FUSE DEMONSTRATOR DOCUMENT
APPLICATION EXPERIMENT 23020
DAPI
(**D**igital **A**udio **P**rocessor **I**nterface)

Professional and Industrial Audio Equipment

Analogue ASIC significantly improves performance/cost ratios of audio and loudspeaker systems.

AE abstract

RCF S.p.A, an Italian company with 292 employees and a turnover of 35 M€, is a world-wide supplier of professional and industrial audio equipment.

The current products are analogue audio PCBs and microprocessor based digital control and automation systems for audio applications, realised with standard components on PCBs in THT technology.

The market in the high added value active loudspeaker sector is demanding but the company believed that, with an improved product based on innovative technology, it could improve its market share and economic performance.

A new generation of products using an Analogue ASIC was developed providing improved audio processing facilities and active loudspeaker controlling functions. In conjunction with a move to surface mount technology rather than through hole PCB the cost was reduced as planned and the sound quality and product reliability improved. These were the primary goals of the experiment.

Moreover, working closely with very expert sub-contractors, allowed RCF engineers to increase their own know-how in designing schematics and opened a completely new application field, i.e. the ASIC design for audio.

This AE was carried out in 19 months with a budget of 138.7 K€ of which 45.7 K€ was for subcontractors, 30 K€ for industrialisation and 19.8 K€ for foundry services.. The pay back period of the FUSE investment is anticipated within 6 months while an ROI of 6 on 3 years sales is envisaged

The chip might be of interest of other companies involved in the professional audio field (audio processing systems) and precision instruments (noise monitoring).

Keywords
Digital radio, Analogue ASIC, I/O Interface, Signal to Noise, time to market.

Signature: 2-01315110132-1-3230-2-32-I

1. Company name and address

Radio Cine Forniture (R.C.F.) S.p.A
Via Raffaello Sanzio, 13 - (loc. Mancasale)
Reggio Emilia
ITALY

2. Company size

RCF is a company of 292 employees of whom 70 are involved in electronics. Turnover in 1998 was circa 35 M€.

The RCF Group includes:

- A V M Srl - Acquaviva Picena (AP). From: September 88. Manufacturing
- Elettronica International Srl - Reggio Emilia. From: October 88. Marketing of RCF's products exclusively for foreign markets.
- R.C.F. Electronics UK LTD - Wickford - Essex (GB). From May 90.- Marketing for U.K.;

- R.C.F. France S. A. - Chatenoy Le Royal - Chalon Sur Saone (FR). From December 1990. Sales office for the French market;
- R.C.F. Artesuono Srl - Reggio Emilia. From December 93. Design and sales of hi-fi home and hi-fi car products for both Italian and foreign markets.
- R.C.F. Nord America Inc. - 41 Loring Drive Framingham, MA 01702. From January 96. Sales office. For the North Amarican market;
- R.C.F. China Ltd. - 188-202 Texaco Road, Tsuen Wan New Territories - Hong Kong. From December 96 . Sales office for the China market.
- R.C.F. DEUTSCHLAND Gmbh - Kuhlmannstr.7 - 48282 Emsdetten. From August 1998. Sales office for German market.

3. Company business description

RCF is a leader in professional and industrial audio equipment in the Italian and European markets, with a significant share of the world market, which is about 15% referring to the public address and professional systems. They design, manufacture, sell and distribute world-wide although primary markets are Italy first and Europe second. The complete catalogue contains more than 1200 different items and the current range of products includes:

a) Audio products dedicated to the sonorisation of industrial environments (from design to sale):
   - Power amplifiers
   - Modular sub-systems
   - Loudspeakers
   - microphones

b) Audio systems for conferences and simultaneous translation (from design to sale).
c) Loudspeakers and power amplifiers for professional use (stadiums, arenas, large environments) (from design to sale).
d) Loudspeakers for Hi-fi home (from design to sale)
e) Systems for video-projection for industrial environments, conference rooms, discotheques, etc. (from design to sale).
f) Loudspeakers for Hi-fi car (from design to sale).
g) Power amplifiers for Hi-fi car, especially suited for RCF loudspeakers.

RCF is active in five main fields with a common characteristic: the sonorization of environments of very different size for music, speech or both. These fields are public address, professional audio, professional loudspeakers, hi-fi home, hi-fi car and video-projection.

On 01/01/94 the hi-fi Home and hi-fi Car fields were transferred to a partner company (RCF ARTESUONO) devoted to the marketing of the correspondent products.

a) <u>PUBLIC ADDRESS</u>:
   This is former and the main field of activity of the company. RCF is one of the few companies in the world with a complete catalogue of products to fulfil every demand in the sector. RCF has a share of the 20% of the public address Italian market. In the last years the company has carried out a strong marketing action toward the foreign markets, thus increasing exports up to 38% of the whole company turnover in this sector. However, larger foreign competitors, such as PHILIPS, TOA, INKEL, JBL, ELECTROVOICE and SIEMENS, have been devoting an increasing effort for the development and the marketing of their products. This is causing some problems for an Italian medium-size factory like RCF to maintain its market share in this

important sector, which is foreseen to progressively increase in the next years.

b) PROFESSIONAL AUDIO
This field was introduced in the company in the last years. However, in spite of strong foreign competitors such as JBL, ELECTTROVOICE, DAS, BOSE, which exhibit a long tradition of design and manufacturing in this field, RCF gained a significant market share. Actually, 34% of the company turnover is related to this product line, whose 77% is due to the foreign markets.

c) PROFESSIONAL LOUDSPEAKERS
RCF is a company leader in this small, but interesting market. This position was gained by means of the high product quality and of the investments in the research. RCF supplies some of the most famous factories in professional audio field and it has positive impact on the corporate image. The market of the professional loudspeaker is strongly related to the one of the professional passive and active loudspeakers. This is a promising market for the future, but more and more demanding in terms of quality and cost of the product, even in consideration of Far-East competitors which are providing competitive low-cost products in the last years.

d) VIDEOPROJECTION
This line was developed to give to the customers a complete catalogue of products for the sonorisation of large environment (factories, conference sites, arenas, etc.), thus covering the demand for the visual diffusion aside to the more traditional audio diffusion. The catalogue offers two models of cathode-tube-based projectors and several accessories (screens, cables and optional electronic equipment). It is a promising market, due to the increasing in the last years, but it requires a significant economical effort to support the research, needed to progressively increase the product quality and better track the market demand.

e) Hi-fi HOME
This product line is dedicated to the acoustic cases. In the seventies and in the first eighties, RCF was a company leader in the Italian market. Nevertheless, the entry of the Japanese and American marks in the first eighties posed several problem of competitiveness to the company which loose its leadership. Actually, an external company, ARTESUONO SRL, (owned 99% by RCF) takes care of the marketing and sales of the products manufactured by RCF and AVM, another RCF partner company.

f) Hi-fi CAR
The company is involved in this field from 1987. Actually, to better contrast the traditional foreign competitors (SONY, PIONEER, PHILIPS, ALPINE, etc), emerging manufacturers from Korea and Taiwan and the crisis of the last years, the marketing and sales of the RCF’s and AVM’s products were committed to ARTESUONO SRL.

The core business of RCF is the selling of professional loudspeakers with its own brand or like OEM supplier: in this field RCF supplies the most important Pro Sound equipment manufacturers in the world: for example, Nexo (France), Yorkville (Canada), EAW (USA), Zeck (Germany), Martin Audio (UK); the following pie chart shows the RCF/OEM turnover partitioning in the 1997.

The RCF market presence is organised in Italy by means of PA and PRO agencies, in USA, Hong Kong, France and UK by means of its own offices and all over the world by means of many distributors in each country; in every country assistance and technical consult are guaranteed by distributors or, when necessary, directly by the Company headquarter.

4. Company markets and current competitive position

The company participates in the world-wide market for professional audio equipment and professional loudspeakers (active and passive speaker boxes, loudspeakers, speaker systems, that is systems formed by speakers and processors to drive them). A 15% share was held of this market world-wide where the object of the application experiment was targeted.. In the public address market place a share of 8- 10% was held world-wide while, remarkably a share of 50% of the domestic market was achieved. The loudspeaker market is today a high added value market where price is not the most important parameter. However things could be changing as competitors from the low cost consumer markets seek to exploit their technology know how in this market. Pressure on price/performance is likely to be a feature. According to market experts the global word market of the professional audio equipment is expected to grow annually with a rate of about 20%.

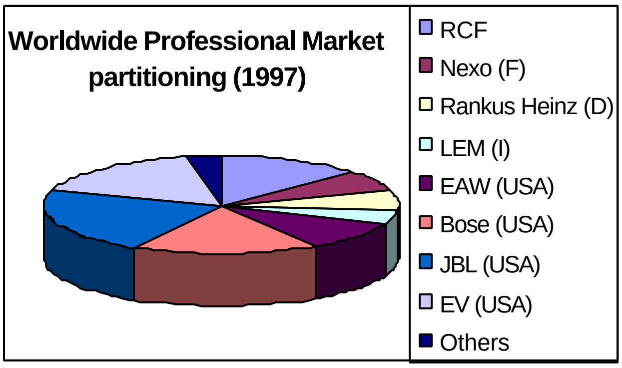
The main competitors in the Pro market are the JBL and Electrovoice.

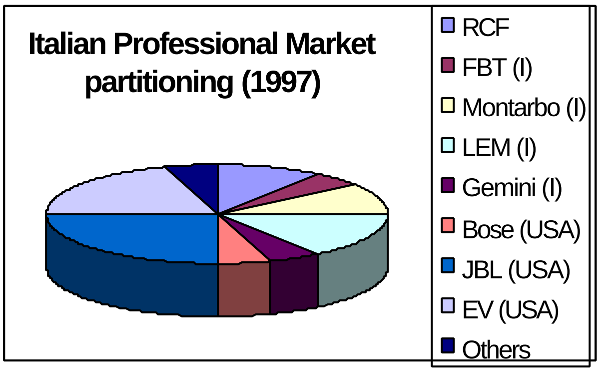
JBL with his EON series of active loudspeakers and Electrovoice with the SX Series, are in direct competition with RCF ART series

In the PA markets the main competitors are: TOA and Philips in World-wide market Optimus , Bouyer and Philips in Europe and Paso in Italy.

The field of application of the FUSE Application Experiment is the professional market: nowadays the market is mainly held by a restricted number of Companies that normally offer traditional devices (it means, audio analogue electronics). Moreover, there are some little companies specialised in new digital techniques that are showing something new in the field: digital processors, digital delay lines, DSP, etc.

It's important to point out more that big Companies (such as Sony, Matsushita Corporation, Harman-Kardon Group, Marantz) coming from consumer markets are approaching the professional market and their technical know-how and production capability could be a strong challenge for the professional companies.





Partitioning of the markets in 1997.

As part of its Audio Pro market, RCF is manufacturing Active Speaker Systems, i.e. portable speaker systems in plastic enclosure and power amplifier on board. This kind of product, due to the strength of their low cost and their 'plug and play' facilities, is gaining a noticeable success all over the world. For example, RCF sold, last year, 20.000 pieces of these devices and those are big numbers for this particular market. For these products other important characteristics are reliability and light weight. and it's easy to foresee good improvements of these qualities by using the Digital Audio Processor Interface that means to implement a quite huge number of functions in a single chip.

The market of this particular kind of devices was shared by RCF with a little number of Companies; the most important are:

NAME	PRODUCT	% of Market
JBL	EON	35
EV	SX200A	25
RCF	ART	15
DAS	DAS12A	5
Others	-	20

Another important field of application is the manufacturing of audio processors to be coupled to speakers in order to create powerful kits (the systems presents the right equalisation, cross over and protection features to allow to speakers to work as well as possible); in this market the most important Companies are:

NAME	COUNTRY	% of Market
JBL	USA	30
EV	USA	20
Bose	USA	30
Irelem	France	5
Others	-	15

sales of product in the three years prior to the introduction of the AE product are shown in the following chart

	1997	1998	1999
Sales of AE object (K€)	4200	5000	6500

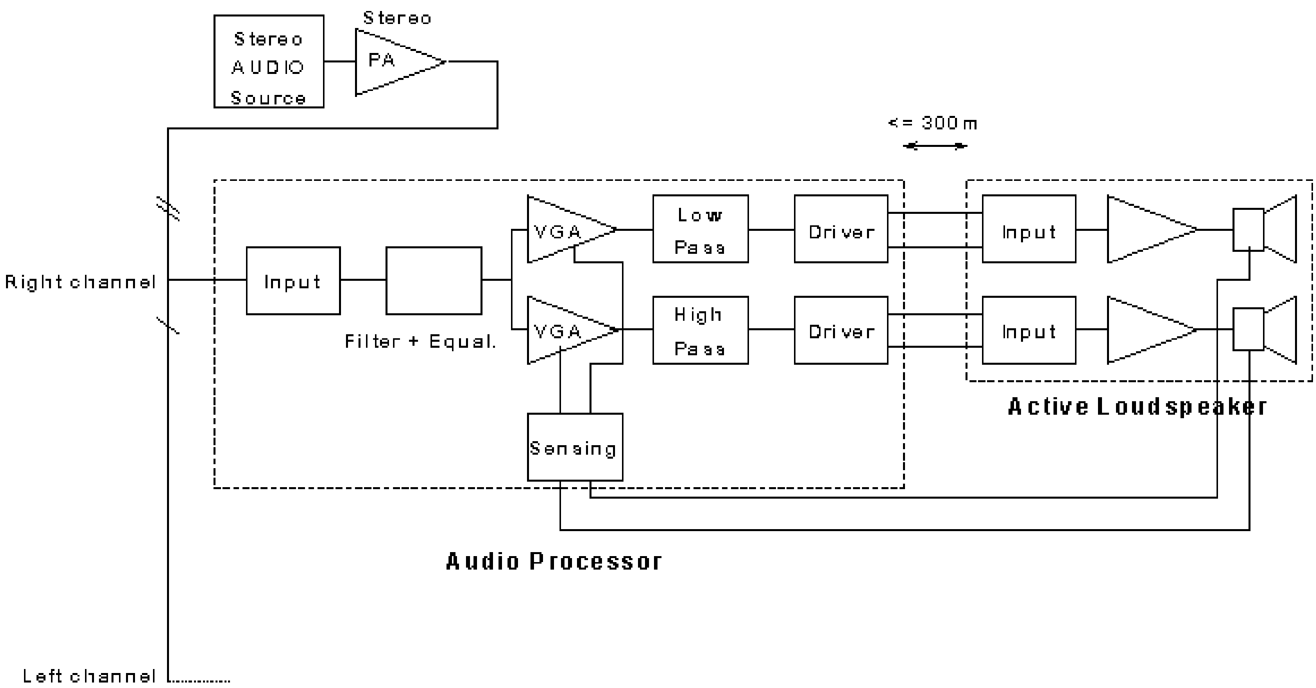
The entry of competitors such as the Japanese and American companies necessitates a leap in performance cost to maintain target market sales and shares. The market is driven by constant innovation of product and RCF anticipates a growth in market share with a very competitive product. This new technology will allow RCF to compete for significant parts of the market, thanks to the innovative and performance aspects of the new RCF products developed in active speaker systems and audio processor applications

5. The products to be improved and their industrial sector

The product to be improved was an active loudspeaker for professional Audio systems as shown in the following photograph.

Active loudspeaker from the ART series

The block diagram following is typical of what can be found in the active loudspeakers.



Black-box schematic of "Process control CP512" RCF stereo processor for professional audio applications

RCF has launched two series of Active Speaker Systems named ART

	ART200A	**ART200AM**	**ART300A**	**ART600AS**
TYPE	powered bass reflex	powered bass reflex	powered bass reflex	Subwoofer bass reflex
LOUDSP.	12 inches woofer	12 inches woofer	12 inches woofer	12 inches woofer
	1 inch comp. driver	1 inch comp. driver	1 inch comp. driver	
Freq. Resp.	55-20000 Hz.	58-20000 Hz.	55-20000 Hz.	45-250 Hz.
Sound Press.	121 db /1m Peak Power	121 db /1m Peak Power	126 db /1m Peak Power	123 db /1m Peak Power
Cross.Freq.	1800 Hz.	1800 Hz.	1800 Hz.	150 Hz.
Cross.	24 db / oct.	24 db / oct.	24 db / oct.	24 db / oct.
Amplifier	120W LF 40W HF	120W LF 40W HF	300W LF 60W HF	300W LF
	ART400A	**ART500A**	**ART800AS**	
TYPE	powered bass reflex	powered bass reflex	Subwoofer bass reflex	
LOUDSP.	15 inches woofer	15 inches woofer	15 inches woofer	
	2 inches comp. driver	2 inches comp. driver		
Freq. Resp.	50-20000 Hz.	48-20000 Hz.	40-200 Hz.	
Sound Press.	127 db /1m Peak Power	129 db /1m Peak Power	126 db /1m Peak Power	
Cross.Freq.	1800 Hz.	1200 Hz.	150 Hz.	
Cross.	24 db / oct.	24 db / oct.	24 db / oct.	
Amplifier	300W LF 50W HF	400W LF 100W HF	400W LF	

The difference between the two families was just the size of the products and the power of the components, whereas the designing philosophy was the same):

- Moulded plastic cabinet
- Professional two-ways speaker (woofer and horn driver)
- 'Plug and play' products with power supply section and audio power amplifier inside
- Double amplifier, one for every way
- In the back of the speaker there was the place for a control board different for the different applications of speaker (it could be a graphic equaliser, a wireless mike receiver, a mixer, an audio processor, etc.)
- Volume control, equalisation facilities, XLR connectors for input and output
- Dynamic protection for loudspeakers

The technology of the existing product was through hole plated PCB with discrete analogue electronics.

RCF shares really a little part of this market and the reason for the innovation was to attempt to capture a share increased by at least 50%..

Parameters to be improved include
- cost reduce by >30%
- Complexity- reduce by 30
- Reliability - improve through reduction of component count by at least 50%
- System upgrade cost - reduce
- Warehouse costs - reduce by 10%
- Signal to Noise ratio (S/N) and Total Harmonic Distortion (THD) improve through complexity reduction
- Market demand for more sophisticated equalisation/processing features cannot be met without further increasing technical efforts, complexity and size.

6. Description of the technical product improvement

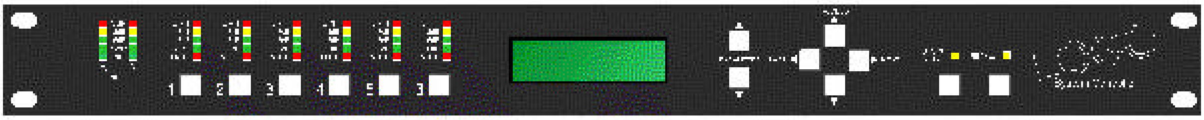
The functional objective of the development of the proposed ASIC was the implementation of a universal interface between a variety of signal sources, both musical and speech, and the audio quality A/D and D/A converters available on the market, providing at the same time separate output channels for different frequency bands, allowing direct connection of active loudspeakers without additional electronics. This entails a reduction in component variety and cost, higher board reliability and an overall improvement in the manufacturing process, thanks to the adoption of surface mount technology.

The introduction of an ASIC embedding all the analogue I/O interface and processing functions in the active loudspeakers produced by the company carries the following two benefits, both leading to increased volume of sales:

- **Reduced cost**
  This is due to the lower component count required in the audio processor boards including the DAPI. This lowers warehouse costs, increases reliability of the product and lowers design cost and redesign effort.
- **Higher quality**
  The introduction of the DAPI increases the sound quality of the active loudspeakers (lower Harmonic distortion, lower noise, higher EMI robustness) and allows the introduction of new features in the audio processor with reduced cost.

Moreover, the design of the Audio Processor embedding the DAPI has a high degree of flexibility and reusability, leading to lower redesign cost, lower design risks and shorter time-to-market of the new products.

The introduction of the DAPI chip in these products carries almost the same benefits reported for the active loudspeakers.



Audio processor

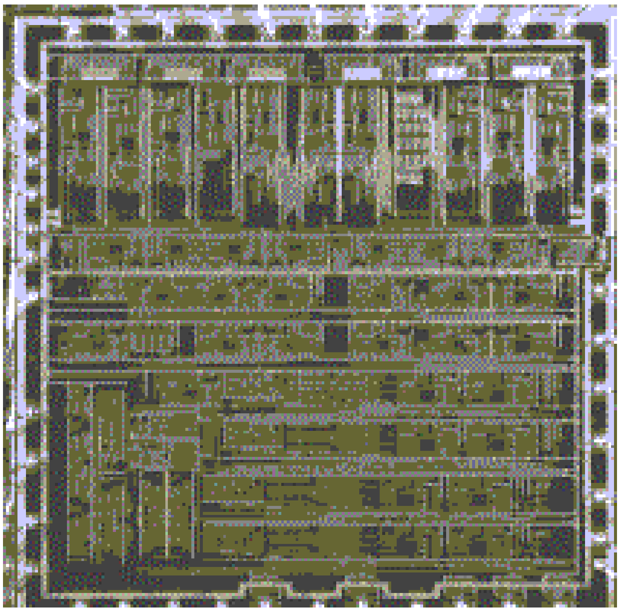
- 1 rack unit ready for flight case mounting
- Filtering and control/monitoring operations on the audio signal (using DSP)
- Driving capabilities of active loudspeakers
- Equalisation, time alignment, delay line facilities (using DSP)
- Two-channel stereo device for three-ways speakers driving
- Speakers protection by means of gain limiting

The aim of the experiment was to design an integrated audio controller embedding all the signal conditioning and processing functions usually required in professional audio equipment such as an active loudspeaker. The functional blocks included in the chip were:

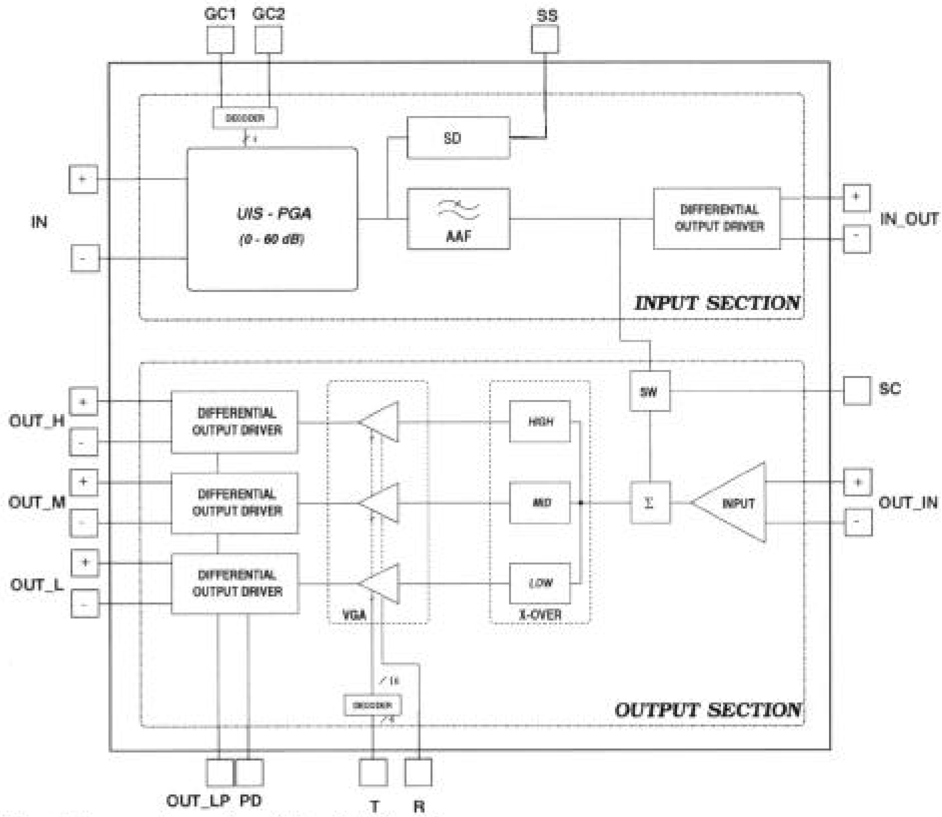
1. input preamplifier
   1.1. digitally programmable gain (0dB, 20dB, 40dB, 60dB)
   1.2. universal input interface (balanced/unbalanced)
2. signal detection
3. anti-aliasing filter (for optional, external Digital Processing Chain)
4. balanced I/O interface to an optional, external Digital Processing Chain
5. active crossover filter
   5.1. configurable for 2 or 3 ways applications
   5.2. minimum number of external components
   5.3. crossover frequencies adjustable by means of external trimmer
6. Variable Attenuator (digitally controlled)
7. Balanced Drivers for the external power amplifiers
   7.1. Capability to drive huge capacitive loads (corresponding to a 300m long cable)

This component (DAPI) may be introduced in several RCF products. In particular, the new series of active loudspeaker has been designed to easily introduce the DAPI to replace an audio controller designed with the PCB technology.
The main advantages of introducing the integrated controller in the active loudspeaker are:

1. Simplification of the Design of the compete audio controller for active loudspeakers
   1.1. Reduced the time to market of the products
2. Reduced component count
   2.1. higher degree of standardisation
   2.2. higher reliability
   2.3. lower warehouse costs
   2.4. reduced costs due to the redesign of the audio systems to track the new targets and the market requirements
3. Higher performance
   3.1. Signal-To-Noise ratio (SNR)
   3.2. Harmonic Distortion (THD)
   3.3. EMI robustness



Chip photograph of the DAPI (33mm2 in AMS CBZ technology, 44 pin CLCC package)



Black-box schematic of the DAPI chip

Moreover the integrated audio controller allows an easy introduction in the active loudspeaker of an optional Digital Processing Chain (ADC,DSP,DAC), which can be introduced as a "plug-and-play" PCB, with no extra cost for the interfacing circuitry.

In the high-level products of the company's catalogue, the DSP will perform digital linear and non-linear filtering operations on the audio signal originated from different sources, allowing partial correction of the non linear response of the driven loudspeaker and an improvement in sound quality.

The component implemented during the experiment was a Digital Audio Processor Interface ICs: it was divided in an input section and in an output section. The former included a universal input stage, a programmable gain amplifier, a signal detector and an anti-aliasing filter. The output section provided separate processing channels for three bands: very low frequencies (sub-woofer) low frequencies (woofer) and high frequencies (driver). The cross over active filter can be easily configured for 2 or 3 ways operation and exhibit a 12dB/octave attenuation in the stop-band. Each channel included an output differential driver, capable of directly driving the connection line to the active loudspeaker.

The device accepts at the input both single ended and differential audio signals. The differential input voltage range was 12.4V pp. The programmable gain amplifier allows matching the level of the signals provided by the different sources (nominal levels 0dBm, -20dBm, -40dBm e -60dBm) to the input range of the chosen A/D converter. The anti-aliasing filter was designed as a function of the chosen over-sampling ratio (typically 64, for which a 2nd order filter is usually sufficient).

The maximum output signal amplitude is 6.2V on a typical load modelled by a 10KOhm resistor in parallel with 10nF, corresponding to a 300m connection cable; the chip can be set in low consumption mode if the full line driving capability is not requested by the application. By setting external commands, it is possible to select the two-ways or three-ways mode; the chip was realised in a 44 pins PLCC package for SMT mounting.

In order to improve the actual line of active loudspeaker, RCF was developing a new series called "Performer Active Series" .

In this new series of active loudspeaker, the model 3A and 4A has a three way system Amplifier board with a unique motherboard supporting the input connectors and the power amplifiers for each of the 3 ways and an SMT board that implements the amplification stage and the three ways active crossover.

These two functions are provided by the DAPI chip.

7. Choices and rationale for the selected technologies and methodologies

As stated in the previous sections the need generally was to improve the performance cost ratio of the system through a large reduction of complexity while maintaining the audio performance as it relates to signal to noise ratio, amplitude variance and sound purity and quality. Cost reduction was also a significant requirement through improvement of the assembly and test process and, component procurement and stock management.

The first choice which was carried out before the beginning of the AE was for a fully analogue architecture which was preferred to mixed-signal solution. The motivation for this choice may be summarised as follow:

- In a signal conditioning and processing chain of an audio system such as an active loudspeaker, there is a predominant and unavoidable part of analogue circuitry needed to interface the systems to the most part of audio signal sources. These interface circuits have to handle signal being very different in amplitude: from –60dBm (microphones) to 12dBm. This poses significant design constraints in term of Harmonic Distortion (with high-level input signals) and Noise Figure (with low-level input signals). Also the interface circuit to the audio power amplifier must be analogue.
- Conversely, a Digital processing chain, involving an ADC, a DSP and a DAC might almost completely replace the crossover filter. However, even if this was evaluated as an interesting solution to be investigated in the future, this was still too costly to be introduced in high-end active loudspeakers of the RCF's catalogue.

The increased costs are due to the required components (ADC, DSP, DAC) and the higher design complexity, involving problems such as interference, coupling between the digital and the analogue part and EMC issues.

- Issues in term of sound purity and quality, critical in Hi-fi applications, can be met at lower cost (today) with a fully analogue approach instead of a Digital Processing, even if the latter would allow to partially correct several non-ideal performances of the loudspeakers.

A possible technology to be used to implement an audio processor providing all the required I/O interfacing and processing functions was the SMT-PCB with discrete components. However, the higher and higher complexity of the audio processor circuits due to the increased features and sound quality required by the market would have led to very large PCBs with increased cost due to the component count and warehouse, lower reliability, higher noise and lower EMI robustness. High cost was expected also due to the time spent to redesign the audio processor to track the new targets and market requirements in the near future.

A comparison for the implementation of such a audio processor in SMT-PCB with discrete components and in ASIC technology was done, based on an exploratory quotation obtained by a foundry of 6 € unit price for 20,000 units.

The following table shows the estimated savings for the smallest configuration

Product	PCB and Assembly Cost (€)	Component Cost (€)	Testing Cost (€)	Quality Cost (€)	Total (€)
Audio Processing board with discrete components	2.2	8.3	0.8	1.1	12.4
Audio Processing board with DAPI	0.5	6.1	0.4	0.3	6.6

Moreover the microelectronics seemed to offer some interesting benefits such as simplification of the system design, higher reliability, higher project reusability and flexibility and higher quality of the processed audio signal.

Therefore the company decided to develop an analogue ASIC embedding almost all the functions required in a typical audio processing board: pre-amplification, signal detection, active crossover, controlled attenuators and drivers of the power amplifiers. However the architecture of the ASIC was designed in order to allow introducing the Digital Processing Chain as an optional "Plug-and-Play" board with minimal extra cost due to interfacing and anti-aliasing filtering. This was found to be very cost-effective solution, minimising the time-to market of the company's product embedding the developed ASIC.

Standard-cell approach was used in order to minimise the design risks and to increase the probability to have the component fully operational since the first silicon run. Nevertheless, some special blocks with stringent requirements in term of noise (microphone preamplifier) and output driving capability (output drivers) had to be designed by means of full-custom cell.

Cadence DFW was used as CAD software platform.

Concerning the silicon technology, two solutions were evaluated: the HBIMOS 2um from MIETEC-ALCATEL and the AMS 2.0 CMOS technology (CBZ) from AUSTRIA MIKRO SYSTEME INTERNATIONAL SRL. After some preliminary investigations and simulations, with special attention to the related analogue cell libraries, AMS 2.0 CMOS technology (CBZ) was definitively chosen for this project.

The main reasons were:

- Higher supply voltage (up to 25V against the 15V for the Mietec technology) for the analogue cells: important to meet the Harmonic Distortion issues.
- Reliable MOS model for spectreS simulator (MOS LEVEL 15) available
- Special devices (FETs, high linear capacitors and resistors) available

About the package, a 44-pin PLCC was chosen, due to the estimate convenient cost for a pre-series of 10K pieces, the good exploitable silicon area (30 square mm), the satisfactory thermal dissipation.

The testing of the stand alone component, as it is normal for analogue components, was carried out with bench instrumentation, such as spectrum analysers, high purity tone generators and high resolution digital oscilloscopes. A dedicated test board has been developed and all specification parameters were checked.

8. Company expertise & experience prior to the Application Experiment

The electronic experience of RCF was, before the Application Experiment, restricted to the field of analogue audio PCBs and to microprocessor based digital control and automation systems for audio applications; RCF has got an R&D Department based on 25 employee divided in three sections: Electronic Dept. (one PCB designer, five audio engineers, two video engineers), Mechanical Dept. (four engineers, two employed for technical documentation drafting, one for part lists managing, one for R&D Documentation Archive managing), Electro-acoustic Dept. (nine engineers). Expertise was in the area of analogue and digital design of audio channels and includes experience of discrete analogue circuit design and layout.

6 personnel were involved in the experiment with technical managerial, extensive analogue audio design, loudspeaker design, microprocessor implementation, DSP design and PCB layout expertise and experience.

9. Workplan and rationale

RCF did not have the skills and expertise to implement an ASIC such as that envisaged and did not feel that they would be able to embark on this task without expert assistance from an external source. It was hoped that through the use of external subcontractors sufficient knowledge would be transferred to allow the company to conduct a similar development in the future.

The project activities were carried out by the company with the assistance of two external subcontractors (UPR-DII and UBO-DEIS), plus the AMS silicon foundry for the chip manufacturing, using an MPW run.

The following bar chart shows the plan and real workplan and task times:

Plan	
Real	

Task	T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Design of whole component at the schematic	1																			
Design of whole component at the schematic	2																			
Chip manufacturing	3.1																			
PCB Design and SMT Training	3.2																			
Test Equipment Set-up	3.3																			
Test of the IC	4																			
Dissemination of results	5																			

Relationship between the Company and the subcontractors and their contribution to the project per task, depending on each own expertise, are described in the following table:

Phase	**Activities**		
	RCF	UPR-DII	UBO-DEIS
T1	Technical management Reporting Training in analogue tools and schematic design. Training on simulator. ASIC functional and high level design specification.	Design and simulation of the whole ASIC (but the active crossover) at schematic level	Schematic design of the active crossover Training
T2	Technical management Reporting Training Floor planning support to sub.	Floor-planning and layout Verification Post-layout simulations Preparation of the GDS file	Training
T3	Technical management Reporting Training on SMT PCB design rules and tools.	Design of the test PCB Dedicated test-equipment set-up. SMT training	
T4	Technical management Reporting Experiments with the DSP development System.	Chip characterisation	
T5	Dissemination of results	AE presentation	

Rationale

In T1 the specifications and the functions to be included in the ASIC were defined by RCF. Afterwards, the high-level design of the ASIC was carried out by the RCF personnel involved in the AE, in co-operation with the subcontractors. The design at schematic level was performed mainly by UPR-DII, but the active crossover filter was designed by UBO-DEIS. The simulations were planned in co-operation with RCF in order to guarantee that the developed blocks individually met the Hi Fi requirements. In this phase a training on the schematic design of an analogue IC, including the simulation tools was carried out by UBO-DEIS.

In T2 the floor-planning and the layout of the ASIC were carried out by UPR-DII in co-operation with RCF, thus ensuring the necessary knowledge transfer from the subcontractor to the FU.

In T3 the chip was manufactured by AMS; UPR-DII took care of the test equipment set-up and of the design of the test PCB in SMT. The personnel of RCF were involved in training on the SMT PCB design.

In T4 the chip was tested and characterised, while in T5 RCF took care of the dissemination of the results.

The project management activities, carried out by RCF to co-ordinate, plan and control the project, checking how the project itself was running and monitoring the budget, were spread in every task.

Modification of the original work-plan

Three months were added to T1 and T2, leading to an equal increased time for the AE (from 16 to 19 months). This delay was the consequence of the initial technology tuning: a necessary remedy to reach the project performance and avoid the technology obsolescence. RCF was forced to shift from the MIETEC technology to AMS 2.0 CMOS technology (CBZ), to meet a better performance related to input differential amplifier signal-to distortion ratio. The AMS CBZ technology provides an operational amplifier (OPBUF3H) which exhibits an excellent Total Harmonic Distortion - THD (better than 70 dB) whereas the equivalent MIETEC OP-AMP (P_CFOA4) demonstrated a THD of about 60dB.

Furthermore , the CADENCE HIT-KIT with full layout capability (Design Rules Check and extraction tool) for the above referenced AMS CBZ technology was made available only for the middle October, 1997; at the project start a reduced HIT-KIT with schematic simulation capability was only made available by AMS.

The new scheduling was determined by the availability of AMS CBZ run on March 27th, 1998 with samples out on May 22nd 1998.

The following table shows the actual against planned costs.

	FU				Subcontract		Foundry		Total	
	Effort		Cost		Cost		Cost		Cost	
Task	Plan	Real	Plan	Real	Plan	Real	Plan	Real	Plan	Real
T1:Design at schematic level	57.3	40.3	12.0	9.8	19.0	19.0	0.0	0.0	31.0	28.8
T2: Floor-planning and Layout	48.3	30.0	9.0	7.9	12.0	12.0	0.0	7.0	21.0	26.9
T3-1:chip manufacture	92.4	52.7	20.0	12.5	6.0	9.7	18.0	12.8	44.0	35.0
T4: test of the IC	69.9	42.1	14.0	8.8	5.0	5.0	0.0	0.0	19.0	13.8
T5: dissemination	21.0	16.6	5.0	4.2	0.0	0.0	0.0	0.0	5.0	4.2
Totals	288.9	181.7	60.0	43.2	42.0	45.7	18.0	19.8	120.0	108.7

The differences in the above chart can be explained as follows:

The staff allocated to the project proved to be more effective than first thought and the training planned was reduced by 14 days in T1 and 8 days in T2.

The development of the application board (T3) to be used for test purposes has taken less effort. Part of the work has been transferred to the subcontractor.

Since the first target application has been changed (not DSP based) (T4), 30 days less were spent on this activity.

In the project FU, according to Technical Annex, has not provided for tools purchasing, because during the whole on-job training and design phase subcontractors renting facilities for HW and SW tools were used.

The cost for the analogue cell library purchasing by AMS foundry was 7 K€, while the cost for 20 chips manufacturing with AMS MPW Service was 12.8 K€. The cost of the chips was much less than expected.

Technology knowledge was transferred in a number of stages each increasingly involving the First User in the design activities.

Firstly an awareness training on the use of the design tools and the design methods and rules particularly for the analogue section of the circuit was conducted. Basic knowledge which allowed the First User to Experiment with the tools was provided. While the subcontractor and the first user shared the design tasks from there on with the subcontractor also in an advisory role, simulations were conducted jointly so that maximum information concerning the performance of different designs and structures could be assessed by the first user. The testing by the first user completed the learning process of the technology again with advice from the subcontractor.

The risks envisaged in this project were clearly substantial since it was not clear that the analogue signal performance could actually be achieved from the technology. Indeed this proved to be the case when the technology had to be switched. The planning of time and resources contained a great deal of uncertainty But at the end of the day and with the benefit of the TTN knowledge it was felt that the risks were acceptable. In fact the company felt that this was the only way to improve market performance in the short term and survive in the long term and so the risks balanced against the needs.

10. Subcontractors information

The subcontractors required to assist with this project were clearly required to exhibit advanced knowledge of the application of mixed signal ASIC technology in high performance audio applications as a priority while costs were to be moderate. Previous experience of working with external bodies suggested that the nearer the location of the subcontractor the better.

In this AE the company chose two subcontractors which guaranteed the required experience and expertise in the field of analogue and mixed-mode IC design with CMOS and BiCMOS technologies. They are closely located with respect to the company and this made the interface easier. The two subcontractors are the Dipartimento di Ingegneria dell' Informazione of the University of Parma (UPR-DII) and the Dipartimento di Elettronica Informatica e Sistemistica of the Univeristy of Bologna (UBO-DEIS). Both exhibited a curriculum of academic and industrial design of analogue and mixed-mode ICs. Moreover they successfully co-operated in a previous experiment funded by the EC. It should be remarked that the most part of design centres located in Italy have expertise in the digital designs, while only few of them can exhibit a proven experience in the field of analogue IC designs.

Subcontractor 1

Name: Università di Parma - Dipartimento di Ingegneria dell' Informazione (UPR-DII)

Size: 26 staff

Relevant Expertise & Experience

The Department was equipped with hardware and software tools for the design of integrated circuits. Several analogue and mixed mode ICs were design so far, as documented by publications on conference proceedings and international journals. Activity on the A/D converter test dates back to 1990 and it was documented by several scientific publications, some of which in co-operation with other academic and industrial partners.

Service provided

Design at schematic level of the ASIC (except the crossover active filter), layout, verifications, post-layout simulations and testing.

Links with other suppliers: The subcontractor had a consolidated experience gained with direct co-operation with some European silicon foundries.

Rationale for choosing / evaluation of the subcontractor

UPR-DII had all the expertise and resources for the required service and was conveniently located not far from RCF, making the interfacing easier.

Contract and compliance

The contract was in the form of costs related to the services provided in each phase of the AE. This kind of contract has demonstrated its effectiveness and adequacy with respect to the project characteristics. UPR-DII carried out all the activities within time and costs. The three months delay in the delivery of the tape with the GDS file was due to the reduced number of silicon MPW runs offered by the foundry for the used technology (CBZ).

Subcontractor 2

Name: Università di Bologna - Dipartimento di Elettronica Informatica e Sistemistica (UBO-DEIS)

Size: 80 staff

Relevant Expertise & Experience

The Microelectronic branch of UBO-DEIS had, among others, a significant experience in both the design and testing of integrated circuits. During the last years, several projects, in corporations with both medium and large industries or for academic purposes had been carried out. Analogue, mixed digital/analogue and fully digital integrated circuits were designed and tested. Additionally, experience had been gained through direct co-operation with European silicon foundries and through EUROCHIP.

Service provided

Choice of the architecture and design of the crossover active filter; training services.

Rationale for choosing / evaluation of the subcontractor

Co-operation between UPR-DII and UBO-DEIS was well established and successfully tested in a previous EU project of an analogue IC design.

Personnel and operative interface

The subcontractor supported the Company in two different phases of the project:

1. Design and simulation of the crossover at schematic level , training.
2. Floor-planning, layout and verification: training

Contract and compliance

The contract was in the form of cost related to services provided in each phase of the AE. This kind of contract had demonstrated its effectiveness and adequacy with respect to the project characteristics.

11. Barriers perceived by the company

1 Knowledge and Cultural Barriers

- 1.1 Lack of microelectronics culture and experience
- 1.2 Difficulties to understand (and quantify) the advantages of the microelectronics with respect to a well proven technology based on retail components mounted on “pin in hole” PCBs.
- 1.3 Lack of internal know-how in order to conduct a feasibility study (what has to be integrated and what cannot) and to manage the project of an ASIC (from the definition of the specifications to the layout).
- 1.4 Poor experience in the usage of advanced analogue circuit simulators

Before the AE all the electronic parts internally developed and manufactured were designed by means of electronic components, such as op. amps (low cost or low noise or low distortion depending of the specific application) mounted on PCB (often 2-layers) with a “pin-in hole” technology. There was an established knowledge and experience in this field: a collection of well-proven schematics covering a wide variety of sub-circuit involved in an Electro-acoustic system were available; they involved preamplifiers, active and passive cross-over filters, amplifiers with AGC, drivers for power amplifiers, variable delay blocks, threshold detector and automatic power-on, etc.. A large part of these circuits had been developed without resorting to an advanced circuit simulator, but by means of prototypes implemented on bread-boards.

A good experience had been acquired in the selection and evaluation of components such as op. amps, analogue components for audio signal processing, power transistors (MOST, FET and BJT) and integrated power amplifiers. Before the AE there was no microelectronics culture and experience in the technical staff of the company involved in the design and development of Electro-acoustic systems.

Due to the lack of knowledge and specific experience, the design of an Application Specific Integrated Circuit (ASIC) by means of a standard-cell or semi-custom approach was perceived as a high-risk approach with poor advantages from the point of view of the quality of the product. Moreover there was no internal know-how in order to manage a very complicated project such as the development of an ASIC. In particular, significant difficulties were perceived in the construction of a work-plan, involving the selection of the most suited microelectronics technology (CMOS, BiCMOS, Bipolar), of the appropriate EDA tools and of external consultants (such as University research departments, research centres or design centres). Furthermore, the technical staff of the company did not have the capability to carry out a feasibility study of an ASIC for audio application, neither the necessary know-how to understand what were more convenient to be integrated in an ASIC and what could be left on the board as active or passive external component.

Due to the poor knowledge and experience, there was a small reliance on circuit simulators and on their advantage of cutting the development time of a discrete-component circuit.

2 Financial barriers

- 2.1 Cost of EDA tools
- 2.2 Cost of training
- 2.3 Cost of prototyping (using MPW silicon runs)
- 2.4 High production volume required by the silicon foundry and related costs.

The management of the company felt the microelectronics approach as a non-convenient approach to improve the quality of its product, due to the high cost of the design involving the required software EDA tools, the required high-cost work-stations and the training of some employees to be devoted to the design and development of audio ASICs. Furthermore, the cost of prototyping and the high volume required by the silicon foundry emphasised the reliance on the well proven PCB with retail components technology against microelectronics.

3 Technology Barriers

3.1 Due to the lack of analogue microelectronics design skills significant difficulties were perceived in the design of an ASIC with standard CMOS or BiCMOS technologies in order to fulfil stringent specifications such as low-noise and very low distortion at the same time.

At the end of the day the company perceived very large risks to the success of such a project to the extent that there was no guarantee that the circuit would work and the investment and resource effort would be wasted. Timescales were felt to be very optimistic and the estimated development cost subject to a very large exposure. It is fair to say that staff were very nervous and lacked confidence in their abilities to succeed with such a new and difficult development.

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

1. Knowledge and Cultural Barriers

Almost all the knowledge barriers were overcome thanks to the subcontractors of this AE, i.e. the Electronic Departments of the University of Bologna (UBO-DEIS) and Parma (UPR-DII). Indeed the former technical director of the department devoted to the design an development of electronic part for audio systems, i.e. he perceived that the technology know-how of the company should be improved in order to better contrast the technology enhancements of the competitors' products. Indeed, even if the quality of the RCF loudspeakers placed the company in a leadership position in some market sectors with respect to the competitors, he thought that in the near future the benefit of the Digital Signal Processing should be investigated and introduced in some high-end products of the RCF active loudspeaker catalogue in order to correct some unavoidable loudspeaker limitations and to generally improve the sound quality. Nevertheless, the cost of the digital processing core (ADC-DSP-DAC) was still too high to be a viable solution at that time. However, a reduction of the cost of some components (e.g. DSP) was foreseeable in the near future. From here, the need to design the electronic circuitry of the novel active loudspeakers in order to easily introduce the digital processing options into the analogue processing chain by means of a form of "plug and play" board, thus avoiding the redesign cost and minimising the costs related to the circuit interfaces.

Moreover, the need for several product lines to be developed and manufactured at the same time in order to fulfil the market requirements led to high cost of technical management and warehouse. This was due to the frequent redesigns of PCBs that had to be adapted to improved or novel products and to the large number of involved electronic components.

Since the project leader knew The Professor of the UBO-DEIS, he contact him and asked about the possible benefits of the microelectronics and about the feasibility of an ASIC embedding almost all the required analogue processing circuitry and the interfaces to the (optional) digital processing core (ADC-DSP-DAC). They worked together in order to define a first rough black-box schematic of the new ASIC. The Professor helped The project leader to understand the benefits that the microelectronics could add to the whole audio system, with special emphasis to the active loudspeakers, in term of performance such as Signal-to-Noise ratio, Harmonic Distortion and EMI robustness.

Since the co-operation between UBO-DEIS and UPR-DII was already well established and successfully tested in a previous EU project of an analogue IC, the companies worked to select a first technology from the ones available through EUROPRACTICE. Moreover the future subcontractors gave to the project leader all the information about the design flow of an analogue ASIC (using a standard-cell approach to minimise the design risks) and the required EDA tools. The project leader perceived that the excellent knowledge and specific experience of the people devoted to microelectronics design at both University Departments would have guaranteed all the required support to RCF to construct the workplan, to manage the project and to handle the problems with the software EDA and technology dependent tools.

2. Financial barriers
The future subcontractors helped The project leader to carry out some preliminary cost evaluation of the ASIC prototyping, using the MPW prices of the technology available through the EUROPRACTICE consortium. The project leader realised that the cost for the software EDA tools and for the training of an engineer to be completely devoted to the ASIC design would have been unacceptably high for the company which did not have any internal know-how and experience in this field.

Therefore the solution was to leave to the future subcontractors (UBO-DEIS and UPR-DII) the management of the EDA tools and of the technology dependent tools. Moreover, while the definitions of the specifications and of the black-box diagram of the novel ASIC would have been carried out by the company, the implementation of the schematic diagram, the simulations and the layout (ready for the mask preparation) would have been carried out by UPR-DII and UBO-DEIS. Nevertheless, during the whole design flow, there would be a strict co-operation between the company and the persons of the subcontractors involved in the design, in order to guarantee a significant knowledge transfer to the company. Through this project, the aim was to give to the some people of the RCF's technical staff the following a microelectronics know-how:

- a clear understanding of the advantage and the disadvantage of the microelectronics technology if introduced in some company's products, in particular active loudspeakers.
- capability to independently carry out a first project feasibility study
- knowledge of how to find technology and cost information
- capability to perform a first technology selection, in particular with respect to the provided analogue standard cell libraries.
- clear knowledge of the standard cell design flow of an ASIC.

Thanks to the information provided, some preliminary economic evaluations such as ROI and pay-back period, were carried out by The project leader.

About the high cost related to the silicon prototyping which could not be supported by the company management not relying on this new technology, The project leader and the future subcontractors looked for some form of funding from the European Community. Both the Universities had been involved in a previous industrial project funded by the EC (ESPRIT-MEPI) and were aware of the FUSE programme. CESVIT was approached as TTN, being geographically close to the company and to the subcontractors. The project was submitted to the TTN which encouraged to submit a FUSE request and helped RCF in the preparation of the documentation. Moreover, CESVIT helped RCF to define a workplan and to identify the part of the project which should have been transferred the subcontractors.

Thanks to the EC and TTN support the company management decided to introduce the microelectronics technology in the active loudspeakers and to partially devote some people of the technical staff to this project.

3. Technology Barriers
The technology barriers were removed thanks to the knowledge and the experience offered by the subcontractors in the design of analogue and mixed-mode ASIC with CMOS and BiCMOS technologies.

Some barriers not perceived by the FU at the time of the definition of the workplan were encountered during the implementation phase of the AE.

The lack of experience of circuit simulator caused some difficulties to the FU to understand which simulations should be performed (behavioural, mixed schematic-behavioural, etc.) in order to validate the block designed by the subcontractors, in particular with respect to the requirement posed by the Hi-fi market. A long time was spent by the University's engineers to refine the schematics by means of exhaustive simulations in order to take into account the effect of the run-to-run device parameter variations, of the random offset and temperature and supply voltage variations. This systematic approach was accepted with some difficulty by the FU, used to design and immediately verify the electronic circuits by means of prototype boards.

Other problems were encountered in the definition of the ASIC blocks. Indeed, for some of them RCF's technical staff placed some difficult requirements, for example because of the impossibility of integration of µF capacitors. Moreover, the request for some circuit parameters to be varied over a wide range by means of external components would have posed extreme design difficulties, high design risk with a low performance improvement of the overall system embedding the ASIC. A stereo architecture was not possible due to the limitation of die area imposed by the silicon foundry on an MPW run.

Other problems were posed by the fact that RCF experienced the changing of technical director of the Electro-acoustic department twice during the AE. Indeed the project leader resigned and was replaced after the approval of the proposed FUSE by the EC. Afterwards, in the last phase of the AE, i.e. the ASIC verification and test a second resignation necessitated a replacement. These changes were critical for the company because of the risk of know-how and experience loss. However, both people who resigned took care to transfer all the acquired knowledge together with all the information related to the project in progress to the their successors. Moreover, the company management took care of the co-ordination and of the overview of the two change of hands between the outgoing and the incoming technical directors.

In summary the knowledge imparted by the TTN concerning what could be done and how to do it together with the expert know how of the subcontractors succeeded in reducing the level of perceived risk and increasing the First User confidence to such an extent that fear was reduced and the barriers removed.

13. Knowledge and experience acquired

Managerial knowledge and experience

The present AE involved the technical staff of RCF in a challenging experience such as the design of an analogue ASIC. This opened RCF to the microelectronics, which is now positively evaluated by the technical staff and by the company direction too as an attractive alternative to the well established PCB technology. Thanks to this experience, most of the cultural and technical barriers against the introduction of the ASIC technology in some RCF products, with special emphasis to the active loudspeakers, have been completely removed. The experience of the technical management of an analogue ASIC project gave to the company the following knowledge and capabilities of:

- independently carrying out a first project feasibility study
- independently carrying out a cost evaluation
- performing a first technology selection, in particular with respect to the analogue standard cell libraries
- choosing the right subcontractors
- taking care of the technical management of an ASIC project, co-ordinating the internal resources with the external analogue IC designers (subcontractors)

Thanks to this AE, all the knowledge needed to plan the design of a new ASIC to be introduced in a company's product was transferred to the technical staff from the subcontractors. This know-how involved elementary but essential information's such as the software instruments needed to design an analogue IC, the European silicon foundries which provide MPW services, the available silicon technologies and their cost and the design centres which may assist the company in such a project.

Therefore, the people involved in the technical management of this experiment are now able to independently perform a first feasibility study in the case of future designs. This capability involves both technical and economical considerations. It is important that every preliminary evaluation will be internally performed without the assistance of external consultants who usually do not have a deep knowledge in the field of the professional audio products and of the requirement posed by this market.

Technical knowledge and experience

The main technical experience and the skills transferred to the company during the AE may be summarised as follow:

- Planning the design of an analogue ASIC: from the specifications definition to the design partitioning and the ASIC black-box diagram.
- Confidence on advanced IC simulators to verify that the designed circuits meet the specifications with respect to the audio Hi-fi requirements.
- Surface-mounting PCB technology

Regarding the first two items, the knowledge was transferred by the subcontractors and will enable the company to independently manage the first steps of an ASIC design. This involves the definition of the specifications, not only with respect to the requirements posed by the system engineers, but also with respect to the feasibility of the project. In particular, the company has the necessary knowledge to evaluate what is advantageous to be integrated and what should be left on the PCB as external component. This evaluation involve both technical aspect, e.g. the technologies made available by the silicon foundries to external users, and economical consideration, i.e. the impact of the design partitioning on the cost of an ASIC to be produced in medium/low quantities (from 1K to 10K samples per year).

Another important fall-out in term of technical skills involves the Surface Mounting Technology (SMT) which was preliminarily investigated by means of external consultants, successively acquired by means of a self-learning process and, finally, definitively introduced in the company. The evident benefit of this technology against the "pin-in-hole" technology are the reduced assembly cost (especially in the case of large productions), the reduced components cost, a lower error rate in the PCB mounting, a higher reliability and a higher component density, leading to reduced PCB size, which is important in some products.

There were obviously some unplanned activities which threatened the learning process but at the end, with the additional time, the company gained the knowledge which it had expected.

14. Lessons learned

The first lesson learned by means of this experiment was the **need for a correct economic and technical evaluation** in the case of the design of an ASIC replacing a proven product, internally designed and developed with the PCB technology.

The **impact of the introduction** of an ASIC in a system should be carefully evaluated, regarding to the benefits and to the disadvantages. Indeed, if many circuit blocks will have a general improvement in term of performance, other blocks will suffer the lack of components not available in standard CMOS or BiCMOS technologies, such as large capacitors, large linear resistors, low-noise FETs, optical devices, varicap, etc. Often, they should be left on the PCB as external components, while some of them may be avoided at all, but at the cost of a higher design complexity, leading to a longer design time, a higher design cost and higher design risks.

Moreover, the cost of the design of an ASIC for audio applications must be carefully evaluated and compared to the expected benefit in term of increased competitiveness and volume of production of the product embedding the ASIC. This cost involves:

- software EDA tools including cost for the training, workstation and system management
- technical management and design; re-qualification of internal employees to be devoted to future ASIC designs
- silicon manufacturing: prototyping and volume production

The high cost related to software tools may be conveniently circumvented by resorting to external design centres, which may also take care of the schematic design, under a strict control of the company's technical staff, and of the layout preparation. Indeed the high costs for the training and re-qualification of some engineers to be devoted to ASIC designs would not be justified for the company. Nevertheless, it is essential, for the future, that the technical staff have the necessary skills to manage novel designs.

During the AE some part of the design were modified to satisfy some new requirements and changed targets. First of all, the interest of the technical direction for the introduction of the Digital Signal Processing in the active loudspeakers has weakened since the beginning of the experiment, in particular after the first resignation. Therefore, even if the DAPI maintained its characteristic of interface to a digital processing chain, it assumed more importance (for the company's products) as audio preamplifier and active crossover. To this aim some refinement of the original design was carried out: a control pin enables an internal analogue switch connecting the input section of the DAPI with the output section, thus avoiding to drive the signal off chip when the Digital Processing Chain is not present in the system. Moreover, due to the increased demand for three-ways active loudspeakers the company decided to introduce a three-ways crossover filter in the DAPI, replacing the two-ways crossover in the former black-box schematic of the chip. To minimise the number of external components in the low-cost application demanding for a two-ways crossover, the company engineers devoted to the technical management asked the subcontractor for a re-configurable crossover. Another design refinement not planned at the time of the FUSE AE submission was the introduction of a low-power mode by means of an external control. Indeed the DAPI was request to be able to drive up to 300m long cables, connecting the preamplifier and active crossover board to the active loudspeakers, in the case of amplification of large areas such as stadiums, arenas, etc. The high capacitive load led to a high bias current required by the output drivers, with a consequent high power consumption of the ASIC (about 2W). This leads to higher cost in term of packaging and due to a required heat sink. However, since a small fraction of DAPI samples will be required for this special application, while the most part of samples will be devoted to active loudspeakers, the company asked for a correcting design action to reduce the power consumption by means of a control pin.

In the design of an ASIC the **role played by the subcontractors seems very important**: indeed, external design or research centres devoted to the IC design may better track the technology trend and the improvement of the software EDA tools. However, the technical interface and the co-operation with the subcontractors are an important and critical issue in such a project. Since the subcontractors usually do not have a specific knowledge and experience in the filed of the design of systems for professional audio applications, the starting tasks such as the definition of the specifications, the design partitioning and the ASIC black-box schematic should be performed under a strict control of the FU to guarantee that all the requirement posed by the system engineers are met by the new device.

15. Resulting product, its industrialisation and internal replication

The experiment yielded a working prototype of the new product. The first implementation of the DAPI chip in RCF will be in the new series of Active Loudspeaker called Performer Series. Two models of this series will have the DAPI chip inside. Model 3A is a three way system with 15 inches woofer, 6 inches medium and 1 inch compression driver, medium and high frequencies are horn loaded. Model 4A is a three way system with 15 inches subwoofer ,15 inches mid-bass woofer and 1 inch compression driver horn loaded. In both loudspeakers there is the same power amplifier board with three separate power amplifiers. Each amplifier board embeds a separate daughter-board made in Surface Mount Technology with the DAPI chip inside .

This board has 3 functions:

-Variable gain amplifier

-3 Ways crossover

-Output buffers

Industrialisation Plan

The following activities , costs and schedule are envisaged to industrialise the product.

ACTIVITY	PLAN	COST (K€)
Validation of the audio system embedding the DAPI • Introduction of the DAPI in some active loudspeaker in production • Design of the dedicated SMT PCB • Test and validation	April 1999	5
Redesign of the chip for its industrialisation • Schematic and layout refinements • Protection pads • (Few) added features and controls • Definition of the test procedures and new Packaging	Dec. 1999	25

In addition, although not solely for the industrialisation a run of 10,000 samples will be procured.

Replication of the project/industrialisation

About active loudspeakers it is foreseen that the DSP option will be introduced in the high-end products of the RCF catalogue. Moreover, it is foreseen that the DAPI could be introduced in other RCF products such as PA power amplifiers and high-performance audio processors for professional use.

16. Projected improvement in competitive position

The global word market of the professional audio equipment is expected to grow annually with a rate of about 20%; this new technology will allow to RCF to conquer significant parts of the market in spite of its competitors, thanks to the innovative and performing aspects of new RCF products developed in active speaker systems and audio processors applications.

The main benefits expected by the introduction of this ASIC in several RCF products, in particular new-generation active loudspeakers, are in term of cost reduction due to:

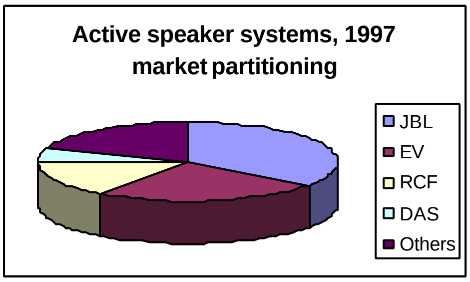
- Lower component count and PCB size
- Lower warehouse cost
- Lower design cost and shorter time-to market
- Higher Reliability (expected also from SMT)
- Lower mass-production cost (expected also from SMT)

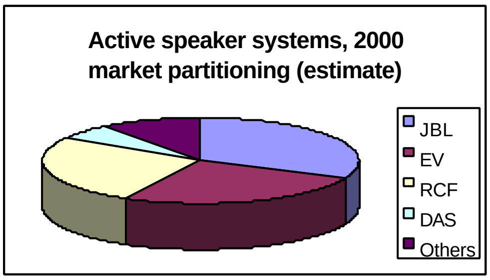
Moreover, aside to this expected advantages in term of cost, the RCF products will experience a general increased in term of quality due to the introduction of the DAPI. This will be due to:

- Higher sound quality from the audio processors
- Increased Features (such as DSP) with reduced extra cost

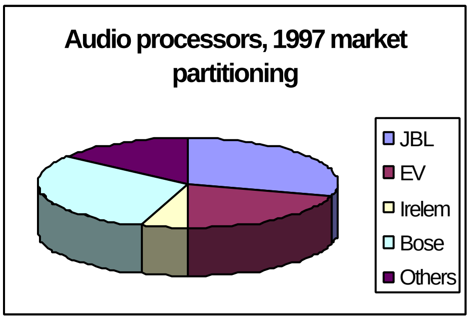
Moreover a significant increase in technology image of the company is expected by the introduction of the microelectronics.

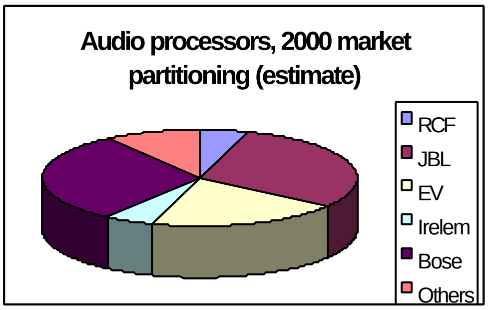
In the following previews you can see budget and trend analysis, compared to the present market share and sales volume.





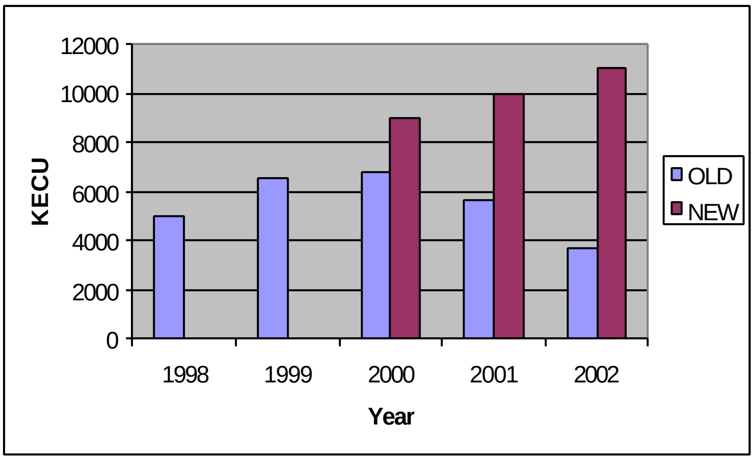
Expected sales trend for the active loudspeakers





	With FUSE		Without FUSE	
YEAR	QUANTITY (pieces)	TURNOVER (K€)	QUANTITY (pieces)	TURNOVER (K€)
1998	12,000	5,000	12,000	5,000
1999	16,000	6,500	16,000	6,500
2000	20,000	9,000	15,000	6,750
2001	25,000	10,000	14,000	5,600
2002	30,000	11,000	10,000	3,650

Expected sales trend for the active loudspeakers



Anticipated sales without and with FUSE

ROI and Investments Payback

From the table, concerning the foreseen sales volume and turnover, you can note that DAPI contributes in two ways to the return of the investment:

- diminishing the variable cost, replacing the PCB with discrete components
- increasing the product sales

From the data of the previous tables, taking in consideration the cost saving replacing the PCB with discrete components with DAPI and the delta profit due to the sales increase (assuming 15% of profits in the turnover attributable to FUSE), with an investment of 138.7 K€, the payback period is estimated at less than 6 months with an attainable ROI of 6 over the 3 years of sales.

17. Target audience for dissemination

The Company has learned that best practice processes employed in this experiment, such as how to choose a technology, how to plan and manage an analogue ASIC development and how to choose a subcontractor can reduce perceived risk and improve the chance of success of such projects.

From a functional point of view, the ASIC component will used in Active Speaker and Audio Processor Systems where the Audio Controller and the Digital Audio Processor Interface functions are used.

Probably, many other companies involved in the professional audio field would be interested in using this ASIC, as now the market does not offer an economic standard chip, that is able to concentrate the functions introduced in DAPI.

More in general, the project is well targeted toward many SMEs operating in different industrial fields related to professional audio market (audio processing systems) and precision instruments market (noise monitoring). This project arose from the co-operation with the University of Bologna (Parma is linked to Bologna). This University is promoting the technology transfer toward the SMEs, with the training innovative methodology. This technology transfer is very difficult because the companies, operating in many Italian regions, always SMEs, are not interested in research or new project developing, if this activity doesn't assure a prompt payback. This AE proves that it is possible a new technology approach with a profitable payback.

With the ASIC technology, it is possible the development of a variety of products characterised by low production costs, higher reliability and higher performance as S/N (Signal-to-Noise ratio) and THD (Total Harmonic Distortion).

The large replication power of this AE could be applied in at least the following product sectors:

Sectors	ProdCom	Rationale
Electronic Components and Tele, Audio and Video		
Telegraph and Telephone Apparatus and Equipment and Radio	3220	The Analogue ASIC technology solution for audio processor and audio signal interface assures: • reduced time to market of products • use of digital processing techniques • less schematic complexity (reduced PCB size, reduced costs for components and assembly, higher reliability) • reduction in testing times • immunity: it is a good result under the EMC noise immunity point of view • confidentiality: it is possible to protect the know-how higher reliability: with short number of components, MTBF (mean time between failure) is higher
Television and Radio Receivers, Sound or Video Recording etc	3230	The use of the Analogue ASIC (DAPI) inside the RCF audio controller permits to simplify the active loudspeaker design, reducing the time to market, to increase the performances, with EMI reduction, less THD and better S/N and to reduce the variable costs. In addition the new control will allow RCF to introduce an optional Digital Processing Chain with no extra cost for the interfacing circuitry.
Precision Instruments		
Instruments & appliances for measuring, etc	3320	The functionality performed through this ASIC can be applied on any instrument measuring sound parameters.

The following advantages, due to the miniaturised ASIC integrated audio control are the reasons for a wide target audience:

- Low production costs,
- Space saving,
- Minimising factory costs: space for material stock, easy testing, few material codes
- Reusability of the same chip for different applications,
- High quality design,
- Fit to noisy environments,
- Reduction of external hardware needed,
- Miniaturised integrated audio controller,
- Usefulness for replication in companies who are facing similar barriers,

Many Companies, operating in Electronic Consumer (professional market) and in Precision Instruments (noise monitoring in industrial and urban environment), should be interested to replicate the RCF S.p.A. experience.

From the company profile point of view, all the companies matching with the RCF S.p.A. profile should be interested in acquiring experience from this AE. This AE implies a high power for local replication because in TTN region there are several industrial districts such as that where RCF S.p.A. is operating. The typical electronic companies that design and supply Consumer Electronics and Precision Instruments on these industrial districts are mainly featured on this mask:

Management: Resistance to change
Starting technology: PCB and microprocessor
Applications: Electronic Components and Tele, Audio and Video: *Telegraph and Telephone Apparatus and Equipment and Radio, Television and Radio Receivers, Sound or Video Recording etc* Precision Instruments: *Instruments & appliances for measuring, etc*
Development Methodology: Traditional, before the AE
Barriers: Knowledge and Economical worries
Company Size: Small and medium companies
Company turnover: About 3/50 M€