ELECTRONIC PRODUCT DESIGN

Introduction

What is engineering?

The word ENGINEER − comes from the latin − means INGENIOUS or CLEVER DEVICE.

Designing new product is therefore at the core of engineering.

Engineers, especially academics, often focus on small technical and intellectual specialisms.

They like calculations which give RIGHT or WRONG answers (good for examination and tutorial questions).

Real engineering involves many aspects not amenable to rigorous calculation, such as:

Does it do what the customer wants?

Can it be made at the right price?

Is it robust?

Will people buy it?

How shall we manage the development of this product?

We will spend the next few months looking at these 'soft' issues. There will often be no definite RIGHT or WRONG answer, just a MAYBE.

The design process is like a very large juggling act with a combination of art, finance and just a LITTLE BIT of engineering.

Need the answer to the question, 'Can we make a lot of this product and sell it at a profit?'

It can be a very tricky question to answer − but you need some idea BEFORE you mortgage your home.

Most engineers work from a functional specification. Take the following spec. for an audio amplifier:

Frequency response: 50Hz−20kHz

Input signal: 700mV pk−pk

Input impedance: 1kW

Output power: 100W pk−pk

Output impedance 8W

Distortion: #0.001%THD

Operating voltage: 230V ac

Most engineers could design such an amplifier. But would it sell? Would it still work after a year? five years? How much would it cost? How much profit could one make from it?

The specification is purely electronic; it contains no statements about the environment in which the product is required to function, quality of build or production volume.

It is not possible to design a satisfactory product based purely upon a technical specification because it is only a partial specification.

The history of British engineering is littered with great technical ideas that failed in the marketplace because of lack of attention to the DESIGN of the product. Other countries (notably Germany and Japan) have done things better and a vast number of our large companies are now owned and managed overseas.

The UK consumer electronics industry is almost entirely foreign owned.

There are no UK−owned mass−market car manufacturers.

The British Advanced Passenger Train (APT) was scrapped at the end of development in 1982. A much improved version is now being built in the UK by a German−Swedish conglomerate.

So what's the best design? How do we get it together?

Or should you be thinking about a different career?

THE BASIC PRODUCT DEVELOPMENT PROCESS

A process has a START and an END.

At the start we need a TARGET − usually a FULL SPECIFICATION. This specification needs to embrace:

Electrical specification

'Ilities (see later)

Product processes

Production unit cost

Production documentation package

Product approval requirements

Production volume

Quantity of prototypes for test

The 'Ilities address the suitability of the product for its intended market:

Manufacturability

Environmental compatibility

Reliability

Safety

Testability

Servicability

Liability

There are also some CONSTRAINTS on the design; available budget, development time, reporting requirements, available resources.

We can now represent the process with a diagram:

DEVELOPMENT PROCESSES AND ORGANISATIONS week2

Processes − A process transforms a set of inputs into a set of outputs.

The product development process involves a set of steps (intellectual, organisational and physical) which result in the commercialised product.

A well−defined process is vital for:

Quality assurance

Coordination (everyone knows what they should do)

Planning (milestones, timing)

Management (benchmark for assessing progress)

Improvement (highlight opportunities for improvement)

GENERIC PRODUCT DEVELOPMENT PROCESS

A five−phase methodology is used:

1 Concept development − *market needs* identified; concepts are generated; single concept is selected for development.

2 System−level design − definition of *product architecture*; division of product into subsystems; final assembly scheme for the production system.

3 Detail design − complete specification of the circuit, geometry, all parts, details of production. Output of this phase is *control documentation.*

4 Testing and refinement − construction and evaluation of many preproduction versions. *Alpha prototypes* are built with production−intentparts. Later, *beta prototypes* are built using standard parts (but assembled using non−production techniques) and evaluated externally.

Slow build may also be employed (eg GM cars).

This phase answers questions about performance and reliability.

5 Production ramp−up − product is made using standard production systems. Initial samples are supplied to preferred customers and evaluated to identify any remaining flaws. Product is then *launched.*

The process described here is generic − it will vary slightly from one organisation to another.

It will also vary according to the *context* of the product. Products can exist in five contexts:

Generic (Market Pull) − Firm begins with market opportunity, then chooses appropriate technology to meet needs. Examples: most low−tech products.

Technology−Push − Firm has new technology and then finds appropriate market.

Examples: colour TV, CD, satellite TV, cellular telephone.

Platform − New product built around existing technology platform, perhaps with small improvements. Examples: much consumer electronics, printers.

Process−Intensive − Characteristics of the product are determined mostly by the production process. Examples: semiconductors, chemicals.

Customisation − New products are variations of existing standard products.

Examples; IC=s, software, switches, enclosures.

IDENTIFYING CUSTOMER NEEDS

Products offer benefits when they satisfy needs − this is true for any product.

For the product to be successful in the marketplace the development team must have a clear understanding of the customer needs − this includes *latent needs* as well as *explicit* needs.

Identifying customer needs is an involved process − this six step methodology makes it easier:

1/. Define the scope of the effort

2/. Gather raw data from customers

3/. Interpret the raw data in terms of needs

4/. Organise the needs into a hierarchy

5/. Establish the relative importance of each need

6/. Reflect on the results

Let's look at each of these steps in detail:

1/. Define the scope of the effort.

Start out with a *design brief* (or *mission statement*) − gives general direction of work, but no specification. The design brief may include:

One−sentence description of the product

Business goals

Target markets

Basic assumptions

2/. Gather raw data from customers.

Need high−quality data direct from likely customers.

There are three ways to do this:

One−to−one interviews − in the customer environment for one or two hours. Good for specialist products (eg medical equipment) . Typically 10 − 50 interviews needed to get most needs.

Focus groups − group of customers (about 10) are paid to undertake a two−hour discussion about the product. Reactions are observed and noted. Now very popular.

Observing the product in use − observer follows the customer around, taking notes. Good for tools etc. Not so good for some other products (eg software).

Iterviews are the primary method for most products.

Distinguish between *standard users* and *lead users*. Lead users are intensive users, often professionals, with acute knowledge of needs.

3/. Interpret raw data in terms of customer needs

Convert the set of written statements into needs according to guidelines:

Interpret the needs in terms of **WHAT** the product does, not **HOW** it does it.

Express need at a basic level (same as the raw data).

Try to express need in positive, not negative, terms.

Express need as an attribute of the product (ie what it does − not what you do with it).

Avoid words like must and should − wait until later before deciding the importance of each need.

4/. Organise needs into a hierarchy

The result of the previous step will be large number of need statements. This step organises these into a hierarchical list. Typically, this work is done by the design team:

Write each need on a separate card

Eliminate redundant (ie basically identical) needs by stapling those cards together.

From the remaining cards, arrange them into groups which express similar needs (not similar technology etc.).

For each group, summarise the group needs with a single need statement.

If possible, try to create 'supergroups' comprising two to five of the groups mentioned above.

Review and edit the needs hierarchy − try alternative needs and groupings

5/. Establish the relative importance of the needs

Having got a hierarchy, the team must consider the relative importance of each need − there are two approaches:

The team use their experience to decide on a hierarchy, or:

The team go back to the customers and do a further survey − this costs more money but gives a more accurate result.

6/. Reflect on the results

The development team must be self−critical and determine whether the process has been properly carried out:

Have they talked to all important customers?

Have latent needs been captured?

How might the process be improved?

The outcome of the needs analysis is a hierarchical listing of customer needs, with some assessment of their relative importance (say on a 1 to 5 point scale).

ESTABLISHING PRODUCT SPECIFICATIONS week 3

Customer needs are expressed in the customer's language − rather subjective.

Specifications turn the needs statements into clear, quantitative nformation useful to design engineers.

They say WHAT the product must do, not HOW it does it.

Example:

For a guitar amplifier the customer need is *'must be loud'*.

Specification says: *'output power must be greater than 100W RMS'*

A *single specification* consists of a *metric* and a *value*. So, 'output power' is a metric and '100W RMS' is its value.

The *product specifications* are the set of metrics and values for the product, together with information on their relative importance.

There are two types of product specification:

After analysing the customer needs a *target specification* is generated.

Then, once a product concept has been selected, trade−offs are made and a *refined specification* is produced.

We need to consider the steps involved in generating both the target and the refined specification.

ESTABLISHING TARGET SPECIFICATIONS

Four steps are involved:

1/. Prepare the list of metrics

Try to convert each customer need into a metric − not as easy as it sounds.

A good idea is a **Needs−Metrics Matrix** − an XY chart linking needs to metrics.

When considering the suitability of metrics, note the following:

Metrics should be dependent variables.

Metrics should be practical and easy to evaluate. Use standard units.

Some needs are difficult to translate into metrics (fashion, emotion).

Use standard criteria for comparison with other products (eg tests used by consumer magazines).

METRIQ

		Mass (Kg)	**Dimensions (frame size)**	**Material**	**Cost**		
N	**Good brakes**						
E	**Light weight**						
E	**Robust**						
D	**Gears**						
S	**Corrosion Resistant**						

2/. Collect benchmarking information.

Decide on the *position* of the new product relative to its competitors.

Gather information on competing products.

Produce a *benchmarking* chart by entering metric values for the competing products on a chart. Time consuming, but invaluable. Could also use *customer perception* data.

3/. Set *target* and *marginally acceptable* values for each metric.

Target value is the best you could hope for. Marginally acceptable value would make the product barely viable. The final value will be somewhere between these extremes.

There are five ways to express the value of a metric:

At least X − lower limit on metric; higher values better.

At most X − upper limit on a metric; lower values better.

Between X and Y − establish upper and lower limits.

Exactly X − precise value necessary (rarely used).

Discrete set of values − stepwise set of values (eg bearing sizes).

4/. Reflect upon the results.

Some iteration may be needed to agree on a target.

Are targets reasonable or too tough?

Any specifications missing?

With the target specifications set, the team can begin to develop product concepts.

Once a concept has been selected the team can look again at the target specifications and begin refining them.

<u>REFINING SPECIFICATIONS</u>

Here, again, there are four steps:

1/. Develop technical models of the product.

Team develop physical and analytical models of the product.

Perform a range of experiments to investigate if the target specification can be met.

2/. Develop a cost model of the product.

The team must produce a bill of materials (BOM) for the product and then generate a chart indicating maximum and minimum costs. This list is continuously updated through the project.

3/. Refine the specifications.

Having constructed technical models, and constructed a cost model, these tools can be used to develop refined specifications.

Make trade−offs between cost and technical performance.

Produce a competitive map − a 2D plot of competitor products' performance versus cost.

Use the competitive map to position the product relative to competitors.

4/. Reflect on the results.

Ask some pertinent questions:

Is the product a winner?

Is there much uncertainty in the technical and cost models?

Is the concept right for the intended market?

Does the team have enough engineering expertise to meet the specification?

<u>CONCEPT GENERATION</u> week4

A *product concept* is an *approximate description of the technology, working principles and form of the product*.

Commercial success depends on the quality of the concept.

A poor concept can never be 'made good' later.

Concept generation is cheap.

Concept generation starts with the customer needs and target specifications. All possible product concepts are then thoroughly explored − this results in a listing of many possible concepts from which the final concept must be selected.

Concept generation is an involved problem − but it can be broken down into simpler sub−problems using the five−step methodology described here:

1/. Clarify the problem.

Understand the problem (use target specification and needs analysis)

Decompose the problem into simpler sub−problems.

Focus on the sub−problems critical to the product.

Functional decomposition is the key; it can be performed in two ways:

By sequence of user actions − go through the process of using the product, as the customer would.

By key user needs − consider key needs and tackle them independently.

2/. Search externally.

An *external search* is aimed at finding existing solutions to either the overall problem, or critical sub−problems.

There is nothing wrong with using existing ideas.

Combine an existing solution for one sub−problem with a new solution for another to get a better product.

There are basically five ways of gathering information:

Lead user interviews.

Use consultants.

Search patents.

Search literature (including the Internet).

Benchmark competing products.

3/. Search internally.

An *internal search* uses the resources of the product design team − their experience, skills and knowledge.

Four guidelines:

Suspend judgement − no criticism of other's ideas.

Generate lots of ideas − ideas stimulate more ideas.

Welcome weird ideas − they can be 'debugged' later by others.

Use graphical and physical media − sketch, model, doodle etc.

The idea is to generate lots and lots of ideas − can be done singly or in groups.

Use 'brainstorming' sessions − make a 'gallery' of ideas in the meeting room.

4/. Explore systematically.

As a result of the external and internal searches the team will have lots of concept fragments − answers to sub−problems.

For each sub−problem there will be many fragments.

The fragments build into a 'concept classification tree' − offers many varied routes to the final product.

Sketch the tree − then 'prune' branches (the less likely solution fragments).

When a few promising branches are left they should be explored in more detail and refined.

This process needs managing − a team leader.

The outcome should be a set of *viable concepts* for the problem − ready for the next step, concept selection.

5/. Reflect on the solutions.

Finally, look at the set of concepts generate and ask questions?

Does the team have confidence in the concepts?

Have all members of the team contributed?

Have all external sources been investigated?

Two pitfalls to think about:

Has the boss had too much influence?

Are you re−inventing the wheel?

CONCEPT SELECTION

The result of the concept generation process is a set of concepts that provide solutions tothe customer needs.

Concept selection is the process of evaluating the concepts and seeing how well they satisfythose needs, and other criteria.

Basically, we start out with a large number of concepts and 'weed out' the weaker ideas. We then have a small pool of good concepts from which the winner can be picked − or perhaps we combine several concepts to give one 'winner'.

Every product design team must use some method to select the best concept:

External decision − concepts turned over to outsiders (customers, consultants) for selection.

Product champion − powerful member of the team chooses one concept based on personal preference.

Intuition − done by 'feel' (eg fashion, product name).

Pros and Cons − team draws up a list and scores each concept, then picks the winner.

Prototype and test − team builds a set of prototypes and then makes a selection based on performance (can be expensive).

Decision matrices − refined version of 'pros and cons' − each concept is marked against a set of weighted selection criteria.

We will look in detail at the last of these options − decision matrices.

It is very important to deal with this process in a structured and logical way: it is at this stage that much of the manufacturing cost is decided and also the market reaction to the product.

There are basically two phases:

Concept Screening − rough initial evaluation to give a few viable alternatives.

Concept Scoring − careful evaluation of the few remaining concepts to give the final concept most likely to yield product success.

For both processes we can use a common six−step methodology known as the Pugh Concept Selection, developed during the 1980's.

CONCEPT SCREENING

The six steps here are:

1/. Prepare a selection matrix. The team prepares an XY matrix with each concept along the X−axis and selection criteria along the Y−axis. Selection criteria are parameters such as 'ease of manufacture', 'user friendliness' and 'durability'.

2/. Rate the concepts. For each criteria, each concept is then rated '+' (better than benchmark), '0' (same as benchmark) or '−' (worse than benchmark). Where possible these should be quantitative judgements derived from objective metrics.

3/. Rank the concepts. After filling in the table, the team adds the number of 'better than', 'same as' and 'worse than' scores to get an overall score for each concept.

The concepts can then be ranked according to their scores, and the parameters which really differentiate the products can easily be identified.

4/. Combine and improve the concepts. After ranking the concepts there are two issues to consider:

Is there a very good concept spoilt by one bad feature?

Are there two concepts that could be combined to give a good result?

5/. Select one or more concepts. The team will now have a good idea of the worth of the remaining concepts and can judge which are worthy of further analysis.

6/. Reflect on the results.

Do the results make sense?

Are all team members comfortable with the outcome?

If the answer to either of these questions is 'no', then perhaps a vital criterion has been left out of the process.

CONCEPT SCORING

With concept scoring the process described above is repeated − but this time with much greater resolution to differentiate competing concepts.

1/. Prepare a selection matrix. As before, the team prepares a matrix with relevant criteria and also defines a benchmark product. This time, however, the relative importance, or weighting, of each of the criteria is assessed.

The weightings can be obtained from marketing data, or defined subjectively by the team.

2/. Rate the concepts. As before, we need to rate each concept relative to the reference but this time a finer scale is used, say 1 to 5.

1 = much worse than benchmark, through to;

5 = much better than benchmark.

3/. Rank the concepts. After ratings have been entered for each concept, the ratings are multiplied by the weightings. The total score for each concept is then the sum of the weighted scores. Each concept can then be ranked.

4/. Combine and improve concepts. Again, it may be possible, even at this late stage, toimprove the final product by combining the best bits of several concepts.

5/. Select one or more concepts. Although it is possible to simply select t he highest scoring concept, it might also pay to do a sensitivity analysis:

Enter the selection matrix as a spreadsheet and experiment by varying the weightings − it might be found that small changes in weightings produce very different rankings.

What is the uncertainty in the process?

6/. Reflect on the results. This is the 'point of no return' for the product − so the whole team should feel convinced that it will be a winner. It should satisfy customer needs and be economically successful.

THINGS TO WATCH OUT FOR:

Think about the following:

Subjective criteria − some criteria are very subjective (aesthetics, user friendliness). Weightings need to be chosen

carefully, perhaps with customer help.

Cost − cost is not a customer need, but it does set the minimum sale price and also decides economic viability.

Cost divides into:

parts costs

manufacturing costs

For economic viability, ease of manufacture is very very important − we will look more at this later.

The process − treat the process seriously, it builds consensus in the team and creates a record of the product design process.

PRODUCT ARCHITECTURE

An understanding of product architecture is vital when designing a product. It can mean the difference between success and failure, and influences every aspect of product development, manufacturing and marketing.

A product can be thought of in two ways;

In functional terms

In physical terms

The functional elements of the product are the individual operations that the product performs (eg for a VCR − 'load cassette', 'thread tape', 'rotate head').

Functional elements can be described in terms of block diagrams, rather than specific components.

The physical elements of the product are the parts and components that

implement the functions. The physical elements are defined at the time of concept selection.

The physical elements are organised into major building blocks called 'chunks'.

Each chunk then implements a function of the product.

MODULAR VERSUS INTEGRAL ARCHITECTURE

For an engineer, the most important characteristic of a product's architecture is whether or not it is modular.

A modular architecture has the following properties:

Chunks implement one or a few functional elements in their entirety.

The interactions between chunks are well defined.

A typical modular architecture is one where each functional element is implemented by a chunk − for example individual op−amp and timer chips in a circuit.

There are other examples − like the Swatch watch and the Triumph motorcycle.

In the modular architecture, one chunk can generally be modified without affecting the others.

The opposite of the modular architecture is the integral architecture.

An integral architecture has the following properties:

Functional elements of the product are implemented using more than one chunk (ie they are 'spread').

OR

A single chunk implements many functions.

The interactions between chunks are ill−defined.

Examples of products with integral architecture include products with custom IC's, Formula 1 racing cars.

A product with integral architecture has usually been designed for highest performance;unfortunately modifications may require extensive re−design of the product.

In reality, products are rarely 100% modular or 100% integral − usually a combination of both.

IMPLICATIONS OF ARCHITECTURE

The architecture of the product determines how easy it is to change the product, once designed. The reasons for change are:

Upgrade − as technological capability and user needs advance there may be the need to upgrade (eg Intel processor, latest inkjet cartridge).

Add−ons − consumer can buy bits to add on to a basic product (eg Psion Organiser computer).

Adaptation − different markets may require different product, needing adaptation (eg different mains voltage, different TV standards).

Wear − how does the consumer replace a rapidly wearing part? (eg video heads in VCR, bearings in a motor).

Consumption − many products consume materials that need to be replenished (eg batteries, printer paper).

Re−configuration − product may need to be re−configured by the user (eg 35mm camera with lenses, vacuum cleaner).

Re−use − the manufacturer may wish to retain the 'core' of a previous product and produce a 'new' product by altering a few functional elements (eg many electronic products).

The MODULAR architecture allows a firm to minimise the physical changes required to achieve a functional change.

OTHER CONSIDERATIONS

Product variety. Variety is the range of products that a firm can manufacture in a given period of time. architecture enables the manufacture of a wide variety of products at low cost. Swatch saved the Swiss watch industry using approach and it is widely applied in consumer electronics.

Component standardisation. Often, the same component or chunk can be used in many products. Standardisation allows the chunk to be manufactured in high volumes and reduces stock costs.

Standardisation across many manufacturers allows a vendor to make a sophisticated, low−cost, chunk (eg many IC's, LCD displays etc.).

Product performance. Performance is generally enhanced using an integral architecture.

Consider:

A Formula 1 racing car uses the powertrain casing as part of the chassis and to support the rear suspension. This saves weight and volume − a good example of function sharing.

It is now possible to incorporate a PCB into the plastic casing of an electronic product; thus the casing is both the circuit and the product's enclosure. This saves weight, material and assembly costs.

Manufacturability. To allow the product to be made easily (Design for Manufacturing − DFM) we want the least number of components. The implications of component integration need to be considered at the design stage.

Product development management. With a modular design, each chunk can be given to a small design team, who will interact minimally with the other design teams. Modular architectures are therefore good when the design team is geographically diverse.

When a function is implemented by two chunks, as in an integral design, there must be a great deal of internal coordination across a large group. Integral design is therefore more difficult to manage over long distance (consider the Airbus aeroplanes).

ESTABLISHING THE ARCHITECTURE

Decisions about the architecture should be made by the cross−functional development team. The end result should be an approximate geometry for

the product, descriptions of the major chunks and the interactions between chunks.

There are four steps to this process.

1/. Create a block diagram of the product. This should be the team's understanding of the product. Where possible, each element should be physically detailed; where this is not possible it must be functionally detailed.

The way in which the schematic is drawn will, to some extent, determine the architecture of the product (eg is 'control' a single element or distributed around the product?).

It may be necessary to draw several schematics − then choose the one that seems to suit the product best.

2/. Cluster the elements. Examine the elements and attempt to cluster them into chunks. There are guidelines:

Geometric integration and precision. High precision mechanical and optical parts can be grouped into one chunk (eg CD player optical/focus system).

Function sharing. When one component can implement several functional elements, these elements should be clustered together (eg a housing with brackets, location holes, heatsink).

Capabilities of suppliers. Having a good supplier may encourage a team to cluster elements in a particular way.

Localisation of change. If the team suspects that one element of the product may need altering later, then that element should be isolated into its own chunk.

Accommodating variety. Elements should be clustered so that a variety of models can be manufactured using the basic chunks.

3/. Create a geometric layout. Draw or model the product so that the relative positions of all the chunks can be seen and the practicality of the design judged. Geometric interfaces should be studied. Think about the mechanical/electrical layout of a VCR.

4/. Identify fundamental and incidental interactions.

Fundamental interactions are the desired paths between the chunks (eg electrical signal and power flow in a circuit). Incidental interactions are those due to the geometrical arrangement of the chunks (eg thermal transfers, vibration, EMC issues).

It can be useful to draw an interaction graph or interaction matrix which represents the incidental interactions. Knowledge of the incidental interactions develops as the product design progresses.

INDUSTRIAL DESIGN

All products are designed for the end user − who must 'interact' with the product. As Design Engineers we are involved mainly with the technology and manufacture of the product − but, increasingly, we need to become involved with the Industrial Design (ID) aspects.

Industrial Design deals with:

The product's aesthetic appeal (how it looks and feels)

The product's functional interfaces (how it is used) − ergonomics

With increasing global competition, companies are using ID more and more − to satisfy customer needs and to differentiate their products.

BACKGROUND

Industrial Design originated in Germany and Switzerland in the early 1900's. Whereas US and British companies tended to employ artists to package their products, the Germans and Swiss employed engineers and technicians. This led to:

'Form follows function' − less ornamentation.

The Bauhaus movement − simplicity, geometry, precision.

This concept of industrial design spread to the UK in the 1930's but has only reached the US and Asia within the last 20 years.

Many US products have traditionally had non−functional features (eg tail−fins on cars).

Many US and Asian products still have non−functional decoration (eg HiFi's, TV's). Compare with European products.

−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−ooOoo−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−−

There are five critical areas that ID looks at:

1/. Utility − each feature should be clear to the user (user friendliness).

2/. Appearance − the shapes, colours and proportions should make the product attractive.

3/. Easy maintenance − should be clear how the product is dis−assembled for service.

4/. Low cost − the form and features should be cheap to tool for manufacture (how much does a curve cost?).

5/. Communication − product should communicate the manufacturer's identity and culture.

The effort put into ID on a product depends on the product's market. Low−volume

technical/industrial products may have little spent on ID. High volume, interactive, products such as cars, VCR's, mobile 'phones will have a large ID investment.

WHICH PRODUCTS NEED ID?

The importance of ID depends on the product.

Consider the ergonomic needs:

1/. Ease of use − very important if the product has a lot of technical features (VCR, photocopier, mobile 'phone). Also important for emergency/safety equipment and life−critical equipment (in a hospital, aeroplane). Each feature must communicate its function.

2/. Ease of maintenance − either make it maintenance free or get the product to communicate its needs (eg photocopier).

3/. How many user interactions are required? − a door knob has only one interaction; a calculator has many buttons including 'second function' keys.

4/. Any novel interactions? − do you operate it differently from standard (eg non−QWERTY keyboard). Very important when safety is an issue.

5/. What are the safety issues? − how will the product be used? Children/elderly? Medical? High voltage?

Now consider the aesthetics:

1/. Product differentiation − in a stable, mature market, ID is very important (eg cars). Non−visible, technology−driven products are less sensitive to ID (eg disc drives).

2/. Image and fashion − clothes, cars, watches, 'phones, TV and HiFi. The look and feel is important. People 'buy a brand' − eg Mercedes cars, Bang and Olufsen electronics.

The design team need to decide whether ID is necessary for their product.

Remember, there will be costs:

Direct cost of the ID personnel − eg ?700/day.

Manufacturing costs − expensive shapes, colours, textures, special buttons etc.

Time cost − longer lead time for the product.

An Open University study of 221 products found that using ID increased profits in 90% of cases and increased sales by an average 41%.

If done properly, ID helps you sell more, and sell for more.

PRODUCT IDENTITY

ID can give a 'visual style':

Apple Computer − upright style, neutral colour.

Bang and Olufsen − visually impressive and geometric.

Motorola 'flip − phone'

BMW cars − classic style and front grille.

Dyson vacuum cleaner.

THE ID PROCESS

A big company will have its own ID department; a small company will 'contract−in' from a local consultancy. Either way, the ID people will need to

work with the engineering team. The ID process involves six discrete phases;

1/. Customer needs. The industrial designers will look at how the product is going to be used − they are likely to be more skilled than the engineers at predicting how the user will interact with the product.

Decide shape, size, colour of indicators and buttons etc.

Forces and movements required to operate the product.

2/. Conceptualisation. While the engineers concentrate on the technical functions, the industrial designers concentrate on the product's form and user interactions;

Make many sketches and models.

Often ID ideas are technically non−feasible (need to talk to the engineers).

May promote the concept at a trade show to gauge public reaction.

May render the product using CAID 3−D software.

3/. Preliminary refinement. The designers make soft models − using foam, balsa wood etc.

Cheap and quick method.

Enables product to be held and felt.

4/. Further refinement and selection. Designers make hard models (cut or moulded from plastic) and draw renderings to help decide the final concept.

Renderings are very detailed colour drawings − usually showing the product in use. Renderings are shown to customers and focus groups.

Hard models are coloured, textured and have 'semi−working' features (knobs that turn, sliders that move).

5/. Control drawings. The designers produce control drawings which document product functionality, features, dimensions, surface finishes and colours.

Control drawings are NOT engineering drawings.

They are used to make final prototypes and as a source for the engineering drawings.

6/. Liaison with engineering and manufacturing. The industrial designers work closely with the engineers throughout the subsequent stages of product development − right up until launch.

ASSESSING THE QUALITY OF THE ID

When the industrial designers have finished their work we can try to quantitatively assess

the quality of the ID:

1/. User interfaces − Is the product's use intuitive? Are all the features safe? Can you find the power switch?

2/. Emotional appeal − Is the product attractive? Does it look good quality? Would you like to own one?

3/. Maintenance − Can you clean it easily? Can you change the batteries easily?

4/. Use of resources − Are materials sensibly chosen? Are there unnecessary features?

5/. Product differentiation − Does the product look memorable? Does it enhance the corporate identity?

As engineering design and industrial design continue to converge, many industrial design consultancies are now employing engineers so that they can offer a complete 'product design' service − just leaving the manufacturer to do the detail design work.

DESIGN FOR MANUFACTURE

What is Design For Manufacture (DFM)?

Many teams practice 'Design For X' (where 'X' is reliability, robustness etc.)

The most common is Design For Manufacture, which also incorporates Design For Assembly (DFA).

Cost of manufacture is the main determinant of the economic success of a product − it sets the profit margin and the sales volume. Consider:

Sales volume and price are largely set by product quality.

A successful design should be high quality with a low manufacturing cost − this enables a high profit margin.

DFM is a methodology for achieving this goal.

Successful DFM requires a cross−functional team (design engineers, manufacturing engineers, accountants and production personnel) and a detailed understanding of production processes.

DFM must be performed throughout the development process − it can't be 'bolted−on' later.

At the concept generation phase, each concept should have a Bill Of Materials (BOM) to keep an eye on component costs.

During system level design, the team should break up the concept into components (clusters, chunks) based on the manufacturing implications.

A DFM METHODOLOGY

There are five steps to the DFM methodology:

1/. Estimate the manufacturing costs.

Companies use the unit manufacturing cost as the cost metric for a product − it is defined as the total manufacturing cost for a period (say, 3 months or a year) divided by the production volume for that period.

The total cost will comprise:

Component costs − these will include the cost of standard parts and custom parts.

Assembly costs − these will consist of the labour costs, plus the costs of all tooling and equipment.

Overhead cost − this incorporates all the other costs. It subdivides into two:

Support costs − covers materials handling, equipment maintenance, QA and shipping costs.

Indirect allocations − these are costs that cannot be assigned to any one particular product, for example building costs, security, heating etc. DFM is not relevant here.

Manufacturing cost estimation is fundamental to DFM and therefore it is essential to have an up−to−date BOM for the product.

Some of the material will have associated non−recurring expenses (NRE's), such as specialised tooling and set−up costs (eg IC masks, test software).

To complete the BOM, the firm's overhead costs (for ordering and handling) should be added.

Remember that parts price falls with volume; this is particularly true for

semiconductors.

For high volumes, custom parts become viable.

Cost of assembly is also critical. Very low volume products are usually assembled manually; automatic assembly is used at higher volumes.

Manual assembly costs can be estimated by summing the time of each assembly operation and multiplying by the labour rate. Special software is available to estimate particular processes, including PCB assembly.

Automated assembly requires heavy investment in specialised equipment (eg IC Manufacture!).

Estimating overhead costs is notoriously difficult. Generally companies apply a fixed percentage to all other costs; eg calculate overhead cost as 40% of the total parts and labour cost. Many firms do not even know their real overhead costs.

2/. Reduce the component costs.

For most highly−engineered volume products, the component cost is most significant. The product designer must fully understand all the manufacturing processes and their costs, and then seek to minimise component costs:

Parts should not be over−specified (eg don't use a 1A voltage regulator to supply 100mA).

Use the lowest level of technology that will do the job − TTL and CMOS are OK! Only use an FPGA if it works out cheaper. Remember, the customer is not buying technology.

Do not specify tight tolerances (mechanical or electrical) unless they are essential.

Design for loose tolerances.

Try to use a small range of parts; eg design for just one type of npn transistor, one pnp transistor, just a few values of R and C. This increases purchasing volumes, makes stock control easier and reduces assembly costs.

Attempt internal standardisation of parts (ie all designers should work from a common 'parts bin').

Buy−in ready−assembled 'chunks' from specialist suppliers (eg CD laser head,VCR head−drum assembly).

3/. Reduce the assembly costs.

DFA is a subset of DFM. Contrary to popular belief, for a well−designed product, assembly contributes only a small part of the total cost.

The product design can be evaluated for DFA by using the DFA index − this assumes that the minimum time for assembling a part is 3 seconds: (theoretical minimum number of parts) x 3 seconds

DFA Index =
−−−

estimated total assembly time

The theoretical minimum number of parts is obtained by using the checklist below − only if you answer 'yes' should the part be separate:

1. Does the part move relative to the rest of the product?

2. Is the part made of a different material to the rest of the assembly?

3. Does the part have to be separated from the rest of the assembly for repair or access?

Integrate parts where possible − this leads to a cheaper, more precisely controlled assembly.

Make assembly easy − each component should be assembled with a single linear motion from above, using one hand. The part should 'self−align' and lock immediately into the assembly. This is known as z−axis assembly.

4/. Reduce the support costs.

This is achieved by using the smallest number of standardised parts:

Reduces inventory (paperwork, stores floorspace).

Reduces number of workers required for assembly.

Reduces demands on engineering support and quality control.

The 'complexity' of the support structure can also be reduced, for example:

Using a smaller number of suppliers will proportionately reduce ordering and liaison work.

Use the minimum number of production processes.

Use the minimum number of major tools in the production process.

Another important part of DFM is to anticipate production errors − this is error proofing. Production errors can cost a lot of money.

Exaggerate differences between parts, use:

Colour coding.

Legends on PCB's.

Connectors and parts that fit only one way.

5/. The impact of DFM on other design factors.

Manufacturing cost is important, but don't allow DFM to interfere with other project−critical factors. For example:

Development time. The cost benefits of DFM may not be worth the delay to the project.

Development cost. Same applies as for development time − however, good design practices should ensure low manufacturing costs within development time and cost constraints.

Product quality. Very often DFM will result in a simpler, cheaper, lighter and more reliable product. Sometimes this will not be the case − so keep in mind those aspect of the design that are important for quality.

External factors. Sometimes there are implications beyond the d evelopment team:

Component re−use. Sometimes an assembly can be re−used in other products (very common in electronics). It is worth pursuing DFM for such an assembly.

Life−cycle costs. Sometimes products present a social cost not accounted for during design (eg toxic substances). Products may also incur service and warranty costs. Keep these in mind during the DFM process.

DFM − Nicholas Hayek, Chief Executive Officer (CEO) of SMH, Switzerland told the Harvard Business Review:

"First, it is possible to build high−quality, high−value, mass−market consumer products in a high−wage country at low cost. Notice I said build, not just design and sell. We build all of our Swatches in Switzerland, where the most junior secretary earns more than the most senior engineer in Thailand or Malaysia. We are all global companies competing in global markets. But that does not mean that we owe no allegiance to our own societies. We must build where we live. When a country loses the know−how and expertise to manufacture things, it loses its capacity to create wealth and financial independence. We have to change the reflex, the instinctive reaction that if a company has a mass−market consumer product, the only place to build it is in Asia or Mexico. CEO's must say to their people, 'We will build this product in our country at a lower cost and with a higher quality than anywhere else in the world.' And they have to figure out how to do it."

PROTOTYPING

In this section of the module we will look at what a prototype is and look at a methodology for effective prototyping.

The word prototype refers to production of a trial approximation of the final product. The term can be used as a noun, verb or adjective:

Engineers prototype a product (verb).

Industrial designers produce a prototype of their concept (noun).

Software engineers produce prototype programs (adjective).

All practising engineers need to engage in the process of prototyping − to confirm predictions, try out new ideas or demonstrate new possibilities to customers. Effective prototyping is not easy − it takes planning and forethought.

TYPES OF PROTOTYPE

Prototypes can be classified along two dimensions:

The first is PHYSICAL versus ANALYTICAL:

Physical prototypes are artifacts which look and feel like the product or work like the product. They prove the concept.

Analytical prototypes represent the product in an intangible (usually mathematical) way. Examples include equations and computer simulations.

The second dimension is COMPREHENSIVE versus FOCUSED:

Comprehensive prototypes implement most, or all, of the attributes of the product. They are what most people understand as prototypes.

Focused prototypes are built to examine just one feature of the product. For example, using Veroboard to test a circuit function, or making a mock−up of a housing from foam.

Different prototypes are used at different phases of the project. Typically, a couple of focused prototypes are built in the early stages (a 'looks like' and a 'works like'). If these are acceptable a comprehensive physical prototype (the 'beta prototype') is built for customer evaluation.

The xy−plot shows the different types of prototype that can be used. Note that focused prototypes can be either physical or analytical, whereas comprehensive prototypes must generally be physical. In electronics, some prototypes contain a combination of physical and analytical elements (eg a microprocessor−based product with hardware and software).

WHAT ARE PROTOTYPES FOR?

Learning

Here, prototypes are used to answer two questions:

Will it work?

How well does it meet customer needs?

Communication

A prototype vastly improves communication with top management, vendors, production staff and financial backers. It is much better to show a physical prototype than sketches or simulation results.

Demonstration of a physical prototype is excellent for provoking feedback.

Integration

Prototypes can be used to ensure that all the different parts and subsystems will fit together and work together. This makes the team work together better.

Comprehensive physical prototypes are required to demonstrate integration.

Alpha prototype − first comprehensive prototype.

Beta prototype − second comprehensive prototype (for 'customer debugging').

Preproduction prototype − final prototype prior to launch.

Milestones

Prototypes can be used to demonstrate that engineers have achieved goals and met the project schedule. Can be used to check that certain critical technical criteria can be met to enable the project to proceed.

SOME GENERAL PRINCIPLES

Analytical prototypes are more flexible than physical prototypes.

Using computer simulations allows many possible circuits to be evaluated. It's cheap and fast to change things − but you have to buy the EDA system first.

Physical prototypes are required to detect unanticipated phenomena.

For example, EDA is poor at detecting thermal, stray capacitance and EMC problems. Moreover the analysis is only as good as the data put into the software.

A PROTOTYPING METHODOLOGY

It is possible to get mired in a 'hardware swamp', where a lot of effort is given to developing and debugging hardware prototypes without advancing the project much. Before starting work on prototyping a plan must be adopted.

1/. Define the purpose of the prototype.

Recall the four purposes of prototyping.

Concentrate on the areas that the team needs to cover.

2/. Establish the level of approximation of the prototype.

How closely must the prototype resemble the finished product?

The best prototype will be the prototype that will serve the purpose decided in Step 1.

3/. Outline the experimental plan.

Since the prototype is an 'experimental product', the process should follow experimental practice:

Identify the variables.

Formulate a testing strategy.

Decide on measurements to be performed and criteria.

Decide how results will be analysed.

4/. Create a schedule for procurement, construction and test.

Producing the prototype can be considered a 'subproject' within the overall roduct development program.

Produce a schedule for the prototype engineers; there are three important dates:

When parts are available for construction.

When prototype is ready for switch−on.

When test results are available to the team.

MILESTONE PROTOTYPES

Few well engineered products are developed without at least two prototypes; typically three re involved: alpha, beta and preproduction prototypes.

Alpha prototypes are used to determine whether the product will work as intended. Material and geometry is as for the final product, but prototype production processes are used.

Beta prototypes are used to iron−out 'bugs' and verify reliability. They are given to customers for checking. Parts are similar to those used in production − often from the intended suppliers.

Preproduction prototypes are made in small numbers on the production line to test processes and check assembly capability.

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APPROVAL TESTING

APPROVAL TESTING

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COST

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C

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New businness good

Target

New business bad

BAD

GOOD

COST

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