AN2316
Application Note

Improved ST7LITE05 AC Chopper Driver Solution

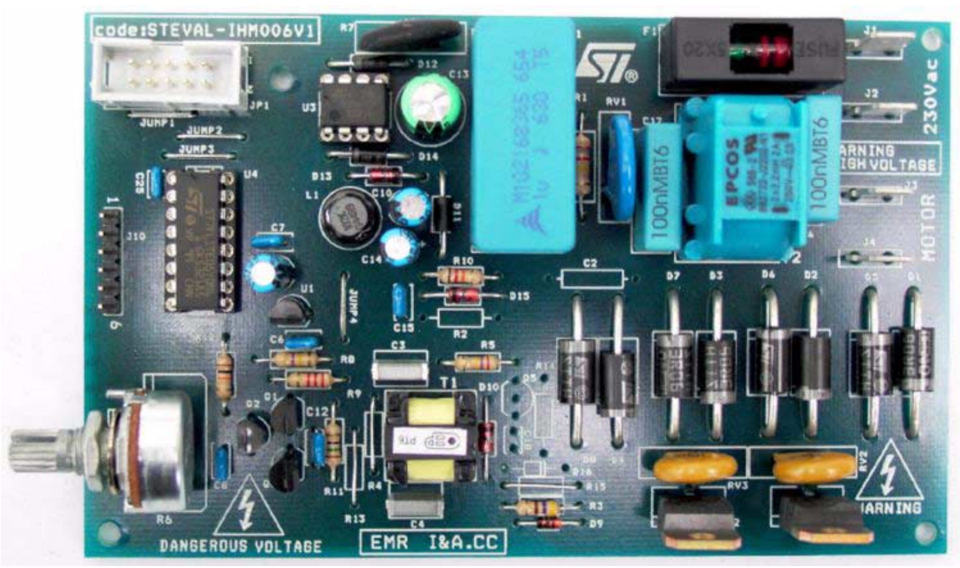
Introduction

This application note presents an AC motor or load circuital solution improvement of efficiency over the one discussed in a previously published application note, AN1255.

Above all, this solution does not have limits on where it may be applied, embracing all types of AC asynchronous monophase motor applications (e.g. refrigerators, hydraulic pumps, fans, and lamps).

Due to the increasing electric pollution of the environment, European standards impose restrictions on Electromagnetic Compatibility (EMC). The proliferation of non-linear loads and the consequential increase in harmonics pollution in power distribution lines have induced various technical committees to establish maximum limits on the harmonic content produced by all industrial and domestic devices. Manufacturers of these devices are required to conform to this new standard and develop products which function with new operational characteristics.

The most common method used to vary the AC monophase motor voltage is a TRIAC-based phase angle partialization technique. Although this is a simple, low-cost solution that has been used for several years, it is problematic because of the excessive harmonic distortion which reduces the efficiency of the entire system. These systems typically include a complex inverter drive which is quite expensive, and, while they can solve the load's harmonic content problems, they do not address those same problems in the electric lines.



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This ST-patented solution uses a working switch mode to solve third harmonic problems. The base circuit can be viewed as a mains voltage double-chopper without any preliminary AC/DC conversion type (see *Figure 1 on page 6*).

Note: The AC chopper STEVAL-IHM006V1 provides customers with a demo that regulates the voltage in AC motors or loads of up to 300W. This allows the user to demonstrate smooth, silent, and efficient regulation with respect to TRIAC solutions.

The double-chopper is a device which energizes the load beginning from any level of the sinusoidal voltage wave and demagnetizes the load with a freewheeling current system, thereby obtaining voltage and current regulation of the load.

Starting from a perfect sinusoidal-shaped mains curve, the regulated current is also sinusoidal for all the power levels that the user desires to transfer to the load. By neglecting the electronic device losses, the circuit incoming power S is equal to the outgoing power:

Equation 1

$$S = V_{AC(RMS)} \cdot I_{AC(RMS)} = V_{LOAD(RMS)} \cdot I_{LOAD(RMS)}$$

where,

$V_{AC(RMS)}$ = Root Mean Squared (RMS) Mains Voltage,

$I_{AC(RMS)}$ = RMS Input Current,

$V_{LOAD(RMS)}$ = RMS Load Voltage, and

$I_{LOAD(RMS)}$ = RMS Output Current.

The $I_{AC(RMS)}$ and $I_{LOAD(RMS)}$ currents are related as follows:

Equation 2

$$\frac{I_{LOAD(RMS)}}{I_{AC(RMS)}} = \frac{V_{AC(RMS)}}{V_{LOAD(RMS)}}$$

The circuit operates as a converter, particularly as an AC/AC converter or transformer. It has no limitation in terms of load impedance since it works with both, inductive and ohmic loads, with notable angles between the current and the voltage.

The circuit is based on the following parts (see *Figure 1*):

- IGBT Z1

  Together with diodes D1, D2, D5, and D6, it performs current freewheeling (only for inductive load).

- IGBT Z2

  Together with diodes D3, D4, D7, and D8, it is the main switch through which the load is energized.

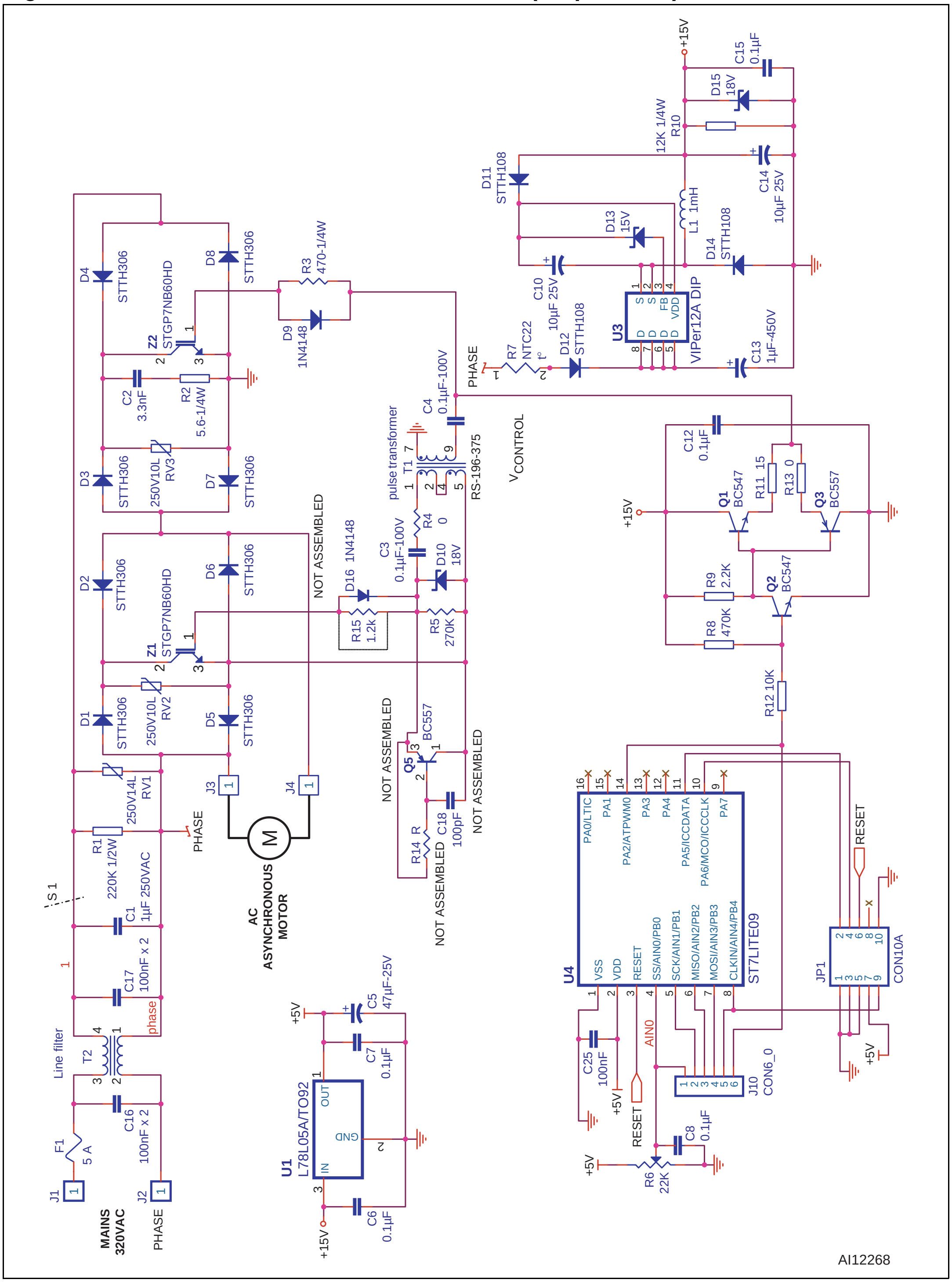
- Pulse Transformer T1

  It allows the signal derived from the PWM generator to be transferred to the Z1 gate. This component electrically insulates the input from the output's entry signal and phase inversion.

- PWM generator

  This is provided by the ST7Lite05 microcontroller.

Figure 1. Two-Switch Drive Motor Schematic (ST patented)



In order to avoid short-circuiting the mains through switches Z1 and Z2, they must work in a complementary manner. When Z1 is ON, Z2 must be OFF and vice-versa.

For example, if the line voltage at J1 is positive with respect to J2, and the PWM signal goes from high-to-low, Z2 switches ON with a delay inserted by its own gate capacitance and by resistor R3 so the load is energized. In the meantime, Z1 switches OFF instantaneously.

Note: In this condition, if the current is positive (i.e. it goes into J1 and comes out from J2), it will flow through D4, Z2, D7, and the load. Conversely, if the current is negative, it will be going out from J1 and closing through the load, D3, Z2, and D8.

As is the case with the current, when the PWM goes from low-to-high, Z2 is turned OFF instantaneously, while Z1 is switched ON with a delay. This enables a freewheeling current to flow through Z1.

Given these relationships, if “δ” is the duty cycle (see *Figure 2 on page 8*), the load voltage is may be expressed as:

Equation 3

$$V_{LOAD}(t) = \delta \cdot V_{AC}(t) = \delta \cdot V_{MAX} \cdot \sin(\omega t)$$

where,

V_{LOAD} = Load voltage,

V_{AC} = Mains voltage, and

V_{MAX} = Maximum sinusoidal voltage.

The load current may be expressed as:

Equation 4

$$I_{LOAD}(t) = \frac{1}{\delta} \cdot I_{AC}(t) = \frac{1}{\delta} \cdot I_{MAX} \cdot \sin(\omega t + \varphi)$$

where,

I_{LOAD} = Load current,

I_{AC} = Input current,

I_{MAX} = Maximum current value, and

φ = the angle between the current and voltage.

The relationships expressed in *Equation 3* and *Equation 4*, and *Figure 2* show that it is possible to control power fed to the load by changing the PWM signal duty cycle.

Note: The load is assumed to be inductive so the high frequency harmonics are filtered in the current waveform (see Figure 3 on page 9 for system waveform details).

Figure 2. Basic Working Principal Illustration

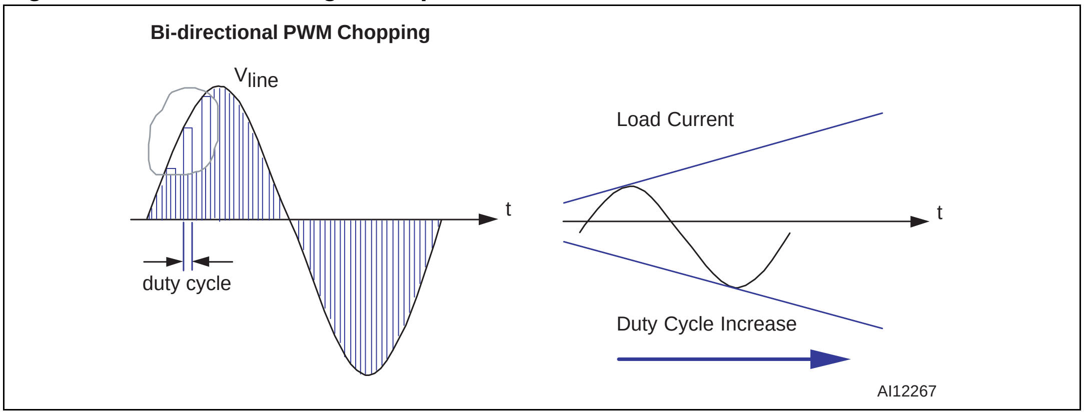
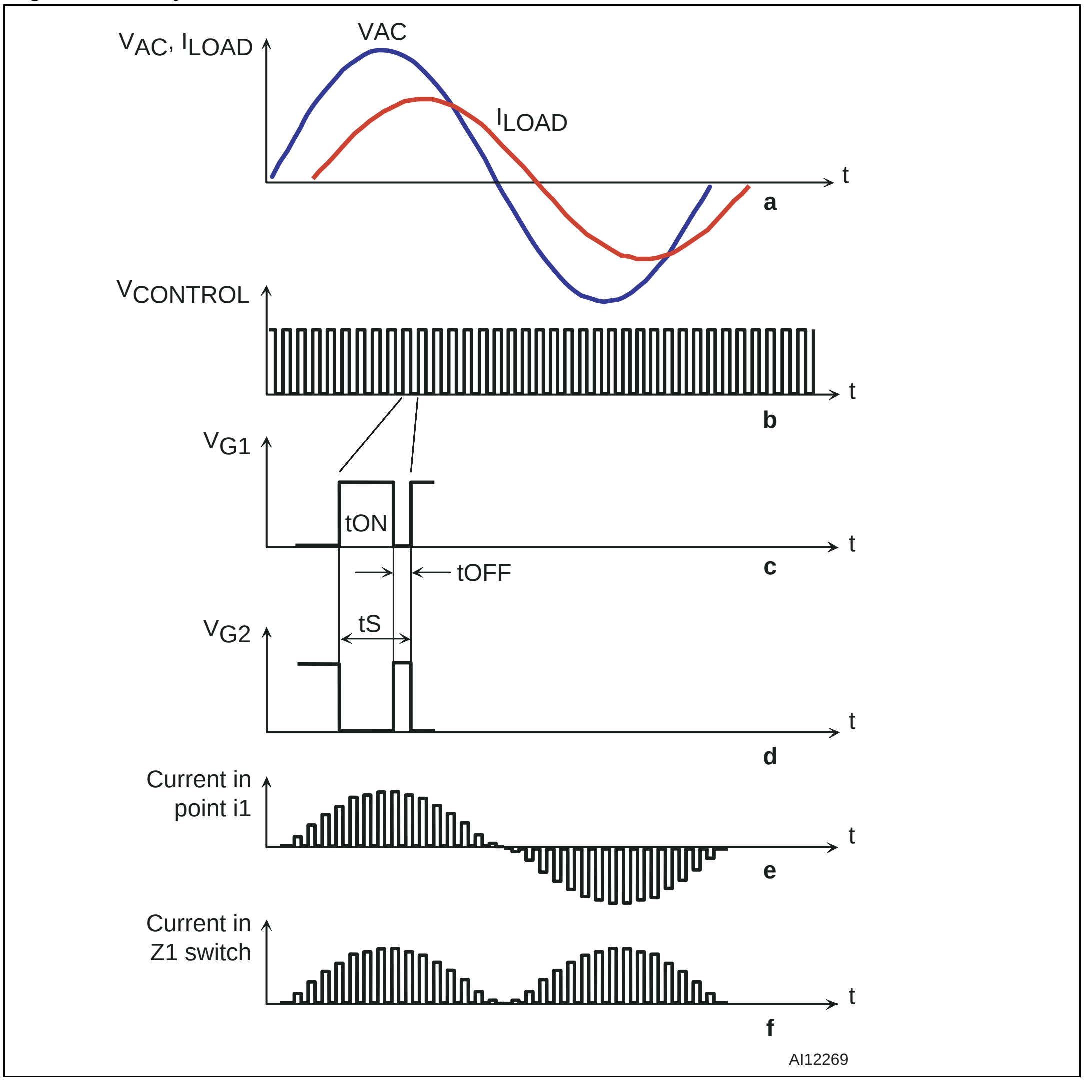


Figure 3. System Waveforms



Legend:

a = line voltage and load current

b = PWM control signal generated by the ST7Lite05 microcontroller

c, d = Z1 and Z2 gate signals

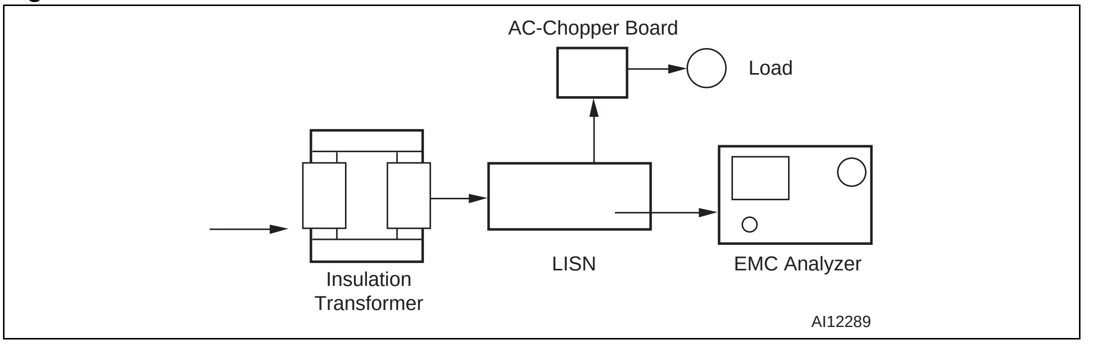
e = section S1 current (see *Figure 1 on page 6*)

f = current through switch Z2

2 EMC Precompliance Measurement

Electromagnetic Compatibility (EMC) measurement requires use of the Line Impedance Stabilization Network (LISN).The LISN operates as a filter between the line and test board, providing clean energy to the system under test. It collects all the emissions coming from the systems under test (>9kHz) and sends the noise to the EMC analyzer (see *Figure 4*).

Figure 4. EMC Measurement Schematic



Caution: For safety reasons, an insulated 1:1 transformer is used to avoid a possible ground current loop.

Table 1. AC Chopper EMC Limits

Description(1)	Limit Line	Frequency Range(2)
EN55014	Conducted <700W, Motors, Quasi-peak	150kHz to 30MHz
EN55014	Conducted <700W, Motors, Average	150kHz to 30MHz

1. EMC AC chopper measurement at 20kHz switching frequency (CISPR-14), per EN55014 standard.
2. Instrument used: E7400 Agilent Technology

2.1 Electrical Conditions

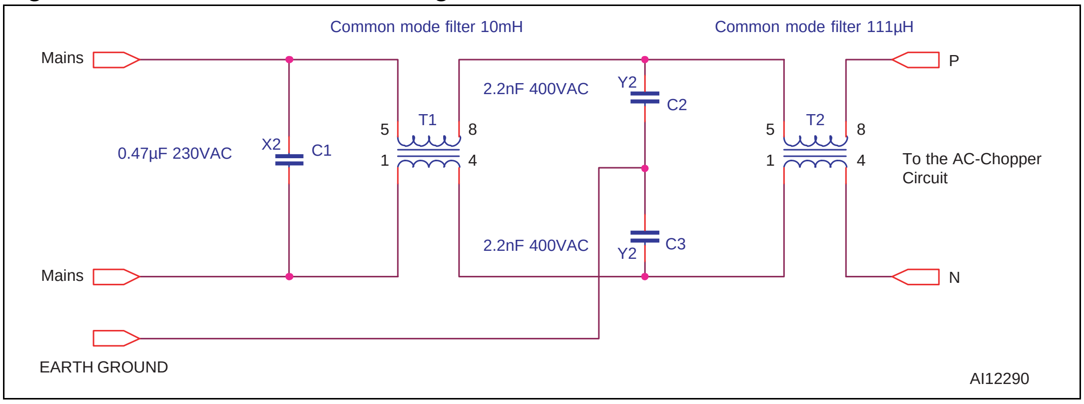
- $V_{INPUT} = 230V_{AC}$
- Motor type = Asynchronous with capacitor
- Motor voltage = $230V_{AC}$
- Motor current =1.5A

The on-board EMC filter is not optimized for every kind of load, so users need to consider that the included filter might be inadequate for certain applications.

A double-filter stage (see *Figure 5*) is required to obtain good EMC results (acceptable EMC level) without the included filter (T2, C16, and C17), use the recommended filter mentioned in *Figure 5*. The measured results are shown in *Figure 6* and *Figure 7 on page 12*.

Note: In order for the filter to be effective, the motor case must be connected to the earth-ground.

Figure 5. EMC Double-Filter Stage Schematic



2.2 EMC Double-Filter Bill of Materials

C1 = 0.47µF $230V_{AC}$ X2

C2 = C3 = 2.2nF $230V_{AC}$ Y2

T1 = 10mH common mode filter (to be designed in terms of current, depending on the final load to be driven). For this application, the type used is TDK 103Y1R2X3X.

T2 = 111µH common mode filter (to be designed in terms of current, depending on the final load to be driven).

Figure 6. 20kHz Switching Frequency EMC Analysis

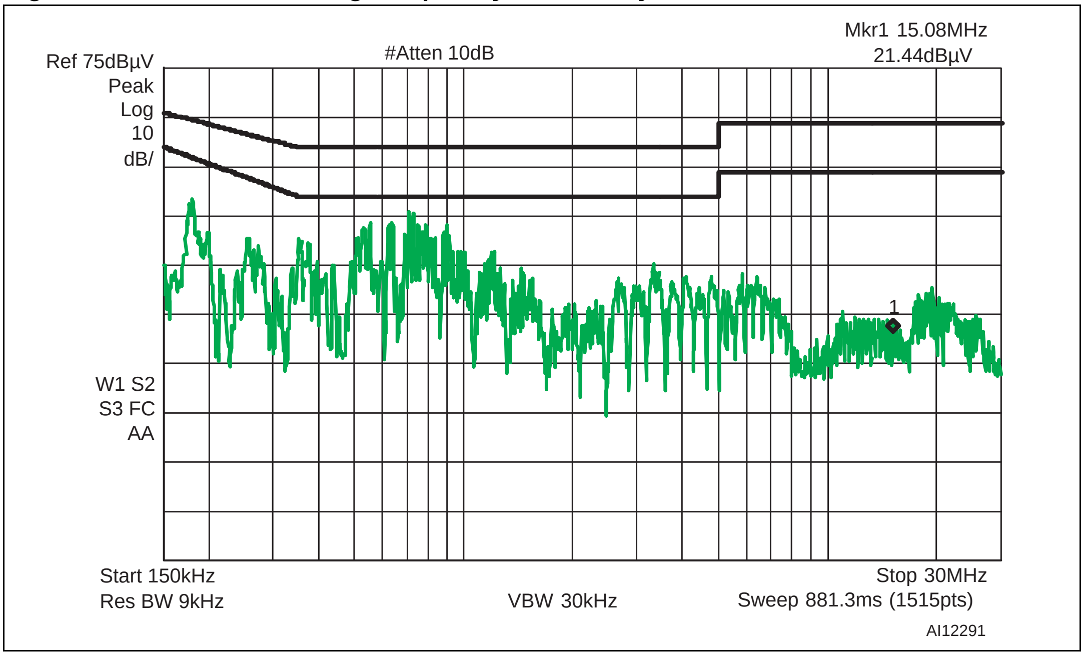
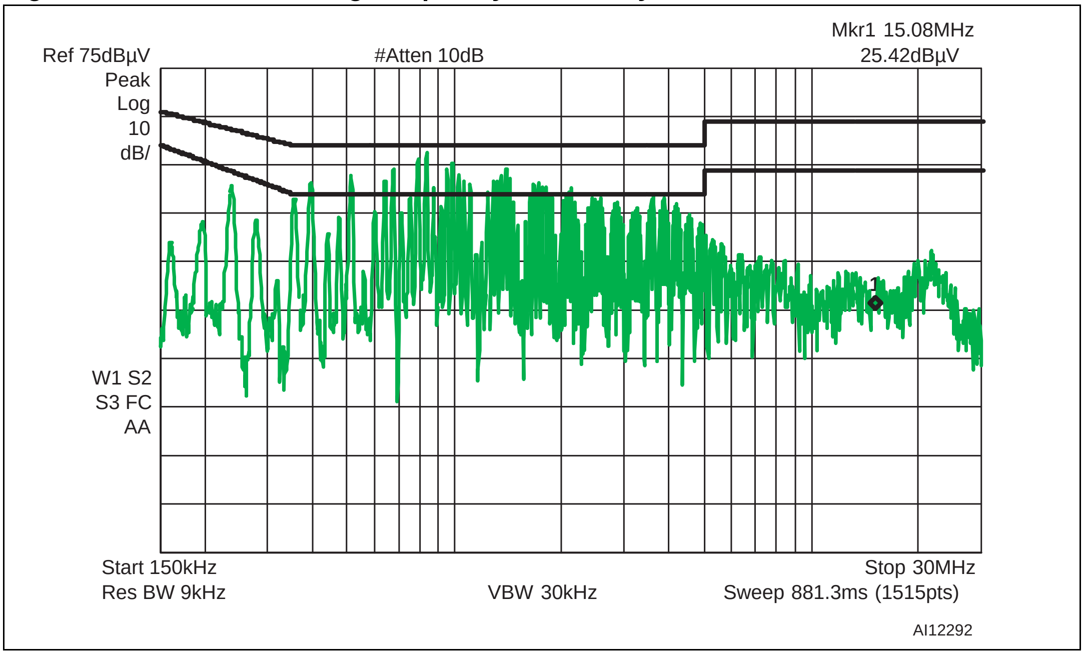


Figure 7. 35kHz Switching Frequency EMC Analysis



3 Safety and Operating Instructions

Note: Please read this section before attempting any operation with this manual.

The AC chopper board is designed for demonstration purposes only, and shall not be used for electrical installation or machinery. The technical data, as well as information concerning the power supply conditions shall be taken from the documentation and strictly observed.

The AC chopper driver poses several inherent hazards during installation and operation, including bare wires and hot surfaces. All operations involving transportation, installation and use, as well as maintenance are to be carried out by skilled technical personnel (national accident prevention rules must be observed). For the purposes of these basic safety instructions, “skilled technical personnel” are defined as suitably qualified people who are familiar with the installation, use, and maintenance of power electronic systems.

Danger: There is danger of serious personal injury and damage to property, if the Kit or its components are improperly used or installed incorrectly.

3.1 STEVAL-IHM006V1 Board Installation

The installation and cooling of the demo board shall be in accordance with the specifications and the targeted application.

- The motor drive converters shall be protected against excessive strain. In particular, no components are to be bent, or isolating distances altered during the course of transportation or handling.
- No physical contact shall be made with electronic components and contacts.
- The boards contain electrostatically sensitive components that are prone to damage through improper use. Electrical components must not be mechanically damaged or destroyed (to avoid potential health risks).

Warning: Applicable national accident prevention rules must be followed when working on the main power supply with a motor or AC load.

Note: Do NOT expose the kit to ambient temperatures of over 35°C, as this may harm the components or reduce their lifetimes.

3.2 Environmental Considerations

The STEVAL-IHM006V1 AC chopper demo board must only be used in a power laboratory. The high voltage used in any AC drive system presents a serious shock hazard. A complete laboratory setup consists of:

- an isolated AC power supply,
- the STEVAL-IHM006V1 demo board,
- an AC Induction motor, and
- an isolated (laboratory) power supply for +15V (as needed).

The Kit is not electrically isolated from the AC input. The microprocessor is grounded without insulation with respect to the mains so that it and the associated circuitry are hot. They MUST therefore be isolated from user controls and serial interfaces.

Note: Any measurement equipment must be isolated from the main power supply before powering up the motor drive. To use an oscilloscope with the Kit, it is safer to isolate the AC supply AND the oscilloscope. This prevents a shock occurring as a result of touching any SINGLE point in the circuit, but does NOT prevent shocks when touching TWO or MORE points in the circuit.

An isolated AC power supply can be constructed using an isolation transformer and a variable transformer. A schematic of this AC power supply may be found in the Application Note, “AN438, TRIAC + Microcontroller: Safety Precautions for Development Tools”. (Although this Application Note was written for TRIACs, the isolation constraints still apply for fast-switching semiconductor devices such as IGBTs).

Note: Isolating the application rather than the oscilloscope is highly recommended in any case.

3.3 Mandatory Checks Before Operation

The following verifications must be performed before operating the demo board:

- The motor load is connected and earth-grounded,
- there is no metal part on, below, or around the PC boards, and there are no unintended earth/ground loops caused by peripheral (e.g. test) equipment (e.g. PC or oscilloscope), and
- the motor and mechanical load are safely housed so that rotating parts cannot be inadvertently accessed and cause injury (e.g., loose clothing, long hair).

Warning: The high voltage levels used to operate the motor drive could present a serious electrical shock hazard. This demo board must be used only in a power laboratory only by engineers and technicians who are experienced in power electronics technology.

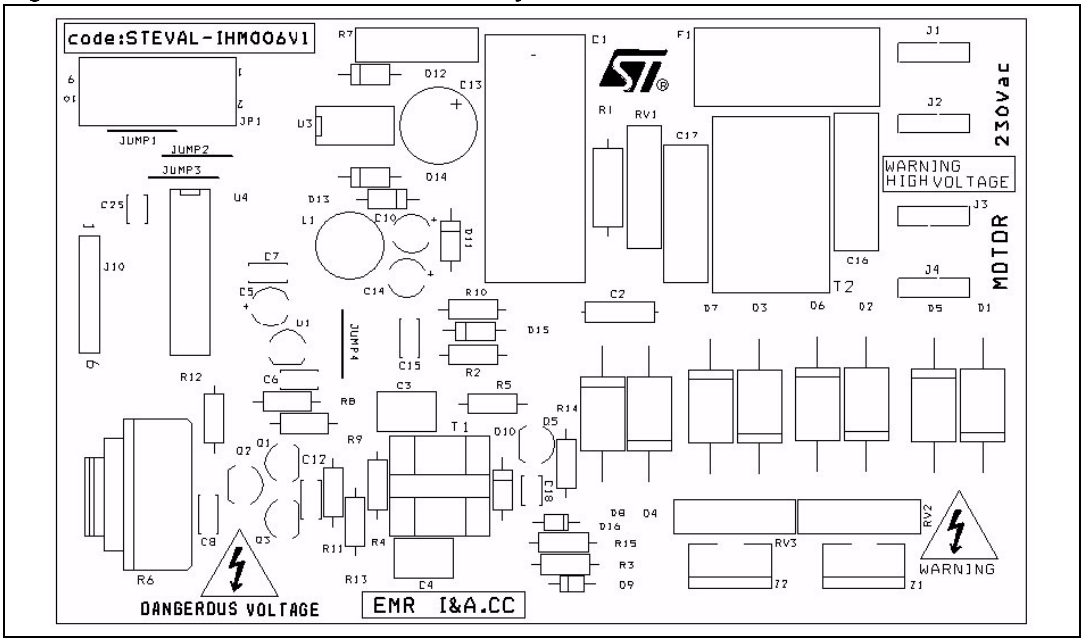
3.4 Start-up Procedure

1. Connect the AC motor or AC load on the board to connectors J3 and J4 (see *Figure 8*). Sequencing is arbitrary.
2. Connect the current probe on one motor line in order to monitor motor current on the oscilloscope.
3. Apply the heat sink spreader (not included in the STEVAL-IHM006V1) on the two IGBTs using the appropriate insulation foil.
4. Set the potentiometer R6 in arbitrary position. This changes the main switch Z2 duty cycle.
5. Apply the main voltage supply to connectors 230V_{AC} J1 and J2.
6. Rotate potentiometer P2 Clockwise (CW) to begin increasing the motor load voltage.

The resulting current waveform should remain fairly sinusoidal.

Warning: The entire circuit board and motor output terminals are always "hot" with respect to earth ground, even when the drive is in a stopped condition.

Figure 8. STEVAL-IHM006V1 Board Layout



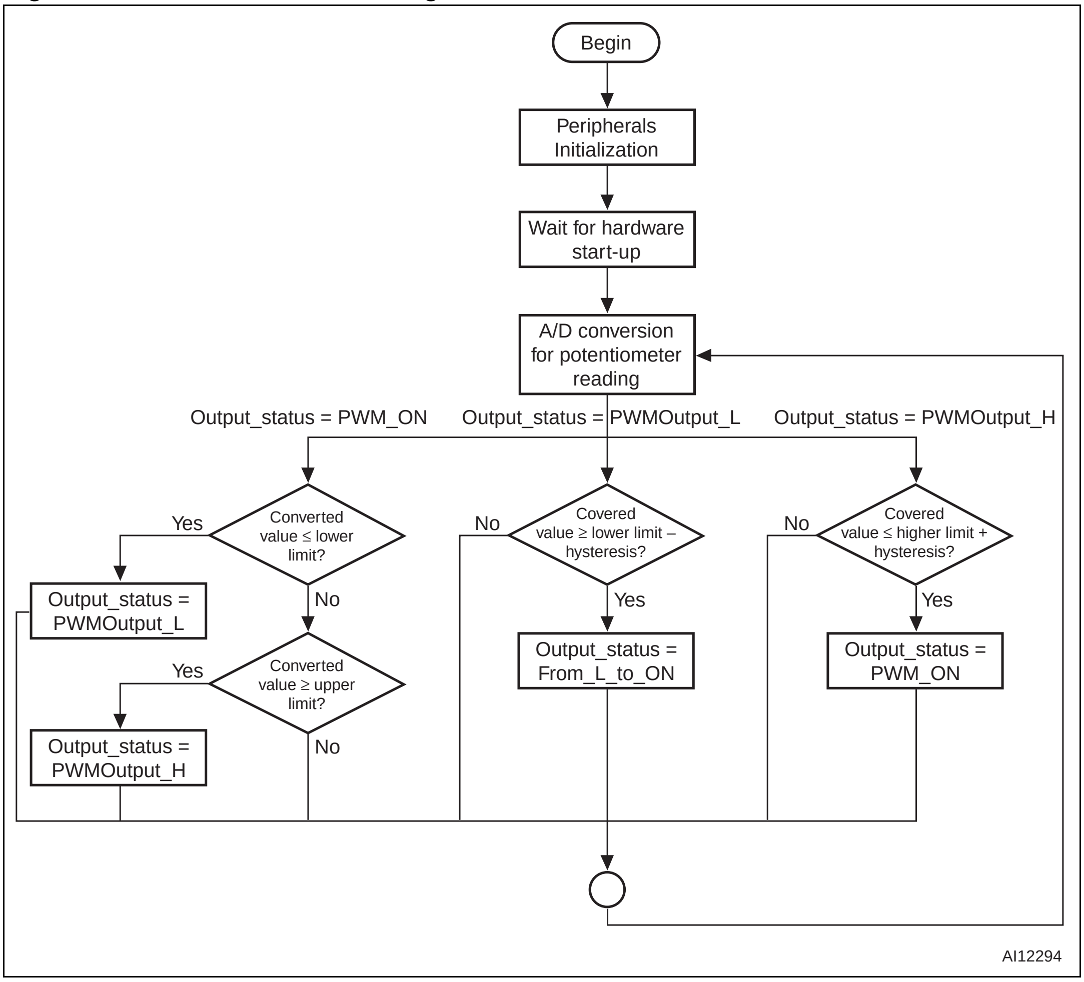
4 ST7FLITE05 Software Description

The ST7FLITE05 firmware allows designers to generate the PWM signal required to drive the STEVAL-IHM006V1 AC chopper Z1 and Z2 IGBTs (see *Figure 9*). It was developed with the Softec STVD7 Toolset v3.10 and 16K limited free version of Cosmic Compiler v4.5c.

The system may be customized by setting parameters in the “Param.h” header file, including:

- switching frequencies,
- maximum and minimum applicable duty cycle, and
- related hysteresis.

Figure 9. ST7FLITE05 Flow Diagram



4.1 Peripheral Initialization

The peripherals are initialized. After initialization, the firmware waits 255ms for the hardware to be start up. The potentiometer is read, and the digital values are used to compute those to be loaded into the successive DCR registers. Initialization activities include the following:

4.1.1 Auto-reload Timer (AT) Configuration

The 12-bit AT is configured in PWM mode so that the ATR registers contain the auto-reload value used to set the PWM frequency.

4.1.2 PWM Duty Cycle, Overflow and Compare Interrupts

The PWM frequency and the DCR registers contain the value which sets the PWM duty cycle.

Furthermore, the PWM output on the ATPW0 pin is enabled by setting the OE0 Bit in the PWMCR register, and both, the overflow and compare interrupts have been enabled.

Note: In order to guarantee the proper operation of the overall system, using very high and very low duty cycle values are discouraged.

If the duty cycle exceeds a higher threshold, the PWM must be switched off and the microcontroller pin must be kept continuously in logic high state. The PWM output is enabled again only if the user turns the potentiometer so the corresponding duty cycle is below the higher threshold minus hysteresis (see Figure 9 on page 16).

If the duty cycle goes below a lower threshold, the PWM must be switched off and the microcontroller pin must kept continuously in logic low state. The PWM output is enabled again only if the duty cycle related to the potentiometer position goes above the lower threshold plus hysteresis (see Figure 9).

4.1.3 ST7LITE Timer

The 8-bit LITE Timer is configured so that an overflow event (and the related interrupt) occurs every millisecond. This allows users to have a time base at their disposal to implement, for example, the soft variation of the PWM duty cycle.

4.1.4 Channel 0 A/D Conversion

The 8-bit A/D conversion of Channel 0 is enabled at the $f_{cpu}/2$ frequency.

4.2 Firmware Configuration

The user-modifiable parameters are defined in “Param.h” header file, particularly:

4.2.1 Switching Frequency

```
#define PWM_FREQUENCY Fx0kHz
```

Use F20kHz, or F40kHz to set the respective 20kHz or 40kHz frequencies (see *Section 4.1.1 on page 17*).

4.2.2 Maximum Duty Cycle

```
#define MAX_DUTY 90 //in percentage
```

Use the PWM frequency and the DCR register values to set the duty cycle (see *Section 4.1.2*).

4.2.3 Minimum Duty Cycle

```
#define MIN_DUTY 10 //in percentage
```

Use the PWM frequency and the DCR register values to set the duty cycle (see *Section 4.1.2*).

4.2.4 Hysteresis

```
#define HYSTERESIS 5 //in percentage
```

Use the PWM frequency and the DCR register values to set hysteresis (see *Section 4.1.2*).

4.3 Development Tools

This section presents the available material that is required to start working with the ST7FLITE05 and the AC chopper software library.

4.3.1 Integrated Development Environments (IDE)

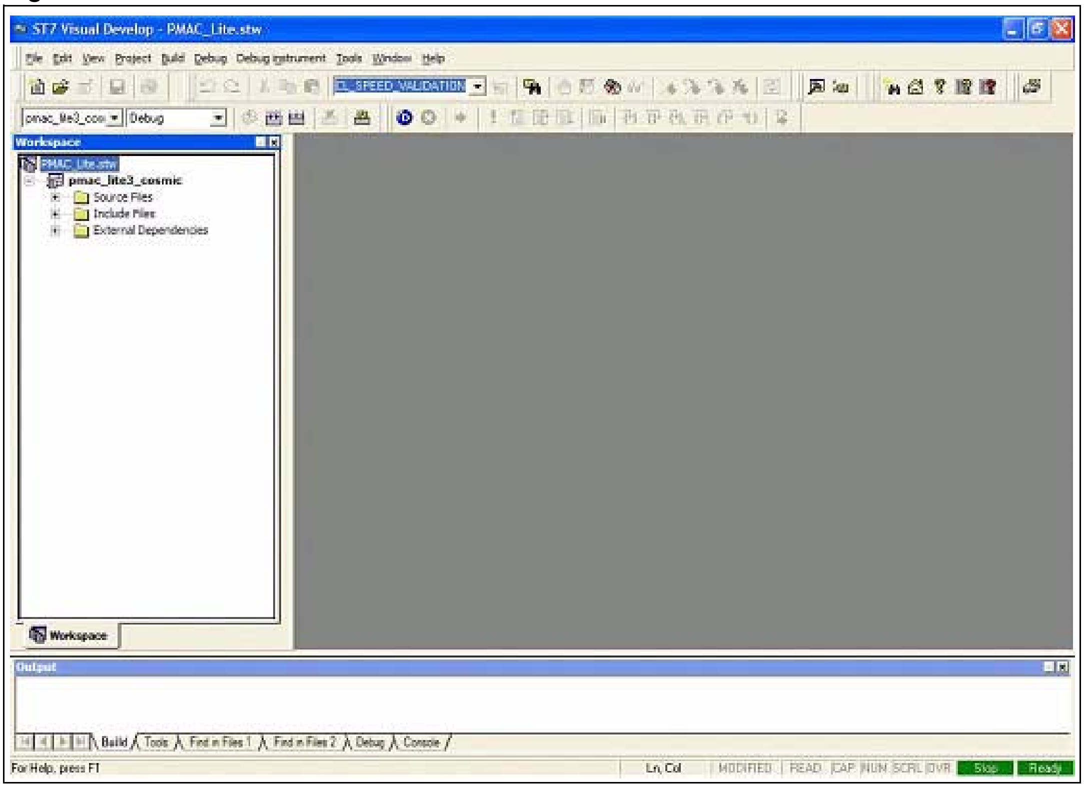
Different (free) IDE interfaces are available:

- ST's proprietary STVD7 (free download available at **www.st.com**), or
- a third party IDE (e.g. Softec Microsystems' STVD7 for InDART-STX).

The software library presented in this document has been compiled using Cosmic C compiler (v4.5c), launched with Softec STVD7 v3.10 (see *Figure 10*).

Note: The 16K limited free version of Cosmic compiler permits users to compile all of the objects in the software library.

Figure 10. Softec STVD7 v3.10



4.3.2 Real-Time Emulators

Two types of real-time development tools are available for debugging applications using ST7FLITE05:

- Softec In-circuit Debugger (STXF-INDART/USB)

  The inDART-STX from Softec Microsystems is both an emulator and a programming tool. This is achieved using the in-circuit debugging module embedded on the MCU. The inDART real-time features include access to working registers and 2 breakpoint settings. However, trace is not available.

- ST7MDT10-EMU3 Emulator

  This fully-featured emulator includes:

  - real-time with trace capability,
  - performance analysis, advanced breakpoints, and
  - light logical analyzer capabilities.

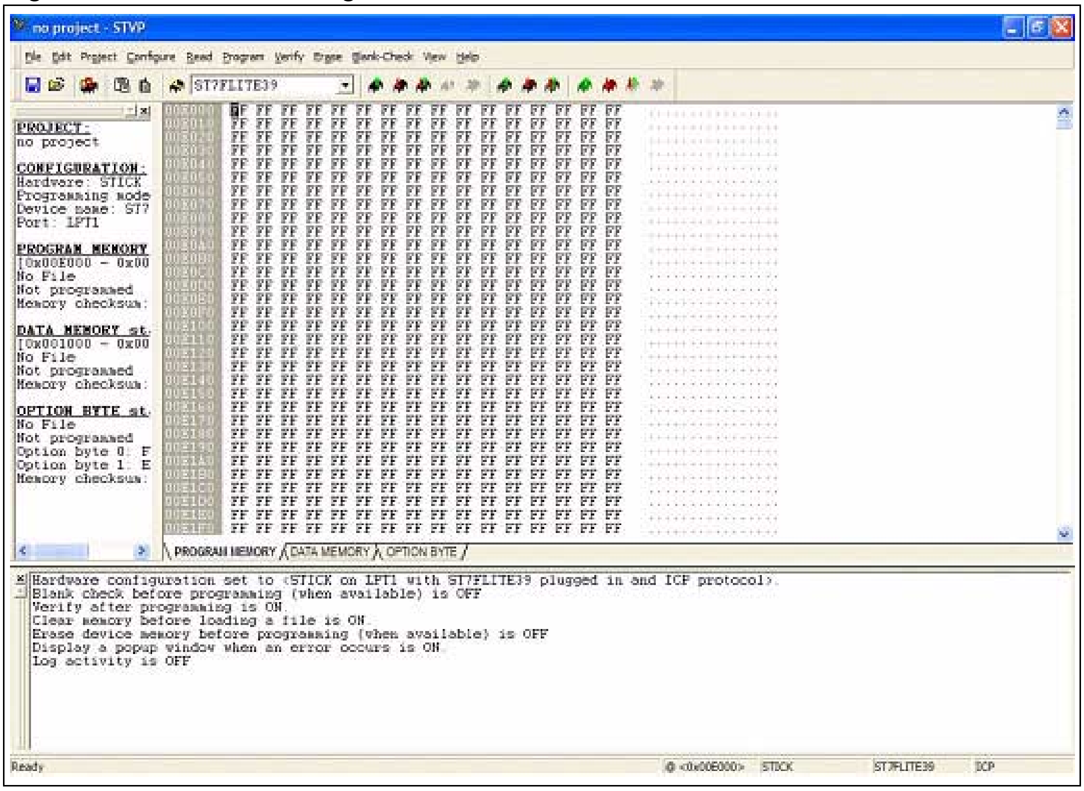
  It can also be a programming tool when it is used with the ICC ADDON module (included) which allows users to do STVD7 in-circuit debugging.

4.3.3 Programming Software

In order to program an MCU with the generated .S19 file (compiled output), the ST Visual Programming software should also be installed (available at **www.st.com**), and a dedicated hardware programming interface (e.g. in-circuit programming stick programmer) should be used. The Visual Programming tool provides an easy way to erase, program, and verify the MCU content (see *Figure 11*).

Note: The inDART-STX from Softec Microsystems is also a programming tool (installation of DataBlaze Programmer software is required).

Figure 11. ST7 Visual Programmer



5 Library Source Code

5.1 Software downloads

The complete source files are available on the ST website (**www.st.com**) as a “zip” file.

*Note: Checking for and verifying the latest library releases as well as release notes **before starting any new development is highly recommended**. This helps users stay informed as to new features which might affect the project.*

5.2 File Structure

The unzipped library files produce the following structure:

```
..\sources
..\Debug
..\Release
```

5.2.1 .S19 File

To produce the target .S19 file:

1. Open the ST7VD work space “ac-ac20K.stw”.
2. Compile the project by pressing the “Rebuild All” button in the ST7VD development tool.

5.2.2 Compiler and Linker

Two different sets of compiler and linker options (Debug and Release) can be handled by the tool, depending on the development stage.

6 Revision history

Table 2. Document revision history

Date	Revision	Changes
27-Mar-2006	1	Initial release.

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