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## **Li/CF<sub>x</sub> Cells Optimized for Low-Temperature Operation**

**Several prior developments are combined.**

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Some developments reported in prior *NASA Tech Briefs* articles on primary electrochemical power cells containing lithium anodes and fluorinated carbonaceous (CF<sub>x</sub>) cathodes have been combined to yield a product line of cells optimized for relatively-high-current operation at low temperatures at which commercial lithium-based cells become useless. These developments have involved modifications of the chemistry of commercial Li/CF<sub>x</sub> cells and batteries, which are not suitable for high-current and low-temperature applications because they are current-limited and their maximum discharge rates decrease with decreasing temperature.

One of two developments that constitute the present combination is, itself, a combination of developments: (1) the use of sub-fluorinated carbonaceous (CF<sub>x</sub> wherein  $x < 1$ ) cathode material, (2) making the cathodes thinner than in most commercial units, and (3) using non-aqueous electrolytes formu-

lated especially to enhance low-temperature performance. This combination of developments was described in more detail in "High-Energy-Density, Low-Temperature Li/CF<sub>x</sub> Primary Cells" (NPO-43219), *NASA Tech Briefs*, Vol. 31, No. 7 (July 2007), page 43. The other development included in the present combination is the use of an anion receptor as an electrolyte additive, as described in the immediately preceding article, "Additive for Low-Temperature Operation of Li-(CF)<sub>n</sub> Cells" (NPO-43579).

A typical cell according to the present combination of developments contains an anion-receptor additive solvated in an electrolyte that comprises LiBF<sub>4</sub> dissolved at a concentration of 0.5 M in a mixture of four volume parts of 1,2 dimethoxyethane with one volume part of propylene carbonate. The proportion,  $x$ , of fluorine in the cathode in such a cell lies between 0.5 and 0.9. The best of such cells fabricated to date have

exhibited discharge capacities as large as 0.6 A-h per gram at a temperature of -50 °C when discharged at a rate of  $C/5$  (where  $C$  is the magnitude of the current, integrated for one hour, that would amount to the nominal charge capacity of a cell).

*This work was done by William West, Marshall Smart, Jay Whitacre, Ratnakumar Bugga, and Rachid Yazami of Caltech for NASA's Jet Propulsion Laboratory.*

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*Refer to NPO-43585, volume and number of this NASA Tech Briefs issue, and the page number.*

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## **Number Codes Readable by Magnetic-Field-Response Recorders**

**Where useable, these codes offer advantages over conventional optical bar codes.**

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A method of encoding and reading numbers incorporates some of the features of conventional optical bar coding and radio-frequency identification (RFID) tagging, but overcomes some of the disadvantages of both: (1) Unlike in conventional optical bar coding, numbers can be read without having a line of sight to a tag; and (2) the tag circuitry is simpler than the circuitry used in conventional RFID.

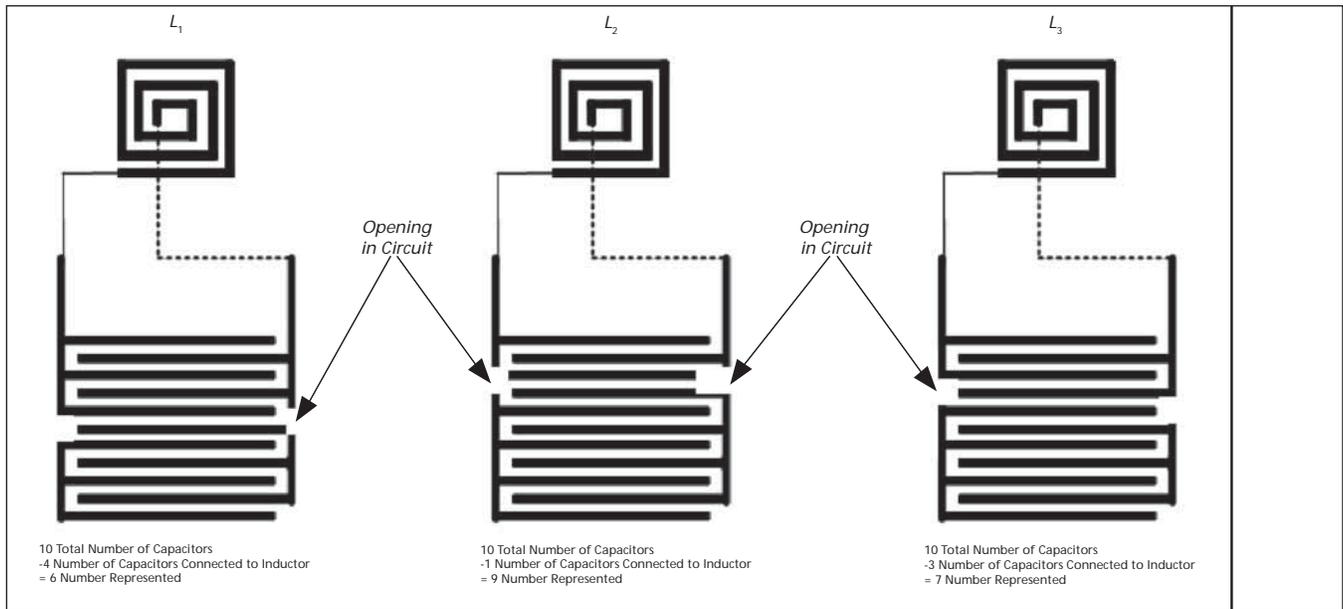
The method is based largely on the principles described in "Magnetic-Field-Response Measurement-Acquisition System" (LAR-16908), *NASA Tech Briefs*, Vol. 30, No. 6 (June 2006) page 28. To recapitulate: A noncontact system includes a monitoring unit that acquires measurements from sensors at distances of the order of several meters. Each sensor is a passive radio-frequency (RF) resonant circuit in the form of one or more inductor(s) and capaci-

tor(s). The monitoring unit — a handheld unit denoted a magnetic field response recorder (MFRR) — generates an RF magnetic field that excites oscillations in the resonant circuits resulting in the sensors responding with their own radiated magnetic field. The resonance frequency of each sensor is made to differ significantly from that of the other sensors to facilitate distinction among the responses of different sensors. The MFRR measures selected aspects of the sensor responses: in a typical application, the sensors are designed so that their resonance frequencies vary somewhat with the sensed physical quantities and, accordingly, the MFRR measures the resonance frequencies and variations thereof as indications of those quantities.

In the present method, the resonance circuits are not used as sensors. Instead,

the circuits are made to resonate at fixed frequencies that correspond to digits to be encoded. The number-encoding scheme is best explained by means of examples in which each resonant circuit consists of a spiral trace inductor electrically connected to a set of parallel-connected capacitors in the form of interdigitated electrode pairs (see figure). The inductor and capacitor(s) in each resonant circuit can be fabricated as a patterned thin metal film by means of established metal-deposition and -patterning techniques. The capacitance and, hence, the resonance frequency, depends on the number of interdigitated electrodes connected to the inductor. In a similar manner, sets of electrodes could be used.

Initially, in each resonant circuit as fabricated, the number ( $N$ ) of interdigitated electrode pairs equals the base (e.g., 10) of the number system of the



Three Resonant Circuits contain interdigitated-electrode capacitors that can be trimmed to encode digits between 0 to 9. In this case, they have been trimmed to encode the number 697.

digit to be represented by that circuit.  $N$  electrode pairs represent the digit 0 with the corresponding resonance frequency having the lowest assigned value. To encode a given nonzero digit ( $m$ ), one punches a hole or makes a cut in the electrode pattern so as to disconnect  $m$  of the electrode pairs (or, sets of electrode pairs) from the inductor, reducing the capacitance and thereby increasing the resonance frequency to a value assigned to represent the digit  $m$ . The resulting frequency,  $\omega_m$ , becomes (the capacitance for each electrode pair or set of electrode pairs is  $C$ )

$$\omega_m = \frac{1}{2\pi\sqrt{(N-m)L_1C}}$$

In the example shown at the left side of the figure, to encode the digit 6, one disconnects the electrodes of the lowermost 6 of 10 electrode pairs. If there is a need to encode more than one digit (e.g., three digits as in the figure), then one can fabricate the corresponding number of resonant circuits having the same capacitor arrangement but having inductance values ( $L_1, L_2, L_3$ ) that differ sufficiently so that their resonance-frequency ranges do not overlap.

This method offers the following advantages in addition to the ones mentioned above:

- A number can be read, irrespective of the orientation of a tag containing the resonant circuits that encode the number.

- Numbers can be read at distances greater than the maximum reading distances of optical bar-code readers.
- A tag can be embedded or enclosed in electrically nonconductive material.
- A tag is secure in the sense that once it is embedded or enclosed in a protective material, there is no way to alter the encoded number in normal use.
- The method cannot store or acquire information providing ease of mind to consumers when used in retail.

*This work was done by Stanley E. Woodard of NASA Langley Research Center and Bryant D. Taylor of Swales Aerospace for Langley Research Center. Further information is contained in a TSP (see page 1).LAR-16483-1*

## Determining Locations by Use of Networks of Passive Beacons

This method could be an alternative to GPS in some situations.

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Networks of passive radio beacons spanning moderate-sized terrain areas have been proposed to aid navigation of small robotic aircraft that would be used to explore Saturn's moon Titan. Such networks could also be used on Earth to aid navigation of robotic aircraft, land vehicles, or vessels engaged in exploration or reconnaissance in situations or locations (e.g., underwater locations) in which Global Positioning System (GPS) signals are unreliable or unavailable.

Prior to use, it would be necessary to pre-position the beacons at known locations that would be determined by use of one or more precise independent global navigation system(s). Thereafter, while navigating over the area spanned by a given network of passive beacons, an exploratory robot would use the beacons to determine its position precisely relative to the known beacon positions (see figure). If it were necessary for the robot to explore multiple, separated terrain

areas spanned by different networks of beacons, the robot could use a long-haul, relatively coarse global navigation system for the lower-precision position determination needed during transit between such areas.

The proposed method of precise determination of position of an exploratory robot relative to the positions of passive radio beacons is based partly on the principles of radar and partly on the principles of radio-frequency identi-