

Polymorphic Electronic Circuits

Circuits are designed to perform different functions under different conditions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Polymorphic electronics is a nascent technological discipline that involves, among other things, designing the same circuit to perform different analog and/or digital functions under different conditions. For example, a circuit can be designed to function as an OR gate or an AND gate, depending on the temperature (see figure). Polymorphic electronics can also be considered a subset of polytronics, which is a broader technological discipline in which optical and possibly other information-processing systems could also be designed to perform multiple functions.

Polytronics is an outgrowth of evolvable hardware (EHW). The basic concepts and some specific implementations of EHW were described in a number of previous *NASA Tech Briefs* articles. To recapitulate: The essence of EHW is to design, construct, and test a sequence of populations of circuits that function as incrementally better solutions of a given design problem through the selective, repetitive connection and/or disconnection of capacitors, transistors, amplifiers, inverters, and/or other circuit building blocks. The evolution is guided by a search-and-optimization algorithm (in particular, a genetic algorithm) that operates in the space of possible circuits

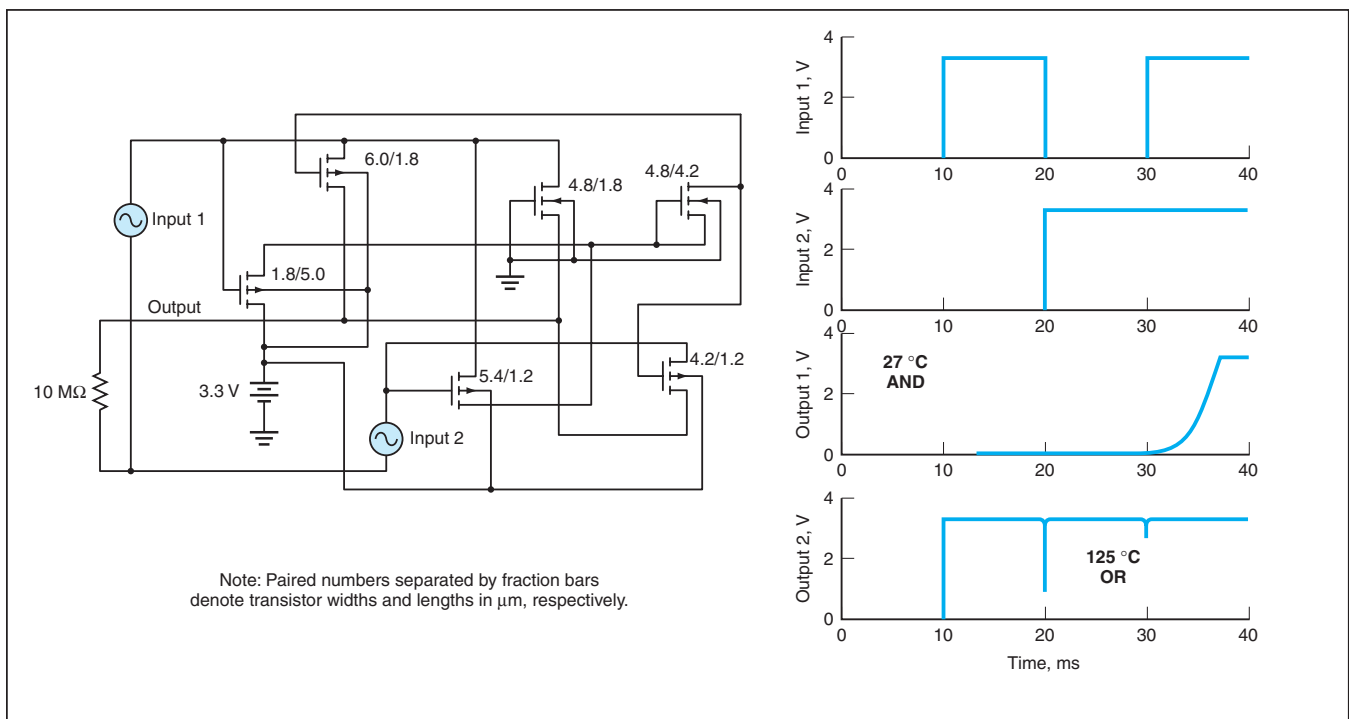
to find a circuit that exhibits an acceptably close approximation of the desired functionality. The evolved circuits can be tested by computational simulation (in which case the evolution is said to be extrinsic), tested in real hardware (in which case the evolution is said to be intrinsic), or tested in random sequences of computational simulation and real hardware (in which case the evolution is said to be mixtrinsic).

The *NASA Tech Briefs* article most relevant to the emergence of polytronics is the preceding article, "EHW Approach to Temperature Compensation of Electronics." Polytronics originated from recognition that the EHW approach makes it possible to go beyond mere compensation for deterioration of circuit functionality with temperature: The EHW approach is a means of designing a circuit to perform an acceptable approximation of almost any desired function at one or more temperatures. In addition to or instead of temperature, the functionality of a circuit could be made to depend on such variables as supply or bias potentials, states of digital control signals, signal frequencies, and/or the intensity of illumination.

Going beyond the temperature-dependent AND/OR gate, the following are a few additional examples of multifunctionality that could be implemented in polytronics:

- A digital circuit could pass data in either of two opposite directions and perform the same function or different functions in the two directions.
- The modes of operation of an entire computer or other complex circuit could be changed almost instantaneously by changing the temperature, supply voltage, or other parameter(s).
- A circuit could be made to perform one (or more) hidden function(s) in addition to a readily observable main function. For example, a hidden function could be an authentication signal that would appear only under specified conditions (for example, supply voltage above a specified level and temperature below a specified level).
- An increase in temperature beyond a specified level could trigger a desired reactive behavior. For example a "smart fuse" circuit could cause guidance circuitry to function differently at higher temperature.

The current research in polytronics involves two modes of evolution that, in EHW,



The Same Circuit Performs as One of Two Logic Gates, depending on the temperature. At 27 °C, it is an AND gate; at 125 °C, it is an OR gate.

would have been denoted as extrinsic and mixtrinsic, respectively. Each mode is characterized by a different combination of advantages and disadvantages.

- In one mode, evolution occurs entirely by computational simulation. For example, circuits can be computationally modeled as consisting only of negative-channel metal oxide semiconductor (NMOS) and positive-channel metal oxide semiconductor (PMOS) transistors that can be connected in arbitrary topologies. The advantage of this mode is that it enables free exploration of the search space, with few or no topological restrictions like those that occur in practice; the lack of restrictions can favor the emergence of new designs. The disadvantage of this approach is that there is no implementation of evolved designs in hardware.

- In the other mode, the circuit topologies are restricted to those of field-programmable transistor arrays (FPTAs). Evolution involves both (1) simulations on computational models of FPTAs and (2) experiments on real FPTAs that are constructed and tested in efforts to implement the models. The advantages of this mode are that circuits can be implemented in practice after evolution, and FPTA chips can be reconfigured to map different polymorphic gates onto them, as needed. The disadvantages of this mode are that (1) the topologies are restricted and (2) in some cases, circuits evolved taking account of the nonideal characteristics (e.g., non-zero “ON” resistances and finite “OFF” resistances of transistor switches) of realistic components can be more complicated than those

evolved through models of ideal components.

This work was done by Adrian Stoica of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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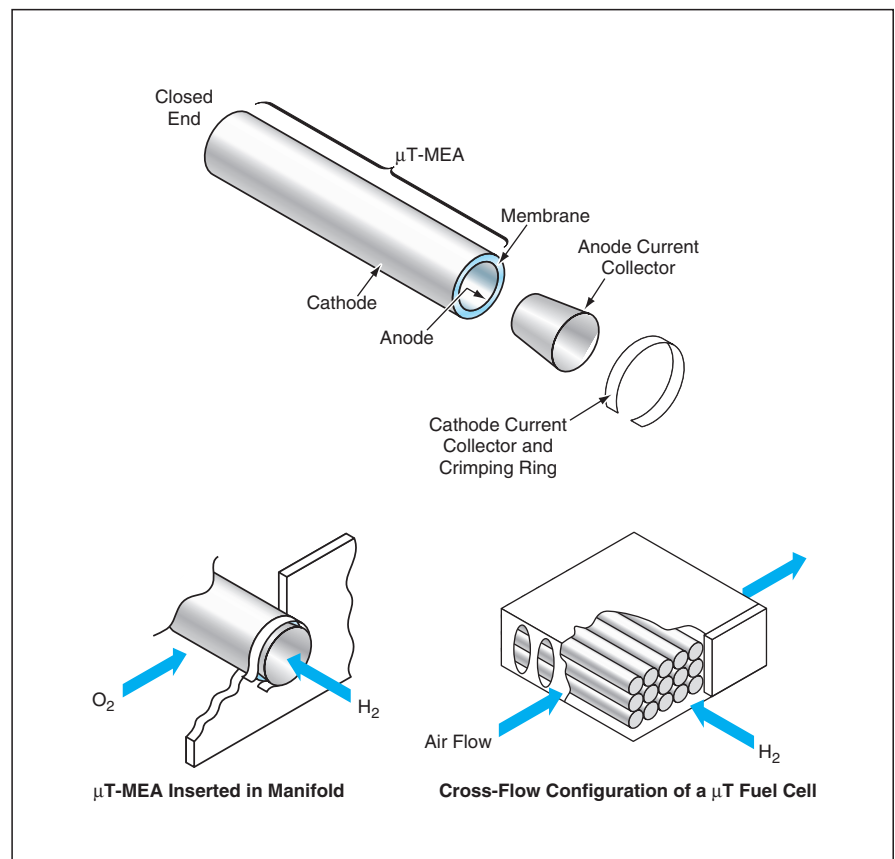
Micro-Tubular Fuel Cells

Power densities would be much greater than those of conventional fuel cells.

Lyndon B. Johnson Space Center, Houston, Texas

Micro-tubular fuel cells that would operate at power levels on the order of hundreds of watts or less are under development as alternatives to batteries in numerous products — portable power tools, cellular telephones, laptop computers, portable television receivers, and small robotic vehicles, to name a few examples. Micro-tubular fuel cells exploit advances in the art of proton-exchange-membrane fuel cells. The main advantage of the micro-tubular fuel cells would be higher power densities: Whereas the mass and volume power densities of low-pressure hydrogen-and-oxygen-fuel plate-and-frame fuel cells designed to operate in the targeted power range are typically less than 0.1 W/g and 0.1 kW/L, micro-tubular fuel cells are expected to reach power densities much greater than 1 W/g and 1 kW/L. Because of their higher power densities, micro-tubular fuel cells would be better for powering portable equipment, and would be better suited to applications in which there are requirements for modularity to simplify maintenance or to facilitate scaling to higher power levels.

The development of PEMFCs has conventionally focused on producing large stacks of cells that operate at typi-



A Micro-Tubular Fuel Cell contains multiple tubular membrane/electrode assemblies that operate in an oxygen/hydrogen cross flow. The hydrogen manifold and the edge-tab electrical current collectors take up much less space than do the bipolar plates of conventional plate-and-frame fuel cells.