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Title: Assessing, Introducing and Inserting RFICs into a Flexible Integrated Circuit Based Manufacturing System

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Abstract: The case study describes how a small subsidiary assessed, introduced and inserted a high level technology. A survey of peer companies was conducted and will be described as part of this assessment, and a second necessary adoption component is described that is proving successful in transferring a technology into a company.

Assessing, Introduction and Inserting RFICs into a Flexible Integrated Circuit Based Manufacturing System

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INDIVIDUAL PROJECT REPORT

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INTRODUCTION:

The following case study describes how a small subsidiary, lets call it "Sub", assessed, introduced and inserted a high level technology. One of the biggest problems a company faces in aquiring technology, is successfully bringing it to life in the company culture. Quite often technology is purchased or acquired but it is not accepted in the corporate culture. That is, a technology may be brought into a company through a high level manager, but have no engineering or manufacturing owner. Without such an owner the program cannot get implemented beyond lip service. In this review I show how a technology was assessed and successfully adopted in a corporation. As part of this adoption a survey of peer companies was conducted and will be described as part of this assessment. Furthermore, a second necessary adoption component is described that is proving successful in transferring a technology into a company. (Dean)

BACKGROUND:

Initially, we performed a quick and dirty assessment of the impact of the technology. This tentative assessment showed that the technology could provide a strong ROI, and strong growth. But, this assessment was incomplete, not all major areas were discussed and analyzed. Without such an assessment it was not known if that technology would truly fit the company. Unfortunately, some unknowns could result in a bad fit which could result in an expensive wrong investment. (Meredith, Arbel)

The initial assessment used a Delphi approach where a number of experts of various RFIC companies were called and surveyed. However, there are very few RFIC companies and very few RFIC experts. Therefore, the survey is small and statistically prone to errors.

This review describes how "Sub" pulled a high tech flexible RFIC capability into its product line. As a background, the company is controlled by a parent company. Sub is a cash source for "parent." This parent corporation invests the minimum dollars in the development of skills and necessary equipment of sub corporation, but allows it to keep a high percentage 8 -10% of its revenue for R&D efforts. This division is a flexible manufacture, providing a mix of more than a hundred products. Typically each product is sold in quantities from ten to ten thousand.

Sub, to keep in good graces with their parent corporation, should provide beyond 25% profits on revenues to the parent corporation. At the same time, the competition has learned the Cell phone business is a very lucrative market. This competition cuts strongly into the profits of Sub. To keep the profit level up Sub's management tried a bold venture, the development of radio frequency integrated circuits (RFICs). First, this is bold because the design of RFICs can be risky. Second, to be successful, there must be ownership of the product at all levels from engineering to production to sales.

This diffusion of RFIC technology is over a small concentrated area. That is, there are a small number of manufactures of the GaAs IC (Gallium Arsenide integrated circuit) technology, due to very high investment costs. There is a similar approach to the technology among the four different competing IC manufacturers, with no one particular manufacturer dominating the technology. Thus the diffusion area for the IC is small. On the other hand, the diffusion area for the plastic packages for the RFIC is huge, because the initial investment in the packaging area is quite small, while ROI can be high. So, there tends to be a lot of competition and a lot of variation in the packaging arena.

ASSESSMENT APPROACH:

Now, I describe the adoption approach of the new technology into Sub. Sub is a company where RFIC technology is not part of the status quo, and the employees will have to take personal risk to use it. RFIC technology does not fit the innovation mode of the company. This company's innovation mode is evolutional. Furthermore, their evolutional status requires development of product in less than six weeks (Miller). To adopt the technology the users would have to adopt an entrepreneurial innovation mode. Development of the desired entrepreneurial RFIC innovation takes between one and two years. This kind of investment does not fit the typical financial pattern of this corporation. Subs standard operating procedure is to receive any investment money back in two years or less. That is an estimated 30% gross profit and full return in less than two years.

During our Delphi assessment survey, I asked the RFIC experts their company's financial justification approach. Quite often it was ROI or ROR. But it was not analyzed over any one particular RFIC, but a group of IC's. When asked why they "amortized over groups of IC's" they stated that any one particular IC design might fail, but a class of IC's would most likely succeed. Furthermore, a return on investment of two years was unreasonable when the engineering development often required more than two years. Also, they described how RFICs could reduce the parts count and assembly labor.

Table 1. Delphi survey comparison of different RFIC corporations developing commercial products

Parameter	Alcatel	RF Monolithic	Fujitsu	Sanders	M/A-Com
Financial justification	ROI	ROI	ROI	ROR/bottom line profit	ROI
Competitive Strategy	Number one in market	Optimum technology match	Highest quality moderate cost	Satisfy customer profitably	Overwhelm market
Technology acquisition	Develop it your- self	Self-grown knowledge	Intense R&D	some self devel & key suppliers	Buy product suppliers
Marketing	Work closely with key OEMs	Work closely with key OEMs	Marketers only deal with customers	Work loosely with internal	Mass mailings work closely with OEMs
Training	OJT, schooling, Consultants	Key strategic partnership	Conferences	OJT, external courses	Creaming of talent
Communication with customers	conference calls often	E-Mail often	Phone calls	In rare design reviews	Phone calls
How do you get buy in?	By assignment and charm	By assignment and Stock incentive	Japanese type group buy in	Program managers charm	Assignment, manager charm
Development approach	Team brainstorming	Customer and Engineer work together	Japanese style group thought	group brainstorm	IR&D for individuals

Proposition 1) Use of conventional pay back period for traditional flexible manufacturing systems based upon use of RFICs indicates that their use is not justified.

Proposition 2) Use of extended pay back periods of more than two years, the inclusion of pay back from reduced labor count, increased output capability and increased quality indicates their use is more than justified.

Proposition 3) Payback should be based upon a class of RFICs and not any particular one due to the risky nature of any design, but a group of RFICs would most likely succeed.

The financial assessment showed the idea had promise. Management requested an assessment from the social perspective. They stated "the employees are critical to the corporation. They are considered the greatest resource and must be taken care of." If the people can't get along with the technology they will be unhappy and the company will lose money.

To increase the technologies fit with the company and increase buy-in, the survey asked "How do you motivate your people to take ownership of a product?" Quite often the answer was not money, but it was that people bought into a program due to "management charm." That is, management made it pleasant to work on a particular job. Table 2 showed that socially RFICs was a win for the employees, and an operational and strategic win for management.

Table 2. Social change and effect of RFIC technology on the employees

Parameter	Operational Benefits	Strategic benefits	Disadvantages
Socialization	technology not stop socialization	People not affected by RFICs	None
Employment	move to lower mean skill level, but no pay drops	Lower mean wage, & greater output	
Job Security	same as before	same as before	none
Union shop	reduces skill level below what Union can use	No union	none

Proposition 4) If the people fit with the technology, then they will continue to enjoy their work and do their best for the company.

Proposition 5) Introducing RFIC technology into an RF component development company will result in significant financial benefit due to greater output per employee at reduced employment cost.

A brief history on the selected technology reveals that in the 1970s, the military wishing to make their electronic warfare products smaller and cheaper, developed a technology that would allow entire radio frequency amplifiers on a single integrated circuit. It took another 20 years before the technology was mature. When it did mature, the manufacturing system was only useable for large quantities of a very limited number of types. Thus it was not flexible for use in low quantity, highly diverse products. There were high engineering costs with minimal product flexibility. While this is acceptable for military and very high quantity commercial products (>1 million parts), this is cost prohibitive for medium to small commercial broad mix suppliers.

In 1996, a lone engineer was hired to bring in RFIC development into the sub. First he was tasked with a technological assessment. In the assessment the engineer performed a simple ROI, and schedule. In the ROI he found that the NRE (non refundable engineering) dollars would be high but the cost of the product would be quite low beyond a 5,000 part break even point. Naively, he felt he could bring about the introduction of the technology in a little more than a year. Immediately there were problems, his development was not started until six months after his arrival. It took four months to design the part and it took eight months verses the typical three months to process the parts. Unfortunately, supplier could not be motivated to expedite the processing. After the design, processing and testing was completed the engineer was able to make the assessment in Table 3.

Table 3. Assessment of the organizational parameter of the technology

Parameter	Operational benefit	Strategic benefit	Disadvantage
Technology	product more consistent	less technical labor req.	longer design cycles
Productivity	greater product output	less plant space required	can't handle large mix
development cycles	shorter if IC in stock	less plant space required	Longer if no IC in stock
fit with product mix	Reduce effort on largest product	Greater output capacity	key suppliers slowness is a critical issue.
Uniqueness	somewhat	Stronger hold on niche	Engineers may not use it
Costs	on large qty much less	greater revenue	req. larger minimum qty
Sales	increase in smaller mix	less products	less diversity
Management trends	move to long term development	more mature products	less flexibility in short term
Political legal and environmental	not a concern	not a concern	

Generally, this assessment was positive, but it showed under management trends a move to long term development. This is not consistent with customer's need for short development policies. This need to increase the development rate, quality, and speed of the key supplier, showed a second and third engineer needed to be hired. This is consistent with current thought (Parthasarthy). Hiring one engineer from the key supplier would help expedite the suppliers efforts. This assumption proved correct and designs were reduced from four months, and the suppliers processing time dropped from eight months to four months. This improved the rate and quality.

A second problem with the assessment was the inability to handle a broad mix of products. This is because the most expensive part of RFIC processing is the masks; they cost $32,000. The greater the product variety, the greater the need for a variety of masks. Thus to minimize the costs of masks you need to minimize the product mix. The survey showed that the way to minimize the product mix is by working very closely with customers, providing them with just what they need, and not providing additional similar products until requested by the customers. (Aranacost)

Proposition 5) Traditional RFICs, when used in a flexible manufacturing system, cannot provide the necessary flexibility and schedule to cover the mix range of product requirements and the minimum cost requirements for low quantity lots. This must be resolved by close customer/supplier interactions.

A third problem found in this assessment is that the internal customers, the engineers, were not utilizing this unique product. To attempt to resolve the problem we conducted a technical assessment to determine how to get the technology accepted internally. This is shown in Table 4.

Table 4. Assessment of the technological perspective

Parameter	Operational Benefits	Strategic benefits	Disadvantages
Niche or unique approach	Cost advantage in certain areas	number one or two in market area=profitability	lose some flexibility
Diffusion of technology	not major trend but used	Technology accepted in industry	soon competitors will have it
New Process Development required ?	Process similar to what we have	no new equipment	stringent requirements
How much training to be introduced properly?	moderate engineering, and assembly training	Training not requiring unusual skills	Not minimal training and not intuitive skills
Technology acquisition	Purchased from supplier	R&D on design not process	Design not simple and not truly tunable
Flexibility	less flexible but solid RF performance	reduced technician and assembly people	poor flexibility = reduced performance

Our assessed strengths are similar processing or handling of the parts between RFICs and current procedures. Furthermore, the RFIC technology is similar to that of our currently used transistor amplifiers.

Unfortunately, using RFICs the flexibility would be reduced, and working with internal customers initially you must make a wide mix of products. We also knew that internal customers rarely ever made the 5,000 break even amount of any standard product. Therefore, the company would never make the break-even cost, and never sell any RFICs.

The difficulty was the mask cost. Each time you wanted to run a batch that had a different mix of devices or when you wished to change frequency, FET size, gain, noise figure or power, you needed a different mix of RFIC types. To change the mix you needed to change the mask at $32,000.00. This NRE cost plus running the wafers makes the process prohibitive, due to the high break even point.

To solve this problem we reassessed the RFIC products available. We found by modifying the RFIC product that it makes it less expensive. This new part required only 4,000 to break even (this is an estimate which varies with product). Then we discovered an idea that reduces the number of mask changes. This technology change is the result of brainstorming through the technology.

Proposition 6) Product mix of low lot sizes are cost prohibitive due to the cost of modifying masks to allow the purchasing of different quantities of products.

Proposition 7) Product mix variations can be reduced by unique flexible approaches in RFIC designs, which allow a flexible manufacturing strategy.

To substantiate our approach we needed to place our RFICs into some of the in-house product lines. This approach, placing RFIC products into Sub's mainstream product is, in essence, ownership transfer. We capitalize on a desire of the people who control these mainstream products. These engineers have expressed a strong interest in personally developing RFICs. If they could feel a sense of ownership in the next batch of RFICs, perhaps they would want to use them in the mainstream products (Reddy). The difficulty here is heritage. If the current design approach works even at reduced profits, why change it? The engineers don't want to change a current approach or procedure. Therefore, to introduce a product and get engineers to use it you must show that it is an excellent fit, and that it is a significant cost savings. The key is fit. When assessing the technology, one has to not only be sure it is an excellent fit but to be sure there is no characteristic that will make it fail. It must also exceed some profitability level. (Argote, Chen, Harryson)

Proposition 8: Product insertion of RFICs into new product will require ownership transfer and excellent fit, through product flexibility.

TRAINING:

To try to entice the engineers into using the RFICs, we looked at the Delphi survey. It showed that most engineers were forced to learn how to use RFICs through on-the-job-training. This often results in design failure and reduced desire to use the product. To speed the introductory process and increase involvement we trained them in the basics of RFIC design. This section describes our process of bringing this specialized technology into the corporation through training. The training was based upon a seven step approach described in the "The Green Thumb Myth" by Stiehl and Bessy.

1) To train, first, you must establish specific performance goals and clarify expectations. We selected ones that were both challenging and achievable. This task, called "reverse engineering", is where the engineer checks the performance of an RFIC designed by someone else.

We explained what good performance would look like. We made it clear that their goal would be to develop a portfolio of the following performance items, which would be presented at the design review. The items were gain, VSWR, noise figure, and 3rd order intercept. They would then compare this data against our simulation data to show agreement or disagreement. They were also asked to determine if the part was useful as a company product.

2) Second, they needed to believe that they would be able to reach the performance goals. This was accomplished by showing them that this simulation had been done by hundreds of people before. We knew they were interested in learning about RFICs. This was described to them as the first step to MMIC design. I explained to them that this was a difficult task, but it would be within their abilities, after a little practice.

3) Third, I explained the value of performing the task well. If the RFIC works well you can use it in one of your products. Plus, you would be able to say you are part of a MMIC design team.

4) Next, we needed to identify and provide access to the knowledge, skills and attitudes needed to perform the task. The knowledge included models of the package, substrate, device, inductors, caps, wires, and non linear models. I showed them it was similar to what they do now, with some changes. The best way to teach them was to give them hands-on experience. The agenda was as follows. First, they physically measured the part, from which they determined the electrical equivalent circuit models, finally they putting them all together to simulate the amplifier.

5) Next, we structured and coached skill practice We accomplished this by demonstrating the process by showing an actual procedure, teaching specific skills, proper models and proper approaches.

6) Provided opportunities for learners to demonstrate. Each person was given an RFIC to demonstrate their simulation mastery. They simulated it, and then they were shown the RF performance. Their closeness to the predicted data showed that they had indeed mastered the concept.

7) We celebrated the design mastery at the design review, by saying what we had accomplished, deciding what was the hardest part and deciding on what to shoot for next.

This approach resulted in a serious engineering interest in the RFICs and a strong desire to use them.

ASSESSMENT PROCESS SUMMARY:

The following shows the second more complete assessment process in order of occurrence.

Summary of the Problem: Sub has been a world leader in cellular base station products, but recently with the Asian economy deteriorating, sales are dropping. Asia's decline removed a significant part of our market, and greatly increased the competition. Our sales were growing at a 30% rate in 1996, dropping to 10% in 1997 and it is expected to be flat in 1998. To revitalize our sales we needed to sell for less thus we looked for cheaper ways to develop product. To find the ways, we have an annual goal programming process where new programs are developed.

Goal Programming is used each year to select major development projects to be developed. Formulations are performed where expected revenues and profits of the range of products determine which are developed. Once the goal programming is finished, a Delphi operation is performed to determine technical approach and product parameters.

Delphi evaluation is used to decide which technical product approaches are best. Specifically, we Delphied by phone with experts and consultants from RF Microdevices, TriQuint, Raytheon, Lockheed Martin, and Celwave. The application is to determine the best technical approach from a range of emerging RFIC technologies. We found the following advantage: Several experts reduced the ambiguous issues helping to determine a solution direction, and the following disadvantage: Experts could only help a limited amount, due to time and knowledge constraints.

The Delphi expert input, in Table 1 shown above, was incomplete. A weighted factor scoring model using Delphi inputs and team inputs was used to complete the determination of which approach will meet the best cost and technical performance.

Our risk assessment used this equation $S = \sum_{j=1}^{n} S_{ij} w_j$

With the following weights "w"

product use existing processing system, and facilities	w=.1
product profitability	w=.3
compatibility with corporate goals	w=.2
growth potential	w=.2
minimal risk	w=.1
maintain schedule	w=.1

The following projects were evaluated and the scores are shown

Low power amps	score = 0.5
High power amps	score = 0.7
Low noise amps	score = 0.8

The analysis showed we needed to develop low noise and power amplifiers. We took the outputs of the Delphi and we modeled and built the power amps. Their performance failed to meet specification. Extensive simulation and modeling was used to reassess the options proposed by the Delphi people. From this we determined the best technology and approach. We used the following simulation tools for the tasks shown.

Microsoft Project provided pert simulation
Excel for cost versus profit business simulation
Matlab for mathematical simulation of system performance versus theory
Super Compact for Circuit theory simulations

Harmonica for spectral analysis
em for electromagnetic performance
Monti-Carlo for yield analysis

Our simulation advantages showed the models were accurate for simulation of known technologies and performance where the model could be calibrated. On the other hand, the modeling was inaccurate for simulation of poorly known technology or approaches where the simulator could not be calibrated.

AHP planning: From the output of all of the above, we developed an AHP chart. It was simple enough that a numerical analysis was not necessary. Due to corporate privacy needs it cannot be shown here.

Next we developed a financial risk assessment of power amplifier via Pacifico's Method

Profitability index = $rdpc\ SPL^{1/2}/C$

r= probability of research success	=0.95
d= probability of development success	=0.95
p= probability of process success	=0.88
c= probability of commercial success	=0.80
C= the estimated R&D cost	300K
P= estimated profit per unit	30.00
L= estimated life of product extension	10.00 years

The profitability index = 5.47 which is more than one so it is worth the effort.

This high profitability index resulted in the project being approved by management.

In conclusion, we assessed a RFIC flexible manufacturing system to determine the applicability of RFIC's for use in Cellular RF products manufacturing. The assessment was quite positive, but it was shown that to be successful the manufacturer must replace non-flexible RFICs with flexible ones, and there must be close customer-engineer interaction to maintain control over the non refundable costs. Also, a technology transfer program was implemented to introduce and implement the technology.

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Appendix A - Survey Form

The following survey has been constructed and distributed as part of a research project into the use of technology assessment and acquisition in RFIC development corporations

Company Name ________________________________

Company product orientation ☐ Commercial ☐ Military

Financial Justification technique ☐ ROI ☐ Payback ☐ ROR ☐ Bottom line profit

Competitive Strategy ________________________________

Technology acquisition approach ________________________________

Marketing approach ________________________________

Training ________________________________

Communication with customers ☐phone ☐E-mail ☐other ____________
How often ☐often ☐occasionally ☐rarely

How do you get employee buy-in? ________________________________

Product development approach ________________________________