E^P System™ Theory of Operation
Planetary Gear Operation

- Planetary Gear Sets
  - Made up of three intermeshed gears
    - Sun Gear
    - Pinion Gears held together by carrier
    - Ring Gear
  - Gears rotate together as a set of components
  - Holding one of the components creates output
Hydraulic Clutch Operation

• Provide Driving And Holding Forces For Planetaries

• Two Intertwined Sets Of Clutch Plates
  – *Fiber friction plates*
  – *Steel reaction plates*

• Fluid Pressure Behind Piston Clamps Plates Together
  – *Springs release the piston when pressure exhausts*

• Rotating Clutches Supply Rotational Input To Components

• Stationary Clutches Hold Components
**E³ Drive™ Theory**

- **Electrically Variable Transmission**
  - Two-Mode compound split parallel hybrid architecture
    - **Two Mode:** The E³ Drive™ has 2 operating modes or speed ranges, Mode 1 and Mode 2. The mode shift point varies based on load, engine speed, output speed, and motor speeds.
      - Generally occurs 15-25 mph
    - **Compound Split:** There are two power splits inside the E³ Drive™, an input split that occurs in Motor A and an Output split that occurs in Motor B.
    - **Parallel Hybrid:** Two power sources are used in a parallel configuration, Electrical and Mechanical power.

[View Video]
**EVTM Drive Theory**

- **Motors/Generators Go Both Ways**
  - Generating occurs when mechanical rotation frequency is greater than stator field frequency
  - Motoring occurs when stator field frequency is greater than mechanical rotation frequency

- **EVTM Drive Motors Are Like Variable Clutch Packs**
  - Speeds between -5000 rpm and 5000 rpm
  - Motors are used to control planetary component speeds, as well as apply torque
  - Electrical power is always needed to provide rotational output power
**E^V Drive™ Theory**

- **E^V Drive™ Operation**
  - *Uses input damper instead of a torque converter to transfer engine power to the transmission: absorbs torsional engine vibration and oscillations*
  - *Uses hydraulic clutches in the same manner as other hydraulic transmissions hold rotating and stationary components*
  - *Main pressure is continually modulated based on output torque to reduce engine load*
  - *Vehicle launch in most cases is electrically dominated (motor B)*
E\textsuperscript{V} Drive\textsuperscript{TM} Internal Components

- Input Shaft
- Main Shaft
- Output Shaft
- Motor A
- Motor B
- Control Deck

Points:
- P1
- P2
- P3

Circles:
- C1 - Stationary
- C2 - Rotating
E\textsuperscript{V} Drive\textsuperscript{TM} Speed Diagram

Full Throttle Acceleration

- Unit A
- Unit B
- Engine
- E\textsuperscript{V} Drive Output

Vehicle Speed (mph)

Units A, B and Engine Speed (rpm)
<table>
<thead>
<tr>
<th>Mode 1 (1\textsuperscript{st} Range)</th>
<th>Mode 2 (2\textsuperscript{nd} Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward</strong></td>
<td><strong>Neutral</strong></td>
</tr>
<tr>
<td>C1 applied</td>
<td>C1 un-applied</td>
</tr>
<tr>
<td>C2 un-applied</td>
<td>C2 applied</td>
</tr>
<tr>
<td><strong>Reverse</strong></td>
<td>Reverse speed limited</td>
</tr>
<tr>
<td>C1 applied</td>
<td>C1 un-applied</td>
</tr>
<tr>
<td>C2 un-applied</td>
<td>C2 un-applied</td>
</tr>
</tbody>
</table>
• Mode 1

- Control Main Regulator
- Main Supply
- Lube
- C2 Trim
- C1 Trim
- C1 Block
- C2 Block
- Main Pressure Regulator
- Cooler
- Lube Regulator
**EV Drive™ Hydroschemes**

- **Mode 2**

Diagram showing the layout of a hydroschematic with various components such as Control Main Regulator, Main Pressure Regulator, Lube Regulator, and Coolers.
Main Boost Control

• Dynamically changes system main pressure based on output load
  – *Reduces hydraulic power loss*
    • As much as 4 hp hydraulic power loss reduction at high engine speed

• System main pressure is controlled by normally closed main boost solenoid
  – *Clutch Pressure: 125 - 320 psi*
  – *Main Boost Pressure: 0 - 80 psi*
  – *Control Main: 80 psi*
**E\textsuperscript{V} Drive\textsuperscript{TM} Sensors**

- **Motor Speed Sensors**
  - Two per motor
  - Hall Effect type
    - Provides square wave output between 0 and 11.7 volts
    - Cannot be checked by ohm meter on leads
    - Sensor output can be checked on signal wire for 11.7 volt signal
  - Provides speed and direction of Motors to the DPIM
  - Located on left and right sides of stator housing barrel
• **Output Speed Sensors**
  - Two sensors located on rear cover
  - Reluctance-type device (formed with a pole and coil)
    - Can be checked with a volt-ohm meter across the leads (approximately 300 ohms)
    - Outputs an AC wave form
  - Used to determine speed and direction of output shaft
  - Output signal is not used by TCM until output speed is greater than 100rpm
  - Output speed signal is provided to the TCM
EV Drive™ Sensors

- Motor Temperature Sensors
  - Two RTDs (Resistance Temperature Device) per motor
    - Not serviceable
    - One is a spare
    - Resistance vs. Temperature changes linearly
  - Can be checked external of the transmission with a volt-ohm meter
  - Temperature signal is provided to the DPIM
  - Temperature measured as a voltage input
• **Oil Level Sensor**
  - Located in the transmission sump
    • Mounted on the relay valve body at rear of the transmission
  - Hall effect type device
  - Cannot be checked with a volt-ohm meter
  - Can be read through either PBSS or using Allison DOC™.
  - Transmission Fluid must be at least 20°C (68°F) for an accurate reading to occur
  - Range of sensor: 5 quarts low to 5 quarts high
• Sump Temperature Sensor
  – Located in the transmission sump
  – Measures transmission sump temperature
• **C1/C2 Pressure Switches**
  – Provides a ground signal to the TCM when hydraulic clutch pressure is sensed
  • Main pressure strokes relay valve providing pressure switch with control main signal (80psi)
  – Located on relay valve body in rear of the transmission
E\textsuperscript{V} Drive\textsuperscript{TM} Adaptation
E\textsuperscript{V} Drive\textsuperscript{TM} 3-Phase AC Connections
E\textsuperscript{V} Drive\textsuperscript{TM} Cooling
EV Drive™ Switches

• Motor A & B HVIL Switches
  – Lid switch in circuit designed to prevent access to hazardous voltage
  – Detects presence of lug box cover
  – Open HVIL circuit will prevent ESS pre-charge and engine startup
    • If detected during operation, system will be shut down when Neutral is obtained and restart denied if still active
DPIM: Dual Power Inverter Module

- Includes two inverters
  - A side – Motor A (red 32 pin connector)
  - B side – Motor B (gray 32 pin connector)
- Electrical Output
  - 160 kW continuous 3-phase AC
  - 300 kW peak output
  - 2 independent inverters operate on a common DC buss
- 160 lb. mass
- Dimensions: 48” x 23” x 6.5”
AC Electrical Power

Wall Power - 120 Volts RMS
170 Volts Peak 60 Hz

3Φ Wall Power - 208 Volts RMS LL
300 Volts Peak 60 Hz
Inverter turns IGBTs on and off to control phase currents.
- To produce desired torque, magnitude and frequency is varied.
**DPIM- Inputs**

- **Required Inputs For Torque Production**
  - CAN torque command from TCM
  - 12 volt torque enable input
    - 12 volt ignition input
  - Wakeup signal
    - 12 volt wakeup on both A & B inverters
  - 12v power and ground signals
    - Minimum of 10.5 volts required for IGBT operation
  - DC bus voltage
    - ESS must complete pre-charge and system operational status

- **DC Bus Discharge At Shutdown**
  - Current pushed through motors to create heat instead of torque
DPIM- Inputs (cont.)

- Motor A and B Signal Inputs
  - Motor speeds
    - P1—motor A primary encoder
    - P2—motor A secondary encoder
    - P3—motor B primary encoder
    - P4—motor B secondary encoder
  - Motor temperatures (RTD)
  - Motor A HVIL
  - Motor B HVIL
  - ESS HVIL
DPIM- Cooling

- Cooling Process
  - IGBT switching losses create heat
  - Transmission fluid flow circulates through a channel on the underside of the DPIM to remove heat from the IGBT modules
  - Transmission regulates flow and pressure through orifice in stator housing
  - Pop-off valve in transmission sump prevents pressure buildup greater than 70psi
• DPIM IGBT temperatures during normal operation will be 20-30°C higher than E\textsuperscript{V} Drive\textsuperscript{TM} sump temperature.

• Inadequate fluid fill in the E\textsuperscript{V} Drive\textsuperscript{TM} can starve the DPIM of cooling fluid.
DPIM Mounting- Gillig LF Roof Mount
DPIM Mounting- New Flyer LF Roof Mount
ESS- Theory of Operation

• ESS: Energy Storage System
  – Uses NiMH battery technology
  – On-board management controllers
    • State of charge (SOC)
    • Thermal equalization
    • Cell Equalization
    • Diagnostics
  – No off-board charging provision
  – Approximately 915 lbs.
  – Air cooled via 6 internal multi-speed fans
ESS- Theory of Operation

• ESS Configuration
  – 3 Substrings
    • Parallel combination of substrings (450A, 624VDC)
    • Each substring contains 2 sub-packs in series
  – 1 Sub-pack contains 40 modules (20 blocks)
    • 1 sub-pack is ~312 volts
    • Each module is ~ 7.8 volts
    • BCIM: One per sub-pack monitors temperature and block level throughput
  – In Summary:
    • 240 modules
    • 6 sub-packs
    • 6 BCIM’s
    • 3 Sub-strings
**ESS- Inputs and Outputs**

- **Inputs**
  - 12/24 volt power
    - 12 volts for BCIM and HV relays
    - 24 volt power required for fans
  - HVIL
    - Input from DPIM (12 volt signal)

- **Outputs**
  - HVIL
    - Outputs 12 volt signal to DPIM if HVIL switches sensed closed
  - Relay Closed
    - Redundant ground signal to TCM indicating relays are closed
    - In the event of loss of CAN with ESS, TCM can command motor torque
ESS- Theory of Operation

- ESS Configuration

![Image of ESS with labeled subpacks and junction board]
ESS- Theory of Operation

- ESS Configuration
ESS- Theory of Operation

• NiMH Modules
ESS- Pack Hardware Architecture

Subpack
Subpack
Fuse
Precharge Resistor
High Side Relay
Precharge Relay
Precharge Relay
Subpack
Fuse
Precharge Resistor
High Side Relay
Precharge Relay
Precharge Relay
Subpack
Fuse
Precharge Resistor
High Side Relay
Precharge Relay
Precharge Relay
Subpack
Fuse
Precharge Resistor
High Side Relay
Precharge Relay
Precharge Relay
Subpack
Fuse
Substring 1
Substring 2
Substring 3
ESS- Pre-charge

- **Initial State**
  - All relays opened
ESS- Pre-charge

- Pre-charge State
  - Low side and pre-charge relays are closed
  - Charges DPIM capacitance through pre-charge resistor
ESS- Pre-charge

- Operational State
  - Low side and high side closed
ESS- Welded Relay Diagnostics

- Welded Relay Tests
  Low Side and Precharge at Power Up
  High Side at Power Down
  Will set code 77-01 - Battery High Side Relay Welded Closed
  Cannot be cleared w/ PBSS
ESS- OEM Adaptation

- Thermo King Unit
EP System™ Theory of Operation