FUSE Application experiment 24586
Dissemination/Demonstrator document

DCB TECHNOLOGY FOR PRODUCTION OF VOLTAGE REGULATORS IN MOTORCYCLE APPLICATIONS

A CHIP ON BOARD SOLUTION TO REGAIN COMPETITIVENESS

AE:	**24586**
New technology:	**MCM**
Industrial sector	**Electrical equipment for engines and vehicles (3161)**
Contact TTN	**COREP**

AE abstract

The company IDM S.r.l. (Italy), with 45 persons of which 3 are electronic engineer, is specialised in the designing, manufacturing and selling of electronic ignition systems for a wide range of endothermic engines like those used for motorcycles, stationary machines, gardening and agriculture vehicles. IDM S.r.l. also manufactures several kinds of voltage regulators mainly for the motorcycles market. These kind of regulators are used to provide a constant voltage on the AC loads of the motorcycles, e.g. head, meter and tail lamps and, at the same time, to charge correctly their battery, assuring it conditions for a long operation life. The regulator we are currently manufacturing for scooters uses a traditional PCB substrate where two SCRs (Silicon Controlled Rectifier) in the TO220 case and several through hole components are mounted. In particular the two SCRs preclude us from reducing the size of the regulator and further on they are the critical elements of the product because during their working life, due to thermal shocks, they may de-solder and fail. In this AE the new component is an high dissipation COB (Chip On Board, MCM) where bare SCR dice are assembled onto a DCB (Direct Copper Bonded) ceramic substrate through a soft solder process of die attach. This will assure a very high thermal conductivity with a very low TCE (Thermal Coefficient of Expansion). The main benefits of the new product are reduced production costs (about 28%), reduced component dimensions (overall volume is the 25% in less as regards the old product and the weight is 45% respect the old product) and increased reliability. On the other side the company needs to learn this technology to achieve industrial competitiveness in the European and extra-European markets, since Japanese and Far East competitors, who have been using similar technologies for more than 10 years, can force market demand to change from day to day by simply reducing the size of the case or the plastic connector. Thanks to this AE, IDM invested heavily to have internal assembly DCB and will allow us to introduce this new technology in several products of ours decreasing the payback period and increasing our global market share

The estimated ROI is 1009% over a 5 year period and will paid back in 19 months. The total cost of the application experiment was planned in 90,5 kECU. It started in September 1997 and was ended in June 1998 (10 months).

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KEYWORDS: Voltage regulator, MCM, Direct Copper Bond, Motorcycle, Power substrate, Bare dice, Die bonding, Known good dice, Detailed offer, In house technology management

1. Company name and address

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2. Company size

The company employs 45 persons, of which 3 electronic engineers and 4 technicians within the R&D department. IDM S.r.l. is a medium size Italian company with a turnover around 4,5 MECU.

3. Company business description

IDM S.r.l. designs, produces and sells electronic ignition systems for stationary and no-stationary endothermic engines since 1982.

In 1990, following the request of some endothermic engine constructors for motorcycle industry, the company has also invested in the production of magnetos flywheels with or without power generation, CDI (Capacitor Discharge Ignition) unit and voltage regulators for this market.
Since 1990 a variety of products was developed by IDM S.r.l. for a wide range of different applications: from motorcycle to small pleasure aircraft, from motor for gardening to large stationary motors used on building sites or in agriculture, from nautical applications to the new market of the four wheels vehicles that people can drive on road without license.

This led the company to achieve a practical experience with many reliability problems that are common when dealing with high power electronic devices.
Several new projects are currently analysed in IDM S.r.l. following the requests from our customers that are becoming more confident in our products reliability.
IDM has very high experience and expertise in electronic ignition systems for a wide range of endothermic engines like those used for motorcycles, stationary machines, gardening and agriculture vehicles and, particularly, in PCB technology with power electronic circuitry.

4. Company markets and competitive position at the start of the AE

In the latest years, thanks to the new products for the motorcycle market, the company has remarkable increased its production rate and turnover. As matter of fact, its turnover has

increased from 1,5 MECU in 1991 to 4,25 MECU in 1996, thus consecrating it as a primary firm in the European framework.
IDM is now producing about 60.000 electronic ignition systems per month and about 10.000 magneto flywheel units. As regards regulators, in 1996, we produced about 120.000 pieces with a market share of 11%.

In 1996 the voltage regulators turnover was about 11,5% of the total IDM turnover while magneto flywheels was about 40% and electronic ignitions, both CDI (Capacitor Discharge Ignition) and TCI (Transistor Controlled Ignition), the remaining part.

The overall market is currently estimated in 5,2 MECU in Europe and around 62,0 MECU in the world. The selling price of the voltage regulator is today 4.3 ECU.

In the table below, an overview of the most important competitors for regulator and their market share is given.

YEAR 1996	
COMPANIES	**EUROPEAN MARKET SHARE**
European	11%
Japan and Far East	76%
IDM	11%
Others	2%

During year 1996 IDM S.r.l. and the other European manufacturers were competitive toward Japanese and Far East manufacturers as regard as product price, but reliability of Japanese products were still far to be reached. Despite of this, due to the high change rate of YEN currency, European Motorcycle Industry generally evaluated it convenient the saving on regulator buying price as compared as the cost of some returns from the final market.
Since the 80's, Japanese and Far East product developed a technology of mounting the bare dice of SCRs on an aluminium substrate, while all European manufacturers still use through hole on PCB.
The following table summarises the situation competitive in the European market:

COMPANIES	**technology**	**weaknesses**	**strengths**
European	Through hole	reliability, size	cost
Japan and Far East	MCM, hybrid	cost	Reliability, size
IDM	Through hole	reliability	cost
Others	Through hole	reliability, size	cost

Thank to FUSE program we have the possibility to introduce a new technology on our products that allows us to gain a large quote of the European market.

However already in 1996 IDM S.r.l. forecast for turnover and margin profit of traditional regulator were not very good because we evaluated that a saturation of the market and a reduction of the margin of profit had to take place in order to reduce the price to keep the competitiveness

The analysis that IDM S.r.l. made in 1996 of the market for traditional regulator is depicted in *Figure 1 (the diagram is normalised: 1994=100)*. As a matter of fact IDM S.r.l. and European manufacturers' market share decreased dramatically in the latest 2 years (1997, 1998) (see diagram in *Figure 17*), first because of the better quality of Japanese products and second for YEN currency devaluation.

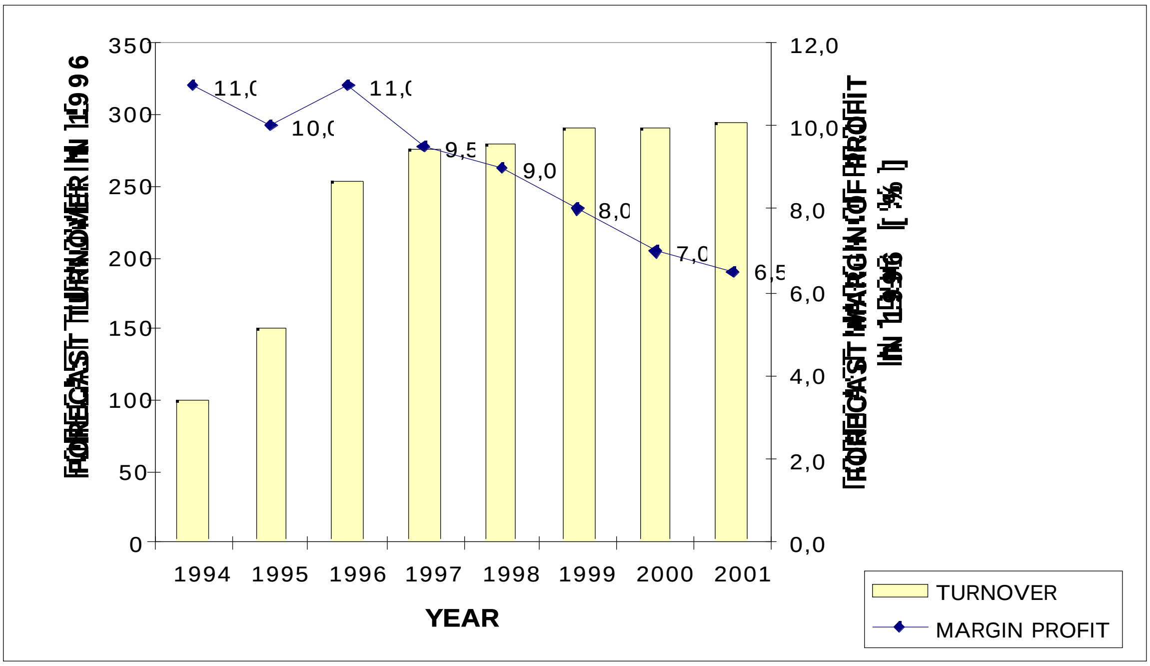


Figure 1
Diagrams of forecast turnover (base. 1994=100) for traditional regulator made in 1996 together with margin of profit.

5. Product to be improved and its industrial sectors

The object of this technological innovation as far as the electronic circuit and the mounting methods are concerned belongs to the class of voltage regulators for motorcycles.

IDM S.r.l. has started manufacturing this device early in 1994 and has since then produced about 250,000 of them. The item is now marketed for a number of motorcycle brands, particularly scooters (see a model in *Figure 2*).

IDM S.r.l.'s current device is outlined in *Figure 3*, where the outline dimensions and the connecting diagram are reported.

Figure 2: A model of scooter where the object of the AE is applied.

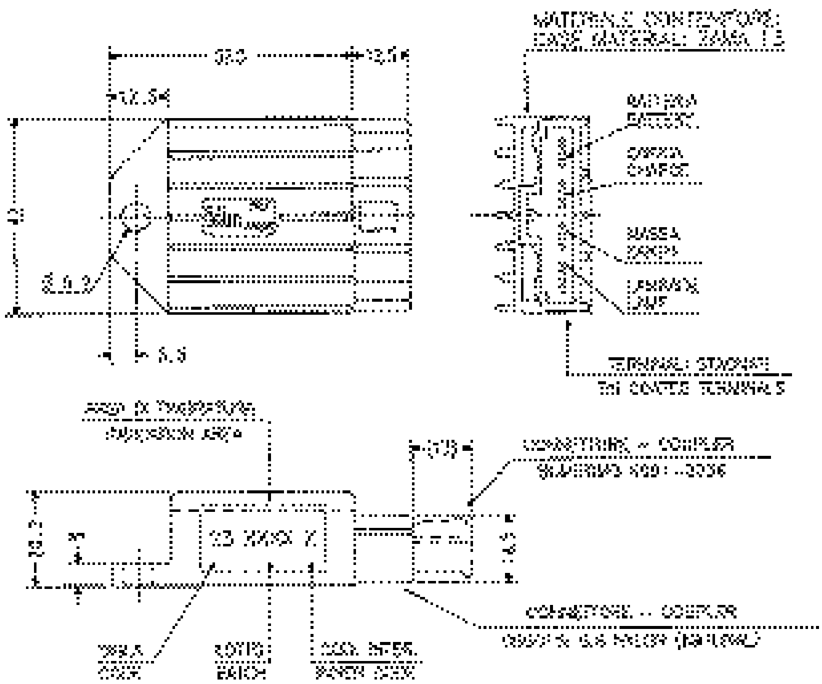


Figure 3: The company's current voltage regulator P/N 446023.

5.1 Description Of A Voltage Regulator For Motorcycles.

Figure 4 shows a schematic view of actual assembly system for our voltage regulator part number 446023. It resemble the actual manufacturing phases too:

1. mounting of PCB (Printed Circuit Board) with components, TO220 SCRs and faston;

2. inserting of PCB in the metallic case;

3. filling the case with epoxy compound;

4. handily inserting of plastic connector.

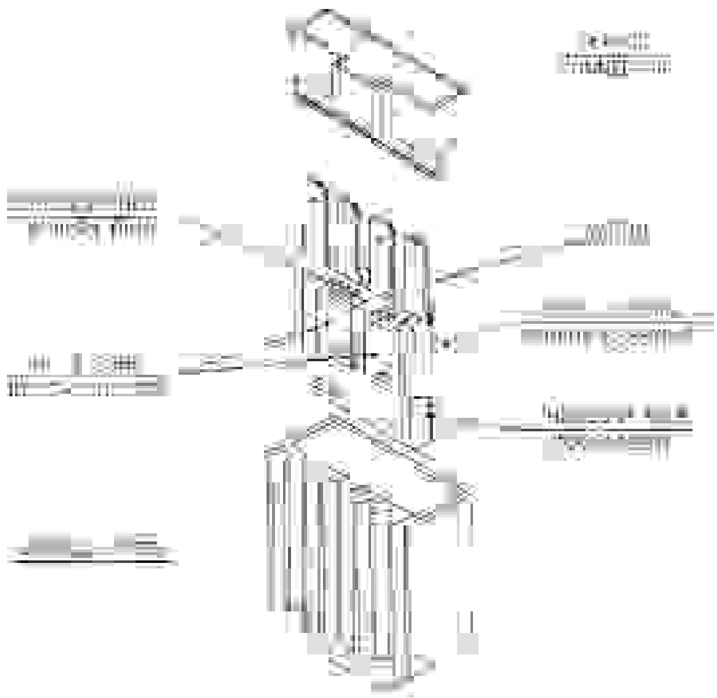


Figure 4: Schematic Assembling phases of traditional voltage regulator P/N 446023.

From *Figure 4* we can gather also that the regulator is chiefly made up of 3 elements:

- a Printed Circuit Board;
- a metallic case;
- a plastic connector.

To assure a good thermal dissipation between TO220 SCRs on PCB and metallic case, after the insertion of the complete PCB, the metallic case is filled with epoxy resin. Due to electric specifications (see different potentials) the TO220 heatsink cannot be stuck on the metallic case.

5.2 Function Of A Voltage Regulator For Motorcycles.

The energy of a motorised vehicle is generated through a flywheel magneto, which is made of a stator winding and a rotor fixed on the driving shaft. Some magnetos are bound to this rotor which, passing before the stator winding, produce a flux variation and therefore an AC voltage at the ends of the stator winding itself. The stator winding can partly be used to feed the ignition system which produces the spark at the ends of the plug, and partly to feed the different loads the vehicle needs to correctly and safely move on the road.

In present scooters loads are divided into two classes: those fed through alternating voltage - such as front lights and rear side-lights - and those fed through direct voltage thanks to a battery - such as rear brake-lights, horns and electrical ignition switches. This division allows the use of batteries of a very small size, i.e. max 4 Ah (Ampère/hour), in such systems where the maximum energy absorption can reach about 100 Watt, thus reducing all problems related to costs and pollution that bigger batteries involve. a.c. loads are mainly lamps with a max.

feeding voltage of about 13V, whereas the tension which is generated through the flywheel at full ratings reaches 25/30V.
The main D.C. load is the battery, to which all electrical elements are connected. The battery must be charged at a voltage not exceeding 14V and, in order for it to be charged, one needs currents which are comparable to its actual state.

Currents generated through the flywheel, especially during day trips when one can reach 6/8A, are considerably higher if compared to the maximum current which the battery can bear.

This application is used to regulate the maximum actual tension figure on A.C. loads and the maximum voltage (and current) figure to which the battery is charged.

Figure 5 shows a general scheme of how the device is connected to the electrical plant of scooters.

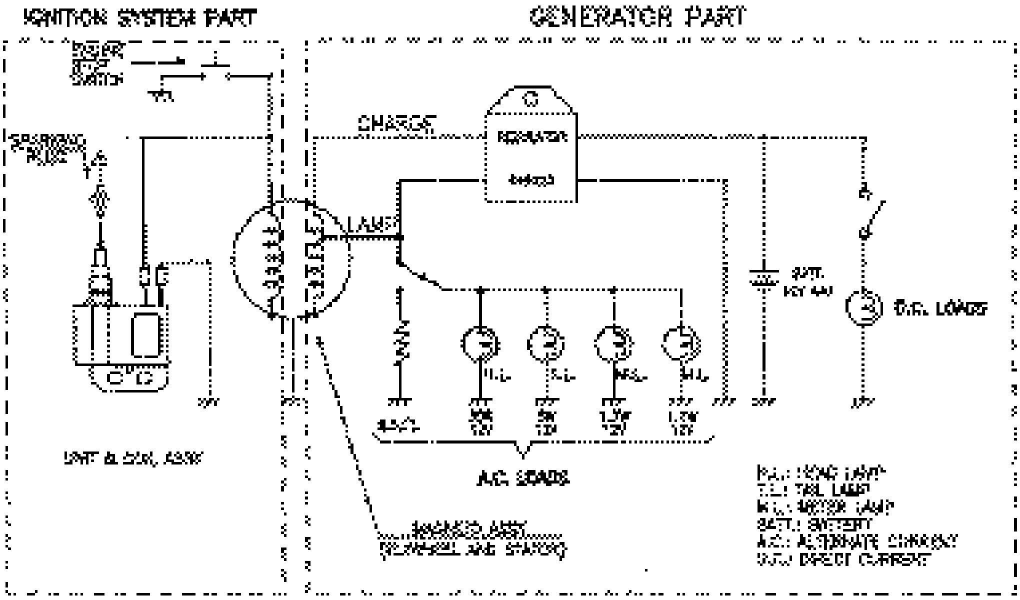


Figure 5: Schematic drawing of wiring connections for a voltage regulator.

Figure 6 shows, through block diagrams, how the device works.

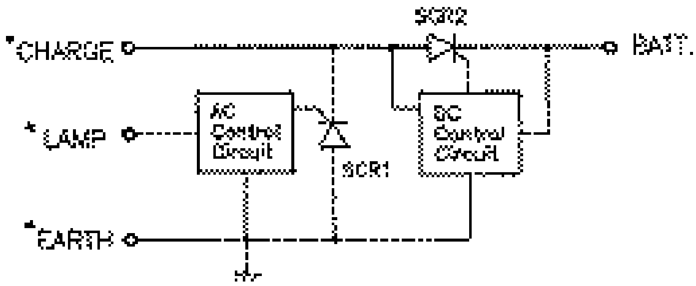


Figure 6: Block working scheme for a traditional voltage regulator.

5.3 Circuit Schematic Of Regulator

Figure 7 shows the electrical circuit of our traditional voltage regulator.

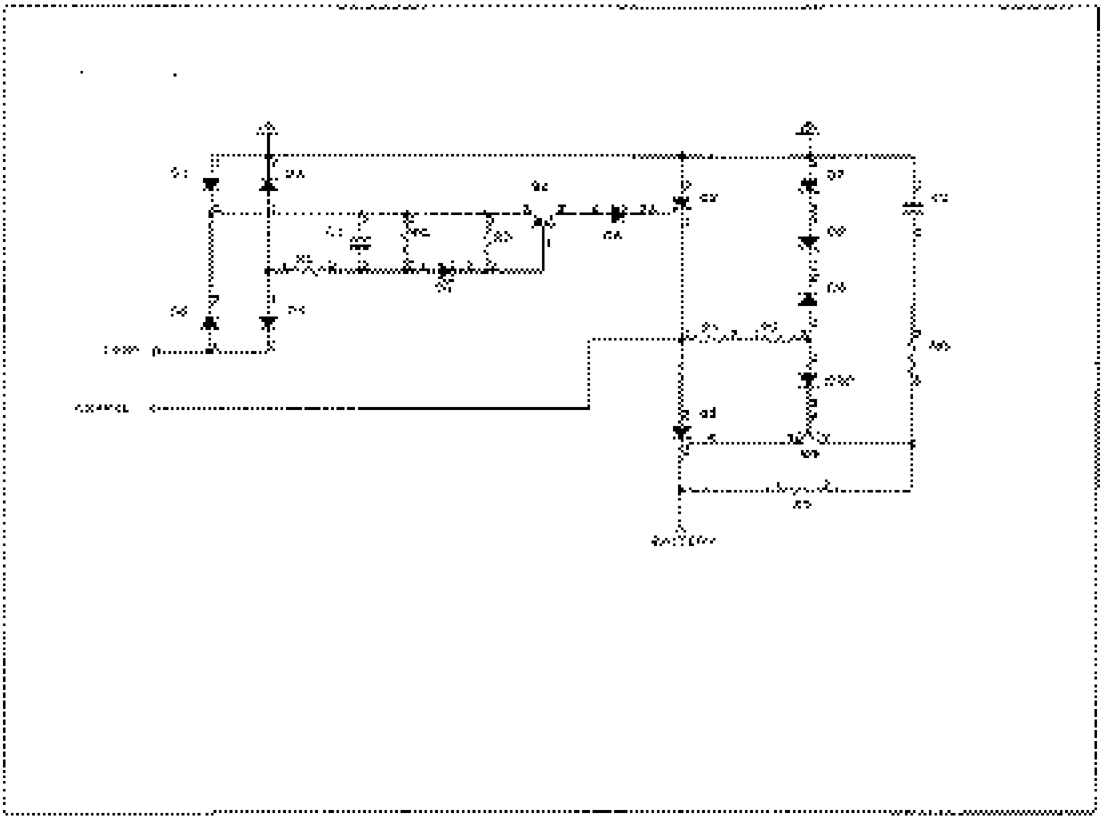


Figure 7: Schematic of the electronic circuit for a traditional voltage regulator.

A problem of this configuration is the temperature coefficient in D.C., that is the variation of regulated voltage on the battery at the varying of working temperature.
The best thing would be for this coefficient to be negative, or if positive, to be very small.

6. Description of the technical product improvements

We have developed the same component as has been up to now produced, though using a mounting technology that allows us the following advantages:

- more automated production with reduced time to market
- Improved reliability with minor return from the field
- Higher power dissipation capability making it suitable for any kind of flywheel
- Reduced size and weight.

6.1 Increased productivity

The scheme of wiring the device to distribution system of the scooter is the same of *Figure 5*. *Figure 8* shows the new block diagram.

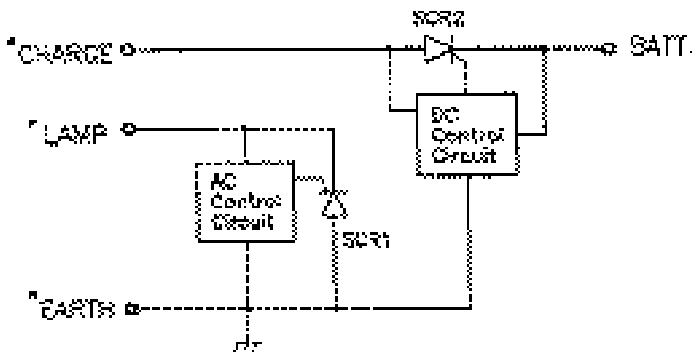


Figure 8: Block working scheme for the new voltage regulator object of the AE.

We have modified the production technology of the printed circuit and the case of components to be used. In fact we wish to remarkably increase (min. 100%) the production/day and while by reducing the work-time of the different phases of the actual mounting technique, namely:

1. time required for components mounting;
2. time required for connector mounting.

1. In current production of this device, all components in their traditional form are used for the printed circuit. Particularly the two power SCRs (SCR 2N6507 25A/400V manufactured by MOTOROLA) are supplied in a TO220 case as shown in *Figure 3*. They must therefore be hand-soldered one by one.
2. After being housed into the metal box, the circuit is moulded with epoxy resin. Then the connector is inserted manually. Since the resin-compound is still liquid, operators must pay special attention in order not to be harmed by resin fumes and in order not to stain the external part of the metal box with resin.

6.2 Increased reliability

By using the new mounting technologies we also aimed to considerably reducing the causes of possible failures in the regulator, namely:

- **a.** bending of SCR pins;
- **b.** heat dissipation of SCRs;
- **c.** SCR positioning inside the metal box;
- **d.** uncorrected fixing of the connector.

a. Owing to a lack of room, SCRs pins must be bent very near to their plastic cases, whereas manufacturers normally require a minimum distance of 2÷3 mm.

b. The two SCRs cannot be really fixed in the metal box: they are simply immersed in a solution of epoxy resins which do not provide a high heat conduction.

c. While the circuit is being put into the metal container, SCR flaps can touch metal, thus causing the non-functioning of the regulator.

d. The connector tends to move during the phase of hot-hardening of resin, finally does not perfectly adhere to the base and the product suffers variations.

Figure 9 shows the assembling phases for the new voltage regulator.

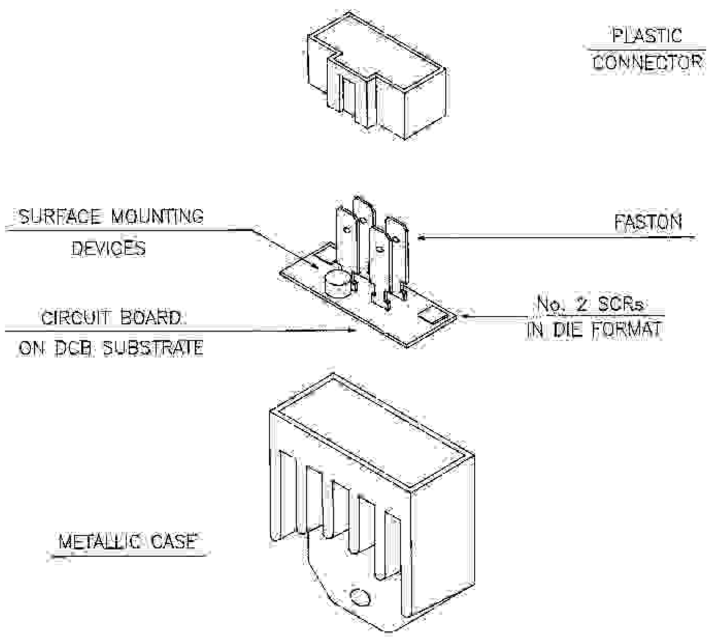


Figure 9: Schematic Assembling phases of new voltage regulator P/N 446034.

6.3 Reduced size

With the new technology IDM S.r.l. has also reduce the item size, see *Figure 10* and the photo of *Figure 11*, so that less filling material is needed, and make it suit for being mounted on all types of motorcycles, even where loading powers over 100W are needed. The remaining circuit components are used in SMD version thus allowing the size of the PCB to be further reduced.

The weight of the new regulator is about 50g while about 115g was the weight of the traditional one.

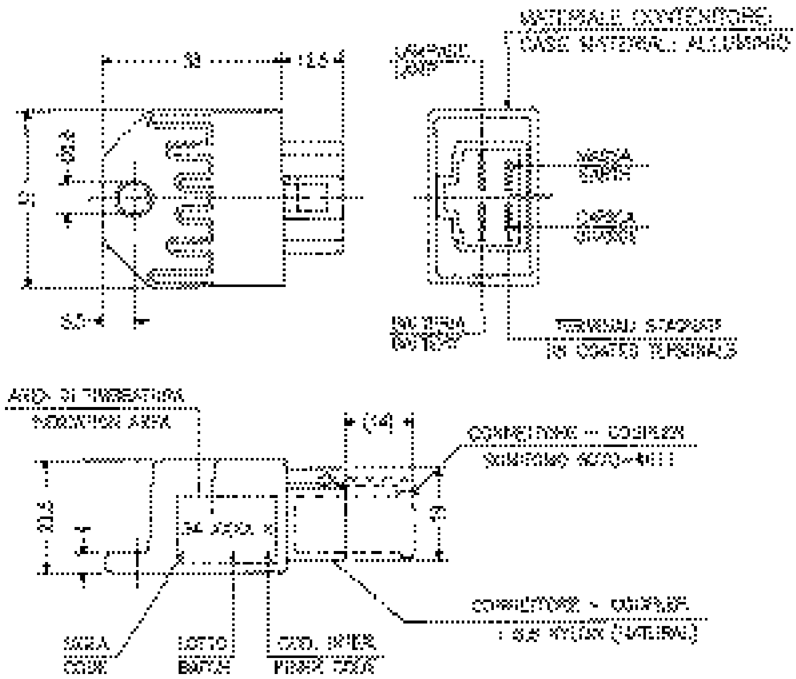


Figure 10: Outline dimensions of the company new voltage regulator P/N 446034.

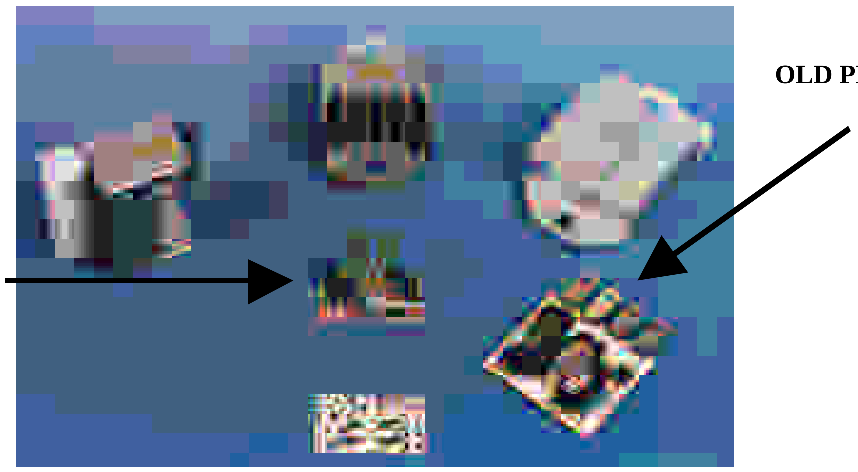


Figure 11: Photo of the traditional IDM S.r.l.'s voltage regulator and of the prototype as outcome of the AE. The different electronic circuits can be seen too.

6.4 Increased power handling capability

With the new circuit we intend also to reduce the number of electronic components to mount on the board and we intend to have a D.C. temperature coefficient of about +5 mV/°C. *Figure 12* shows the new electric schematic of the voltage regulator.

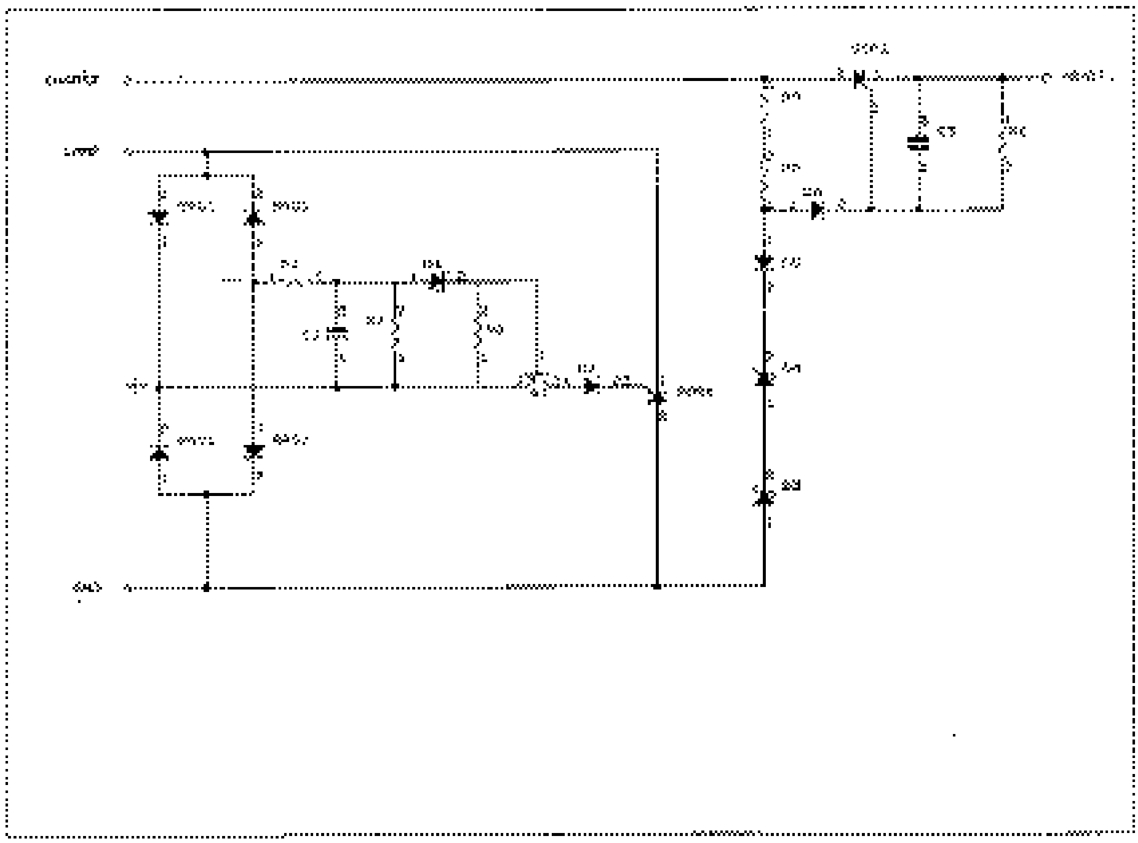


Figure 12: Schematic of the electronic circuit for the new voltage regulator.

Heat dissipation is mainly due to conduction through the circuit substrate and then directly through the metal box. If the circuit substrate is made of alumina or aluminium, the heat conduction coefficients will be much higher (204W/mK for aluminium, 164W/mK for aluminium oxide) if compared to thermal conductivity of traditional FR4 PCBs (10W/mK).

No one among our European competitors is using DCB technology that is also more reliable than the bare dice on aluminium substrate technology used by Japanese because of the better thermal resistance of DCB.

7. Choices and rationale for the selected technologies, tools and methodologies

The choice of design methodologies, fabrication technologies and test methods were divided into the phases summarised in *Figure 13.*

7.1 State Of Art Of Competitive Products.

Japanese have currently the best technological solution for this kind of regulators and the best items. It uses SCRs dice and SMT device on a multi-layers PCB substrate with a base plate of aluminium 1.0mm thick.

This technology has been exploited by the most important Asian manufacturers in this sector and allows to minimise the variations from one circuit to another - even if belonging to the same lot - which is a very common drawback with traditional substrates. These manufacturers have acquired a reputation of high reliability, conquering the lion share of the world market.

The only disadvantage of this technology is that the SCRs dice must be mounted on a spacer in order to increase power dissipation toward aluminium substrate and compensate for thermal expansion.

7.2 Printed Board Substrate.

The technology we used is a SMT (Surface Mounting Technology) on a DCB (Direct Copper Bonded) substrate where we previously directly assemble the bare dies of the SCRs.
Before the AE in our factory we had experience only in using Trough Hole Technology, therefore we evaluated the other technologies available from the market:

1. SMT on FR4 substrate (an epoxy laminate),
2. hybrid and SMT on ceramic substrate (aluminium oxide),
3. SMT on multi-layers PCB substrate made of an aluminium base plate 1.0mm thick, an insulation layer of epoxy varnish 100μm thick and conductive copper foil 35μm thick.

We decided to chose SMT on DCB substrate basing on the following considerations (see *Figure 14*):

1. FR4 is a thermal insulator and will not let the applications to dissipate more than 80W;
2. hybrid technology (deposition of paste on a ceramic substrate to make resistors and capacitors and their laser trimming to centre nominal value) is still too much expensive and the thermal management is not so good;
3. PCB on aluminium base-plate substrate is also interesting, but by now there are difficulties on finding the material; anyway the process of assembling the circuit, treating the material and power dissipation are quite similar to DCB technology and the thermal results are not so good as compared as DCB substrate.

EVALUATIONCRITERIA	COST OF MATERIAL	RELIABILITY OF PRODUCT	THERMAL DERATING	PRODUCTION FACILITIES	AVALAIBILITYOF MATERIALS	TECHNOLOGIC INNOVATION
SMT ON FR4 SUBSTRATE	LOW	FAIR	POOR	POOR	GOOD	POOR
SMT & HYBRID ON ALUMINA	VERY HIGH	HIGH	GOOD	GOOD	FAIR	GOOD
SMT ON ALUMINIUM SUBSTRATE	MEDIUM	HIGH	GOOD	GOOD	POOR	EXCELLENT
SMT ON DCB SUBSTRATE	MEDIUM	HIGH	EXCELLENT	GOOD	FAIR	EXCELLENT

Figure 14. Comparison of Substrate Materials.

7.3 Technology For Assembly

The two SCR components are no more used in their TO220 version, but in the 'bare die' version. This allows to carry out the mounting roadmap shown in Figure 9, and above all to strictly bind both SCRs to the circuit surface, thus obtaining a better heat dissipation. It is in fact our aim to prepare the item in such a way that it can be used even on flywheels where the power generation exceeds 100W, because the market is more and more oriented towards this type of devices.

7.4 Features Of DCB Substrates.

With the aims to increase further the reliability and the performance of its products, IDM S.r.l. decided to use a DCB material as substrate. DCB means Direct Copper Bonded and denotes a process through which two layers of copper are directly bonded onto an aluminium oxide (Al_2O_3) or aluminium nitride (AlN) ceramic base.

The reason for this choice depends on the outstanding features of this material:

- good mechanical strength, mechanically stable shape, good adhesion and corrosion resistant;
- excellent electrical insulation;
- very good thermal conductivity;

- superb thermal cycling stability;
- the thermal expansion coefficient is close to that of silicon, so no interface layers are required;
- good heat spreading;
- may be structured like PCBs;
- environmentally clean.

An advantages to the user is the 0,2mm thick copper layer that allows higher current loading for the same conductor width. Assuming the same copper cross-section the conductor needs to be only 12% of that of a normal printed circuit board.

The excellent thermal conductivity provides the possibility of very close packaging of the chips. This means more power capability per unit of volume and improved reliability of systems and equipment.

On the other side the high insulation voltage results in improved personnel safety.
DCB ceramic is the basis for the “chip-on-board” technology which represents the packaging trend for the future.

7.4 Plan Of Reliability Tests.

IDM S.r.l. planned the reliability tests dividing the workplan into two phases:

1. bench tests,
2. test on field.

1. *BENCH TESTS.*

a. Vibration testb. Cooling-Heating test.
c. Submersion test.
d. Duration test.

2. *TEST ON FIELD.*

a. *On road running*: in accordance with a Customer, a regulator will mount on a proper motorcycle for a test of 10000Km. During this test several bad whether conditions will be simulated.

After this final test we got back this regulator from our Customer and we tested it again on our bench with positive results. During test on field the regulator was clearly affected by different weather conditions and evidence of that was the oxide on some points of the terminals surface and by strong vibrations. On the regulator connector area was also partly present a small quantity of engine oil and on the aluminium case too. However the following tests on bench proved that the regulator can withstand also this harsh environmental conditions.

7.5 Tools

The development tools used are the CAD software already available. IDM uses DrawBase software for both PCB layout and mechanical design.

8. Expertise and experience in microelectronics of the company and the staff allocated to the project

At the start of the AE, the electronic technology that IDM S.r.l. has made use of is strictly bound to a traditional mounting, whereas Japanese competitors of this sector are almost exclusively making use of hybrid mounting. Electronic parts of all our products were mounted on a printed circuit made of FR3, FR4 or CEM1. The components used were all of traditional type i.e. *off the shelf* discrete components. On the other hand, IDM S.r.l. had a remarkable understanding as regards as the discrimination of component characteristics inside our appliances, whether provided with a semiconductor or not. This understanding is also due to our steady relationship with primary constructors of these components, such as MOTOROLA, TEXAS INSTRUMENTS, SGS-THOMSON, etc.
Together with these constructors we have also chosen selected components which have been specially marked for our firm. But no one in the company had experience in alternative substrate than PCB or in the management of bare dice and no one could evaluate cost and ROI of the technology or the environment where to work.
During the development of the project 6 persons employed in IDM company have been involved.

- The General Manager of the company
- A senior engineer (project leader) with a considerable experience in the field of electronic ignition systems for endothermic engines and all electronic parts for motorcycles
- An electronic engineer; who is an expert in power electronic systems design
- The responsible for quality
- A CAD designer, expert on lay out of electronic circuits for motorcycles applications and on mechanical interconnection parts for such products.
- A technician expert on bench tests of motorcycles parts.

9. Workplan and rationale

Following our workplan to achieve prototypes of voltage regulators for motorcycle applications by using bare dies of SCRs and Surface Mounting Technology devices on DCB substrate.

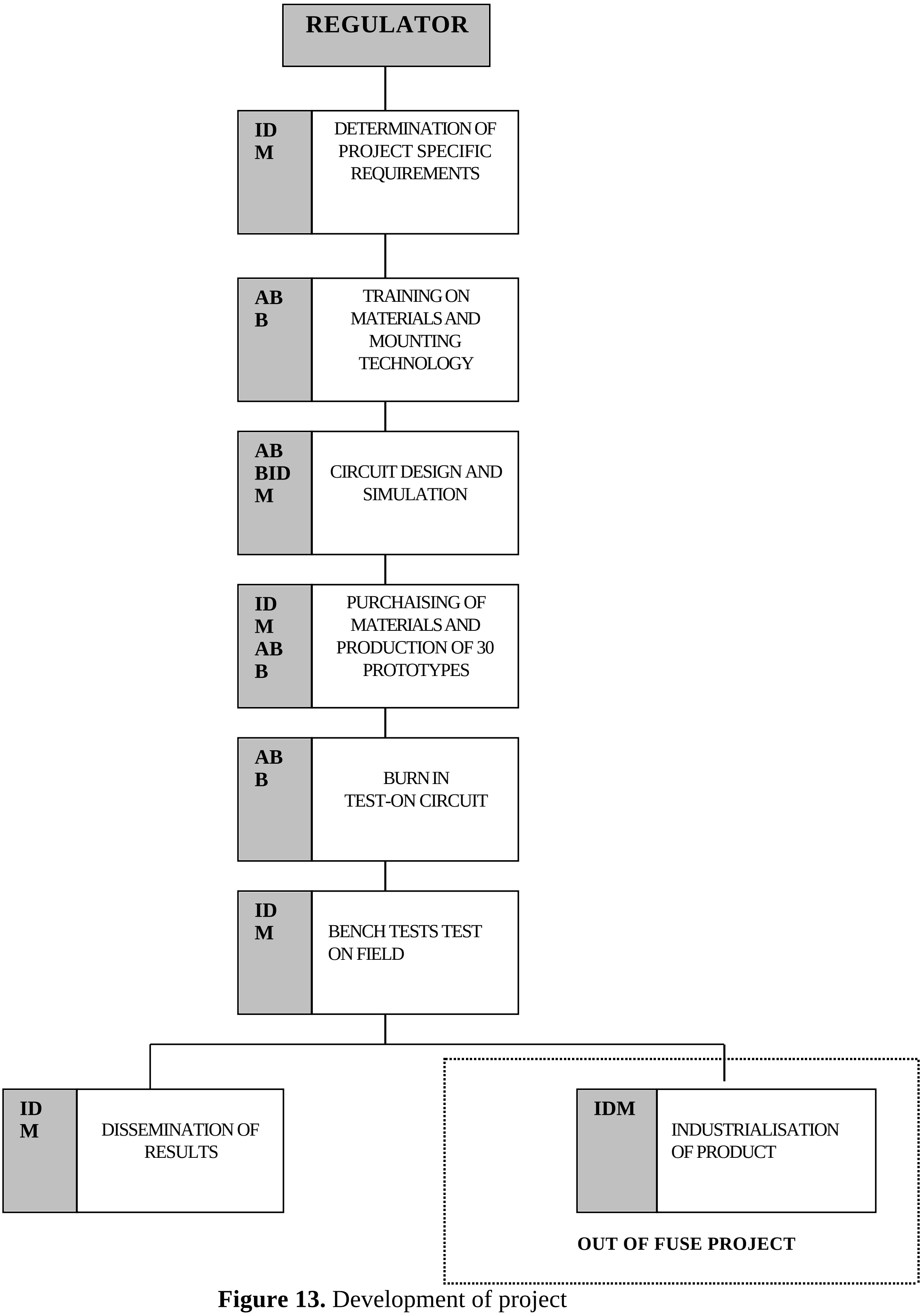


Figure 13. Development of project

WP1: Feasibility, Technical Specifications and Starting Training

1 Purpose: defining a block diagram of the project, achieving product specifications and starting up with human training.

2 Length: 1 month

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working Days*	*Subcontr. Working Days*	*Milestone*
IDM	T11 T12	Defining feasibility and circuit specifications Defining size and new mechanical drawing	33 12,5		 M1
ABB	T13 T14	Training on materials Training on mounting technology	4 4	3 3	 M2

WP2: Suppliers & materials

1 Purpose: to find more than a supplier for substrate materials, for surface mounting devices and for SCR dies. We need also to find suppliers for specific materials concerned with the project like solders, preforms and aluminium wires. We will also purchase these materials directly with subcontractor specifications and assistance

2 Length: 1 month

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working Days*	*Subcontr. Working Days*	*Milestone*
IDM	T21	Substrate Material supplier, dies and SMT devices	28		
IDM ABB	T22	Others materials suppliers and purchasing	16	3	M3

WP3: Achievement of 20 prototypes of the DCB circuit

1 Purpose: designing of the circuit board and making tooling for realise the circuit on DCB substrate.

2 Length: 1 month

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working Days*	*Subcontr. Working Days*	*Milestone*
IDM	T31	CAD drawing of circuit board	6	0,5	
ABB ABB	T32	Technical support and manufacturing of substrate Electrical and thermal tests on circuit prototypes		2	 M4

WP4: Mounting of dies, SMT devices in order to have the prototypes completely assembled, with connections for final tests and verifications.

1 Purpose: to get assembled prototypes and mounting tests, that is thermal dies soldering test, wire bonding of dies test, burn in test of the entire circuit.

2 Length: 3 months

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working*	*Subcontr. Working*	*Milestone*

			Days	*Days*	
ABB ABB	T41 T42	Assembling of prototypes Assembling tests on prototypes		2 2	
IDM	T43	Assistance in the component assembling phase	4		M5

WP5: Tests of prototypes

1 Purpose: to verify reliability in laboratories and on a specific application

2 Length: 6 months

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working Days*	*Subcontr. Working Days*	*Milestone*
IDM	T51	Prototypes testing in laboratory on bench	49		M6
IDM	T52	Prototypes testing on a sample motorcycle	40		M8

WP6: Project management and Dissemination of results

1 Purpose: to plan and follow the development of the project and to produce demonstrations and definitions of the activity. Final a flyer will produced and make reports of the project and to present them in proper fears

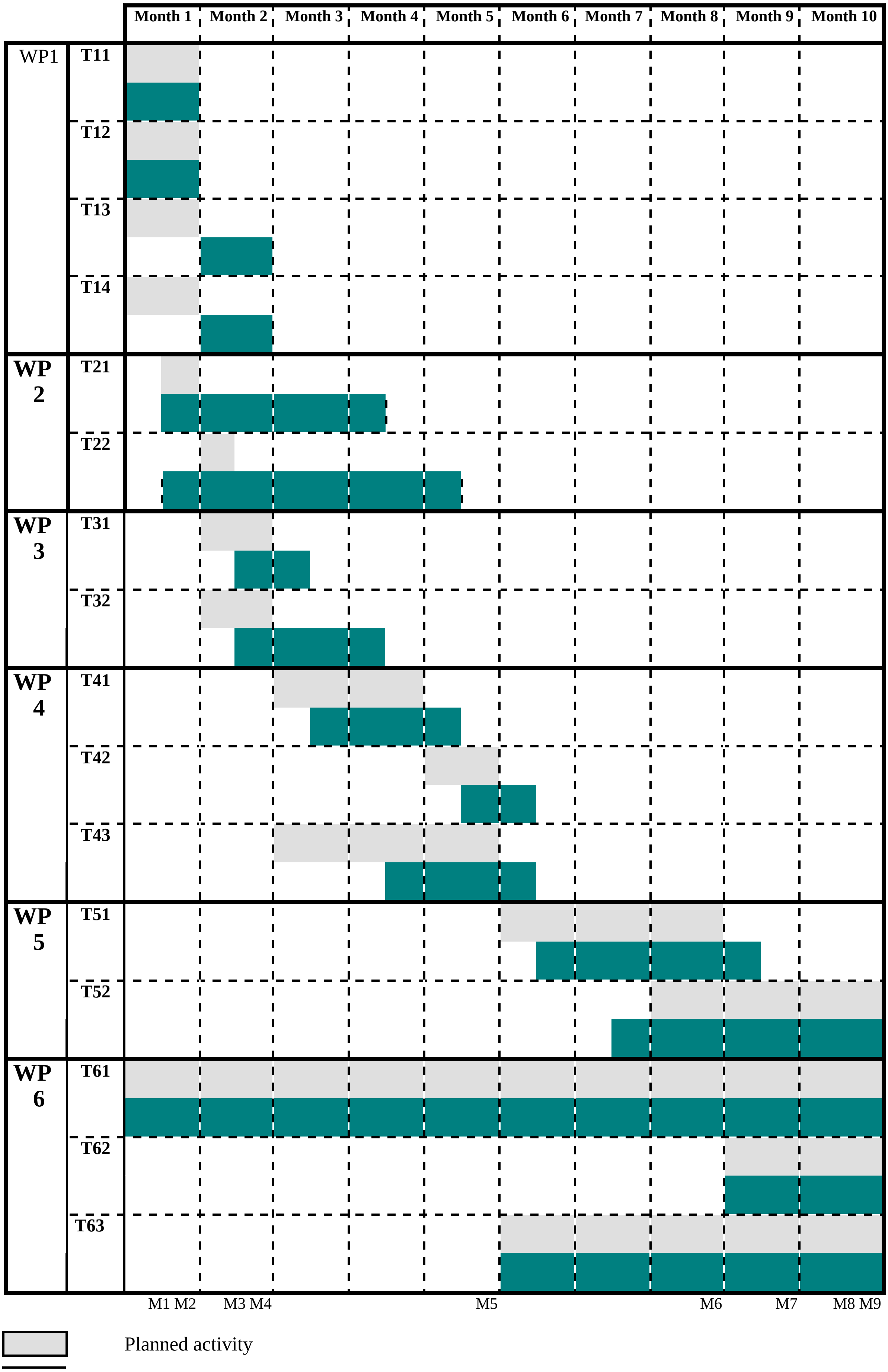
2 Length: 10 months

Responsibilities, Tasks and Timing:

Resp.	*Task*	*Description*	*IDM Working Days*	*Subcontr. Working Days*	*Milestone*
IDM IDM	T61 T62	Following and managing project development Reporting on a flyer of the project	39 2		M7 M9
IDM	T63	Dissemination of results	5,5		

Cost and effort for each participant in each WP

	First User	**Subcontractor**
	Person/days	**Cost [kECU]**
WP1	**53,5**	**5**
WP2	**44**	**5**
WP3	**6**	**10**
WP4	**4**	**18**
WP5	**89**	
WP6	**46,5**	
TOTAL	**243**	**38**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M6
M7
M8 M9
Planned activity

Real activity

Figure 15: Flow Chart of Workplan

All over the proceeding of the application experiment we succeeded in getting a very good relationship with subcontractor technicians. At almost every step of the project, even when subcontractor was not directly involved, we went on to have a feedback with him. Really very important phases were the visit to the subcontractor facilities and mounting lines, because they gave us the necessary confidence with the new technology, from the lower to the higher level, from the practical and manual expects to the theoretical expects of it.

During the proceeding of the AE there were some differences between the scheduled workplan and the real progression of the project. The seminar at the facilities of our subcontractor took place in October and not in September and the wafer with the SCRs dice arrived with 20 days of delay. The time requested by Work Package 2 was longer than that programmed and the problem of the spacer to put under the dice postponed the achieving of circuit prototypes at the half of February. We succeeded in not having delay on the closing date of the AE by beginning the tests on the road with a sample motorcycle before the end of the bench tests.

Subcontractors roles

The subcontractor's role in the development programme was to supply initial training on the DCB technology (DCB substrates, soldering of bare dies and connections on DCB, tests on die and wire bonding, quality and reliability of DCB assembled products), built and supplied 20 prototype of the DCB circuit. ABB and IDM have continuously exchanged information, solutions to resolve problems concerning the mounting of surfaces material, choice the correct materials and test the new board.

Risk assessment

The risk of an MCM development is very high for an unexperienced company. The way we manage to reduce the risk were:

a) Choose an experienced subcontractor with proved skill on all steps of the process
b) Keep the number of components to assemble as low as possible
c) Leave the responsibility for procuring tested bare dies to the subcontractor

It is also to consider that packaging (molding and enclosing in the metal can) will be carried out in house since IDM has experience with this technology on the other side suitable subcontractors can be easily found for it

10. Subcontractor information

By visiting international fairs of the sector and evaluating competitors' products, IDM S.r.l. defined the technology that was strategic to acquire. As a matter of fact the FUSE support motivated the company to begin a prototype development.

IDM S.r.l. started to plan the AE without any internal expertise on the matter, but we thought it a primary point to know as much as possible on the technology from different areas in order to be skilled enough for choosing the right subcontractor.

We believe that the right choice of the subcontractor is the most important step of the AE.

In our case this is firstly due to the small size of our company and consequently to the small contractual power if scheduled time or results would not be reached.

At the very first beginning of the AE we found several subcontractors that were interested to process only a small part of our project: theoretical studies and seminar, die attach, wire bonding, SMT applications, but their different working areas and their intrinsic diversities soon revealed to be a problem for scheduling the development time and the economic cost of the operation.

At the end and with the help of the TTN, we succeeded to find a unique subcontractor with good acquaintance with the technology we pursued. The subcontractor has a foundry, where they can produce and sell DCB substrates and they have a product line, called modules, where they assemble their chips on their ceramic. We evaluated some other European supplier for MCM services with the help of our TTN, but we concluded that no one of them had an high power dissipation technology available at the moment of the decision.

Moreover our choice was also motivated by the fact that the subcontractor seemed very interested in becoming our future supplier for DCB substrates. So they were motivated in helping us to acquire the technology.

For what concern the payment of the subcontractor we divided it in three steps. We considered that only the seminar could be paid in advance. The production of the substrates and the prototypes have been paid 30 days after their delivery to us.

We consider also very important to have a good relationship with subcontractor personnel both in Italy and in Germany so that they can easily co-ordinate and improve the different subcontractor’s teams involved in the AE.

11. Barriers perceived by the company in the first use of the AE technology

At the start of the AE, IDM S.r.l. had experience only with traditional mounting assembly technologies, therefore it found a primary barrier in evaluating the economic impact of the investment for introducing the Chip On Board (COB) technology inside the company.

This was mainly due to the fact that we were not able to find the information on the technology itself, the requested equipment and the minimum requested time to deal in a reliable way with all steps of the assembly process.

Moreover we also lacked project management capability and were not able to understand all the development phases how they were detailed in the potential subcontractors quotations. Another important barrier consisted in the difficulty in persuading the suppliers to provide us with bare dice since they preferred to avoid a new inner procedure for the test of the bare dice and the delivery of a new format of test report to our company.

They looked very dubious about the real capability of IDM to manage a so complex assembly technology.

12. Steps taken to overcome the barriers and arrive at an improved product

Since 1996 we began to visit international exhibitions and fairs, like ELECTRONICA, PRODUCTRONICA and SEMICON, in order to evaluate the machines and tooling involved in the new technology and their prices and productivity. We also visited some of our semiconductors' suppliers facilities to understand the environment where the COB process took place. Our TTN COREP has helped us to deal with the new subcontractors smoothing the lack of skill we had in the technical and project management. Thanks to this assistance we were able to understand the different offers we received sometimes forcing the supplier to detail costs and services in case only a global cost had been included in the offer. During the implementation phase of the AE some technical problems were encountered and solved with the help of our subcontractor. Due to its mesa junction structure the SCR chip was greatly sensible to contamination of alloy on its lateral walls. At the beginning this caused some short circuits of the bonded devices. We solved the problem by means of a series of tests with different solder pad sizes and we learned that this is a critical phase of the process. During the AE IDM S.r.l. learned also the importance of the tests on the bonded dice. This aspect of the process was not well understood at the beginning of the project and has to be taken in due account in the time to market estimation.

13. Knowledge and experience acquired

At the start of the AE, the electronic technology that IDM S.r.l. has made use of is strictly bound to a traditional mounting. With the AE the company IDM S.r.l. learned how to manage semiconductors dice in order to use them in the production process of COB for its applications on the motorcycle market. The persons directly involved in the AE have seen a variety of problems that concern the use of dice and have become confident with them enough to start an inner production of COB systems. The AE has allowed IDM to learn a method for managing complex projects, from the plan of activities to the relationship with relevant subcontractors directly linked to their foundries. The persons of IDM S.r.l. have dedicated full working time for several months in order to learn and acquire this new technology.

During the training at our subcontractor's premises for the first time we realised that the part of the process concerning the soft soldering of the dice on DCB, their wire bonding and further coating, should have been managed in house from our company, thus reducing cost, and avoiding the very critical dependence on the subcontractor to whom IDM S.r.l. had already paid a very high price for the NRE.

Besides we suspected that in the long term quite a few companies would have been available for providing a reliable service to customers.

The capability to handle internally in a reliable and cost effective way the assembly and packaging process on externally supplied DCB substrates was the most important result achieved in the experiment, and IDM was so confident in its increased technology managing expertise that it invested more than 1000 KECU for purchasing equipment, renting workspaces and hiring high expertise personnel.

We believe that the acquired capability has gone far beyond our initial goals. Infact during the AE we decided that we could even manage the assembly technology ourselves and obtain a complete independence from subcontractors service for this stage of the technology process. Therefore we are quite satisfied with the results of the AE also with respect to the future outsourcing policy of our company

14. Lessons learned

IDM S.r.l. got a positive experience from the AE. The problems encountered at the beginning, especially related to lack of knowledge and to the research of materials, have been overcome thank to the help of our subcontractor and TTN. The good results of the project have justified the efforts of all IDM's staff and they make us proud to know a technology that is not used by our direct competitors yet. We think that the course we attended at our subcontractor's facilities was very important because we learnt not only the concepts of the new technology but also we became familiar with the new specific terminology too. Moreover during the seminar we realised that all the phases concerning die attach, wire bonding and die coating could be processed in our company, avoiding a critical dependence on some suppliers. We also learned to face complex project management and to assign roles and responsibilities to all the persons involved.
An MCM of this kind is not a very critical step forward for a company with experience similar to IDM. Though some important advice that can simplify the subcontractor choice should be carefully considered:

- Select someone who has an already established experience with the technology (substrate and assembly)
- The subcontractor should also be able to provide the bare dice requested for the MCM
- Ask for a detailed offer where the costs of the different offered services are clearly detailed

Following these suggestions would allow an easy comparison of the different subcontractors enabling the choice of the most suitable one. As a final suggestion our experience demonstrate that for few components the assembly process can be carried out in house with a great advantage for the company that will not suffer from fluctuations in the supply policy of the subcontractor.

15. Resulting product, its industrialisation and internal replication

The result of the AE is a voltage regulator for the motorcycles market where a COB technology is applied, precisely the die attach by means of a soft solder process on a DCB ceramic substrate. The new voltage regulators we obtained during the AE completely fulfil the project specifications and our expectations. They are very small as compared as our traditional product and the power derating of regulator and its reliability are greatly increased.

The manufacturing process was studied in all its phases in order to minimise the influence of end-of-line testing on the per cent of rejected parts. This aim was obtained, with the help of the subcontractors, defining the critical points of the new technology and considering that the dice are not tested in their power specifications from the foundries. During the AE IDM S.r.l decided to introduce a soft solder line inside its factory in order to increase its competitive in the market. The soft solder phase, the wire bonding phase and the correlated tests were studied and approved. From there we started to acquire the machines and the test equipment.

On November 1998 we will be able to make a first lot of COB circuits for regulator completely assembled in our facilities and at the beginning of 1999 we suppose to start with production. The decision to have inside the new technology came from an inner study about how to replicate the use of the new technology in others of our products. We found that also the circuits for electronic ignition systems are greatly improved with the soft solder on DCB substrate. In these circuits we will employ a die of Darlington instead of SCR.

The work for the industrialisation of the product was carried on in parallel with the AE. On first half of 1998 we began to build up a clean room of about 100sqm where to put the core of the assembling line: the die bonder, the wire bonder and the relative testing machines. At that time we put the orders for such machines to the proper manufacturers. Two new persons were instructed for working in the new plant and environment. At the end of 1998 we suppose to start first deliveries of products with DCB technology inside to our customers. The total financial effort for this new plant and industrialisation process can be estimated in 1.080.000 ECU.

16. Economic impact and improvement in competitive position

The objective of this AE was achieving more industrial competitiveness in the European and extra-European markets, since Japanese and Far East competitors, who have been using similar technologies for more than 10 years, can force market demand to change from day to day by simply reducing the size of the case or the plastic connector.
We expect therefore to be able to play the role of a much more stable and trusty supplier and to gain market share accordingly.
Our customers will certainly experience the advantages of the new technology and especially::

- reduction of costs of the regulator
- increase of reliability
- reductions in size
- easier assembly
- larger power dissipation capability

At the beginning of 1997, a realistic forecast diagram of IDM S.r.l. turnover related to the sales for its traditional voltage regulator had a positive trend, but it was working toward saturation. Instead the same forecast diagram made in 1998 is a completely different one. The two diagrams are compared in *Figure 17.*

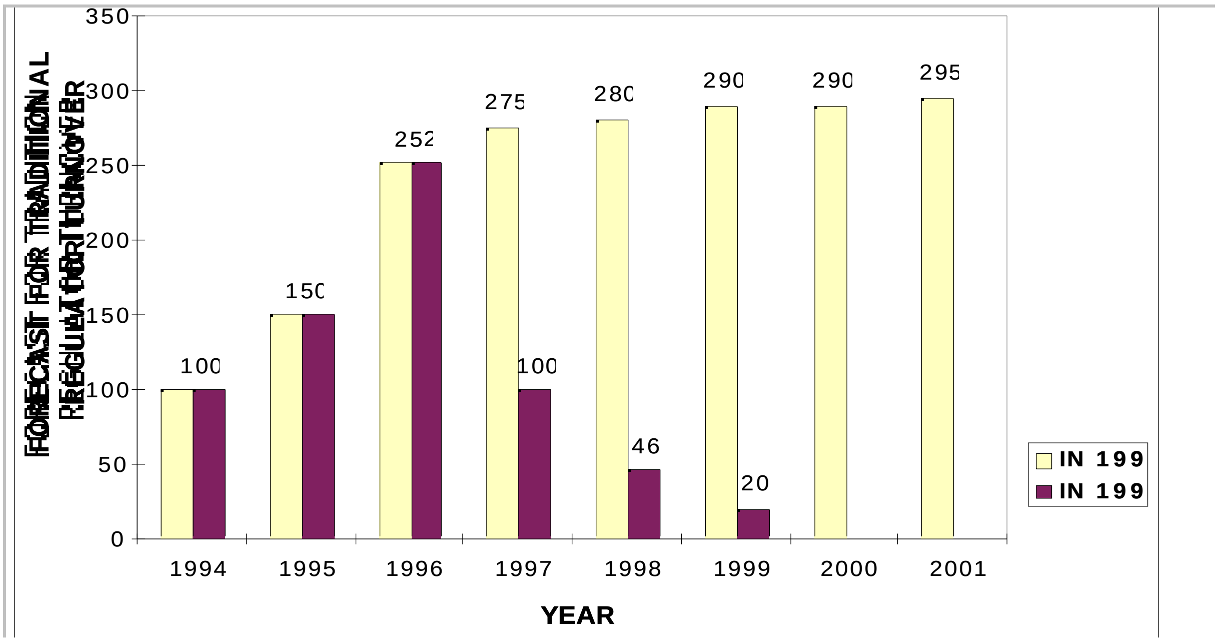

Figure 17: Diagram of forecast turnover (base: 1994=100) for traditional regulator made in 1996 (white columns) and in 1998 (dark columns).

The big difference between the two forecast of turnover was due to the devaluation of Japanese currency: 1,0 YEN was exchanged ECU 0.00749 at the beginning of 1997 while now it is worth about ECU 0.00645.

As a matter of fact, at the end of the AE, owing to international market situation and to the devaluation of YEN, the most important European motorcycle manufacturers turned to the far east suppliers for almost 90% of their scooter production.

It is clear to see that already in 1997 a high drop in the selling of voltage regulator took place.

This decrement continued during 1998 and it convinced us once more of the strategic importance to introduce the new technology in our regulators.

However IDM S.r.l. global turnover, thank to the other products, didn’t follow traditional regulator trend and with now, at the end of the AE, we can reasonably suppose an increment with the next year, due to the new technology. In *Figure 18* a forecast of company global turnover and new regulator is reported.

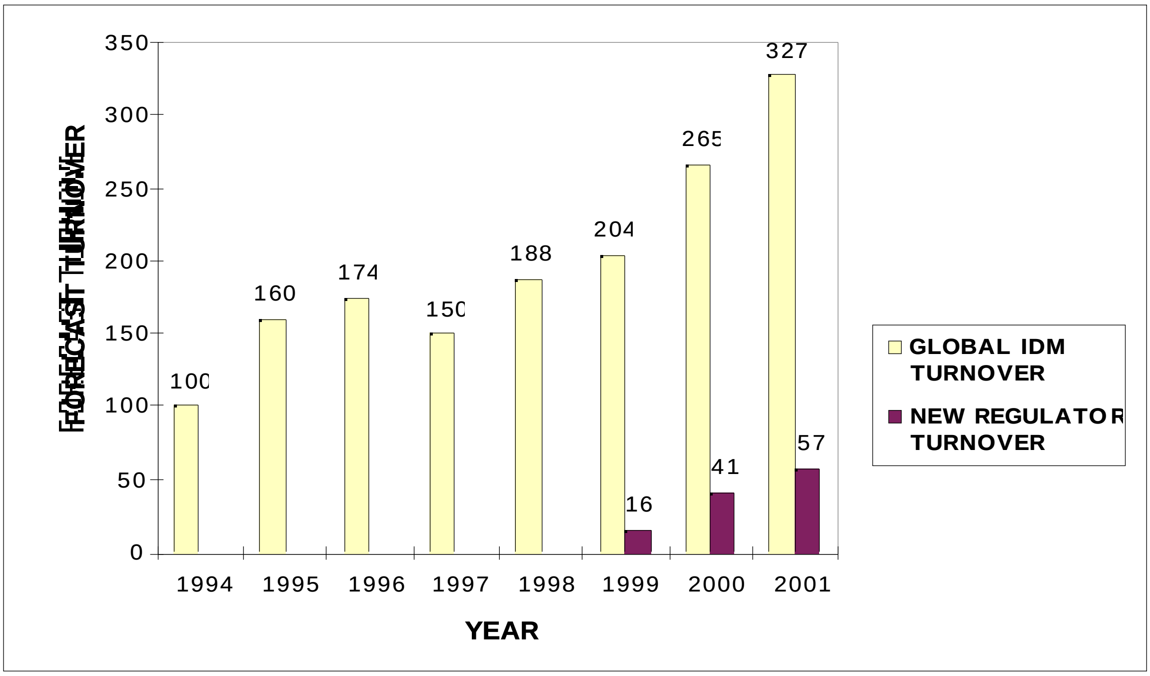

Figure 18: Diagram of global company turnover and forecast (base: 1994=100) after the introduction of the new technology.

The cost of the new regulator with the COB solution will be about 28% less than the traditional one.

Though now we will be forced to reduce the sale price of the new regulator as compared as our initial program (if YEN will remain nearECU 0.0062) in order to be competitive with far east manufacturers, we will still have a better margin of profit than with traditional regulator (11%).

With this reduction of sale price we will set our margin of profit per regulator at 14% instead of programmed 28% so increasing the ROI and the payback period. *Figure 19* shows the forecast of turnover for the new regulator and the related margin of profit.

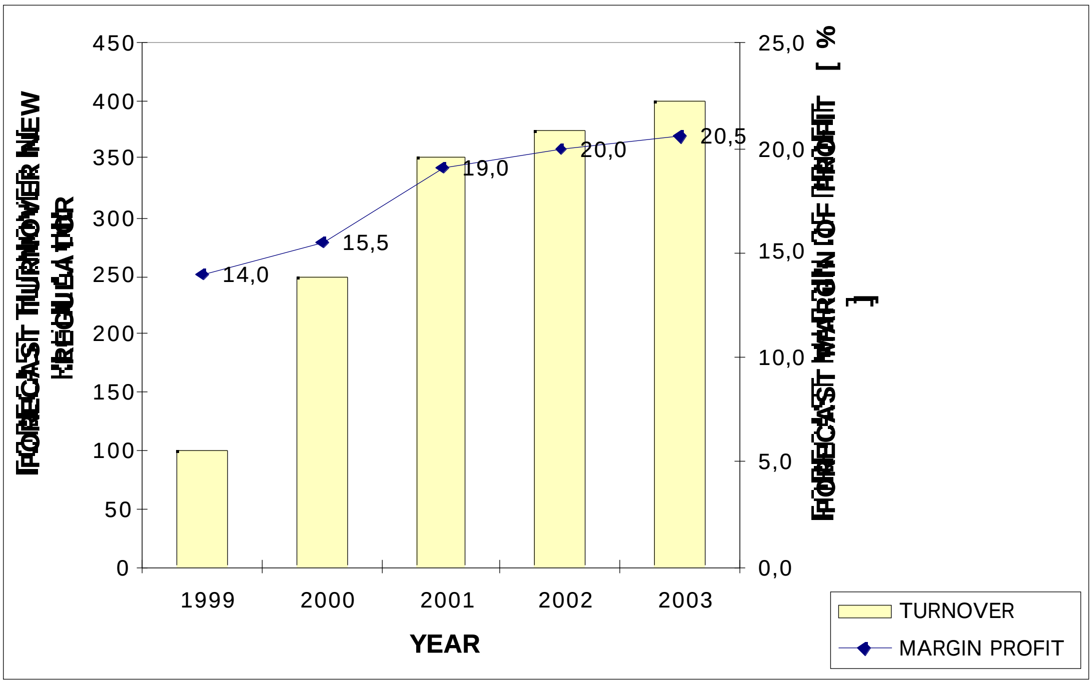

Figure 19: Diagram of forecast turnover (base: 1999=100) and margin of profit for the new regulator.

Moreover IDM S.r.l. have made a further investment to have in house production of COB circuit on DCB substrates of 1080 KECU. We will introduce the new technology also in almost all the production of electronic ignitions.
For the calculation of the ROI on the FUSE costs, we consider the diagram of figure 17 and figure 19.

The expected increase in the company's profitability is show in the following table:

Year	1999	2000	2001	2002	2003	Total
Increase in profitability (KECU)	12	116	230	257	298	913

The ROI over a 5 year period is 1009% and the payback period would be 19 months.

Moreover to the heavy financial effort that IDM S.r.l. has taken, since some months we have been visiting our European Customers to promote the new regulator.

We realised a new brochure of the company where a big relevance to new technology and to the new product was given and we have now a web site at the address www.idm-srl.it where the technology is shown.

We think that with the new technology it is possible for us to reverse the trend of our current market situation related to voltage regulator and to reach a global turnover of the company of 5,0 MECU in 1999 up till 8,0 MECU in 2000.

17. Target audience for dissemination throughout Europe

Our AE can interest many industrial sectors.
First of all our main competitors whose interest is obvious, mainly into the implementation details and market figures. They can easily understand the technological features of the new regulator and its advantages on the global reliability. The same advantages can be easily understood by other manufacturers who have similar power dissipation problems.
Producers of household electric appliances and white good equipment, can appreciate the miniaturisation of the component since they are moving along a similar path for the controller on board of motors and pumps. Those companies who realise and market power equipment like inverters or UPS will understand the worth of the DCB technology.
As the most important lesson that many companies might gain from our reported market figures is that sometimes the innovation is a must even if the forecasts would suggest that the company can stay on the market with the current solutions, since in the globalisation eve, changes of conditions are fast that it would be quite difficult to cope with them if it had not been planned in advance. Another message can be given to all companies planning to introduce some technological process inside their process line. The IDM AE shows that this major innovation can be managed provided that a good initial training and a constant assistance is available from the technology provider.