

# Design for Environment Attributes of the AT&T 5ESS® Switch

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AT&T's goal is to be a leader in applying sound environmental policies in the manufacture and operations of its products. To provide a benchmark assessment for one of AT&T's major product lines, this paper reviews the design for environment (DFE) attributes of the AT&T 5ESS® switch.

Although formal DFE processes did not start in 5ESS design until 1993, the efforts thus far have resulted in a 5ESS design and assembly process that is environmentally responsible. This benchmarking exercise also is an opportunity to identify items in design and assembly that can be improved on, and modifications suggested by this review are now being made to the design rules used by AT&T Network Systems' physical designers.

## Introduction

AT&T physical designers employ design for X (DFX) <sup>1</sup> design tools, where X may stand for a specific process, such as assembly, manufacturing, safety, or recycling. In theory, DFX includes design for environment (DFE), a process that considers the environmentally related aspects of both product design<sup>2</sup> and process design.<sup>3</sup> Individual AT&T products are being designed with the DFE philosophy in mind,<sup>4,5</sup> but the lack of standardized procedures and involvement of subject matter experts has heretofore resulted in relatively little formalized DFE activity in AT&T or elsewhere.

The 5ESS® switching product line is an example of equipment that has not historically been designed a priori with DFE principles fully integrated into the process. However, because of AT&T's policy of environmental responsibility, much effort has gone into the "greening" of AT&T engineering, the current designs embody many environmentally favorable characteristics even though these may not have been formally inventoried. Although formal DFE processes did not start for the 5ESS switch until 1993, the efforts thus far have resulted in a design and assembly process that is environmentally responsible.

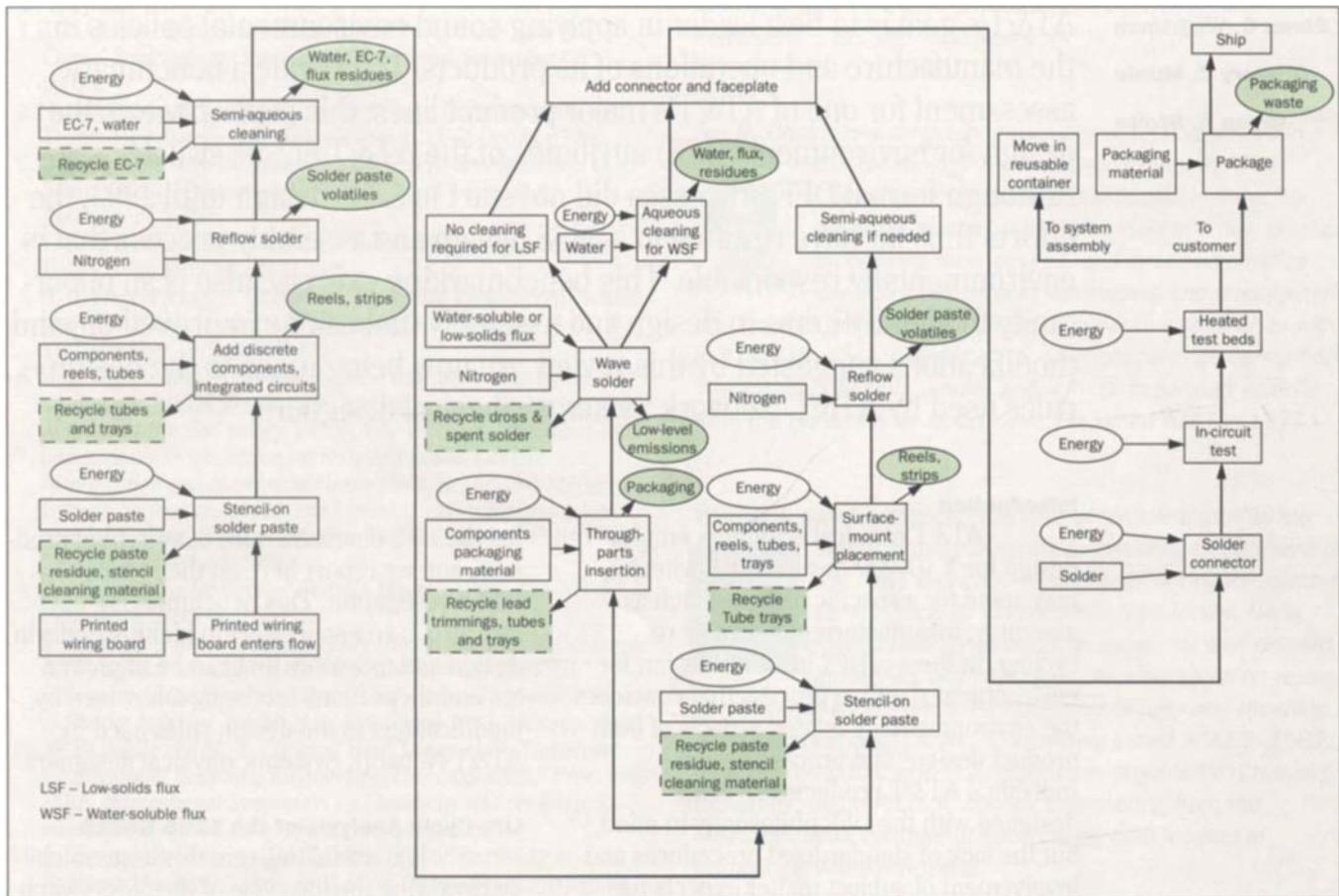
To investigate the degree to which such a perception is accurate, we have stud-

ied the DFE characteristics of switching products, and we report here on the results of that investigation. This benchmarking exercise also is an opportunity to identify items in design and assembly that can be improved on, and these items are being addressed by modifications to the design rules used by AT&T Network Systems' physical designers.

## Life Cycle Analysis of the 5ESS Switch

It is useful to begin this assessment by reviewing the life cycle of the 5ESS switch and the constituent parts from which it is made. The life cycle can be summarized in the following stages:

1. *Fabrication* of individual components and chips, including very large-scale integrated (VLSI) circuits, resistors, capacitors, printed circuit boards, power packs, and frames.
2. *Circuit-pack assembly*, in which discrete components, integrated circuits, and connectors are mounted on printed circuit boards.
3. *System assembly*, in which circuit packs and other electronic modules are assembled into frames, system cabling and wiring are added, software is loaded, system tests are performed, and finished systems are packaged and shipped.



4. *In-service use*, in which the 5ESS system performs the call and data switching actions desired by the customer.
5. *Recycling and disposal*, in which materials from obsolete systems are recycled or are disposed of in landfills, by incineration, or by other disposal techniques.

#### DFE Characteristics of Circuit-Pack Processing

This section discusses the assembly of circuit packs, and the efforts being made to reduce unwanted air emissions and liquid and solid waste, while also reducing energy use.

**Assembly Flow.** The assembly flow diagram for a typical circuit pack is shown in Figure 1. The flow of the product proceeds from the bottom left of the diagram to the top, while components and processing chemicals enter from the left of the flow. Waste products leave processing steps to the left if they are part of a recycling stream, to the right if they are discarded. The semi-aqueous cleaning step is omitted if no-clean technology can be used, and through-hole parts insertion is sometimes needed.

**Figure 1.** The assembly flow of a typical circuit-pack is shown for the manufacture of mixed technology boards at the Oklahoma City Works. The product flow proceeds from the bottom left of the diagram to the top, while components and processing chemicals enter from the left of the flow. Waste products leave processing steps to the left if they are part of a recycling stream, to the right if they are discarded. The semi-aqueous cleaning step is omitted if no-clean technology can be used, and through-hole parts insertion is sometimes needed.

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Although testing and, if necessary, repair functions occur at several points during the product's manufacturing process, the basic assembly functions are:

1. Placement and soldering of surface-mount components, followed in some cases by a flux cleaning step;

**Panel 1. Abbreviations, Acronyms, and Terms**

ABS — acrylonitrile butadiene styrene  
CFC — chlorofluorocarbon  
CRT — cathode ray tube  
DFE — design for environment  
DFX — design for X  
EPA — U.S. Environmental Protection Agency  
ESD — electro-static discharge  
HDPE — high-density polyethylene  
ISO — International Organization for Standardization  
LSF — low-solids flux  
OCW — Oklahoma City Works  
OEM — original equipment manufacturer  
ODS — ozone-depleting substances  
perc — perchloroethylene  
VLSI — very large scale integrated  
WSF — water-soluble flux

2. Placement and soldering of through-hole parts, followed in some cases by a flux cleaning step;
3. Placement and soldering of the connector and faceplate, followed by a flux cleaning step;
4. Circuit-pack test; and
5. Transport to system assembly or packaging, followed by shipment to the customer.

**Air Emissions.** Printed circuit boards in traditional processing require the removal of the solder flux, a manufacturing step that historically has involved the use of chlorofluorocarbon (CFC) solvents. Because of the ozone depletion potential of CFCs,<sup>6</sup> however, the Oklahoma City Works (OCW) does not use CFCs or any ozone depleting substances (ODSs) in its manufacturing. Alternative approaches include:

- Use of semi-aqueous solvents, such as EC-7,\* a natural terpene hydrocarbon product that is largely d-limonene;
- Selection of a no-clean solder flux or a low-solids flux (LSF) with such a low concentration of solids that cleaning is unnecessary; or
- Use of water-soluble flux (WSF) and water-only aqueous cleaning.

AT&T was instrumental in developing these alter-

natives. For example:

- The terpene hydrocarbon used in EC-7 material was jointly developed by AT&T Bell Laboratories and the material vendor.
- The WSF was jointly developed by engineers at the OCW and AT&T Bell Laboratories and as such is a patented material.
- The low-solids flux is under evaluation for replacement by a proprietary material also developed at the OCW.

All of these methods are in use at the OCW at different stages and for different types of circuit-pack manufacture, since processing time, testing, and lubricant additions impose a variety of requirements.

Use of chlorocarbons, that is, perchloroethylene or "perc," has been eliminated over the past three years. No-clean options have replaced perc in the various soldering operations in which it was used as a cleaning material. For example,

- Connector cleaning and the lubrication of connectors and programmable devices for socketing into the final assembly have been re-engineered to eliminate perc, and
- Use of pre-cleaned and lubricated connectors, no-clean solder connector attachments, and an AT&T patented system for programmable device socket lubrication have eliminated "perc" as a cleaner and a carrier of the lubricant in assembly.

Small quantities of other chemicals are exhausted from the facility and tracked in the overall air emissions inventory. These include deminimus, or trace, levels of solder paste volatile components, and high-vapor-pressure solvents such as acetone, toluene, and isopropyl alcohol. Air emissions are tracked by source and reported on an annual basis. Currently, the use of these materials is well below the quantity thresholds that must be reported to the U.S Environmental Protection Agency (EPA).

All ODS use has been eliminated in the factory in both the assembly and the heating and air-conditioning processes. AT&T engineers at the OCW have eliminated the CFCs in the air-conditioning operation by use of a heat exchange system based on the water hydration/dehydration of lithium bromide. This system also has reduced air-conditioning energy consumption by approximately 33 percent. Variable speed fans have been installed for ventilation with an accompanying drop of about 20 percent in energy consumption for this operation.

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ODSs also have been eliminated in all refrigeration and cooling operations at the OCW. Alternative materials have been introduced for these processes, and engineering and maintenance personnel have been extensively trained in their use.

**Liquid Wastes.** Relatively minor use of the solvents isopropyl alcohol and acetone occur at several points in the assembly line, in the repair and touch-up loops, and in some unit assembly operations. Used solvent is collected for "thermal recycling," that is, incineration and energy recovery by an outside vendor.

WSF is used to solder a large percentage of circuit packs at the OCW. Waste water from an associated cleaning operation is sent to the sanitary sewer after filtering. (Obviously, the best approach is to use no-clean technology when this is consistent with process requirements.) The EC-7 cleaning material used was introduced as an alternative to the CFCs used in the cleaning of surface-mount assemblies.

Rinse water from the semi-aqueous and aqueous cleaning steps contains small amounts of flux residues and very low concentrations of tin, lead, and copper from the soldering process and the printed circuits themselves. Typical trace metals concentrations have been found to be one to two orders of magnitude below existing federal discharge standards and are well below either present or anticipated regulatory requirements. This rinse water is filtered and sent to the sanitary drains.

**Solid Wastes.** Solid wastes arising from circuit-pack manufacture are not abundant. Primary among them, however, are the lead residues from the wave soldering operation and from such processes as cleaning the solder paste screen and the aqueous processing machines. At present, the wave solder, cleaner, and solder paste residues are recycled through agreements with metals suppliers.

So long as lead solder continues in use—good alternatives have not yet been developed<sup>7</sup>—minimizing these residues will be the preferred action. One minimization program that has been deployed is inerting the wave solder operations with nitrogen. Not only does this improve the quality of solder joints, but the inert atmosphere significantly reduces the amount of lead solder dross generated during the operation. Typical numbers for reduction in dross by use of nitrogen inerting are on the order of 90 percent.<sup>8</sup>

A second class of solid waste consists of packaging material entering the facility from suppliers of circuit-pack components. AT&T component packaging is returned to the supplying facility via an internal shipping agreement. External suppliers' packaging is shipped back to the original manufacturers or their designated original equipment manufacturers (OEMs) in a "return-to-vendor" program that is contractually arranged with the local purchasing department. At present, most, but not all, suppliers are covered by this type of arrangement. More and more component suppliers are offering their customers reductions in the price of their products based on a pre-determined allotment of returnable packaging.

Specific packaging issues now being addressed are those dealing with the plastic reels containing surface-mount components, the plastic tape that holds those components on the reel, and the cardboard reels used for hand-assembled components. Most recycling programs developed for these types of materials depend upon how close the vendor is to the plant, which determines the shipping and processing costs involved.

Work needs to take place at the corporate level on standards for recyclability and vendor take-back programs, where packaging materials are returned to a vendor for reuse. However, as more companies enter the recycling business, the materials constraints and inefficiencies of the plastics recycling market should improve and, thus, allow more flexibility with plastic solid waste.

Another waste stream that must be considered is that associated with the through-hole parts insertion process. Through-hole insertion into the printed wiring board often requires a trimming operation on the lead. At the OCW, all scrap from the trim operation is collected and recycled through AT&T's metals reclamation program.

**Energy Efficiency in Manufacturing.** The energy efficiency of the circuit-pack manufacturing process is relatively high. The energy demands of processing constitute about half of all energy consumed at the OCW. An analysis of actual use by the assembly step has shown that testing is a significant energy user. Manufacturing engineers are working on methods to decrease this energy demand, while maintaining suitable facilities for circuit-pack test. Automated "power-down" of the equipment when not being used, an approach now being studied by personal computer manufacturers, also has been considered.

**Table I. The 5ESS process audit matrix**

Major process	Design focus			
	Solid waste	Liquid waste	Gaseous waste	Energy use
Surface-mount assembly	1	2	2	2
Progressive assembly	2	2	2	2
Wave solder	2	2	2	2
Connector, faceplate assembly	2	NI	2	2
Circuit-pack test	NI	NI	NI	2

1 = little concern, 4 = highest concern, NI = no impact

**Table II. The 5ESS system assembly process audit matrix**

Major process	Design focus			
	Solid waste	Liquid waste	Gaseous waste	Energy use
Subassembly integration	2	NI	NI	1
Cable integration	1	NI	NI	1
Circuit-pack integration	NI	NI	NI	1
System test	NI	NI	NI	2

1 = little concern, 4 = highest concern, NI = no impact

The energy use of the entire OCW facility is being improved with such programs as the staged installation of variable-speed motors on ventilating fans and the replacement of CFCs in the air-conditioning with more energy-efficient materials.

Table I shows an assessment of each of the four process design attributes for the five different stages of assembly. These ratings are largely estimates, rather than the result of a detailed quantitative scoring system, since such systems are in rather early stages of development.<sup>9</sup>

The numbers indicate the degree of concern from 1 (little concern) to 4 (highest concern). NI indicates "no impact." In general, the ratings are quite satisfactory. The only item that warrants attention is the energy used by the testing machines.

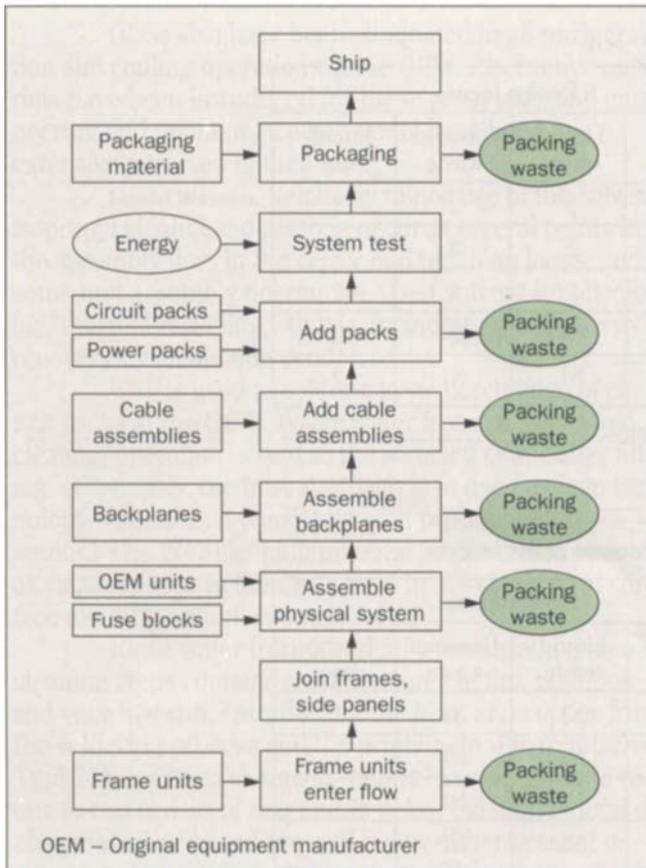
#### **DFE Characteristics of System Assembly**

This section deals with waste and energy issues involving 5ESS system assembly.

**Assembly Flow.** The flow diagram for 5ESS system assembly is shown in Figure 2. The flow of the product proceeds from the bottom of the diagram to the top, while components and subassemblies enter from the left of the diagram. Waste products would leave processing steps to the left if they are part of a recycling stream, to the right if they are discarded.

Although testing and, if necessary, repair occurs during the system assembly process, the basic functions are:

1. Integration of the various nonelectronic subassemblies (fuse blocks and backplanes) with the frame;
2. Integration of the necessary cable assemblies;



**Figure 2.** This figure shows the 5ESS system assembly flow diagram for the Oklahoma City Works. The product flow proceeds from the bottom of the diagram to the top, while components and subassemblies enter from the left of the diagram. Waste products would leave processing steps to the left if they are part of a recycling stream, to the right if they are discarded.

3. Insertion and integration of circuit packs and power packs;
4. System test; and
5. Packaging and shipment to the customer.

**Air Emissions and Liquid Wastes.** There are no significant air or liquid waste emissions arising from 5ESS system assembly.

**Solid Wastes.** Solid wastes arising from 5ESS system assembly are almost entirely due to the packaging entering the facility as part of the arriving frames, subassemblies, and components. For example, frames are

received from suppliers on wooden pallets. In the case of a local supplier, the pallets can be economically returned; but in the case of a major out-of-state supplier, those pallets are compacted at the OCW and used as mulch.

A complicating factor is the construction of pallets with cardboard sides and runners that are stapled to the wood. This approach makes recycling difficult and time consuming because of the mix of materials. In other cases, components such as cable hangers from different suppliers are packaged differently, causing unnecessary diversity in the packaging.

Work is now in the planning stage to reduce both the quantity and diversity of incoming packaging by adding packaging specifications to the suppliers' contracts so that the materials can be more easily and efficiently recycled.

**Energy Efficiency in Manufacturing.** The energy use previously described in the circuit-pack manufacturing process is a similar issue in the 5ESS systems assembly operation. Although circuit packs are designed for energy-efficient use by customers, there are no specific energy reduction measures employed during the testing of the assemblies at the OCW. The energy used during these test procedures should be examined to see if reductions are possible.

Table II shows an assessment of each of the four process design attributes for the five different stages of system assembly. The only concerns of note are the volume and diversity of the incoming packaging and energy use associated with system test.

#### **DFE Characteristics of Product Design**

This section discusses the DFE characteristics of 5ESS product design, including materials, packaging, customer use, and recycling.

**Choosing Materials.** The 5ESS designers have, in general, made good choices of materials from the standpoint of DFE. Few of the materials have any toxicity problems and those materials of some concern are present in small amounts or in situations where the hazardous aspects are minimized. The use of scarce resources is modest, such as copper and gold plating on the backplane pins in backplane pins, circuit-board conduction paths, and cable conductors. Both materials, however, may become restricted in the next quarter century.<sup>10</sup>

Notwithstanding the above, several materials

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should be improved or replaced:

- *Lead solder* on circuit packs. The bioavailability of this lead is not great, and detailed investigations of alternative solders, on an industry-wide basis, have not yet yielded a suitable replacement. Nonetheless, the toxicity of lead and its environmental persistence is such that its use anywhere is undesirable if alternatives can be developed.
- *Lead-acid batteries* for reserve power. The recycling of the lead in storage batteries is better than 80 percent,<sup>11</sup> so little of this material must be disposed. The recycled material currently enters the automotive battery market, and 5ESS reserve power batteries continue to use virgin lead because of its purity. There is impetus here to work with suppliers to improve the purity of recycled lead, but no alternative technologies for reserve power systems appear viable.
- *Metal frames, bolts, and screws* use zinc chromate coating for corrosion resistance. The hexavalent chromium in zinc chromate is biotoxic and, if improperly disposed of, will eventually enter the soil or water waste flow. Legislation to restrict uses of hexavalent chromium is a distinct possibility and would raise an industry-wide problem. As a general policy, removable organic coatings are preferred.
- *Phosphors* on some cathode ray tube (CRT) screens of the 5ESS system controllers contain several heavy metals that, if not properly disposed of, may eventually enter the soil or water waste flow streams. If the CRTs that are used can be designed to contain little or no heavy metals, the product will more closely adhere to DFE principles.
- *Recycling* items or materials purchased from suppliers is another opportunity for improvement. Such an approach is essential for all designers if materials flows are to be sustainable in the long term. Among the possibilities being considered are the use of recycled metals in equipment frames, recycled plastics as ingredients of plastic parts, and recycled material for boxes and other packaging items. In every case, of course, the recycled material would need to meet current performance specifications.

**Product Packaging.** There are two separate aspects of product packaging. One is the circuit packs themselves, many of which are shipped directly to the customer as replacements or running spares rather

than being used as components of new 5ESS systems. The current packing approach is to place the circuit pack in an electro-static discharge (ESD) protective plastic bag, which is then placed in a corrugated box that has thick plastic ESD foam attached to its walls. As there is no provision for shipping several circuit packs in a single container, the volume of circuit-pack packaging is substantial, though it should be noted that it has been shown to be a very dependable packaging technique.

Packaging is minimized not only because the customer desires it, or because such minimization reduces the costs of purchasing and using the packaging material. Germany *requires* the manufacturer or dealer to accept the returned packaging immediately after the product is purchased, and it probably will be the law soon in other countries, especially in Europe. This is a strong incentive to decrease packaging volume, weight, and the diversity of materials as much as possible to minimize the costs of managing the returned packaging.

Over their lifetime, many circuit packs are returned to the OCW for repair or refurbishment. These packs are then returned to the customer in a new box. The design of reusable containers to minimize the use of new boxes is under consideration. As with the pallets discussed above, a complicating factor for recycling is the mix of materials. Many of the current isocyanate "fill 'n foam" materials are sprayed directly on the cardboard, which reduces its ability to be recycled. This design is intended to prevent the movement of the assembly in the package during shipment, but it is not in conformance with good DFE principles.

**Environmental Impacts During Customer Use.** The 5ESS system has a very minimal environmental impact as a result of in-service operation. One that deserves attention is the power required for operation. This power is consumed by several sources. Primary among these is the "loop" power to customer phones. A second use of energy is the control circuitry for the switching module.

Power in the loop—the line connecting the customer to the central office—is vital for maintaining phone service during commercial power outages. However, methods of reducing power consumption—while still ensuring reliable service—are being considered.

Power for control circuitry is being closely monitored. The need for efficient diagnostics, support

**Table III. The 5ESS product audit matrix**

Major component	Design focus			
	Choosing materials	Product packaging	Impacts during use	Recycling, reuse
Frames, shelves	2	3	1	3
Cables	2	NI	NI	2
Power, fans	1	NI	3	2
Backplane	1	NI	NI	2
Circuit packs	1	3	NI	3
System controller	2	3	1	3

1 = little concern, 4 = highest concern, NI = no impact

of multiple new features, and increased distribution of network intelligence is driving an increased use of power for operation.

Minor levels of consumable materials required for operation include the periodic replacement of air filters in the cabinets and the use of computer paper in the system controller printer.

**Recycling After Customer Use.** Greater than 90 percent of the weight of a 5ESS system is reusable or recyclable with no design changes. Examples include the aluminum and steel frames and the steel or plastic shelves. The gold plating of the backplane pins is recoverable, as are the copper, nickel, tin, and lead of the circuitry.

Plastics recycling is continuing to expand. Major recycle streams for plastics such as acrylonitrile butadiene styrene (ABS) and high-density polyethylene (HDPE) have been established for the 5ESS switch. In addition, a recycle operation for scrap circuit-board material, such as FR-4, is under investigation. AT&T maintains its own recycling operation for all equipment owned by AT&T and for equipment from other companies on a negotiated basis.

AT&T is now considering changes in design rules to improve the design for recycling, such as:

- Quick disconnect arrangements that would allow ease of disassembly and still provide reliable vibration and shock resistance. Such arrangements have been used successfully in non-telecommunications industries.<sup>12</sup>
- Improved uniformity in the use of plastics in assembly, to reduce the number of recycle streams at disassembly.

- Identification marking of all plastic, as designated by the International Organization for Standardization (ISO).
- Elimination, if possible, of joining mixed materials. For example, circuit packs are very difficult constructions from which to recover constituent materials and components, a problem AT&T shares with the rest of the electronics industry.

In addition, some sub-system components can be recovered. The tin and lead from the solder and nickel from the component lead frames are recovered as by-products of the copper and precious metals reclamation process.

Table III shows an assessment of each of the four product design attributes for six different types of components. Materials choices are satisfactory, but several areas for improvement exist in the approaches taken to product packaging, power, and design for recycling.

#### **The Greening of AT&T**

As part of a corporate-wide effort, AT&T is investigating a variety of approaches to improve the environmental impact of its products. Some notable items now being considered for the 5ESS switch are listed below.

- Manufacturing.** Some of the manufacturing items being considered are:
- Developing specifications for plastic parts, metal structural components, and packaging material to encourage or mandate the use of some recycled material in their manufacture;
  - Investigating the use of methane from nearby landfills

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to provide part of the electrical power for the manufacturing facility;

- Working with suppliers to develop take-back agreements on plastic reels for surface-mount components;
- Working with suppliers to minimize the diversity of packaging material entering the facility, so that the recycling of solid waste may be optimized; and
- Minimizing the diversity of materials in outgoing 5ESS switch packaging, and developing a labeling scheme for the packaging to indicate appropriate recycling procedures to the customer.

**Design.** Among the design items being considered are:

- Investigating the design of subassemblies and components so that they can be joined with quick-release fasteners;
- Minimizing the diversity of metals used;
- Minimizing the types of plastics;
- Modifying design rules to mandate the marking of all plastic parts using the ISO standards; and
- Working with industry-wide committees to specify a standard recyclable plastic for component parts reels.

**Bell Labs Research and Development.** Included in the research and development items being investigated are:

- Devising alternate conductive fastening techniques for surface-mount components so that the use of lead solder can be eliminated;
- Investigating reserve-power sources that use recycled lead rather than virgin lead in reserve-power battery systems; and
- Developing returnable circuit-pack shipping containers that satisfy physical characteristic criteria and ESD criteria and are ultimately recyclable.

### **The Greening of the Industry**

The effective use of DFE principles requires information concerning environmental impacts throughout the product life cycle. To date, there has been very little partnering between subject matter experts in companies that extract, process, and recycle materials, or among companies that design, assemble, use, and maintain products.

However, the recently increasing level of inter-company activity promises to lead to a greening of the entire electronics "food chain." Essentially, this represents a drive not just for appearances, that is, public sales, but a substantial change in the way business is

done. This trend is creating new interactions among companies spanning the entire product life cycle—from the raw materials supplier, through device and printed wiring-board assembly, to circuit-pack and unit assembly, to shipping and customer use, and finally to the recovery of the used equipment for use or recycling within the supply chain.

AT&T's recent review of customer inquiries indicates that interest in the environmental aspects of 5ESS systems is increasing, although there are differences among customer expectations. A partial listing of these concerns includes:

- Product content information;
- Plans for the reduction or elimination of materials of concern;
- Product documentation, labeling, and marking;
- Manufacturing process information;
- Transportation and packaging information;
- Emissions and environmental effects resulting from product use or maintenance;
- Design for disassembly and design for recycling;
- Life-cycle evaluation; and
- Details on general environmental programs and activities.

Some customers want to clarify their legal responsibility and to be sure they comply with environmental laws. The material content of AT&T's products, and the recommended operation and maintenance procedures, assist in meeting these legal responsibilities.

Other customers want to document their environmental impact to address questions being raised by *their* customers. This group wants to ensure that environmental concerns do not detract from the reputation of their products and services.

Finally, some European customers want to enter into a deeper partnership with AT&T regarding the environmental aspects of 5ESS systems, with the hope of demonstrating that both they and their suppliers are sensitive to environmental concerns. These customers expect a definite market advantage to result from this partnership.

### **Conclusion**

From the standpoint of the DFE perspective, the processes used in the manufacture of the 5ESS switch are world class. The processes themselves gen-

erate relatively little solid, liquid, or gaseous waste, and much effort has gone into minimizing and recycling waste. Additional effort is being devoted to working with suppliers to minimize the diversity of the packaging material entering the facility and to tailor it for efficient recycling or to implement supplier packaging take-back programs. Process energy use is not excessive, although ways to reduce the amount of energy used and provide alternative sources of energy are being investigated.

At present, the product design's adherence to DFE principles can be improved. Materials choices are satisfactory, and the product's in-service impacts are minimal. Work is now underway to reduce the diversity of materials used in packaging and to optimize the recycling of equipment at the end of life.

AT&T has a corporate policy of environmental responsibility<sup>13</sup> that is now being applied to the designs of all AT&T products. The information contained in this paper demonstrates that the family of 5ESS products has a high level of environmentally responsible design. Improvements, however, have been suggested and steps should be taken to implement as many of them as possible.

This audit has demonstrated the usefulness of viewing an AT&T product from a DFE perspective, and deriving recommended courses of action that would be unlikely to arise from other corporate analyses. Of the many recommendations that resulted, some are being implemented quickly, while others will be implemented as designs are modified. Still others offer visions for the longer term, and have broad potential application across the AT&T product spectrum.

#### Acknowledgements

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#### \*Trademark

EC-7 is a trademark of Petrofirm Corporation.

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