Flat Conductor Cable Systems: Originally Developed For Space Flight, Useful For Commercial Applications

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ABSTRACT

Flat Conductor Cable (FCC) technology has now reached a level of development where it is being considered for, and used in, numerous interconnection projects. First developed for aerospace use, FCC is becoming a major contender for commercial wiring tasks as well. This presentation is designed to show why and how FCC has been able to make the transition from the aerospace to the commercial field.

FLAT CONDUCTOR CABLE AND CONNECTORS

What is FCC?

FCC is made up of flat, parallel conductors - usually bare or plated copper - which are laminated between thin flexible insulating films, or otherwise held in a flat, rectangular configuration. Rolls of FCC with various widths are shown in Figure 1.

The Basic Unshielded Cable

The most popular method used to fabricate these cables is lamination under heat and pressure. Other methods are weaving, extrusion and etching. Cable cross-sections depicting various ways of manufacturing FCC are shown in Figure 2. In laminated cable, the conductors are sandwiched between protective dielectric films, and held in place by a dielectric adhesive. Depending on the environmental, electrical and physical requirements, the films employed are polyesters such as Mylar (for low-cost cables), polyimides (e.g., Kapton), fluorocarbons (such as Teflon), and other suitable dielectric materials. Woven cable is made using commercial weaving techniques (the conductors being the warp and the insulation thread the woof) which space and securely hold the conductors in place. The weaving material may be glass fiber for high temperature or other fibers, using pre-insulated (varnished) conductors. Or, the cable is impregnated against moisture with flexible dielectrics, e.g., silicone. Extruded cables usually have thicker insulation in order to reach a certain characteristic impedance between conductors. In the fabrication of etched cable, copper foil is coated with a dielectric. The spaces between the conductors are then etched from the foil, and a top insulation layer is laminated, or applied by other methods.

Shielding of Cable or Conductors

If required, shielding can be accomplished by:

1. Physical separation of sensitive conductors from disturbing circuits, or
2. Mounting the FCC to a grounded metal substrate, or
3. Grounding alternate conductors to achieve electrical separation, or by
4. Using a shield foil in a few critical situations. This shield foil may be an insulated copper foil lying on one or both sides of the cable to be shielded; or it can be laminated, galvanically deposited, or vacuum deposited to the FCC.

Connectors

There are basically two types of FCC connectors: those where the cable conductor is used to make and break contact, and others which require that contact pieces be attached to the cable conductors.

NASA is using the first approach in connectors. MSFC's latest FCC connector, with redundant contacts, is shown in Figure 3. By stripping the conductors and using them as contacts (eliminating needless joints), the overall reliability of the connector is enhanced. Stripping is a very inexpensive operation if the cable is made for this process.

Standardization

Specifications and standards have been published to cover commercial and military/aerospace system components. Industrial cable and connectors are
described by IPC-FC-220 and IPC-FC-240, respectively. MIL-C-55543 and MIL-C-55544 contain requirements for cable and connectors intended for military/aerospace environments. As a result of these coordinated measures, manufacturers are beginning to develop interconnecting components. The future trend should be away from a heavy emphasis on custom jobs, and toward cable systems with broad applications, a necessity for optimum FCC technology advancement.

Why Use FCC?

The benefits of using FCC in many projects - military/aerospace and commercial - have long been recognized. In a growing number of instances, highly flexible FCC is more compatible than round wire with modern circuit designs, component miniaturization trends, and new packaging techniques. Certainly FCC should always be considered in electrical system design where weight, space, cost reduction, flexibility, uniform electrical characteristics, and reliability are of prime importance. In case after case, test results and comparative studies have demonstrated the merits of FCC systems. Some advantages of FCC over round wire cable (RWC) systems are listed in Table I and more fully described in the following paragraphs.

TABLE I
Advantages of FCC When Compared to RWC

<table>
<thead>
<tr>
<th></th>
<th>Weight Saving</th>
<th>Volume Saving</th>
<th>Cost Saving</th>
<th>Increased Flexibility</th>
<th>More Uniform Electrical Characteristics</th>
<th>Increased Reliability</th>
</tr>
</thead>
</table>

- **Weight and volume reductions** - Typical savings are 50 to 75% in weight and up to 50% in volume. Savings are caused mainly by use of strong, thin insulation; and by the collective strength and better heat transfer of the FCC. These strength and heat transfer characteristics can cause substantial reduction in FCC copper gages as compared to copper gages required for hand assembled round wire cables.

- **Cost saving** - Compared with round cable systems, the major savings are in harness fabrication. For example, FCC of a given length and width with 25 conductors simply needs one length measurement and one cut, while round wire cable of equal size would need 25 length measurements and 25 cuts plus the hand lacing or machine braiding.

In addition, to terminate a round wire cable with a connector, each wire has to be electrically checked and hooked up to the proper pin, whereas FCC conductors are always in the same sequence due to the planar form of the cable. More cost savings accrue when improved inspection times, lower reject rates, and consistently repeatable performance are included. Also, although the present cost of FCC at moderate production quantities is about the same as for round wire, substantial price reductions are expected as production volumes increase.

- **Flexibility and long flex-life** - Flexing does not impose a severe strain, because the conductors are sandwiched within tough insulation and lie in the neutral axis of the cable. Flat conductor cables can be easily bent to fulfill unusual packaging requirements.

- **Consistent electrical characteristics** - Fixed conductor spacing and location results in consistent electrical performance.

- **Increased reliability** - As noted previously, long flex-life, consistent electrical properties, increased mechanical strength, and improved heat dissipation (therefore assuring lower operating temperatures), all result from the configuration of FCC. In addition, abrasion resistance is greatly improved as a result of the geometry of the harness cross-section. Termination of FCC layers is simpler, more reliable and easier to inspect than termination of individual round wires.

AEROSPACE APPLICATIONS

The first applications of FCC occurred in the missile field in the late 1950's, prompted by observed system properties of low weight, high flexibility, and potentially higher reliability over round wire cable complexes. Since then, FCC has been used in many important aerospace programs, selected on the basis of those first observed advantages, plus numerous others. It has been used to integrate equipment in earth satellites, in ground support equipment, and to a substantial degree in the Apollo Telescope Mount. It has been permanently corrugated or coiled in reels for deployment capabilities, and twisted or imaginatively looped to enable parts to rotate. In several cases, no other interconnect system could practically meet project specifications. Four important aerospace applications are discussed below as examples.

Saturn IVB Study

To gain experience and to arrive at sound figures relative to the pros and cons of flat cable systems,
NASA/MSFC let a contract to McDonnell Douglas which called for an engineering and installation study of the aft skirt areas of the Saturn IVB stage. As part of this study, completed in 1966, a mockup was made using a total of 50,000 conductor feet of FCC. A section of this 180-degree aft skirt mockup is shown in Figure 4.

The Kapton/Teflon-insulated flat cable used in the mockup ranged in widths from 1/2 inch to 3 inches, and contained from six to 38 conductors on 75-mil centers. Some of the cable was shielded. Cable was terminated primarily to NASA rectangular FCC connectors.

This flat cable installation study proved the feasibility of the flat cable system and showed great savings in weight, time, and material cost. In replacing round wire cable with FCC, the savings listed in Table II were realized. Using current cable prices, material savings for the same mockup would be closer to 72 percent.

| TABLE II
| S-IVB FCC Installation Study Data |
| Factors | Round | FCC | Diff. | % Saved |
| Weight - Lbs | 1,420 | 340 | 1,080 | 76 |
| Material Cost - $ | 9,370 | 6,300 | 3,070 | 33 |
| Man Hours | 3,240 | 960 | 2,270 | 70 |

Pegasus Meteoroid-Detection Satellite

The highly successful Pegasus meteoroid-detection satellites (Figure 5), built by Fairchild-Hiller Corporation for NASA/MSFC in 1965, used FCC in two areas. Flat cable was the interconnection medium for the deployable detector-panel wings, conveying meteoroid penetration data from the aluminum panels to the instrumentation canister of the spacecraft. Also, FCC was the link between canister and attitude control sensors as well as temperature sensors located in the forward solar array.

All of the FCC was Mylar insulated. Wing cable was predominantly unshielded, while cable to the solar array was shielded. On each wing, 24 eight-conductor flat cables were used, some measuring 65 feet in length. Four harnesses of six FCC layers each carried conductors from the wing tip to the center section structure and then to the instrumentation canister. Conductors were branched at selected locations and soldered to flexible circuit bus bars from which ground cables were solder-terminated to AMP connectors at the instrumentation canister's junction box.

Cable flexibility, particularly critical at the hinge sites of the deployable detector-panel wings, was a major requirement leading to FCC selection. Use of FCC also resulted in a significant weight savings.

Apollo Lunar Surface Experiments Package (ALSEP)

The Bendix Corporation, under contract to NASA/Ames Research Center, used FCC in each of several ALSEP packages to connect five experiments with a central station. A model of an ALSEP system is shown in Figure 6. These packages; consisting of instruments designed to provide lunar data in the areas of geophysics, solar wind, atmosphere, and magnetic fields; were left on the lunar surface during Apollo missions 12, 14, 15, 16, and 17. All the ALSEPS are still working, with the Apollo 12 system having three years of service.

FCC was selected as the interconnecting cable because of the resulting (1) weight reduction from 10 pounds for conventional wiring to 2.4 pounds for FCC and (2) ease in deploying the lunar packages up to 60 feet from the central data package.

In the basic ALSEP system, four FCC configurations were used: 2-inch cable with 37 conductors, 2-inch with 39, 2.15-inch with 40, and 2.5-inch with 47. In each configuration, 3 X 26-mil conductors on 50-mil centers were utilized. The insulation for all cable was Kapton/Teflon. Connectors (manufactured by G.T. Schjeldahl and Dale Connectors) for FCC terminations consisted of a printed circuit board in a plug housing which mated with a tuning-fork-contact receptacle.

Saturn GSE Patch Distributors

Patch distributors with flat flexible wiring are used on the Saturn program to transmit electrical energy between various pieces of equipment. They can be used for power or control circuits. A series of receptacles into which outgoing circuit terminations are plugged are mounted on the front doors of the cabinet. The back of the receptacles are connected to patch boards where by means of patch jumpers the desired electrical distribution can be made.

At the beginning of the Saturn program, round wire was used almost exclusively for wiring the patch distributors. However, as flexible flat cable was developed, its many advantages over round wire cable became apparent. Use of this cable resulted in increased flexibility, major cost savings, a 50-percent reduction in cabinet volume, and a
Figures 7 and 8 depict the two types of wiring, both in 60-receptacle patch distributors (40 and 20-receptacle distributors were also produced). Many of the advantages of the flexible flat cable over the round wire cable are apparent. Over 280 patch panel distributors using the flexible flat cable were used on the Saturn program.

COMMERCIAL APPLICATIONS

FCC is now being used in numerous commercial applications, and future usage appears to be on the rise. Industry is selecting FCC for the same reasons which made it desirable for aerospace and military projects: low weight and volume, flexibility, consistent electrical properties, high reliability, low cost.

Computers

FCC is able to meet these critical computer application requirements: flexibility allowing unusual configurations; excellent, uniform electrical properties; and high packaging density.

The Sigma 7 computer, designed and built by Scientific Data Systems of Los Angeles, California, uses Teflon-insulated FCC for the above reasons [1]. This computer, widely used in universities, businesses and branches of the military, performs a range of processing tasks: from real time, to business data processing, and interactive time sharing.

All assemblies in each cabinet of the Sigma 7 computer are interconnected with FCC insulated with Teflon FEP film. In addition, the same cable transmits signal energy within portions of each module. The cable's flat configuration and Teflon insulation with its outstanding electrical characteristics reportedly serve well the severe demands of the computer. Controlled impedance sets the foundation for high performance. Contour Cable Products of Hughes Aircraft Company, Newport Beach, California fabricates the Sigma 7 signal cable from four sheets of FEP film, each 5-mils thick. Each double-layer cable contains 104 conductors on 0.050-inch centers, and is 2 5/8 inches wide. Though each cable is 24-mils thick with a characteristic impedance of 100 ohms, good flexibility is retained owing to double-layer construction. The finished cable is easily strippable in preparation for connection to the printed wiring boards.

Property requirements noted for computers: uniform electrical characteristics, high packaging density, and extreme flexibility, are also specified for airborne systems - and met by FCC. In addition, FCC meets critical low weight requirements, and is reliable under conditions of vibration. Its flat configuration allows it to be fastened down to lessen vibration between cable and connector. Because of these areas of concern, FCC has been selected for use in airborne navigation equipment, communication systems, and considered for auxiliary power units.

The desire for greater weight reduction prompted Boeing to conduct a study in 1970 in which FCC was evaluated for use in an Auxiliary Power Unit (APU) feeder system (Figure 9) for the 747 commercial transport airplane. An FCC assembly was designed to meet requirements of the 200-foot long, 90 KVA, 120 volt, 250 amp, 400 Hz three conductor APU feeder system; and was then tested against a comparable round wire cable assembly. Results of temperature rise and impedance tests indicated that FCC, with 77 percent of the conductor cross-sectional area of installed round wire, could fulfill electrical requirements of the 747 APU. Physical characteristics of the two cables involved in the laboratory tests are summarized in Table III. The surprise is that FCC can be used for higher power transmission and save 26% in weight.

TABLE III

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Round Wire per BMS 13-40</th>
<th>FCC Teflon Kapton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor Material</td>
<td>EC Al</td>
<td>Alloy 1100 Al</td>
</tr>
<tr>
<td>Conductivity</td>
<td>61% IACS</td>
<td>59% IACS</td>
</tr>
<tr>
<td>Size</td>
<td>2/0 AWG</td>
<td>0.025 by 3.32 in.</td>
</tr>
<tr>
<td>Cross-Sectional Area</td>
<td>107 500 sq. mils</td>
<td>82 500 sq. mils</td>
</tr>
<tr>
<td>Max. Cable Wt. of three 200-ft. Conductors</td>
<td>104 lb.</td>
<td>77 lb. (Wt. savings: 25%)</td>
</tr>
</tbody>
</table>

Electronic Equipment Consoles with Moving Parts

The configuration of FCC makes it extremely well suited for applications where two or more pieces of electrically interconnected hardware must move in relation to each other, and yet remain operational. Many electronic systems, especially ground
support equipment, are made up of cabinet-type consoles with doors, sliding panels, and other sections which have to be movable for service accessibility. FCC has the necessary flexibility and long flex life.

Some useful FCC configurations:

- Heat - formed corrugated assemblies to cross hinge-lines of pivoting sections.
- Assemblies housed in reels with deployment and rewind capabilities (Figures 10, 11).
- Various loop configurations for sliding panel assemblies (Figures 12, 13).

**Industrial Robots**

FCC assemblies provide the high flexibility and reliability required for moving parts in industrial robots. These manipulators are increasingly being used to perform a wide range of repetitive tasks such as loading, transferring, handling, stacking and palletizing. They are being used economically in many fields: automotive, metals, stone, clay, glass, machinery, and other fabricating industries. The handling of radioactive materials is an additional important use.

NASA/MSFC is developing a group of electro-mechanical manipulators which should be desirable for many commercial applications. In one, the ADAMS (Advanced Action Manipulator System), two FCC flexible coil assemblies are used in the joints to enable parts to rotate. The ADAMS manipulator is shown in Figure 14. The center coil of one cable assembly is located in the shoulder joint, allowing ±170 degrees rotation and an elevation of +200 degrees from the vertical down position of the upper arm. The second coil is centered in the elbow joint, and again allows rotation of ±170 degrees. Elbow pitch of -60 degrees to +140 degrees is also possible. Each cable assembly consists of two layered cables, terminated at one end to a standard NASA circular 1/2-inch plug, and at the other end to an FCC to round wire transition. Plugs of both assemblies connect to feed-through receptacles below the shoulder joint, thus enabling quick disconnect of the ADAMS from the base structure. The flat cable used is Kapton/Teflon insulated, 1/2 inch wide, and contains six 4 X 40 mil conductors on a 75-mil baseline center to center spacing.

**NASA’s Surface-Mounted FCC System for Standard Home Wiring (110 - 220V)**

**Home Wiring Problems** - NASA is developing a surface-mounted FCC system for standard home wiring (110 - 220V) in an effort to solve some of the problems facing the building industry today. Increasing labor costs, building rehabilitation/renovation, and new concepts in construction have all posed problems. In the case of rehabilitation/renovation, replacing old wiring is often very costly or impractical, especially if conduit is required. A surface mounted FCC system can be an efficient solution to the wiring dilemma. Modular building construction often uses solid masonry walls, where conduit is required. These conduit-wiring networks are not only time consuming and costly to install, they are also difficult to trouble shoot and repair in case of a malfunction. Other forms of new construction have walls too thin for conduit and switchboxes. Even though NASA missions are space oriented, this is not the first time that commercial applications have evolved from NASA projects. By encouraging secondary applications of aerospace technology, NASA can reduce industry's duplication of research, while increasing the return on the taxpayer's investment in the national space program.

**Surface-Mounted FCC System** - The basic system now under development essentially consists of:

1. A power center with circuit breakers (Figure 15) for distribution of electrical energy, and
2. A number of FCC circuits radiating from that center which will serve the electrical needs of the various areas. Standard round wire outlets will be modified for FCC use. Plugs at the end of appliance cords will not be changed. The baseboard system is depicted in Figure 16.

**NASA R&D Contracts** - NASA/MSFC has awarded two contracts for the design, fabrication and delivery of a system of hardware for completely wiring a room with FCC. Abbott Power Company in California will design and fabricate a power distribution breaker panel for FCC by modifying a standard round wire breaker panel. SPACO, Inc. in Huntsville, Alabama is responsible for the design and fabrication of a complete surface mounted system of hardware including: total baseboard covering, door frames, inter-room door routing, and receptacles.
Advantages - The major reason for considering FCC for use in standard house wiring applications is quite simply - lower cost. Although of some importance, several of the attributes of FCC (low volume and weight, high flexibility) are not of critical importance here, unlike many aerospace projects. What the building industry wants is a system which will meet acceptable levels of performance, safety, reliability and appearance; and at the same time - can be obtained for less cost.

NASA/MSFC engineers believe that an FCC house wiring system can be developed which will meet all these requirements.

This baseboard system can be used effectively (and with equal safety) in applications where conduit is normally specified; for example, in buildings with concrete walls. The advantages are obvious, particularly for large-scale housing projects with identical modules.

1. Installation of the prefabricated surface-mounted baseboard units would be faster than casting elaborate conduit networks into walls.
2. Routing of FCC could be rapidly performed, particularly since circuits would be continuous - no joints except at the beginning or ending of a run. This is possible because no wires need be cut for receptacle installation. Receptacle attachment can be made directly to the cable conductors by any of several techniques (contact crimping or soldering, pressure contact). Compare the simple routing of FCC to the present tedious fishing of round wire cable through conduit, cutting wires along the way for receptacle installation. Faster installation obviously means lower labor costs.
3. With fewer joints, the circuit noted above will also result in higher reliability.

Surface-mounted home wiring is not a totally new idea, as round wire cable is used to some degree in this manner. However, here again, an FCC system has more to offer.

1. Installation costs will be lower and reliability will be higher due to the continuous circuits previously described.
2. The FCC system will be more pleasing in appearance. Bulky round wire cable requires larger housings than FCC meeting the same electrical requirements. This will be of great importance to home owners.

Low-Voltage House Wiring

FCC is used in many house wiring applications which have low voltage (24V or less) requirements. FCC is used in high voltage to low voltage switching systems, burglar alarms, intercom systems, with night lights, as hookup between extension speakers and stereo equipment. In these type applications, the major reason for FCC use is appearance. Unlike bulky round wire cable, FCC can be routed under carpeting; or adhesive backed and routed around door or window frames, applied to walls - and then painted or papered over. The result - almost total concealment of wiring.

Hobby Hill, Inc., produces a picture light assembly in which FCC connects a 12-volt transformer with a picture frame-mounted light fixture (Figure 17). Both the transformer and the 5/8-inch width, two-conductor flat cable, known as "CONDUCT-O-TAPE", are adhesive backed for ease in installation. Once painted or papered over, the cable becomes almost invisible, a highly desirable feature for this application, and the major reason for use of FCC.

A unique voltage switching system developed by ABT Associates and Non-Linear Systems to promote use of NASA FCC technology, enables use of low-voltage FCC from wall switch to ceiling lights. Essentially, the system consists of (1) a thin-profile, surface-mounted wall switch (adhesive-backed or screw mounted), (2) the interconnecting flat conductor cable and (3) a tiny revolutionary device known as "Switchpack" (Figure 18) implanted in the ceiling fixture, which transforms 120V power voltage into a safe 2-volt signal voltage. The Mylar-insulated cable is 3/8 inch wide and contains two conductors. Like the wall switch, the flat cable is adhesive-backed, and once fastened to the wall can be easily camouflaged by paint.

Other Uses

Flat cable (FCC as well as round wire ribbon cable - developed as a result of FCC, and used for many of the same reasons) has been used in numerous additional applications, several of which are listed in Table IV.

<table>
<thead>
<tr>
<th>TABLE IV</th>
<th>Some Commercial Uses of FCC</th>
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<tbody>
<tr>
<td>Office equipment</td>
<td></td>
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<tr>
<td>Industrial machinery</td>
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<tr>
<td>Radar and sonar equipment</td>
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<tr>
<td>TV systems</td>
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<td>Telephone systems</td>
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<tr>
<td>Automobile accessories</td>
<td></td>
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<tr>
<td>Home appliances</td>
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</table>
CONCLUSION

Once used exclusively in military/aerospace projects, FCC is rapidly entering the commercial field. Industry is selecting FCC for the same reasons which made it desirable for Government efforts: low weight and volume, flexibility, consistent electrical properties, high reliability, low cost. In addition, the pleasing appearance of FCC wiring is of prime commercial importance – particularly to the building industry.

In recent years, important steps have been taken toward more general usage of FCC. Military and IPC specifications and standards have been written, enabling manufacturers to develop interconnecting components. Manufacturers are beginning to meet the need for suitable connecting hardware. NASA/MSFC’s two contracts for the development and fabrication of a workable system for home wiring should be of great importance to the building industry.

Unfortunately, even today the full potential of flat conductor cable systems is not being made use of. However...

(1) As the production of flat cable and associated hardware increases, bringing with it lower costs;

(2) As flat conductor cable technology expands (particularly in the area of connecting hardware) and items become readily available;

(3) As designers become more familiar with the potential of flat cable systems, and begin thinking in terms of FCC in the first phase of a project - rather than after all details have been set for round wire cable; and

(4) As experience in flat cable application technology increases and becomes widely known,

We will then see a great increase in the widespread commercial usage of FCC systems.

REFERENCES

(1) Tough Packaging Demands met by Cables of Teflon, Electronic Packaging and Production, August 1968.

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Figure 1. Typical Rolls of FCC

Figure 2. Cross-Sections of FCC

FLAT CABLE CROSS-SECTIONS FOR VARIOUS MANUFACTURING METHODS

- LAMINATED
- EXTRUDED
- ETCHED AND COATED
- WOVEN
- COMPUTER CABLE

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