Small Engine Control Systems Using a New System-in-Package (SiP) Solution

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Agenda

• Review of current and new small engine control systems
• Overview of Freescale small engine circuits
• Introduce the new System in Package, SiP solution
• Discuss other multi-chip packaging solutions
• Show examples of Freescale’s new SiP in:
  • CDI applications
  • EFI applications
Small Engine Applications

Motorcycles
Motor Scooters

Hybrid Car Charging

Powered Tools (< 100cc)

Lawn Equipment (> 100cc)

Motorcycles

Mini Cars

Personal Recreation

Pumps, Generators

Lawn Equipment

Motor Scooters

Hybrid Car Charging

Powered Tools

Motorcycles

Mini Cars

Personal Recreation

Pumps, Generators
Small Engine Control Systems

• **Magneto/Carburetor** –
  - Magneto provides energy for spark
  - Carburetor mixes and meters fuel and air

• **Transistor (TCI)/ Carburetor** –
  - Transistor switch generates interruption of ignition coil primary current.
  - Microcomputer (MCU) can provide programmable spark timing

• **Capacitive Discharge (CDI)/ Carburetor** –
  - High voltage stored in capacitor provides input to ignition coil for spark

• **Electronic Fuel Injection (EFI)** –
  - MCU provides programmable fuel and spark, closed loop with O2 sensor.
  - Injection into port or throttle body.

• **Gasoline Direct Injection (GDI)** –
  - Injection of fuel directly into cylinder for highest efficiency, performance and lowest emissions.
What is a Magneto?

• A Magneto is a device that employs a coil of wire, permanent magnets, switch contacts and a capacitor to provide electrical pulses which can be used to generate a spark.

• Early magnetos used only one coil of wire but modern systems, still in use, use two, one to generate a low voltage, high current pulse and the other to convert that pulse into a high voltage spark.

Magnetos are still used today because of their low cost and good reliability. The problem with magneto spark generation is that the spark timing is fixed by the location of the magnets on the engine crankshaft. To improve performance over load, temperature and other environmental conditions, and to reduce emissions, adjustable spark timing is required.
What is a Carburetor?

- A **Carburetor** is a device that controls the flow of gasoline and air into an engine. It uses the vacuum, generated by the piston inside the engine cylinder, to draw in gasoline from the fuel tank, atomize it, and mix it with air in the proper proportion for combustion.

Carburetors are still used today because of their low cost. Carburetors are inferior to fuel injection systems because of their mechanical complexity. The build-up of dirt and other gummy residues of gasoline can cause blockages of the venturi and failures of other critical moving parts. Carburetors are difficult to control fuel delivery over varying engine loads, temperatures, acceleration, and other environmental conditions, compared to microcomputer-controlled fuel injection systems.
What is TCI?

- **Transistor Controlled Ignition (TCI)** is a variation of the mechanical Inductive Discharge Ignition (IDI) system, which was used for many years in automobile engines.

- In **IDI**, a rotating cam is used to open and close a contact breaker called “points” to interrupt the flow of current from a battery to an autotransformer called an “ignition coil”. The high voltage from the ignition coil is conducted to the proper spark plug via a mechanical “distributor” that is driven by the engine camshaft.

- In **TCI**, a transistor switch replaces the points and a microcomputer is used to vary the spark timings, based on timing pulses from a crankshaft mounted, toothed-wheel and a sensor called a “variable reluctance sensor” or **VRS**.
What is CDI?

• **Capacitor Discharge Ignition (CDI)** is a type of electronic ignition system which is widely used in small engines today.

• It was originally developed to overcome the long charging times associated with high inductance coils used in IDI and TCI systems making the ignition system more suitable for higher engine speeds.

• **CDI** uses a capacitor discharge current output to trigger the ignition coil to fire the spark plugs. The capacitor is charged from a high voltage supply. (200 - 400V)

• There are two basic types of **CDI**:
  - **AC-CDI** – uses an AC alternator to generate high voltage
  - **DC-CDI** – uses a DC-DC converter to generate high voltage
What is EFI?

- **Electronic Fuel Injection (EFI)** is a replacement fuel delivery system for the carburetor.

- Fuel injectors are electrically operated valves which are controlled by a microcomputer to deliver precise, metered amounts of fuel into the intake manifold of an engine. The injector atomizes the fuel which mixes with the air entering the intake manifold and this air/fuel mixture is brought into the cylinder by the vacuum produced by the intake stroke of the piston inside the cylinder.

- Fuel injection is independent of the type of ignition system used, however, once an ECU is included, to control the fuel, then the choice of ignition system is usually TCI.
What is GDI?

- **Gasoline Direct Injection (GDI)** is the latest fuel delivery system replacement for the carburetor. It injects fuel directly into the cylinder during the intake stroke and must withstand the high explosive pressure during the combustion stroke.

- To accomplish this, **GDI** Fuel injectors must utilize pressurized fuel rails and special peak and hold drive current profiles, using high voltage power supplies, to open and close the injector valve.

- Presently, there are many automotive engine designs available using **GDI**. In small engine design, **EFI** is available on many engines but **GDI** is still a rarity.
What fuel and ignition systems do small engines use?

- **Magneto/Carburetor** is still the ignition/fuel system of choice for under 100 cc engines.
  
  **Advantages:**
  - Low cost
  - Small size
  - Mature manufacturing experience
  - Simple maintenance
  
  **Disadvantages:**
  - Poor reliability
  - Uncontrolled emissions
  - Low efficiency
  - Poor cold start performance

Under 100 cc Engines
What fuel and ignition systems do small engines use?

- **CDI & TCI/Carburetor** are popular ignition/fuel system choices for 100 cc and above engines.

  - **Advantages:**
    - Good reliability
    - Better efficiency
    - Better emission quality
    - Better cold starting

  - **Disadvantages:**
    - Needs battery or Supercap for **TCI**
    - Higher Cost
    - Needs space for **ECU**
    - Higher complexity - software
What fuel and ignition systems do small engines use?

- **EFI** is gaining popularity for >>100 cc engines.

**Advantages:**
- Excellent reliability (no carburetor)
- Good efficiency
- Performance
- Low emissions
- Excellent cold start and transient fuel

**Disadvantages:**
- Highest Cost
- Needs most space for ECU
- Complex calibration required
- Software most complex

>> 100 cc Engines
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Overview of Freescale’s circuits for small engines

• Freescale has always been a leader in the automotive and small engine microcomputer (MCU) market. Engine controller manufacturers worldwide use Freescale’s 8-, 16- and 32-bit MCU’s to build the most reliable and technologically advanced ECU’s for CDI, TCI, EFI and GDI engine control systems.

• For the small engine market, as in the automotive market, Freescale offers many analog powertrain products to interface the MCU to the electro-mechanical actuators and power devices used to control the internal combustion engine.

• Freescale has targeted the small engine market by providing a family of analog products designed to meet the requirements of CDI, TCI, EFI and GDI engine controllers.
MC33812 – Small Engine Analog Control Circuit

- The MC33812 is the first small engine analog product for CDI, TCI and EFI engine control applications from Freescale

**Diagram:**
- **Battery**
- **ISO9141 Interface**
- **Watchdog Timer**
- **+5 V Regulator**
- **MCU:**
  - ADC
  - Timers
  - SCI
  - Reset
  - I/O
- **Power**
- **Low Side Driver**
- **Pre-Driver**
- **Low Side Driver**
- **Transformer**
- **Relay**
- **IGBT, SCR or Darlington coil driver**
- **Spark coil**
- **Spark plug**
- **Fuel Injector**
- **Carburetor solenoid**
- **Diag/Cluster**
- **Fuel Injector**
- **MIL Lamp**
- **MC33812**
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To meet the reduced size and cost requirements of the small engine ECU, the **SiP** or “System in a Package” solution was developed.

<table>
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<th>Two Chip</th>
<th>One Chip</th>
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<tr>
<td>Board Area</td>
<td>271.2 mm²</td>
<td>256.0 mm²</td>
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<td>Yes</td>
</tr>
<tr>
<td>Cost</td>
<td>More</td>
<td>Less</td>
</tr>
</tbody>
</table>

**SiP** or “System in a Package” solution.

Note: Can substitute S12XS for S12P.
Four members of the SiP family

**MM912JP812** - MC9S12P128 + MC33812
- 96K or 128K Program Flash
- 6K RAM
- 4K Data Flash

**MM912IP812** - MC9S12P96 + MC33812
- 96K or 128K Program Flash
- 6K RAM
- 4K Data Flash

**MM912JS812** - MC9S12XS128 + MC33812
- 128K Program Flash
- 8K RAM
- 8K Data Flash

**PM912NE812** - MC9S12XEP100 + MC33812
- (for calibration use only, not a production part)
- 1MB Flash
- 64K RAM
- 4K EEPROM
MM912JS812 SiP Layout

MC33812 Analog circuit

S12XS MCU
Insulated wire bonds
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Other multi-chip packaging techniques

- The stacked die technique is used in many cell phones and other devices that require extreme circuit density in a small package.

- Two or more die are stacked one on top of the other sometimes with an interposer layer.

**Advantages:**
- Small package footprint
- Good high frequency characteristics
- Excellent circuit density

**Disadvantages:**
- Poor thermal resistance for power die
- Thermal and mechanical stress
- Difficult to manufacture
- Susceptible to vibration damage
SiP vs. IDC

IDC has inter-die connections

SiP has no inter-die connections
Advantages of SiP approach

• Reduces package count on PC Board
• Closer proximity between MCU and analog chip
  - Better for EMC and EMI performance
• Both die attached directly to package flag
  - Better thermal performance
  - Better vibration resistance
  - Better ESD protection and grounding
• All chip pads on both chips bonded out for:
  - ease of test
  - flexibility of circuit design
• Easy to manufacture
• Lower cost
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Use of the Freescale SiP in a CDI ECU

- Spark Coil
- VRS
- Flywheel
- CDI ECU Circuit Board
- Spark Plug Wire
- Other Connections
Basic CDI Block Diagram

- **Battery or Magneto and Supercap**
- **Toothed Wheel**
- **VRS**
- **Power Conditioning & Regulator**
- **High Voltage DC-DC Supply**
- **Capacitor and SCR**
- **Timing and Control**
- **VRS Conditioning**
- **Ignition Coil**
- **Spark Plug**

Diagram elements include: Battery, Magneto, Supercap, Toothed Wheel, VRS, Power Conditioning, High Voltage DC-DC Supply, Capacitor and SCR, Timing and Control, Ignition Coil, Spark Plug.
Basic DC-CDI Schematic Using Discrete Components
Basic DC-CDI Schematic Using MC33812

Battery

Toothed Wheel

Ignition Coil

Spark Plug

VRS

Microcomputer MCU

Eliminates MOSFET
Replace 5 Volt Regulator
Adds ISO-9141
Adds Watchdog

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Basic CDI Block Schematic Using MC33812 SiP

Eliminates MOSFET
Replaces 5 Volt Regulator
Adds ISO-9141
Adds Watchdog
Combines MCU and MC33812 in single package

Single IC ECU?
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MM912JP812 SiP Reference Design ECU PC Board

- VRS Sensor Conditioner
- I/O Connectors on back
- Fuel pump Driver
- HEGO Heater Driver
- Reverse Battery and Transient protection
- Idle Speed Motor Driver
- BDM Connector
- CAN interface (optional)
- IGBT
- +5 Volt Regulator external PNP Transistor
- MM912JP812 SiP
- +5 Volt Regulator external PNP Transistor

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