

# The Real History of Chip on Flex

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Let's start with the present use of electronic chips on flex circuits and chip carriers and then move backwards in time for a surprising conclusion. Flexible circuitry, an important enabling technology for many decades, is ideally suited for bare die applications that include flip chip, TAB (Tape Automated Bonding) and COB (Chip on Board). One of the hot applications with a very high volume potential, is the RFID (Radio Frequency IDentification) tag. Nearly all developers use flip chip for minimum height and area. Flex is the ideal choice for the circuit because of thinness and low cost. That's right! Flex is the lowest cost circuit for building a chip carrier with an integrated antenna. The substrate is typically low-cost polyester and many prefer circuits made with Polymer Thick Film (PTF). The PTF process only requires a print-and-dry process that can produce tens of thousands of circuits every hour. The flip chip is easily attached using conductive adhesives processed at 150°C or lower.

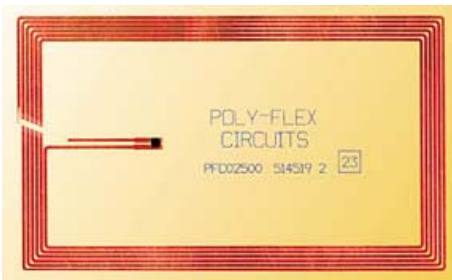


Figure 1. RFID tag---Poly-Flex Circuits (a Parlex Co.).

Figure 1 shows a prototype RFID tag using Flip-on-Flex technology. RFID tags could become the largest market for Flip-on-Flex, but let's look at a more mature high-volume application.

Today, most disk drives use a small flex circuit with a flip chip. This is a good concept since disk drives must be very compact and lightweight. The amplifier chip for the read/write head is typically in a flip chip form factor to satisfy the small footprint, minimum weight constraints and efficient SMT assembly. IBM and Seagate appear to have pioneered the use of flip chip for disk drive circuits.

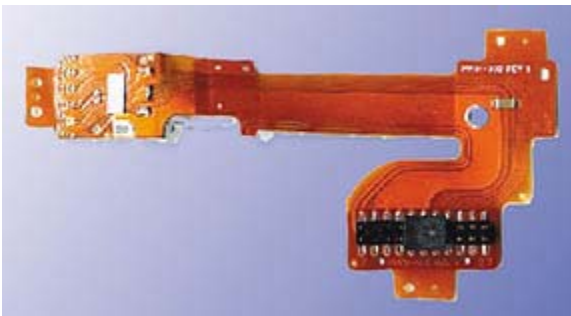


Figure 2. Seagate Flip-on-Flex.

Figure 2 shows an early Seagate Flip-on-Flex circuit that was developed in the early 1990s at their Scotts Valley, CA facility. Before the adoption of flip chip, the drive circuits used COB, but this bare die technology used more area and required the added weight of "glob top" encapsulant.

In the 1980s, several "Solderless" bare die on flex concepts were developed. Sheldahl, for example, tested flip chip on flex using low cost Mylar from DuPont. While this polyester film is solderable with special processes, most developers sought to use low-temperature conductive adhesives. Sheldahl tested anisotropic conductive adhesives (ACA) in the mid-1980s, but called the material "Z-Axis" for simplicity. The adhesive, made with solid metal spheres in a thermoplastic binder, could be cast as film on release liner or screen printed directly.

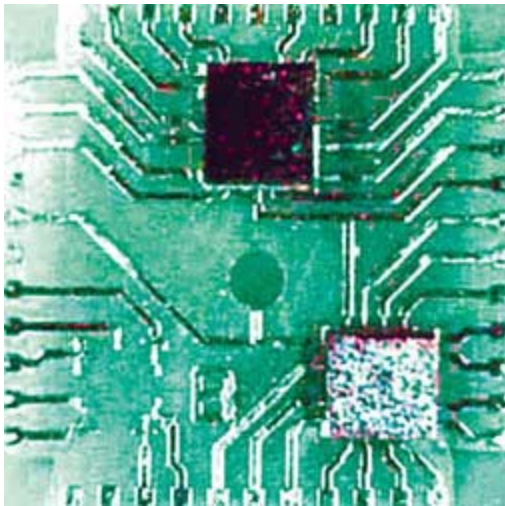


Figure 3. Flip-on-Flex Bonded to Mylar with Z-Axis Adhesive.

Figure 3 shows the 1985 Chip-on-Flex test circuit made with solder-plated copper on polyester. The Z-Axis film was made with silver powder in thermoplastic binder. While the concept demonstrated the ease of CoF assembly, the adhesives of that era were not too reliable. Please note that this 1985 development can be used for the newest application, RFID tags.

Now let's move back even further, when HP and others sought to harness MEMS technology for printers. That's right, MEMS was alive and well in the 1980s as the ink jet chip. Most ink jet chips use thermal actuation to propel ink droplets at paper, although at least one chip uses a piezoelectric mechanism. The packaging challenge was to connect the MEMS ink jet chip to an ink cartridge and to protect it without interfering with ink jetting. A second objective was to connect the chip package to the printer electronics. While the work took many years of development by the flex industry (3M Co., Sheldahl, and others), the end result was a bare die on a flex circuit that also was an integrated connection cable. Take a look at most any ink jet cartridges and you will see an elegant solution that is based on flex. The MEMS chip is connected directly to the flex through cantilevered beam leads made of gold-plated copper.

The interface to the printer is an array of gold-plated pads on the polyimide flex. The encapsulant is needle dispensed so that the interconnect is protected but the jetting holes are left clear, according to Speedline (Cookson). Figure 4 shows such a circuit.

Those familiar with flex-based packaging may say, "Hey, isn't that ink jet flex really TAB?" And that brings us to a key juncture in flex history—the invention of the chip carrier. TAB is actually a subset of flexible circuitry. This bare die method uses cantilevered beam leads suspended over an opening called a window. The chip bond pads are aligned with the beam leads that are then bonded using heat and force. So is the ink jet flex circuit really TAB? This circuit design has been referred to as TAB-Featured Flex, TAB-Flex, and "flex integrated TAB." This concept has been around for a long time and is not restricted to ink jets or single chip circuits. Today's flex processes, that include plasma etching, chemical milling and laser machining, allow windows to be easily fabricated.



Figure 4. Ink Jet Flex.

Let's conclude by going back to the earliest flex-based packaging after a brief look at Chip Scale Packages (CSP). While TAB is still widely used, the outer lead bonding (OLB) requires special hot bar bonders to mate the flex package to a PWB. OLB is far from an ideal assembly process. Fortunately, two companies solved the OLB process by clever designs. More than a decade ago, IBM introduced the TBGA (Tape Ball Grid Array) that retains the inner lead bonding (ILB) with its familiar cantilevered bonds. The outer leads are replaced with metal spheres, or balls for assembly to the PWB. These flex-based packages use a "fan-out" design that gives a relatively large footprint exceeding the CSP chip/carrier limits. However, Tessera developed a somewhat similar approach with a "fan-in" design to produce the now-popular  $\mu$ BGA. Both are flex circuits and both use a TAB format for the bare die connection. But the bothersome outer leads are gone and the package can be assembled using SMT. So, the USA has not ignored TAB, but rather made it into a much better concept that leverages the SMT assembly infrastructure. Now, let's go back to the 1960s when chip carriers were being invented.

Flex packaging aficionados may have heard of "Minimod" from General Electric, often said to be the first TAB. The 1968 GE invention had both inner and outer leads on a tiny flex made with Dupont's Kapton (polyimide). The circuit strip looked like a piece of movie film and it could be fed automatically—hence the tape automated bonding moniker. While GE may have been first with the ILB concept, another company came up with bare die on flex about two years earlier.

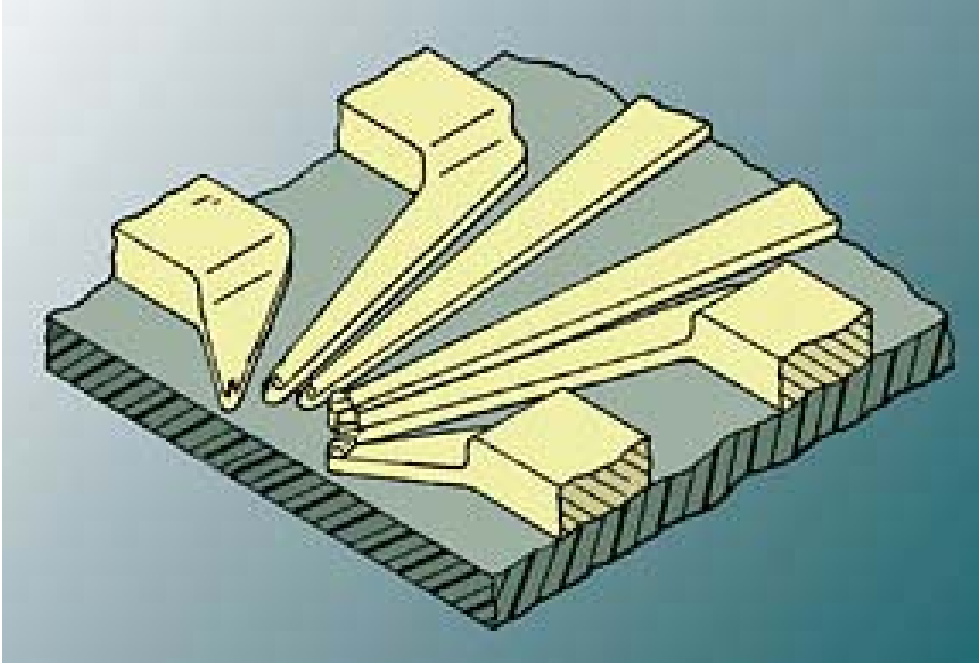


Figure 5. Francis Hogle's Flip Chip Strip (figure from US Patent).

Ms. Francis Hogle (Hogle Industries of California) devised a package that used a flip chip directly bonded to a tiny flex circuit. Her "Flip Chip Strip" appears to be the first flex-based package and a close-up from the patent drawing is shown in Figure 5. A two-stage etching process, or step etching, produced the chip connection "bumps". The Hogle patent appears to be the first public documentation of Chip-on-Flex. The flex material was Dupont's polyester since Kapton was not available yet.

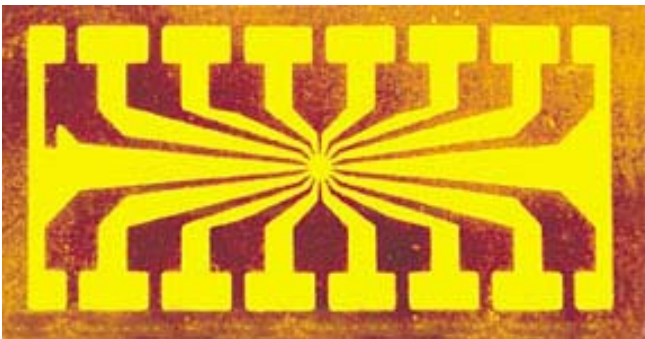


Figure 6. First Chip-on-Flex? (Sheldahl, mfg. for Hogle).

While it's not clear if any chip assemblies were constructed, the prototypes were indeed produced and one is shown in Figure 6. Sheldahl Inc. produced this mid-1960s CoF in Northfield, MN and may never have realized the significance. Flex-based packaging continues to lead the way as the unique enabling technology of the past, present and future.