are derived from one 12-15V input.

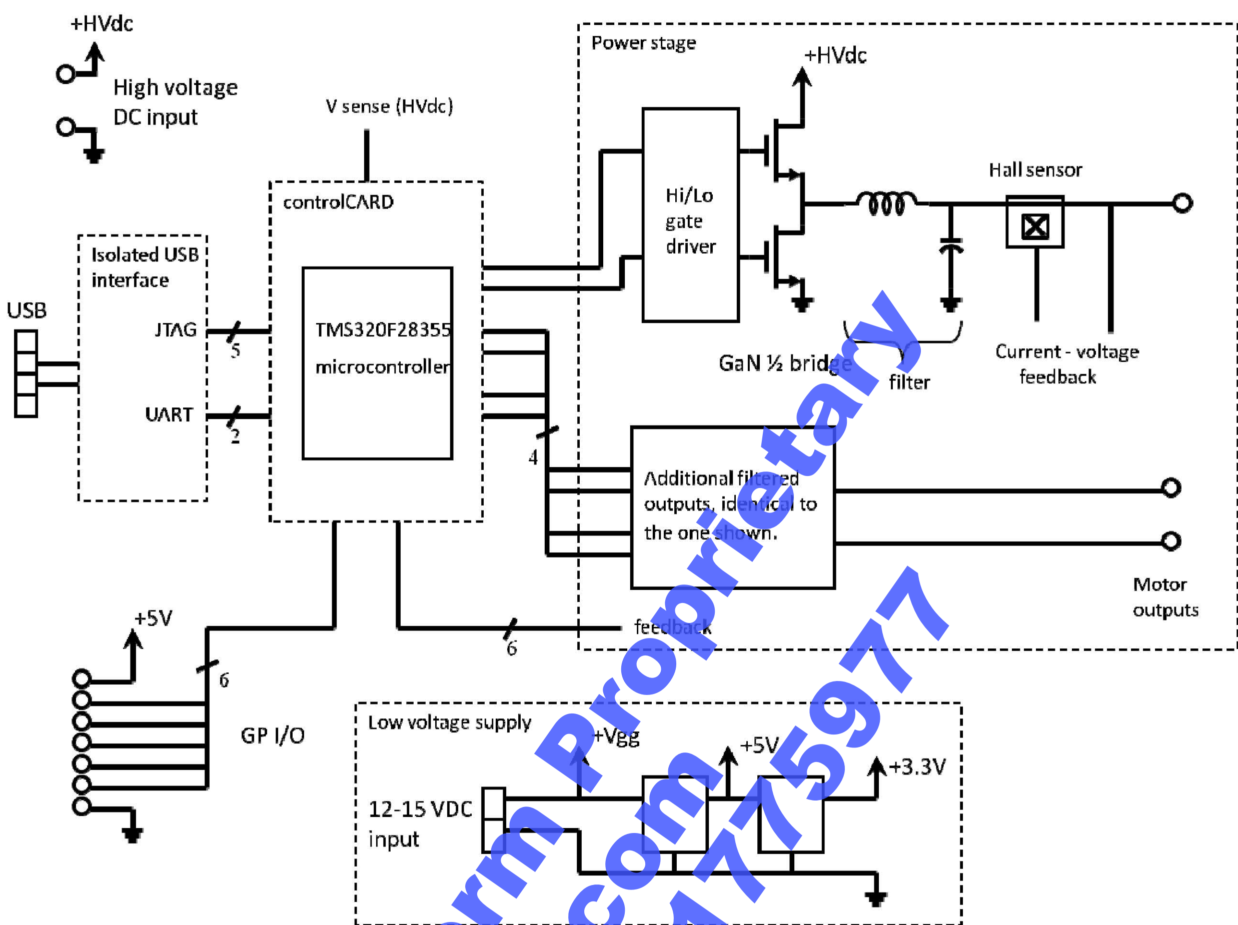


Figure 2. Circuit block diagram

The inverter takes advantage of diode-free operation*, in which the freewheeling current is carried by the GaN HEMTs themselves, without the need of additional freewheeling diodes. For minimum conduction loss, the gates of the transistors are enhanced while they carry the freewheeling current. The high and low-side Vgs waveforms are therefore pairs of non-overlapping pulses, as illustrated in figure 3.

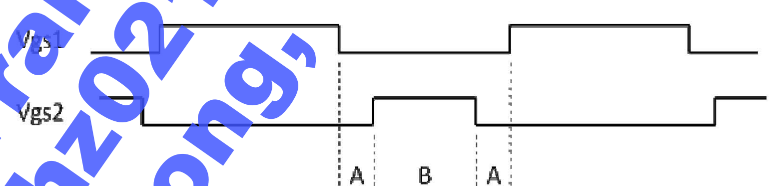


Figure 3: non-overlapping gate-drive pulse. A is a deadtime set in the firmware

GaN Module

The GaN high-electron mobility transistors (HEMTs) are standard Transphorm 600V dies, selected for the power rating of the demo board, and mounted in a module specifically designed for evaluation in inverters. The module itself is not necessarily a standard product, and as such, is only available for evaluation purposes, and not for design-in.

*US patent 7,965,126 B2

Insert the Vgg (12V) plug into jack J1. LED1 should illuminate, indicating power is applied to the 5V and 3.3V regulators. The fans on the heat sink should also turn on. Depending on the specific control card used, one or more LEDs on the control card will also illuminate, indicating power is applied.

Verify correct functionality before applying high voltage power. When using the demo utility (see the software reference guide, below), initialize the inverter and verify communication prior to applying high voltage. Likewise, if changes have been made to firmware or hardware, verify that the circuit and firmware are functioning correctly before applying high-voltage. For unloaded testing (without motor), it is recommended to turn up the HV supply slowly, monitoring the output signals for correct operation. With a motor connected, be aware of the possibility of high current draw at low voltage conditions. Applying a known adequate supply voltage before starting rotation is recommended. Set the current limit on the dc supply. This is important if the motor stalls.

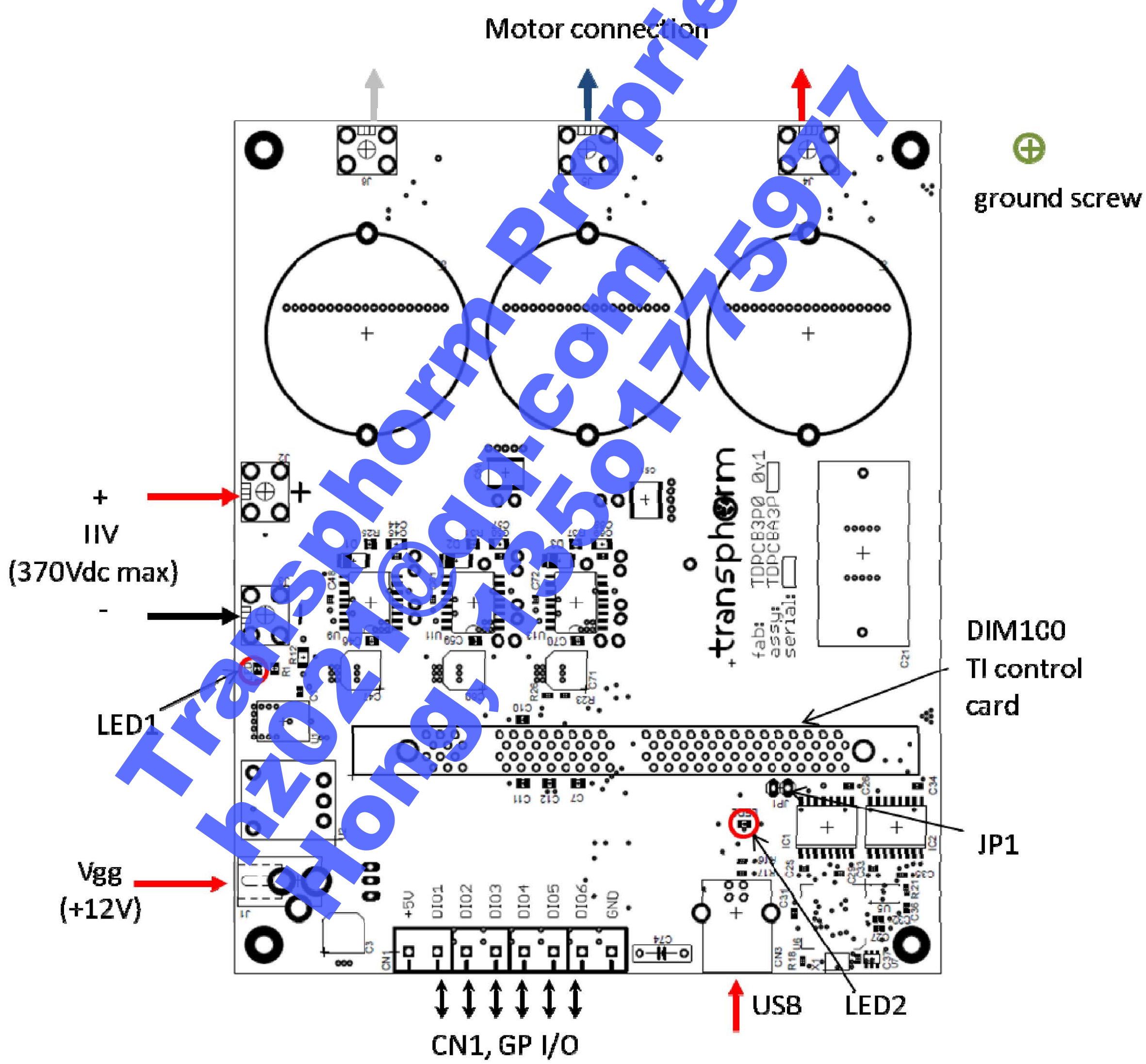


Figure 5. Connections

An angle encoder is not mandatory, but will be automatically detected if connected to the general pupose I/O terminals at CN1. The connections should be:

CN1:	+5V	DIO1	DIO2	DIO3	DIO4	DIO5	DIO6	GND
Encoder:	PG5V	A+	B+	C+	A-	B-	C-	PG0
Wire color:	red	blue	green	yellow	violet	gray	white	black

The complimentary signals, A-, B-, and C- are not actually used and may be left disconnected.

Probing the high-voltage signals

The high-speed signals at the switching nodes are best observed with a soldered probe, as illustrated in figure 5. The probe and ground wire are soldered to the high-side and low side Kelvin sense pins (pins S1-S6 in figure 4) of the module. If an extremely short (<2cm) ground clip is not available with your oscilloscope probe, one can be made by wrapping bus wire around the probe's ground strap. Be extremely careful to solder the probe ground and the probe tip to the correct pins (and only with power off). When the probe is de-soldered, be careful that no solder bridges are left. See also Transphorm application note AN0003: *PCB Board Layout and Probing for Fast Switching GaN HEMTs.*

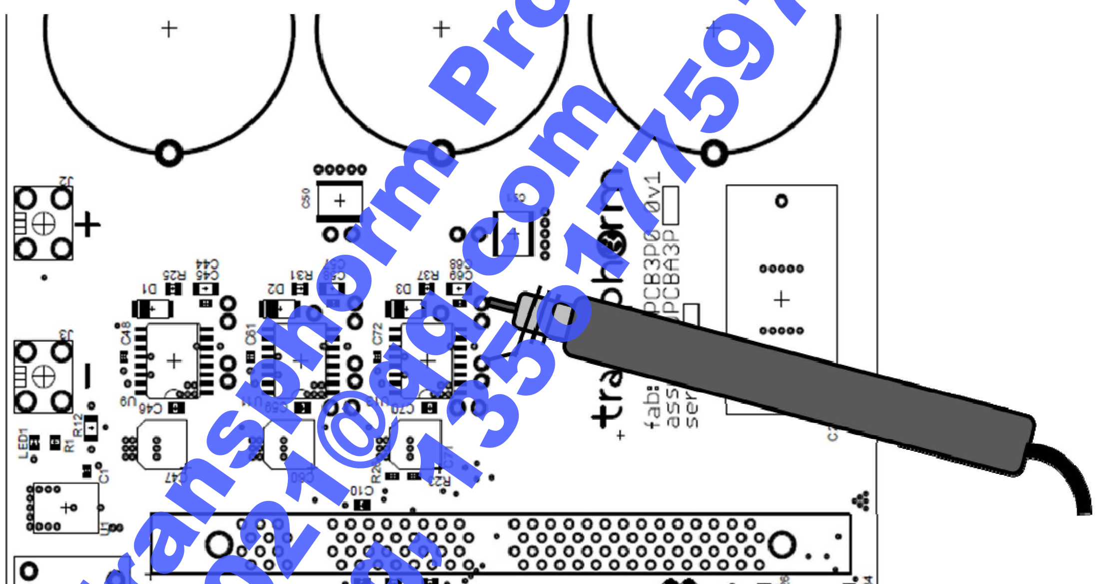


Figure 6: Probing a switching node with a soldered scope probe.

Removing the PCB assembly

The only reason to remove the PCB assembly from the base plate is to change the capacitors in the output filter. The GaN module is soldered to the PCB, but is also secured to the base plate with two screws and nuts. See figure 7. These must first be removed. Note that the nuts are not fixed to the module. Also be aware that there is a layer of rather messy thermal grease between the module and the base plate. Once the two module-mounting screws are loosened, the four screws at the corners of the PCB can be removed and the PCB lifted from the standoffs. Lift the PCB just enough to disconnect the fan cable before completely removing from the base plate.

Software Reference Guide

TDMCX000E0I Demo utility

Transphorm's TDMCX000E0I demo utility runs on a PC and communicates with the inverter. It provides a means of driving motors for test and evaluation using the firmware which is pre-loaded in the microcontroller's flash memory, while also allowing access to key variables. The initial release supports two modes of motor control: permanent-magnet sensorless or AC induction motor V/F. Permanent-magnet servo motors like the one supplied with the kit may be run in a sensorless closed-loop mode, with either speed or current control. Alternately, induction motors may be run in open-loop (V/F) mode. The utility is written in C#, and the source code is provided.

Installation

On the USB memory stick is a single folder titled "Transphorm". Copy this folder in its entirety to the root directory of your computer (C:\). Within this folder are subdirectories with files related to the microcontroller firmware, the PC utility software, and support documentation. Note: Do not run programs directly from the USB stick.

The demo utility communicates with the F28335 microcontroller over a serial port. The firmware was developed with TI's Code Composer integrated development system, and depends on serial-port drivers installed with it. For that reason, Code Composer must be installed on your computer before the demo utility can be used. Download instructions are included on the USB stick in document *Downloading Code Composer Studio*.

Getting Started

Once Code Composer is installed, the TDMCx000E0I demo utility can be used with Code Composer running or not running. The easiest way to get started is to not run Code Composer, and simply allow the microcontroller to boot from flash, as described in the following steps.

Verify that jumper JP1 on the TDMC circuit board is removed. This releases the JTAG port and allows the microcontroller to boot from flash. (keep the jumper for use with Code Composer.) Follow the steps in the Connection Sequence section of the preceding hardware guide. Verify that the current limit of the DC supply is set just beyond what is required for the motor (for the servo motor which comes with the kit, operating without load, a current limit of 1.0A should be adequate.)

The TDMCx000E0I demo utility is located in the following folder:

C:\Transphorm\TDMDx000EOI\TDMDx000EOIDemoSW\TDMDx000EOIDemoSW\bin\Debug

Start the application, TDPCB3P0Demo, from the location given above. The utility will identify available comm ports. Select the appropriate port (probably not Com1, since this is generally assigned to a device on the computer). Select the motor type and mode: Permanent Magnet Sensorless or AC

Iq Reference: Commanded current level for the quadrature axis. For any motor type, this is the component of the current which produces torque. In speed-control mode the outer speed loop generates a torque command, and the value given for Iq Reference is ignored.

Operating Points

Speed Feedback: The shaft speed, in the same units as the speed reference. This is an estimated value derived from the measured motor currents and voltage.

Id Feedback: Feedback value of Id, as determined by the Park transform. Signal Ds in the block diagram of figure 14.

Iq Feedback: Feedback value of Iq, as determined by the Park transform. Signal Qs in the block diagram of figure 14.

Vbus (V): The high-voltage supply, as measured on the PCB. This is an approximate, non-calibrated value.

Starting the motor: Permanent-magnet sensorless control mode

Verify that the voltage and current limit of the bus-voltage supply are at the desired levels. In PM Sensorless mode, set the motor in motion by entering a Speed Reference value between 0 and 1. Select current loop. Click Set. The motor will ramp up to the commanded speed and then maintain that speed with a constant amplitude quadrature current. The default value of 0.1 for Iq is adequate to start the motor, but is generally excessive for continuous operation. Figure 10 shows one phase current during start up.

Figure 10: current of one motor phase during start-up in current loop.

Always start the motor with LSW Flag set to current loop, since the speed-estimation algorithm in the firmware requires shaft rotation in order to estimate speed. Iq_reference should be set higher than the expected running current, to allow for start-up torque requirements. Once the shaft is rotating, the LSW flag can be changed to speed loop. In speed loop the estimated speed is maintained at the commanded value. Normally there will be a drop in current when control switches to speed-loop.

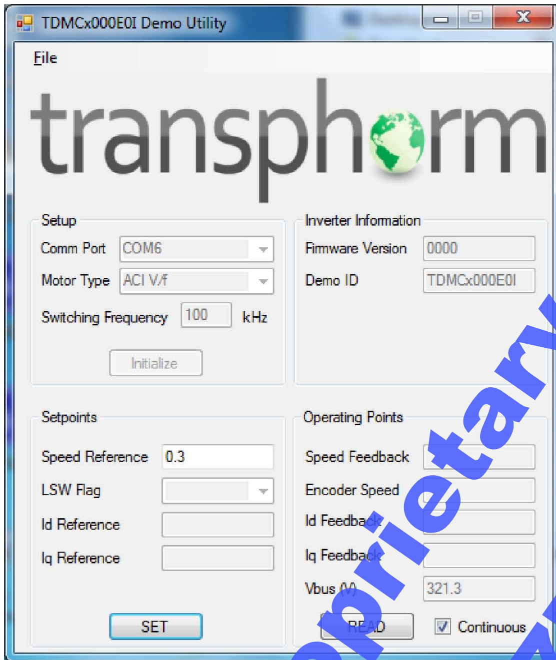
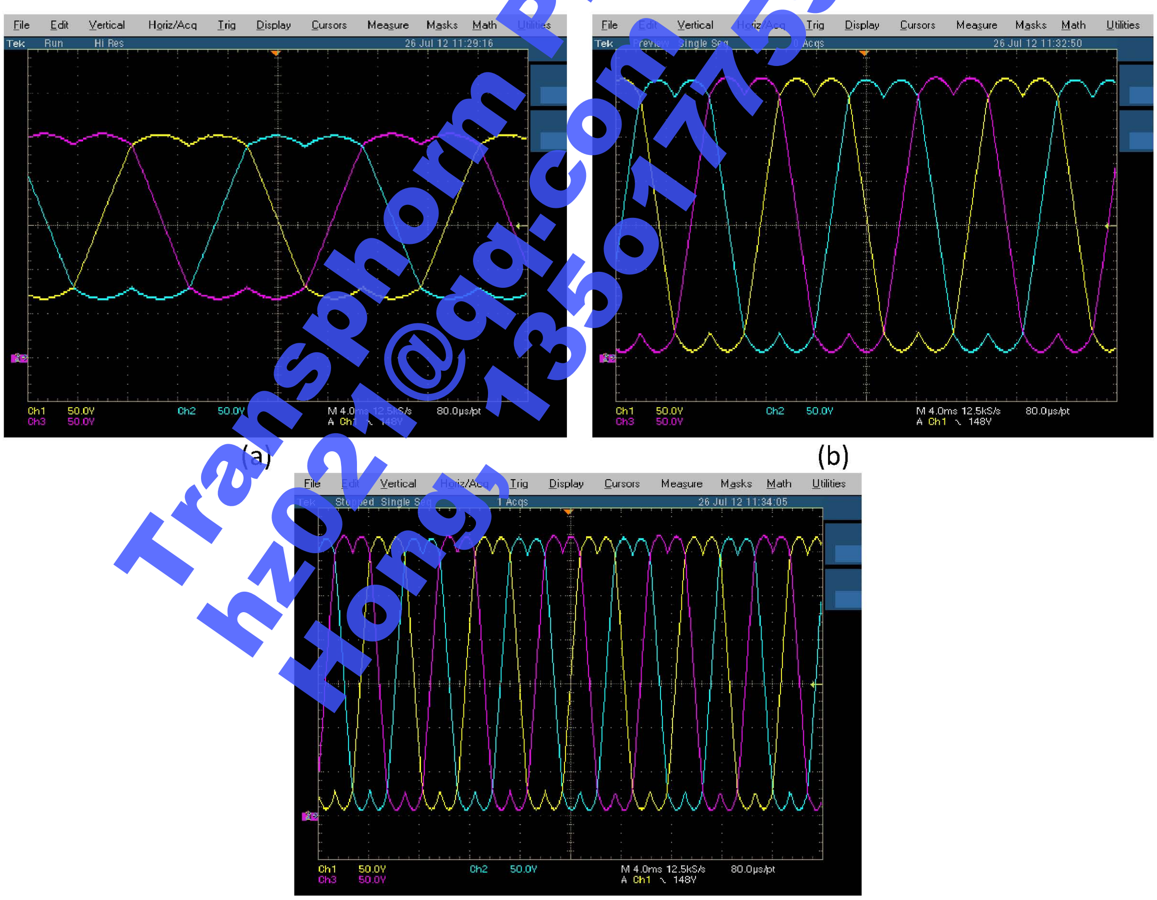


Figure 12: inverter enabled ACIM V/F mode



(a) (b)

(c)

Figure 13: Phase voltages for an ACIM at three values of speed reference (a) 0.30 (b) 0.50 (c) 1.0