Energy Scavenging for Digital ICs

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What is Energy Scavenging

- Process of converting local ambient energy into usable electrical energy
  - Use transducer:
    - thermoelectric generator (TEG): temperature differential
    - piezoelectric element: vibration
    - photovoltaic cell: sunlight
    - galvanic energy: moisture
- Concept has been around for over a decade
- Motivation:
  - Provides power to supplement or replace batteries in systems
    - Useful when battery use may be inconvenient, expensive or dangerous
  - Eliminate need for wires to carry power or transmit data
    - Means of powering wireless sensor networks
  - Economic gain
    - often costs less than implementing supply wires or replacing batteries
  - Use energy otherwise wasted from industrial processes, solar panels, or internal combustion engines

Energy Scavenging System and Considerations

Free Energy Source → Energy Harvester/ Manager → Sensors, A/D, Microprocessor → Wireless Transmitter/Receiver

- Energy Harvester yield power levels in the order of milliwatts
  - In long run, broadly comparable in energy provision and the cost per energy unit provided to long-life primary batteries
  - Can recharge after depletion, systems powered by primary batteries cannot
- Microcontrollers and transducers: consume minimal electrical energy from low-energy environments
  - Low-cost and low-power sensors and microcontrollers available for a couple of years
  - Ultra-low-power transceivers recently commercially available
  - Limiting factor is energy harvester

Considerations and Challenges

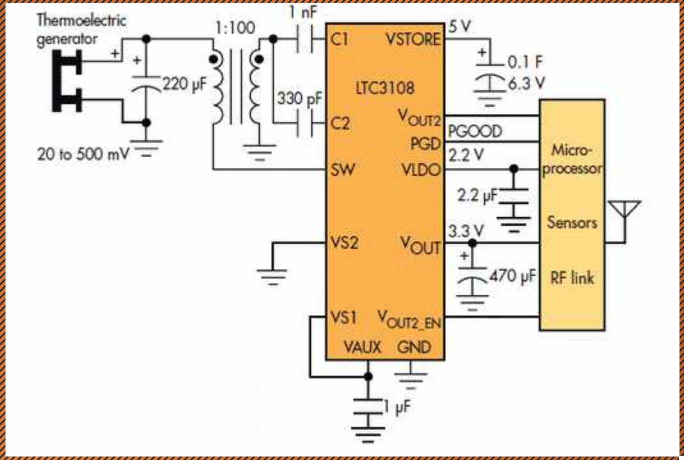
- Challenges:
  - Absence of ambient energy
    - Solution: Secondary Reservoir
    - Considerations:
      - Length of time for absence
      - Size and type of a secondary reservoir (capacitor, supercap or battery)
      - Duty cycle - frequency that data reading and transmission has to be made
      - Availability of ambient energy to be primary energy source and charge secondary reservoir
  - Energy harvester has 30 components or more
    - Compromised performance in end system
      - Low conversion efficiency
        - Increases amount of time to power up system
        - Increases time interval between sensor reading and transmitting data
      - High currents
        - Must first overcome current level needed for operation
        - Limits how low the output can be

New generation of Ics can harvest energy from very low levels

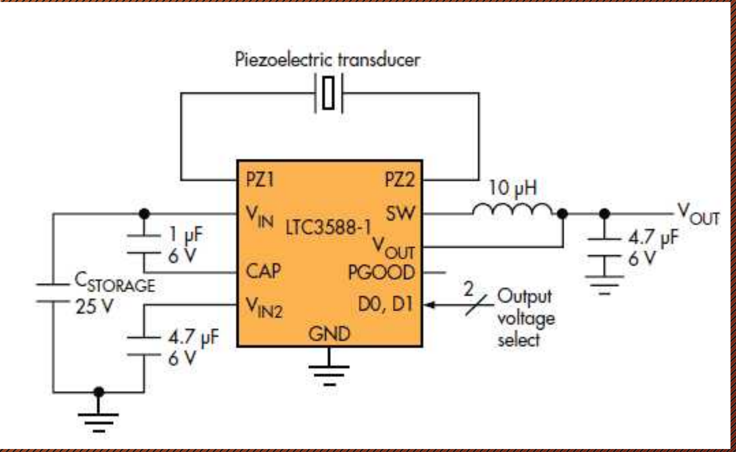
- Increase Market acceptance

New Generation of Energy Scavenging ICs

- Supply all system voltages from piezoelectric vibrating-beam energy harvesters
  - Linear Technology
- Step-up converter/power manager from transducer voltage input
  - LTC3108
  - Transformer-based circuit
  - External step-up transformer + coupling capacitor
    -> resonant step-up oscillator for MOSFET switch
  -> External charge pump capacitor rectifies ac voltage
  -> charges external capacitor that runs chip and external outputs
    - Results: Chip can change standard capacitor, supercapacitor, or rechargeable battery
    - Outputs:
      - VSTORE: charge large storage cap or battery up to VAUX
      - VOUT: main output voltage
      - VOUT2: controlled by host with MOSFET switch, power external circuits
        - Sensors, amplifiers - only draw power when needed
      - Low-dropout regulator runs system controller
    - Energy Considerations: 1.6 microA



- Power supply from Piezo Energy Harvester input
  - LTC3588
  - AC input handled by Internal full wave bridge rectifier
  - Output: rectified and stored on capacitor at Vin
    - Energy reservoir for buck converter
      - Voltage algorithm to control output
      - Charges output capacitor through inducer, whose current could be ramped up with an internal PMOS or down with an internal NMOS
  - Energy considerations: piezo generated current around 10 microA, low loss bridge rectifier with drop of 400mV
- Size: 9mm2
- Price: $3
  - There are also chips that target thermo-electric, photovoltaic, galvanic, and coil/magnet harvest rings



Applications

- Mostly to power sensors and wireless mesh networks that pass data from host of sensor to central processor
- Aircraft Health Monitoring for cracks in metal
  - Ambient thermal energy or piezoelectricity
- Environmental control in buildings: occupancy sensors, thermostats, light switches
  - Harvest from ambient light or temperature differences
  - Eliminate need for power or control wiring
  - Reduce electricity costs, adjusting temperature or turning off lights
- Monitoring stability of highway structures
  - Piezoelectric harvesters collect energy from the vibrations caused by vehicles driving on the structure

What is next

- Battery with cathode chemistry that forms a composite cathode with a capacity nearly triple that used in lithium-ion batteries (University of Colorado)
- Lithium battery cell monitoring IC from ams AG reduces hardware and software requirements in battery cell management systems
- Declining cost of photovoltaics
- Decrease power consumption of harvesters
- Lower power consumption of WSN
- Increase power output

Elements within the WSN	Factors affecting power consumption
Power Supply (or battery)	Discharge rate Battery dimensions Supply voltages Type of electrode material used DC/DC Efficiency
Sensors	Physical to electrical signal conversion Complexity of supporting components Signal sampling Signal conditioning
ADC	Sampling rate Aliasing Dither
Microprocessor	Core operating frequencies Operating voltages Power proportional to process & computational load Ambient temperature Application code Peripheral utilization
Radio	Modulation scheme Data rate Transmission range Operational duty cycle

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