



AN1499 APPLICATION NOTE

DESIGNING A LOW COST POWER BOARD FOR THE ST92141 MOTOR CONTROL MCU WITHOUT USING IPMs

By Motor Control Competence Center

INTRODUCTION

Power Modules have been in use for twenty years in industrial motor drive applications. For power stage designs, they give the advantages of compactness and good thermal behavior.

Over the last few years a new family of Power Modules, called Intelligent Power Modules (IPM), have tried to take the integration of motor drive power stages a step further.

These IPMs target lower power and lower cost motor drive systems compared to those targeted by standard Power Modules.

However it is an open question whether these IPMs suit high volume and very cost-sensitive applications, such as the household appliance market.

Figure 1. General System View

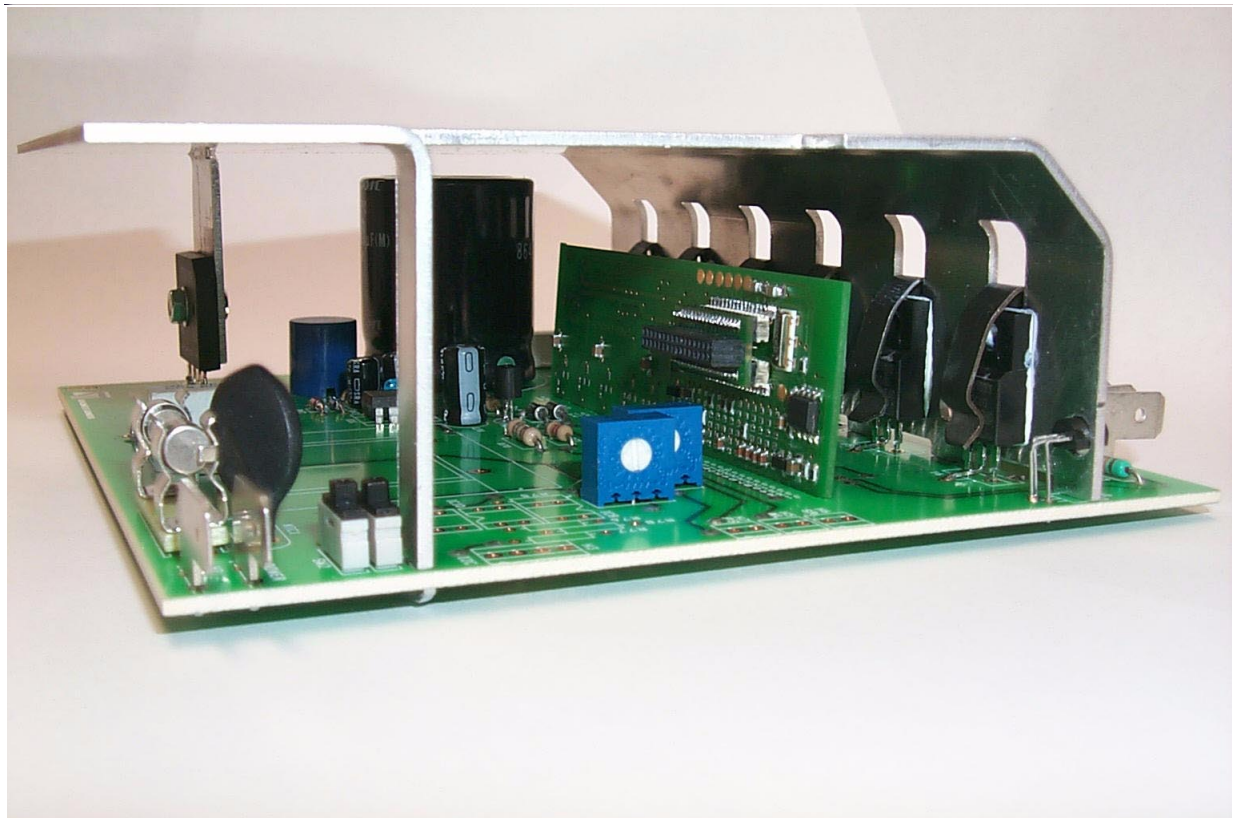


Table of Contents

INTRODUCTION	1
1 INTELLIGENT POWER MODULES	3
1.1 ADVANTAGES OF IPMS	3
1.1.1 Assembly cost	3
1.1.2 Component count	3
1.1.3 Reduction in time to market	3
1.1.4 Higher reliability	4
1.1.5 Product compactness	4
1.1.6 Package inductance	4
1.2 DRAWBACKS OF IPMS	5
1.2.1 Lead frame	5
1.2.2 Heatsink planarity and stiffness	5
1.2.3 Embedded gate drive & filter cost	5
1.2.4 External bootstrap diodes and temperature protection needed	5
1.2.5 Component choice	5
2 AN ALTERNATIVE SOLUTION	6
2.1 ADVANTAGES	6
2.1.1 Assembly & mounting considerations	6
2.1.2 Reduction in time to market	6
2.1.3 Reliability considerations	7
2.1.4 Thermal management	7
2.1.5 Gate drive optimization	7
2.2 DRAWBACKS	7
2.2.1 Component count	7
2.2.2 PCB connections	7
3 CONCLUSION	8
4 MECHANICAL DATA: ST92141-PLATFORM	19
5 CONTROL BOARD LAYOUT (ORCAD FILES AVAILABLE)	20

1 INTELLIGENT POWER MODULES

These products integrate in a single transfer molded package, six IGBTs, six free wheeling diodes and the interfacing circuits needed to enable direct control from a microcontroller.

In their low cost version they do not include the front-end rectification diodes, nor do they have a switch or diode for active power factor correction.

External circuits are still needed, such as bootstrap supplies, current sensing and filtering, and auxiliary supply decoupling.

This application note analyzes the advantages and drawbacks of this power integration approach with regard to the constraints of cost sensitive motor drives.

An alternative solution is proposed that fits better to appliance and large volume applications in term of optimization and cost.

1.1 ADVANTAGES OF IPMS

Out of all the advantages that are claimed, the major ones seem to be the following:

- Less assembly cost
- Lower component count
- Reduction in time to market
- Higher reliability
- Product compactness
- Low inductance package

These are general claims that need to be confronted with reality.

1.1.1 Assembly cost

Assembling an IPM requires placing it on the PCB, wave soldering and later on fixing the heat-sink with screws. These operations are indeed less expensive than assembling six discrete components. You should note however that if an active power factor corrector is needed, external discrete power components are required.

1.1.2 Component count

This is a clear advantage because nine components are replaced by each IPM. However the need for microcontroller and passive component assembly remains and IPMs do not remove any major manufacturing step.

1.1.3 Reduction in time to market

Layout of IGBT and MOSFET gate drives requires special expertise. Using an IPM does not require all this expertise, but a good understanding of EMI and parasitic inductance effects is still strongly recommended!

Assuming this expertise is available, the estimated saving will be hardly be more than the time it takes to have a coffee break!

1.1.4 Higher reliability

From a silicon point of view, there are still about 15 dice inside the module with their own MTBFs related to junction temperature as well as more than 40 wire bonds. So the system MTBF may increase because the connection and assembly count decreases. However it may decrease if the heatsink is not perfectly flat below the whole IPM surface.

1.1.5 Product compactness

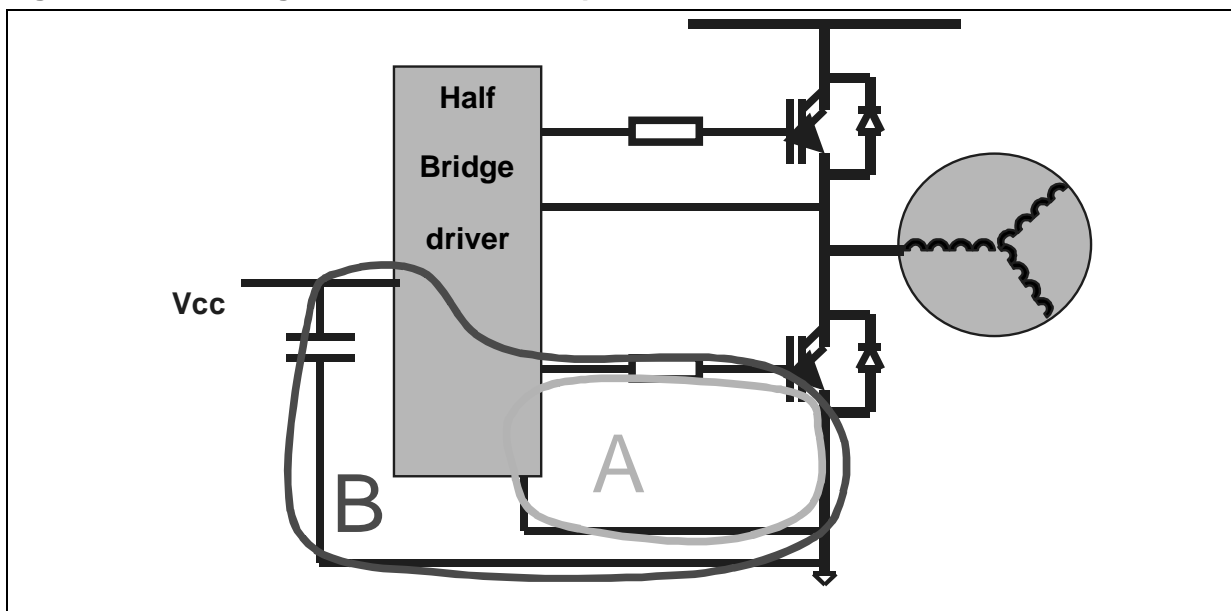
When just comparing power switches, IPMs bring compactness. But when talking about the whole system, the difference is negligible. Passive components, heatsink, PCB and connectors are by far the most bulky parts.

1.1.6 Package inductance

The only circuit area where IPMs reduce the parasitic inductance is located between the gate drivers and the power switches. This is true for the high side gate drivers but not for the low side drivers.

Figure 2 shows that during turn-on, the low side gate drive current loop (B) is not internal to the module but goes outside. In this case, IPMs do not have a significant advantage over discrete solutions.

Figure 2. Low side gate drive current loop



1.2 DRAWBACKS OF IPMS

Counterbalancing the advantages listed above, IPMs have major drawbacks that make their use in cost sensitive applications rather questionable.

Let's review these drawbacks:

1.2.1 Lead frame

Due to manufacturing constraints, an IPM has leads on both sides of the package. This means that the PCB must be installed parallel to the package. So the heatsink must have its contact base parallel to the IPM and the PCB. When you are looking for a very cheap solution, this makes the choice of heatsink difficult.

1.2.2 Heatsink planarity and stiffness

Inside the IPM, power switches are soldered directly on a long and thin lead frame. Then this lead frame is fully molded for isolation between the heatsink and the active parts. As a result, these IPMs have a low stiffness and need to be assembled on a good quality heatsink to avoid internal cracks. As a consequence, cheap heatsinks made of metal sheet are not recommended. This may lead to additional cost.

1.2.3 Embedded gate drive & filter cost

One sensitive parameter, in terms of optimizing the motor drive cost, is gate drive impedance. By adjusting this impedance properly, you can find the right compromise between filter cost and heatsink cost. As IPMs do not give access to the gate drive impedance, you cannot adjust the dV/dt commutation which may lead to additional filter cost.

1.2.4 External bootstrap diodes and temperature protection needed

Most IPMs available today do not have over-temperature protection. This requires additional external circuits.

As bootstrap diodes are not integrated in the module, they need to be added externally. This leads to additional cost.

1.2.5 Component choice

Needless to say the choice of IPMs today is very scarce and does not match the broad range of power switch and interface circuits. This is a real drawback when cost is all-important.

2 AN ALTERNATIVE SOLUTION

The basic idea behind the IPM solution consists of reducing the component count, simplifying assembly and making board layout easier. However it has been shown that the cost benefit is not always easy to determine when you calculate at system level.

Another way to split the system consists of grouping all the system SMD components on a small size FR4 board, called the Control Board, and keeping all the power switches and discrete components on a mother board called the Power Board.

Figure 5, Figure 6 & Figure 7 show an AC motor drive application using this partitioning. An example layout and parts list are given in Appendix 2.

It is worthwhile to review the advantages and drawbacks of this new partitioning.

2.1 ADVANTAGES

2.1.1 Assembly & mounting considerations

Figure 6 shows a control board schematic implementing a microcontroller, its peripheral circuits and three High Voltage Integrated Circuits for interfacing directly to the Power Board schematic shown in Figure 7. This microcontroller is dedicated to AC motor control and is housed in a shrink SO34 package (refer to the parts list in Appendix 2 and ST92141 and L6386 datasheet on <http://www.st.com>).

The size of this type of control board is about 26mm by 87mm. This makes use of available FR4 hardware. This board can be plugged into the Power Board next to the discrete power switches. The Power Board layout is very easy and simple, even if low cost materials like CEM1 are used. This makes the size of the Power Board smaller even if single side copper is used.

The total volume of the Control Board and the power switches is very compact.

Moreover, the discrete Power switches can fit many different heatsink configurations, parallel or perpendicular, with no planarity and stiffness constraints.

Another advantage comes from the soldering process differentiation: SMD components are soldered using a reflow process, discrete components go through solder waves. This improves the production yield.

Finally, if an active power factor is needed, it is easy to add another switch to the power stage.

2.1.2 Reduction in time to market

The physical split between control circuits and power parts make the system easy to layout and quick to debug. The system power range or the input front end can be adapted without affecting the Control Board and vice versa. Any change of microcontroller package or its peripheral circuits does not interfere with the power stage.

In other words, the same Control Board can fit different Power Boards.

This makes the first design shorter and the future re-design even faster.

2.1.3 Reliability considerations

The reflow process used to solder the Control Board is proven to be more reliable than the wave process.

The connection between both boards is done during the wave process. Figure 5 shows a typical implementation and Appendix 1 gives the results of the vibration test performed on this assembly.

2.1.4 Thermal management

Assembling the discrete components by clips enables the dissipation to be spread over the whole heatsink surface. This avoids concentrating the losses on a small area and allows you to use cheap heatsink technology made of metal sheet.

2.1.5 Gate drive optimization

Figure 8 shows the influence of the gate drive impedance on the conducted noise. As the whole gate drive is available on the Control Board, it is easy to adapt the noise level according to the filter attenuation at any time. This noise level optimization can save time and cost.

Moreover the Control Board design allows the use of advanced High Voltage Integrated Circuits that integrate a bootstrap diode and comparators (refer to L6386 on <http://www.st.com>).

This is true for power switch selection (see the fully insulated TO220 products like STGP7NB60HDFP on <http://www.st.com>).

2.2 DRAWBACKS

The main drawbacks relate to:

2.2.1 Component count

Compared to the IPM solution, both the Control Board and the Power Board each implement about six components more.

2.2.2 PCB connections

The double sided Control Board soldering totals 68 contacts that are processed during wave soldering.

3 CONCLUSION

This comparison between two different system partitioning methods has shown that the Intelligent Module approach is not the most flexible and cheap solution when designing cost sensitive motor control applications.

The alternative solution that is presented gives several advantages that are decisive when cost is the overriding factor:

- Access to low cost heatsink technology and better thermal management
- Use of different processes for SMD and through-hole components to improve the production yield
- Flexibility to adapt the Power Board with no impact on the Control Board and vice versa
- Access to gate drive impedance to optimize the EMI level at any time
- Choice of a large portfolio of interface ICs and power switches

For further details about the Control Board hardware and software features, refer to AN1498.

Figure 3. Control Board high voltage interfacing side

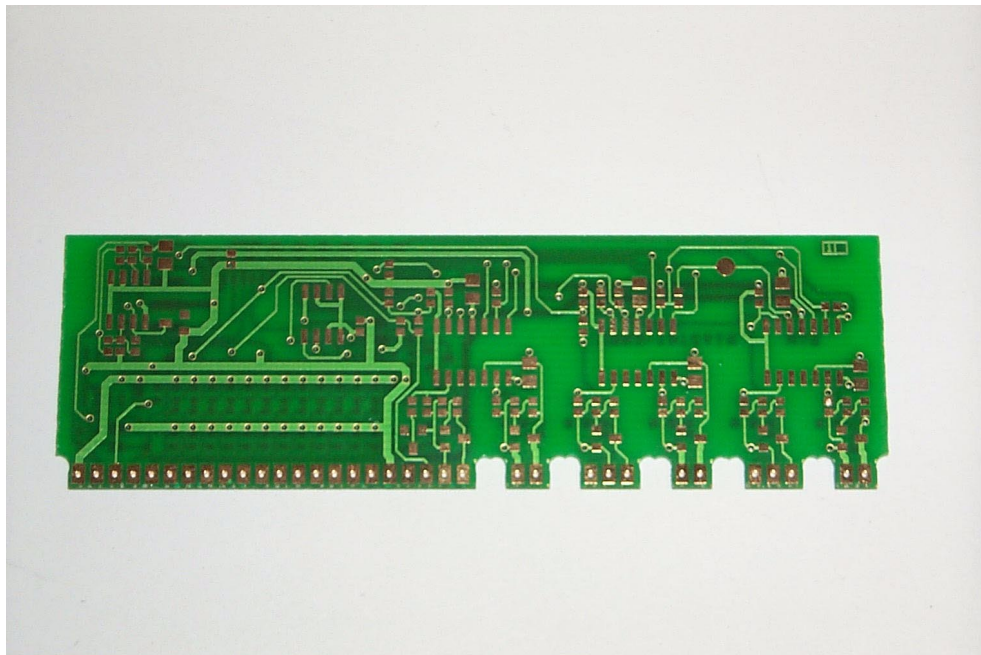


Figure 4. Control Board microcontroller side

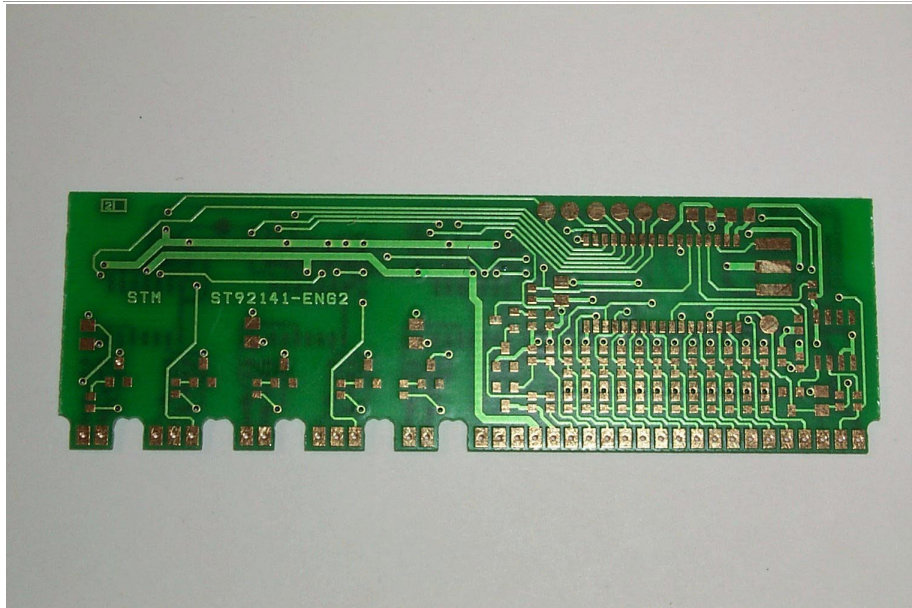
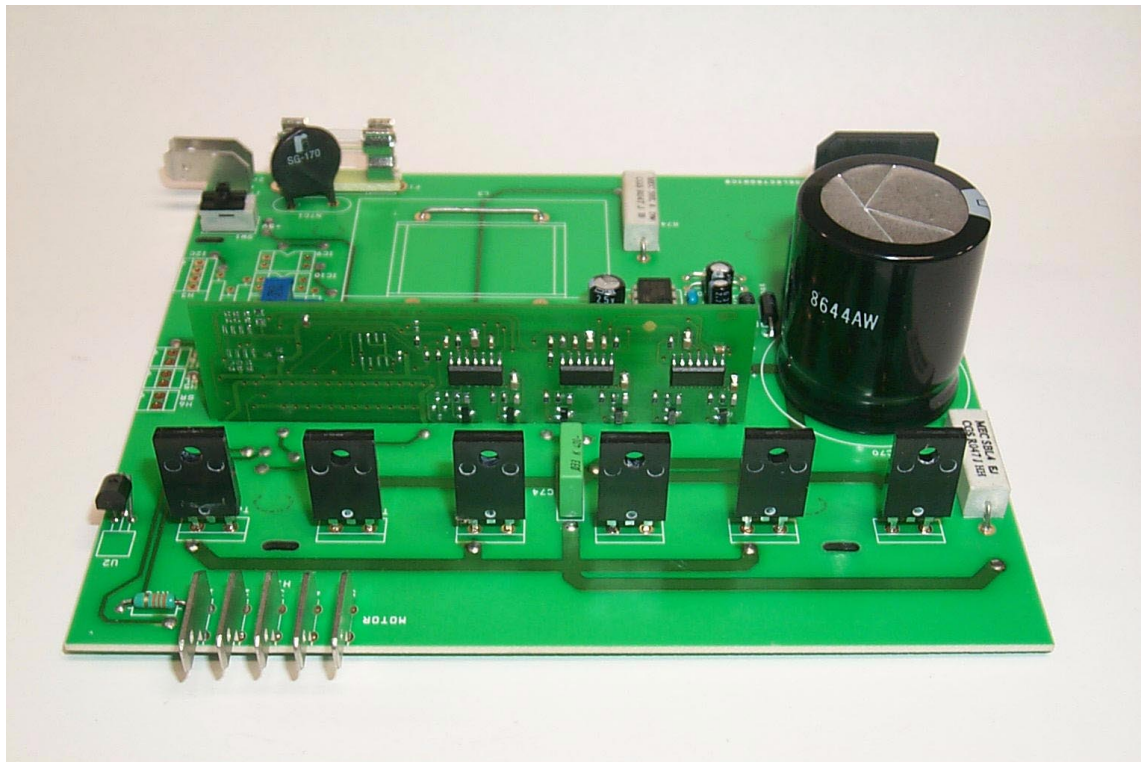


Figure 5. Control Board plugged into the Power Board next to the discrete parts



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Figure 6. Typical Control Board circuit for AC motor control applications

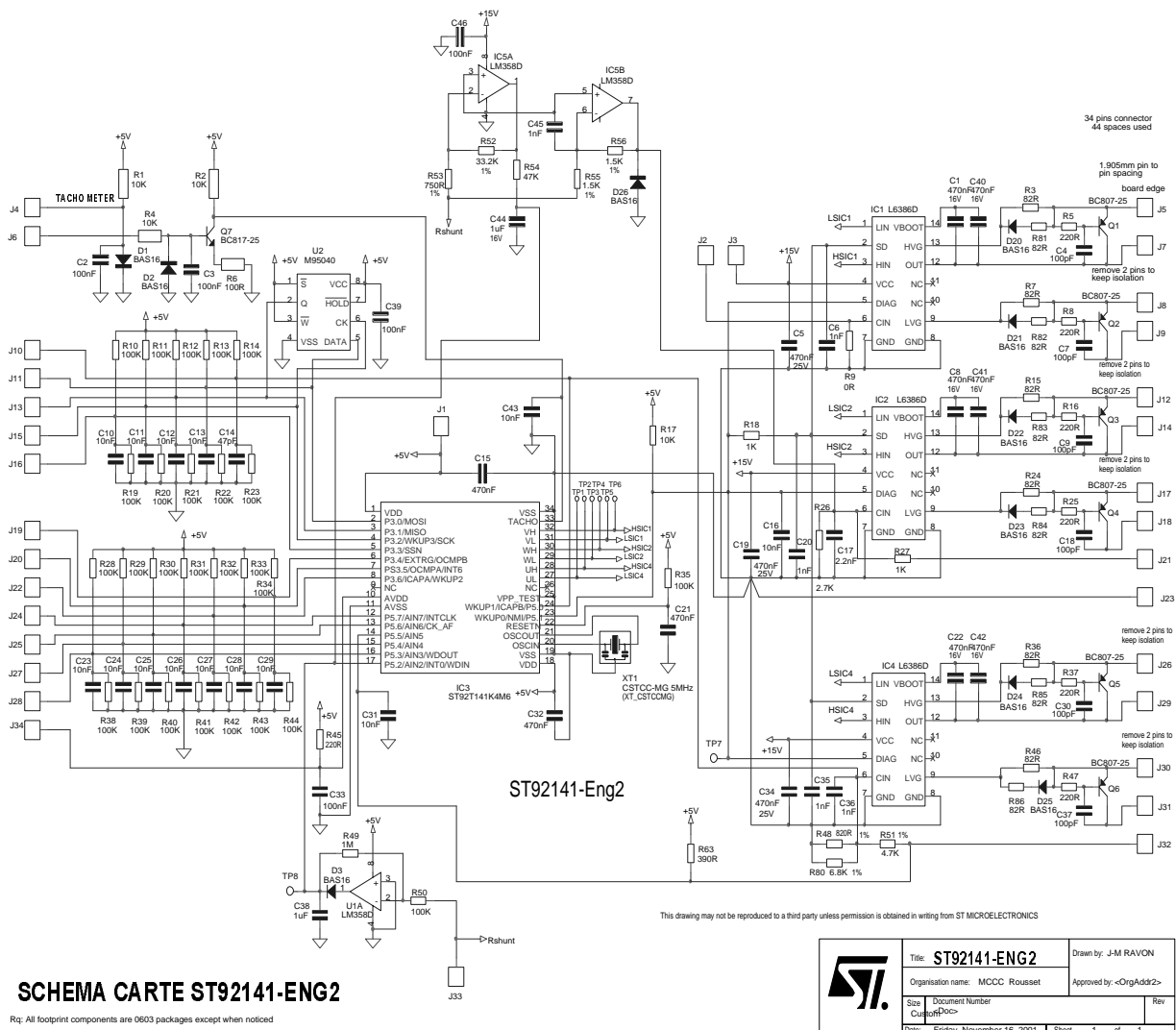
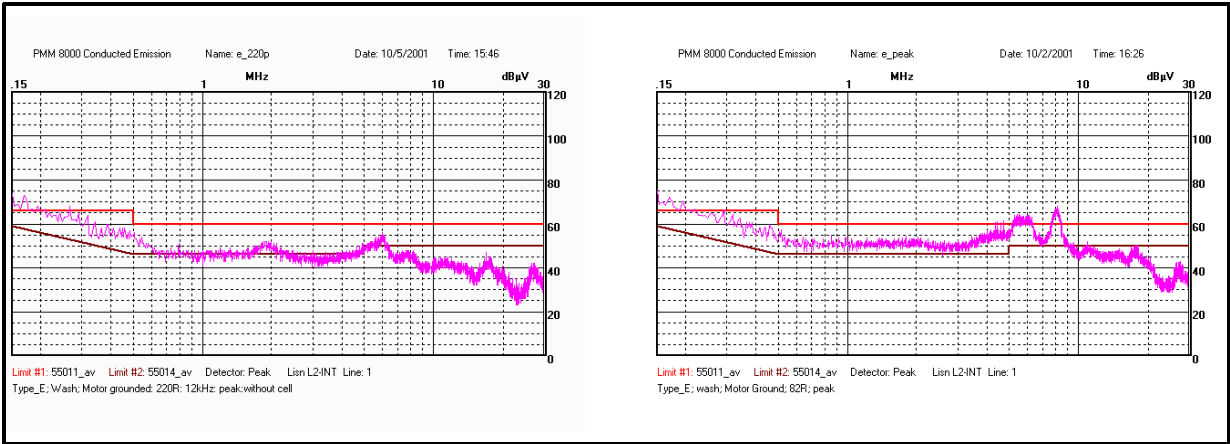


Figure 8. Conducted noise depending on gate drive impedance

On the left: $R_g = 220R$

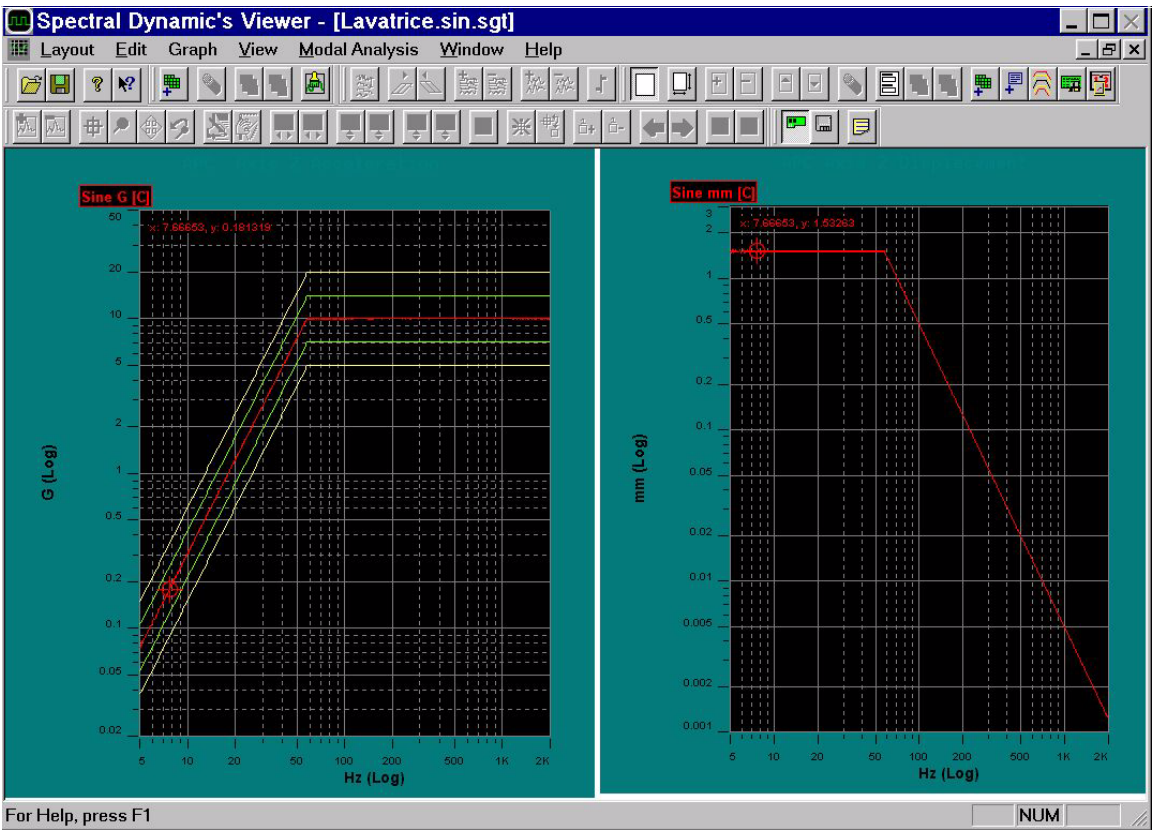
on the right: $R_g = 82R$



APPENDIX 1: Vibration test results of Control Board and Power Board assembly

<p>VIBRATIONS, SINUSOIDAL (Stantard: IEC 68-2-6, test Fc)</p> <p>Electrical limits were tested on two modules after a Vibrations, sinusoidal as below specified:</p> <p>Puma Sine Test Synopsis</p> <p>Test Results: Reason For Shutdown: Normal Test Completion Elapsed Test Time: 0002:052:054 Elapsed Sweeps: 20.00 Remaining Sweeps: 0.00 Points Per Sweep: 800 Test Range: 5.00(Hz) to 2000.00(Hz)</p> <p>Control Parameters Control Strategy: Average Filter Type: Proportional Filter Specification: 80.00% Sweep Mode: LOG Sweep Rate: 1.00 (Oct/Min)</p> <p>Shaker Limits Acceleration: 45.0000 Velocity: 59.0551 Displacement: 0.9843 Velocity: 12.0000 Symetric Limits: Yes</p> <p>Resonance Search And Dwell Setup Max Resonances: 10 Hysteresis: 3 Minimum Q Value: 1.00 Smoothing: Low Channel Number: Control</p> <p>Profile Settings</p> <table> <tr> <th>Status</th><th>Frequency</th><th>Type</th><th>Acceleration</th><th>Velocity</th><th>Displacement</th><th>Lo</th><th>Hi</th><th>Lo</th><th>Hi</th></tr> <tr> <td></td><td></td><td></td><td></td><td></td><td></td><td>Alarm</td><td>Alarm</td><td>Abort</td><td>Abort</td></tr> <tr> <td>#00</td><td>On</td><td>5.0</td><td>Displacement</td><td>0.0755</td><td>0.023562</td><td>1.500000</td><td>3.0</td><td>3.0</td><td>6.0</td></tr> <tr> <td>#01</td><td>On</td><td>57.6</td><td>Displacement</td><td>10.0001</td><td>0.271203</td><td>1.500000</td><td>3.0</td><td>3.0</td><td>6.0</td></tr> <tr> <td>#02</td><td>On</td><td>2000.0</td><td>Acceleration</td><td>10.0000</td><td>0.007804</td><td>0.001242</td><td>3.0</td><td>3.0</td><td>6.0</td></tr> </table>										Status	Frequency	Type	Acceleration	Velocity	Displacement	Lo	Hi	Lo	Hi							Alarm	Alarm	Abort	Abort	#00	On	5.0	Displacement	0.0755	0.023562	1.500000	3.0	3.0	6.0	#01	On	57.6	Displacement	10.0001	0.271203	1.500000	3.0	3.0	6.0	#02	On	2000.0	Acceleration	10.0000	0.007804	0.001242	3.0	3.0	6.0
Status	Frequency	Type	Acceleration	Velocity	Displacement	Lo	Hi	Lo	Hi																																																		
						Alarm	Alarm	Abort	Abort																																																		
#00	On	5.0	Displacement	0.0755	0.023562	1.500000	3.0	3.0	6.0																																																		
#01	On	57.6	Displacement	10.0001	0.271203	1.500000	3.0	3.0	6.0																																																		
#02	On	2000.0	Acceleration	10.0000	0.007804	0.001242	3.0	3.0	6.0																																																		
Sample N.			Visual Inspection			Electrical Test At 25 C (Before and after test)																																																					
1			Passed			Passed																																																					
2			Passed			Passed																																																					

Figure 9. Sinusoidal profile



ANNEX 2: Control Board parts list

Bill Of Materials October 17,2001 11:46:37Page1

Item	Quantity	Reference	Value	Voltage	%	Footprint	
1	6	C1	470nF	16V		X7R	0805
		C8	470nF	16V		X7R	0805
		C22	470nF	16V		X7R	0805
		C40	470nF	16V		X7R	0805
		C41	470nF	16V		X7R	0805
		C42	470nF	16V		X7R	0805
2	5	C2	100nF			Y5V	0603
		C3	100nF			Y5V	0603
		C33	100nF			Y5V	0603
		C39	100nF			Y5V	0603
		C46	100nF			Y5V	0603
3	6	C4	100pF				0603
		C7	100pF				0603
		C9	100pF				0603
		C18	100pF				0603
		C30	100pF				0603
		C37	100pF				0603
4	3	C5	470nF	25V		Y5V	0805
		C19	470nF	25V		Y5V	0805
		C34	470nF	25V		Y5V	0805
5	5	C6	1nF				0603
		C20	1nF				0603
		C35	1nF				0603
		C36	1nF				0603
		C45	1nF				0603
6	11	C10	10nF	63V			0603
		C11	10nF	63V			0603
		C12	10nF	63V			0603
		C13	10nF	63V			0603
		C23	10nF	63V			0603
		C24	10nF	63V			0603
		C25	10nF	63V			0603
		C26	10nF	63V			0603
		C27	10nF	63V			0603
		C28	10nF	63V			0603
		C29	10nF	63V			0603
7	1	C14	47pF	63V			0603
8	3	C15	470nF			Y5V	0805
		C21	470nF			Y5V	0805
		C32	470nF			Y5V	0805

DESIGNING A LOW COST POWER BOARD FOR ST92141 MOTOR CONTROL MCU ...

Item	Quantity	Reference	Value	Voltage	%	Footprint
9	3	C16	10nF			0603
		C31	10nF			0603
		C43	10nF			0603
10	1	C17	2.2nF			0603
11	1	C38	1uF			X7R 0805
12	1	C44	1uF	16V		Y5V 0805
13	10	D1	BAS16			SOT-23
		D2	BAS16			SOT-23
		D3	BAS16			SOT-23
		D20	BAS16			SOT-23
		D21	BAS16			SOT-23
		D22	BAS16			SOT-23
		D23	BAS16			SOT-23
		D24	BAS16			SOT-23
		D25	BAS16			SOT-23
		D26	BAS16			SOT-23
14	3	IC1	L6386D			SO-14
		IC2	L6386D			SO-14
		IC4	L6386D			SO-14
15	1	IC3	ST92T141K4M6			SO-34/P1.016
16	2	U1	LM358D			SO-8
		IC5	LM358D			SO-8
17	6	Q1	BC807-25			SOT-23
		Q2	BC807-25			SOT-23
		Q3	BC807-25			SOT-23
		Q4	BC807-25			SOT-23
		Q5	BC807-25			SOT-23
		Q6	BC807-25			SOT-23
20	1	Q7	BC817-25			SOT-23
21	4	R1	10K			0603
		R2	10K			0603
		R4	10K			0603
		R17	10K			0603
22	12	R3	82R			0603
		R15	82R			0603
		R24	82R			0603
		R36	82R			0603
		R46	82R			0603
		R81	82R			0603
		R82	82R			0603
		R83	82R			0603
		R84	82R			0603
		R85	82R			0603

DESIGNING A LOW COST POWER BOARD FOR ST92141 MOTOR CONTROL MCU ...

Item	Quantity	Reference	Value	Voltage	%	Footprint
23	7	R86	82R			0603
		R5	220R			0603
		R8	220R			0603
		R16	220R			0603
		R25	220R			0603
		R37	220R			0603
		R45	220R			0603
24	1	R47	220R			0603
		R6	100R			0603
25	1	R9	0R			0603
26	26	R10	100K			0603
		R11	100K			0603
		R12	100K			0603
		R13	100K			0603
		R14	100K			0603
		R19	100K			0603
		R20	100K			0603
		R21	100K			0603
		R22	100K			0603
		R23	100K			0603
		R28	100K			0603
		R29	100K			0603
		R30	100K			0603
		R31	100K			0603
		R32	100K			0603
		R33	100K			0603
		R35	100K			0603
		R38	100K			0603
		R39	100K			0603
		R40	100K			0603
27	2	R41	100K			0603
		R42	100K			0603
		R43	100K			0603
28	1	R44	100K			0603
		R50	100K			0603
		R27	1K			0603
29	1	R18	1K			0603
		R26	2.7K			0603
30	1	R48	820R		1%	0603
31	1	R49	1M			0603
32	1	R51	4.7K		1%	0603
33	1	R52	33.2K		1%	0603
		R53	750R		1%	0603

DESIGNING A LOW COST POWER BOARD FOR ST92141 MOTOR CONTROL MCU ...

Item	Quantity	Reference	Value	Voltage	%	Footprint
34	1	R54	47K			0603
35	2	R56	1.5K		1%	0603
		R55	1.5K		1%	0603
36	1	R63	390R			0603
37	1	R80	6.8K		1%	0603
38	6	TP1	TPshort			PAD
		TP2	TPshort			PAD
		TP3	TPshort			PAD
		TP4	TPshort			PAD
		TP5	TPshort			PAD
		TP6	TPshort			PAD
39	2	TP8	TP0			PAD
		TP7	TP0			PAD
40	1	U2	M95040			SO-8
41	1	XT1	CSTCC-MG	5MHz		(XT_CSTCCMG)

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