Professional Considerations in Digital System Design

CASE STUDY: NEST LEARNING THERMOSTAT

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OUTLINE – *Professional Considerations in Digital System Design*

- Case Study: The NEST Learning Thermostat
  - Company History
  - How NEST Learns
  - Common Thermostat Circuits
  - IP Protected by Patents
  - What's Inside
  - Block Diagram
  - Key Functions
  - Schematic Details
- Professional Considerations: Case Study Applications
  - Reliability & Safety
  - Legal
  - Environmental & Regulatory
  - Ethical & Public Policy

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CLICKER QUIZ

Question 1

Indicate your “highest level” of experience with household thermostats:

A. I know that 4 wires are required for the basic interface, and that the control signals operate at 24 VAC
B. I have installed an electronic/smart thermostat
C. I have installed a conventional/mechanical thermostat
D. I understand that temperature control requires hysteresis, but have never installed a thermostat
E. I only know if it’s too hot or cold, and how to adjust the thermostat accordingly

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BACKGROUND

Nest Labs Company History

- Headquartered in Palo Alto, California
- Designs and manufactures sensor-driven, Wi-Fi enabled, self-learning (programmable) thermostats and smoke detectors
- Co-founded by former Apple engineers Tony Fadell and Matt Rogers in 2010
- First product was Nest Learning Thermostat (2011), inspired by Fadell's motivation to build a better "electronic" thermostat than those currently available
- Google acquired Nest Labs for $3.2B early in 2014
- Nest purchased Dropcam for $555M later in 2014
- Latest products include Nest Protect (Smoke and Carbon Monoxide detector with voice alerts), Doorbell, and Lock

BACKGROUND

How Nest Learns

Senses and learns from you.

The Nest Thermostat integrates information from its sensors and the outside weather.

Activity sensors

Nest's activity sensors have a 150° wide-angle view. That range enables Nest to activate Auto-Away in 90% of homes.

Humidity sensor

Nest shows you indoor humidity and can manage your whole-home humidifier or dehumidifier.

Temperature sensors

Three temperature sensors track your home's temperature and how quickly it changes.

Weather aware

Nest uses its Wi-Fi connection to keep an eye on current weather conditions and forecasts so it can understand how the outside temperature affects your energy use.

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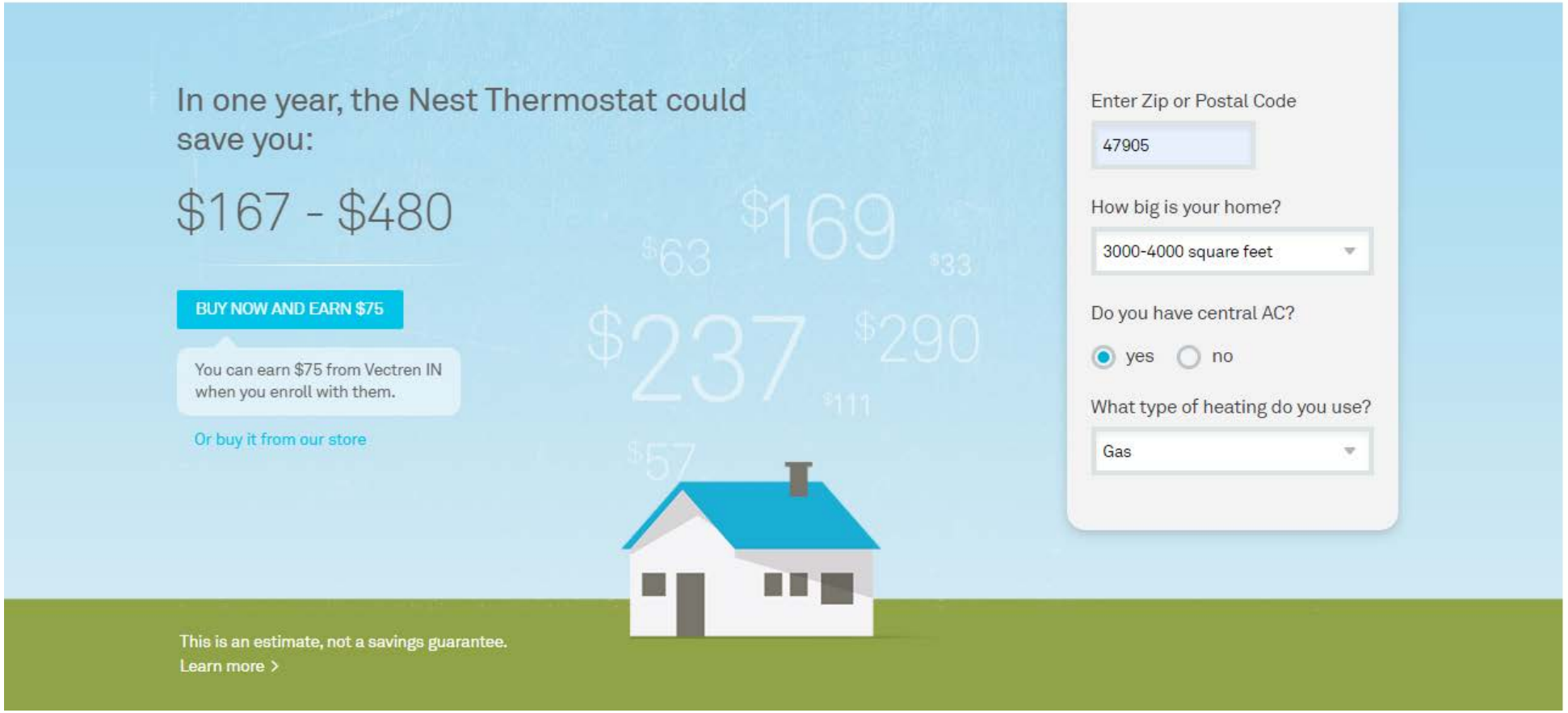
BACKGROUND

Nest Learning Thermostat Energy Savings Claims



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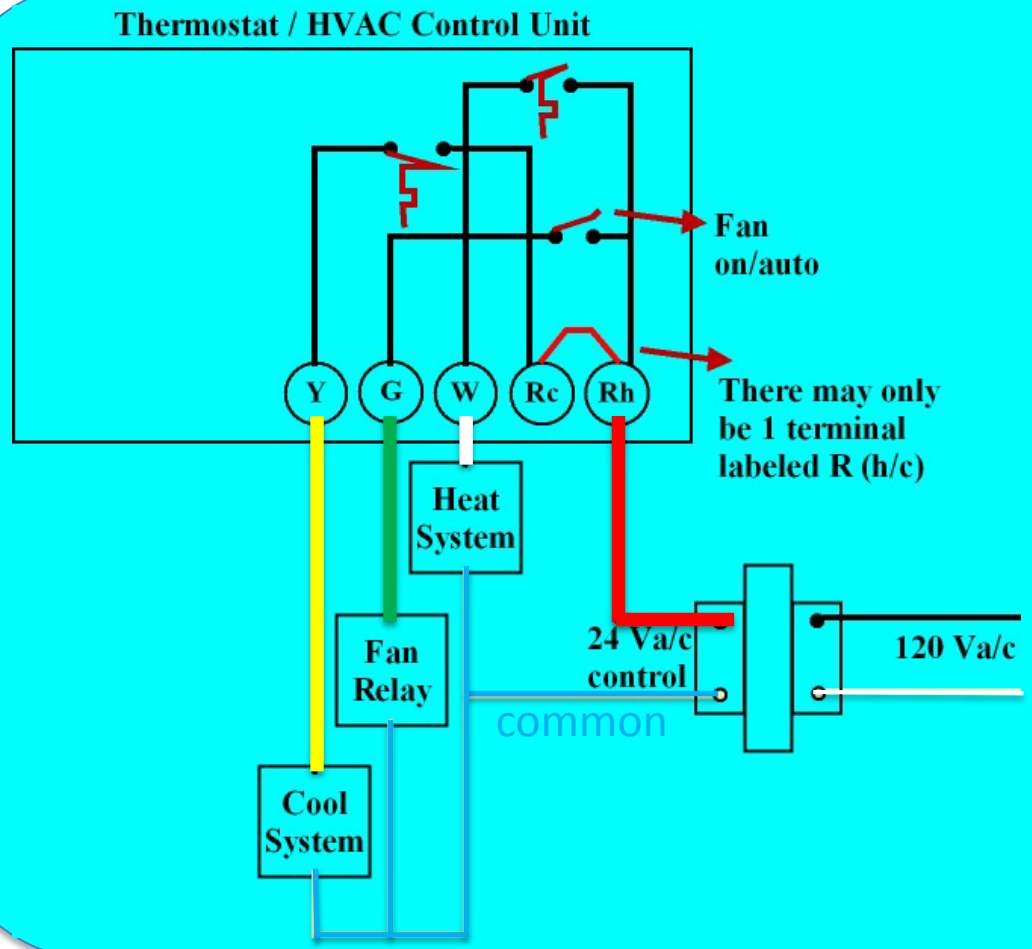
BACKGROUND

Basic 4-Wire Circuit Thermostat Circuit



Questions:

1. What is unknown?
2. What signal is (generally) not available at the thermostat?
3. What are implications of the need to switch 24VAC at up to 1 A?
4. What are implications of the unknown load impedance?
5. What are the implied restrictions on how an electronic thermostat can be powered?

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PATENTS

Ease of Installation

US Patent 8,523,083 (filed Jun. 2012, issued Sep. 2013)

THERMOSTAT WITH SELF-CONFIGURING CONNECTIONS TO FACILITATE DO-IT-YOURSELF INSTALLATION

ABSTRACT *A thermostat is configured for automated compatibility with HVAC systems that are either single-HVAC-transformer systems or dual-HVAC-transformer systems. The compatibility is automated in that a manual jumper installation is not required for adaptation to either single-HVAC-transformer systems or dual-HVAC-transformer systems. The thermostat has a plurality of HVAC wire connectors including a first call relay wire connector, a first power return wire connector, a second call relay wire connector, and a second power return wire connector. The thermostat is configured such that if the first and second external wires have been inserted into the first and second power return wire connectors, respectively, then the first and second power return wire connectors are electrically isolated from each other. Otherwise, the first and second power return wire connectors are electrically shorted together.*

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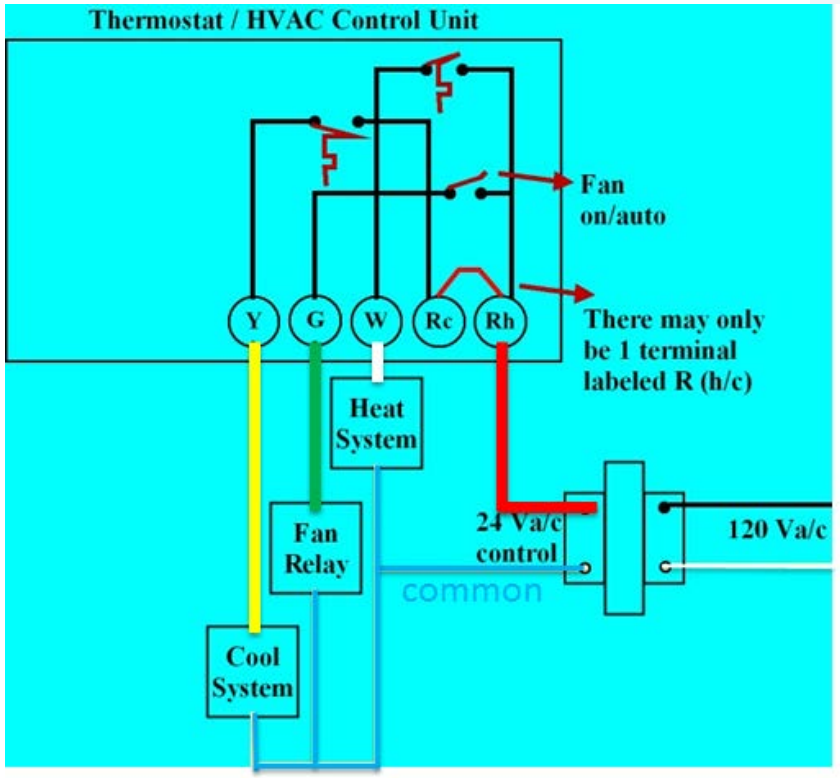
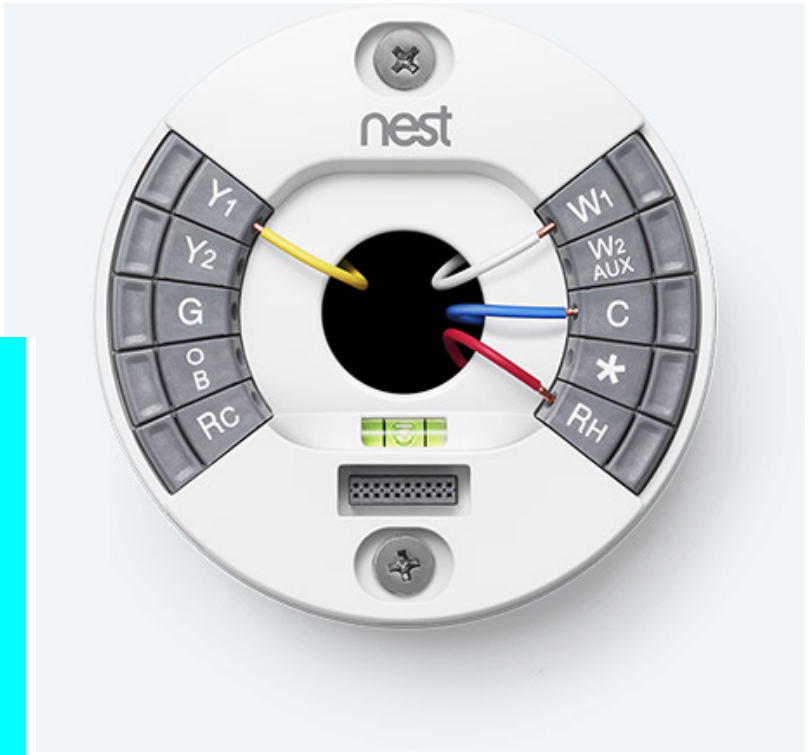
CLICKER QUIZ

Question 2

Contrary to the illustration from the Nest website reproduced here, the following wire connection (color) is typically <u>not</u> included in standard 4-wire household thermostat circuits:

A. RED (R_H / R_C)
B. YELLOW (Y)
C. WHITE (W)
D. BLUE (C)
E. none of the above





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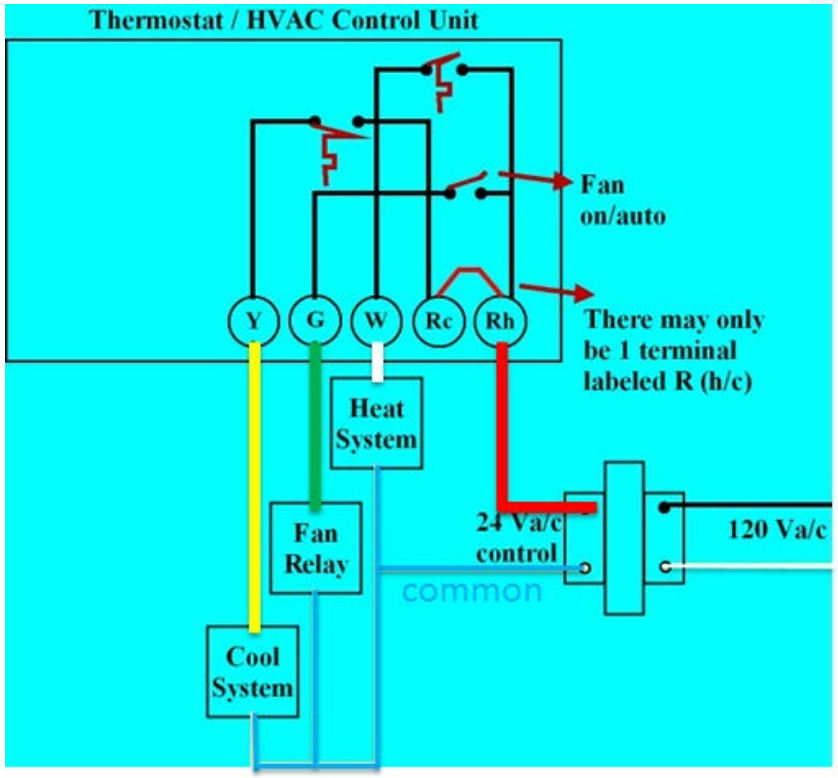
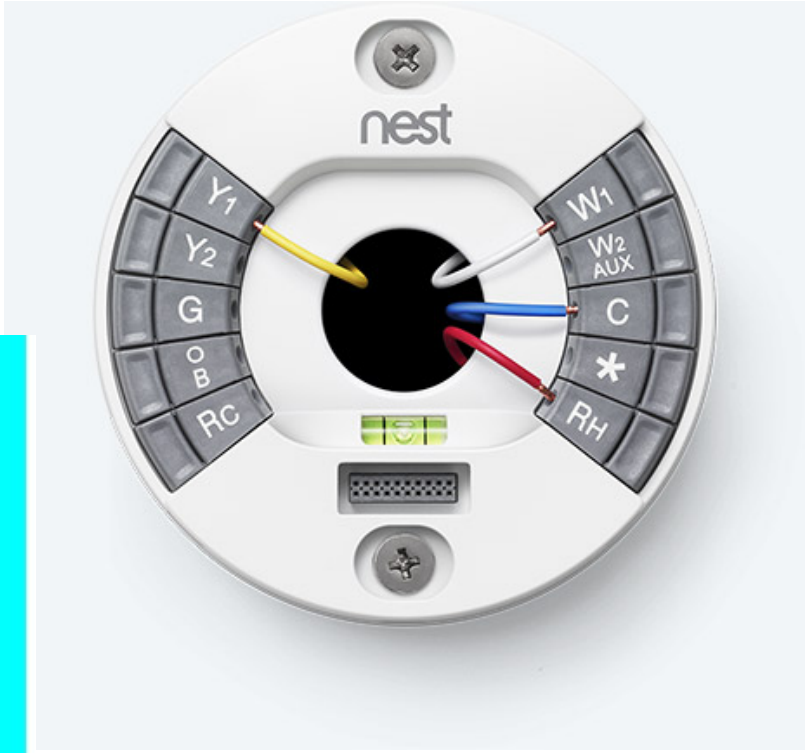
CLICKER QUIZ

Question 3

For the thermostat wiring shown, the following HVAC function cannot be controlled from the thermostat:

A. fan (air circulation) only
B. dehumidification
C. heating
D. cooling
E. none of the above





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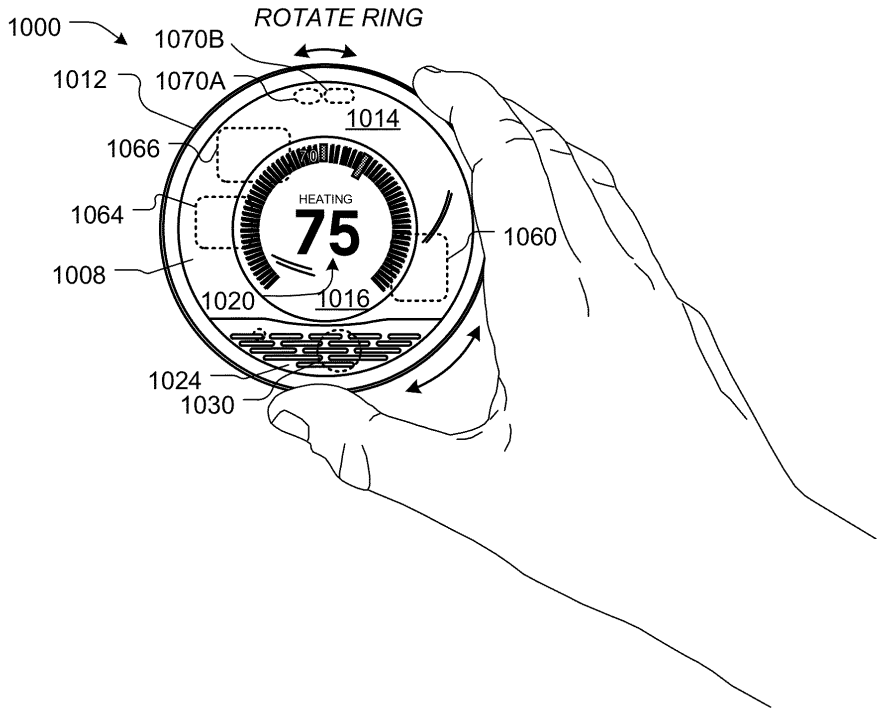
PATENTS

Event Forecasting System

US Patent 8,620,841 (filed Aug. 2012, issued Dec. 2013)

DYNAMIC DISTRIBUTED-SENSOR THERMOSTAT NETWORK FOR FORECASTING EXTERNAL EVENTS

ABSTRACT *Systems and methods for forecasting events can be provided. A measurement database can store sensor measurements, each having been provided by a non-portable electronic device with a primary purpose unrelated to collecting measurements from a type of sensor that collected the measurement. A measurement set identifier can select a set of measurements. The electronic devices associated with the set of measurements can be in close geographical proximity relative to their geographical proximity to other devices. An inter-device correlator can access the set and collectively analyze the measurements. An event detector can determine whether an event occurred. An event forecaster can forecast a future event property. An alert engine can identify one or more entities to be alerted of the future event property, generate at least one alert identifying the future event property, and transmit at least one alert to the identified one or more entities.*



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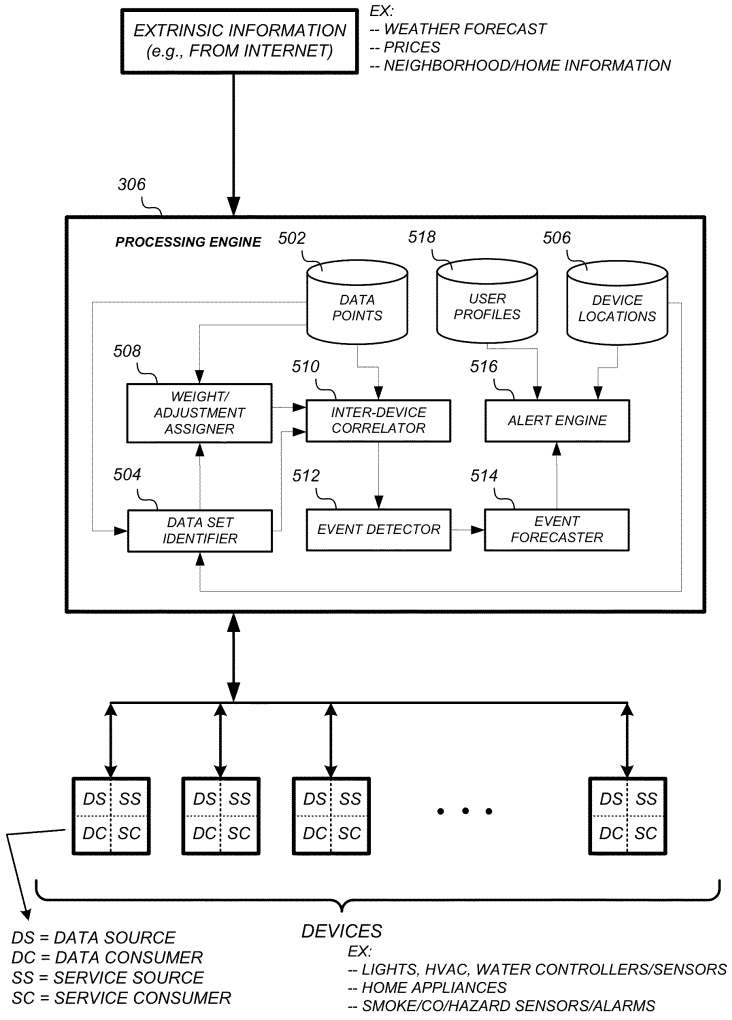
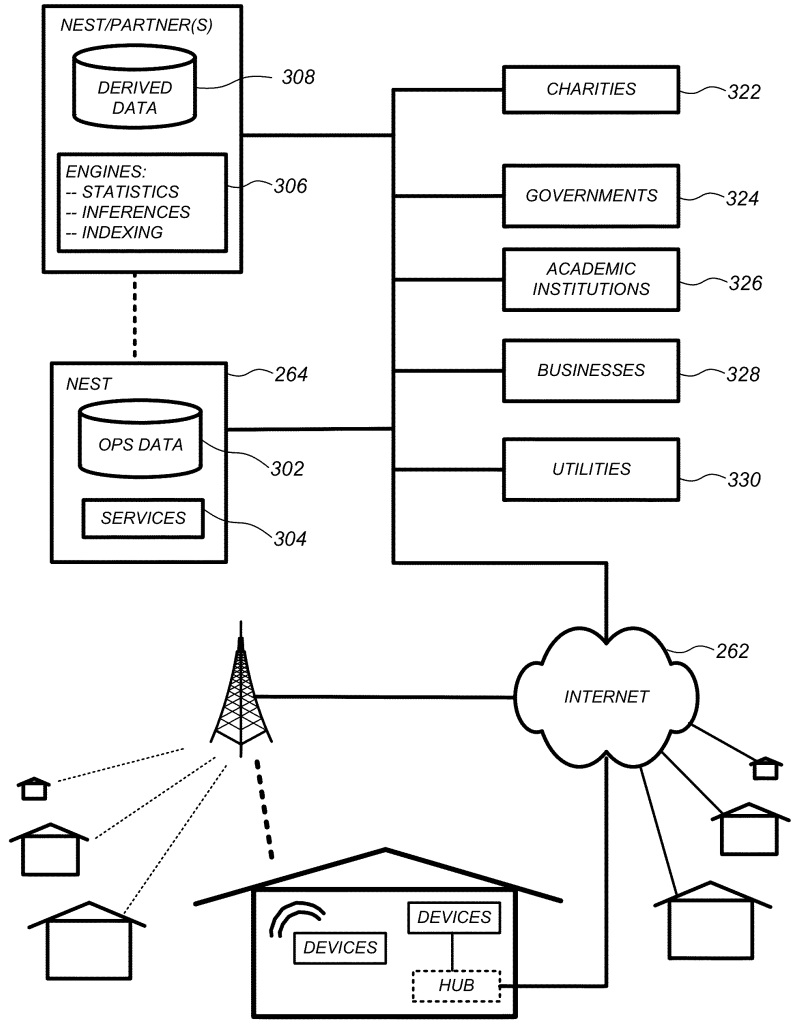
PATENTS

Event Forecasting System is Key Patent Claim





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PATENTS

Advanced Energy Harvesting ("Power Stealing") Strategy

US Patent 8,511,577 (filed Aug. 2012, issued Aug. 2013)

Thermostat with power stealing delay interval at transitions between power stealing states

ABSTRACT A thermostat includes a plurality of HVAC (heating, ventilation, and air conditioning) wire connectors including a connection to at least one call relay wire. The thermostat may also include a powering circuit, including a rechargeable battery, which is configured to provide electrical power to the thermostat by power stealing from a selected call relay wire. The power stealing may include an active power stealing mode, in which power is taken from the same selected call relay wire that is used to call for an HVAC function, and an inactive power stealing mode in which, in which no active call is being made. The powering circuit may be configured to substantially suspend (or at least reduce the level of) power stealing for at least a first time period following each transition of the thermostat from between operating states.

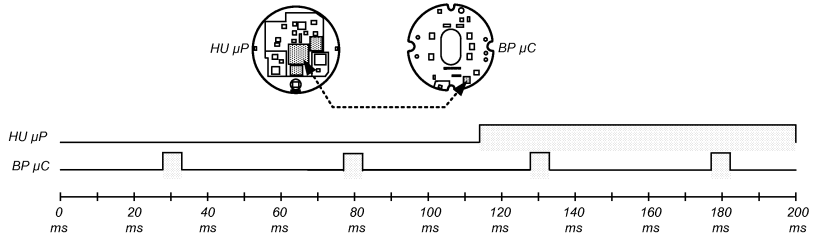


FIG. 17A

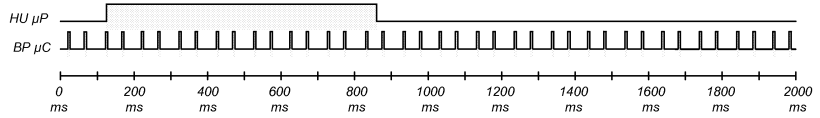


FIG. 17B

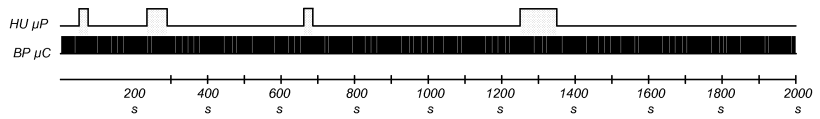
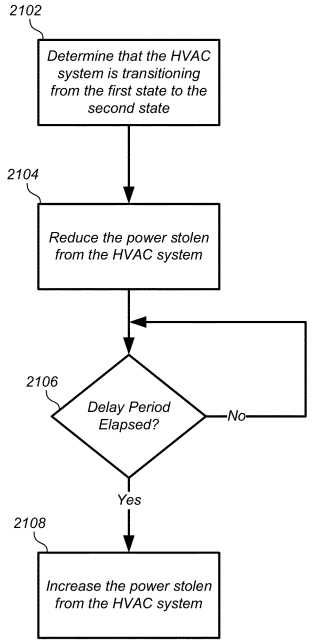


FIG. 17C



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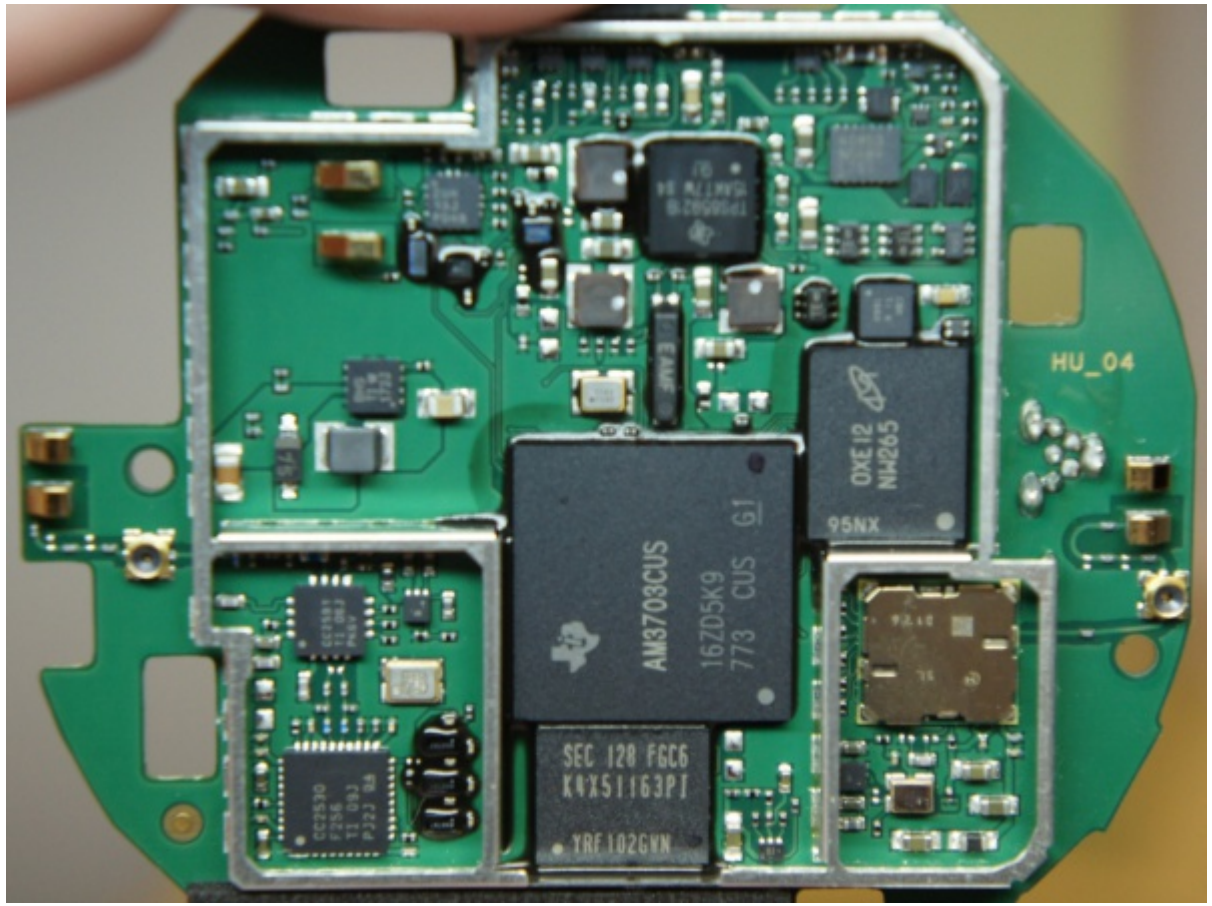
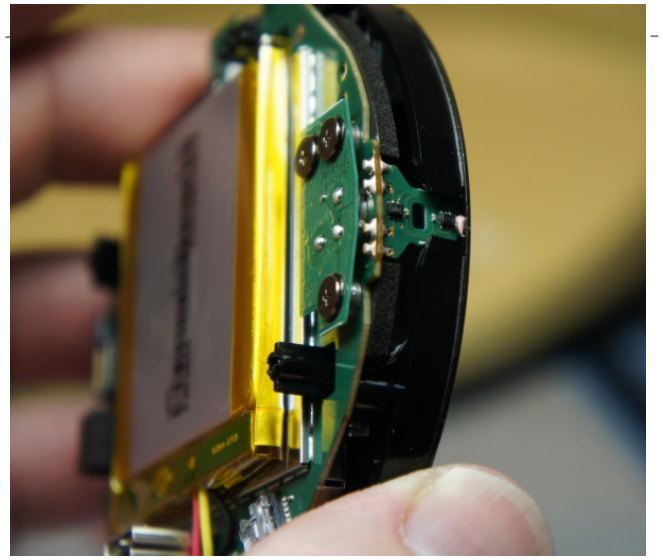
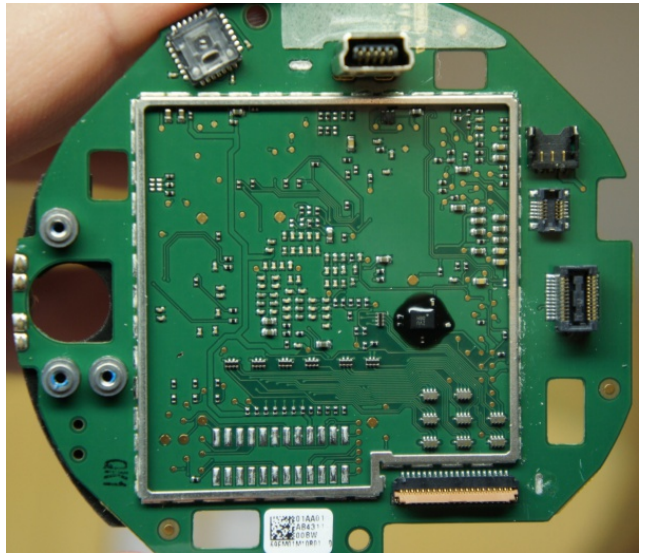
OVERVIEW

What's Inside







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OVERVIEW

What's Inside

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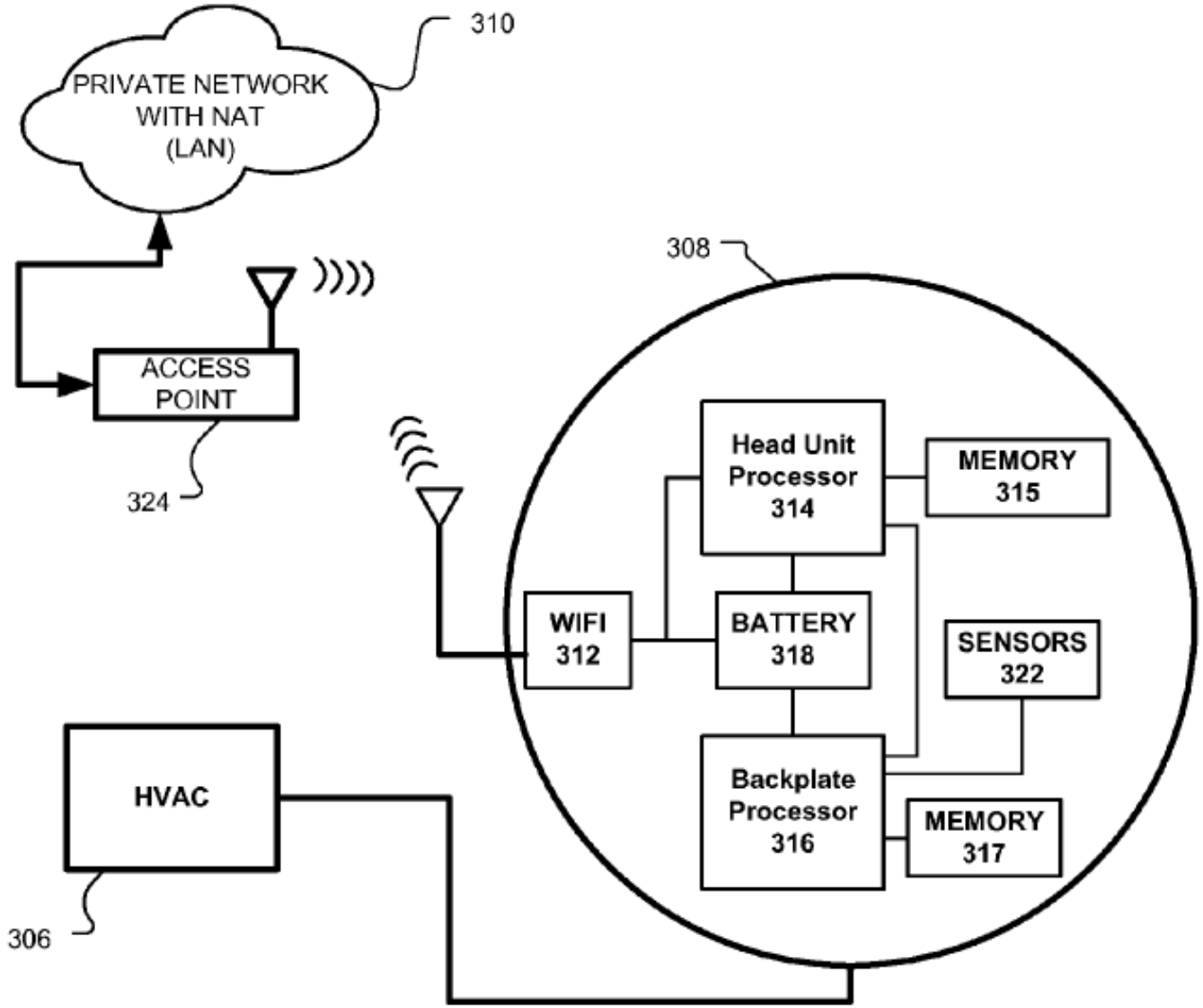
IFIXIT

OVERVIEW

Conceptual Block Diagram



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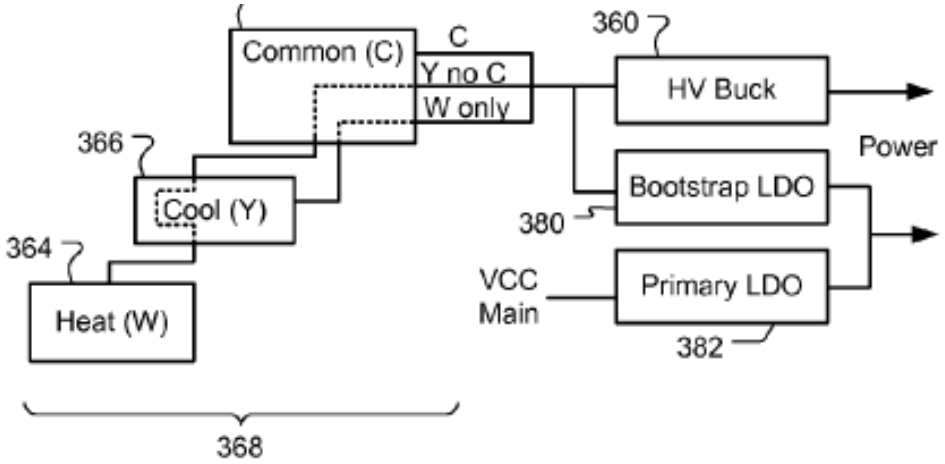
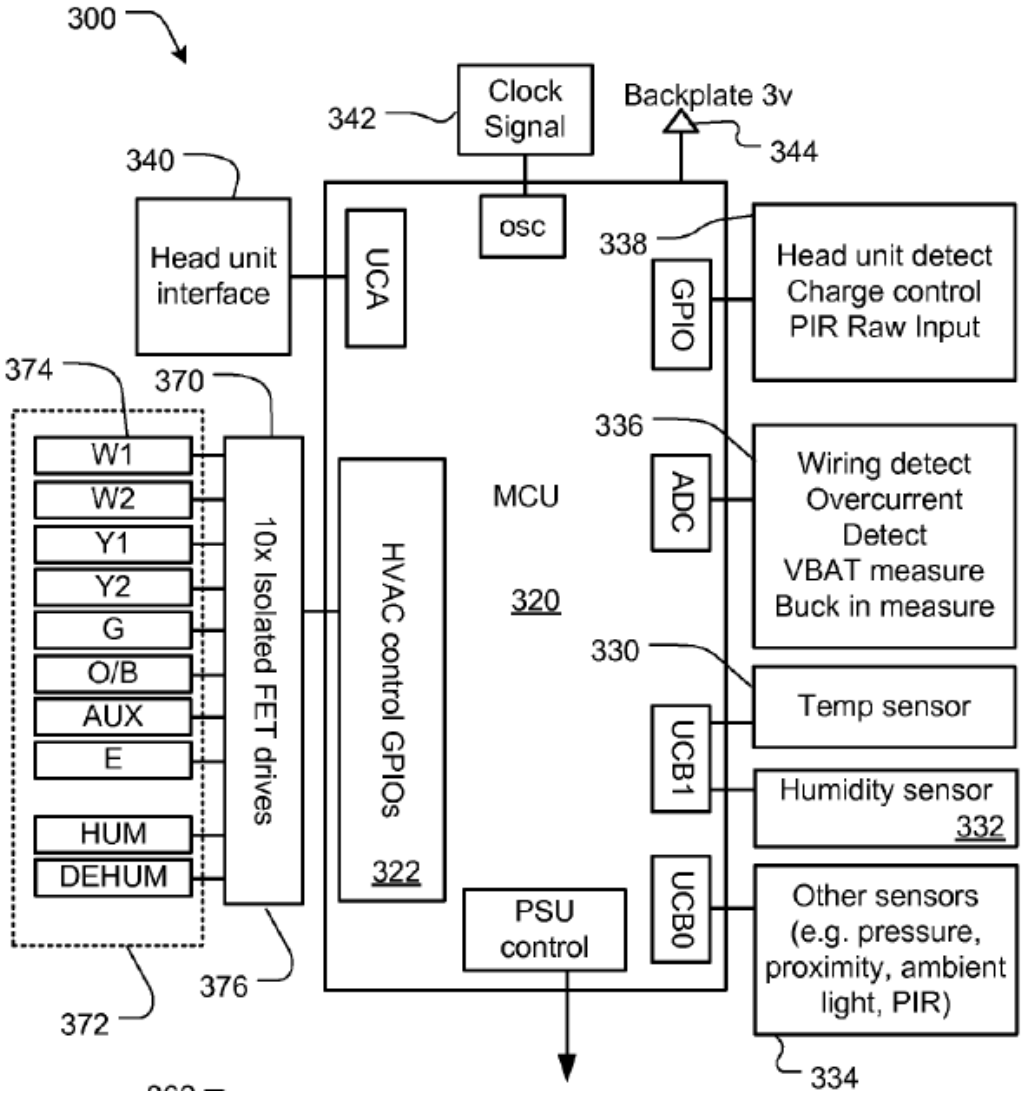
INTRODUCTION

Block Diagram





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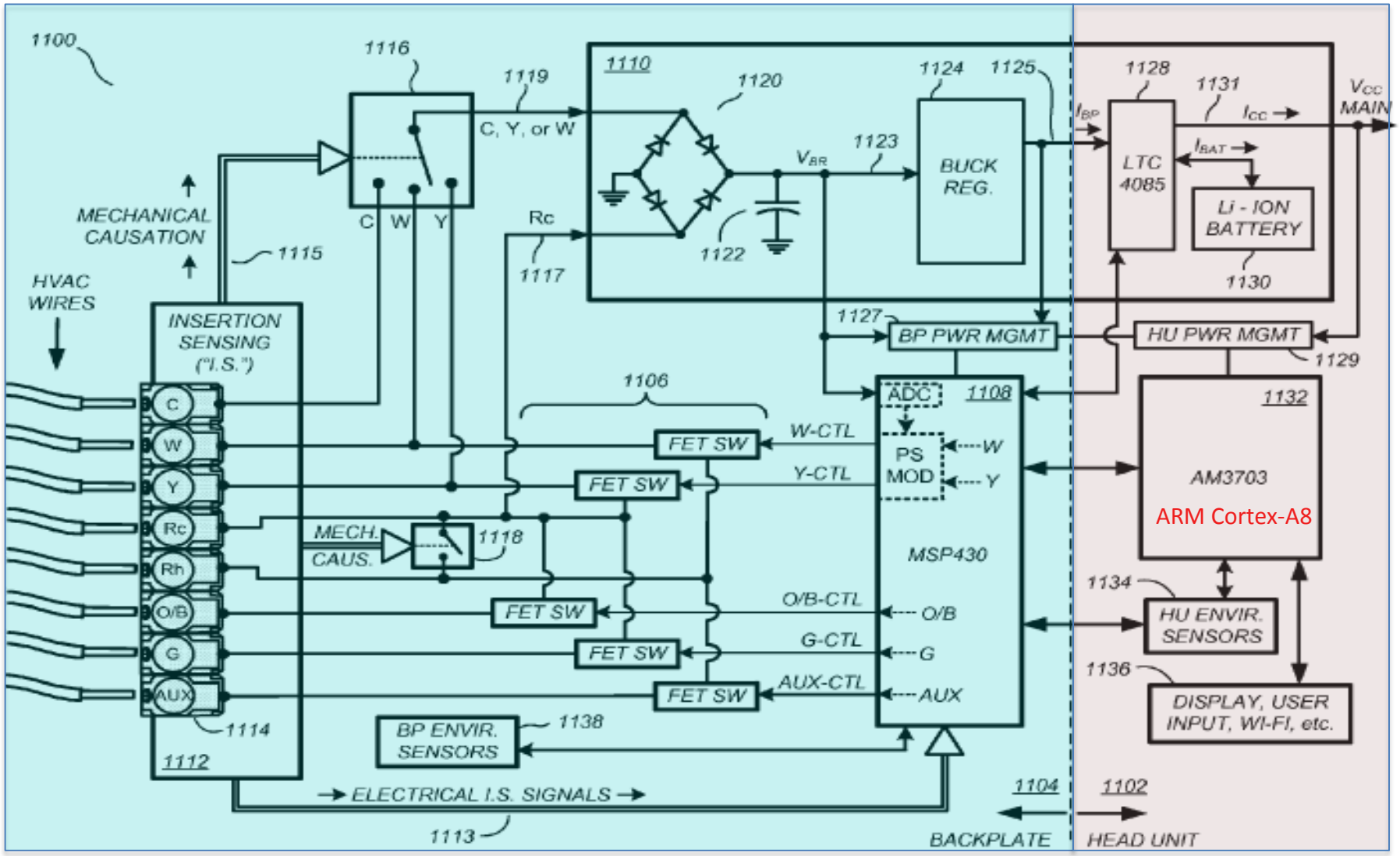
KEY FUNCTIONS

Mechanical Causation of Insertion Sensing Signals



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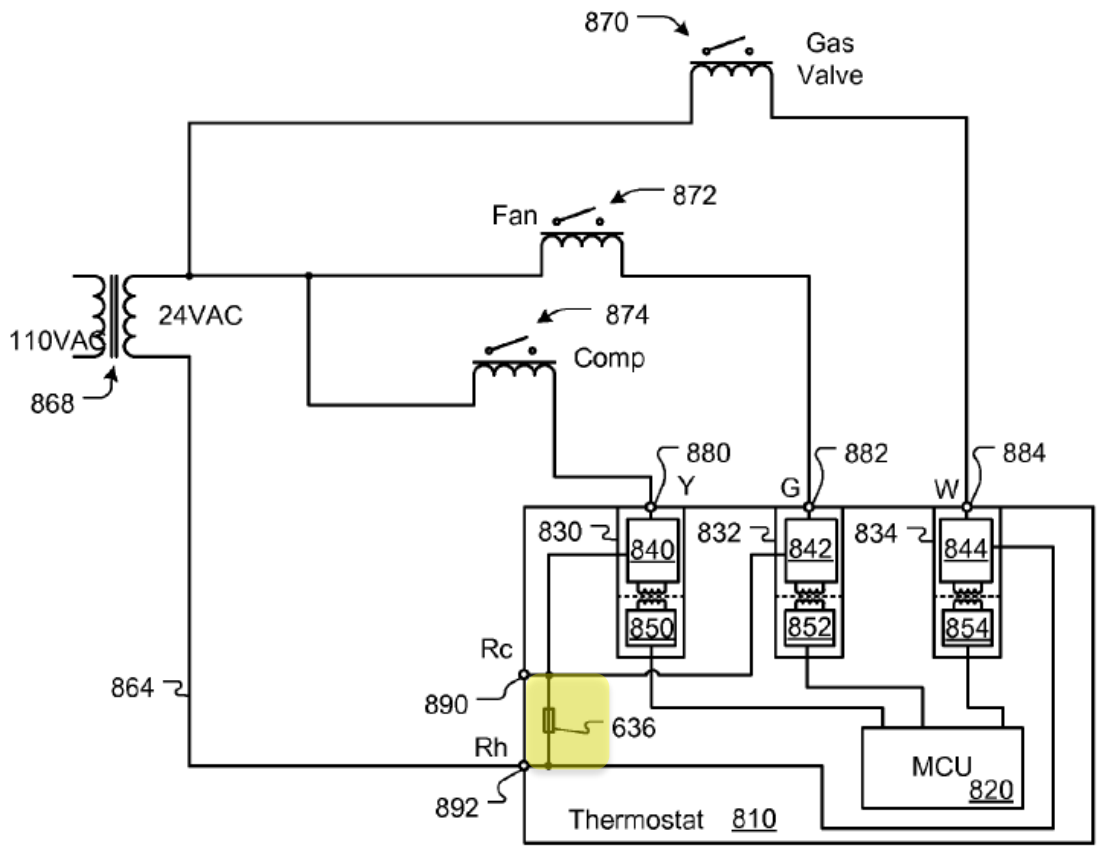
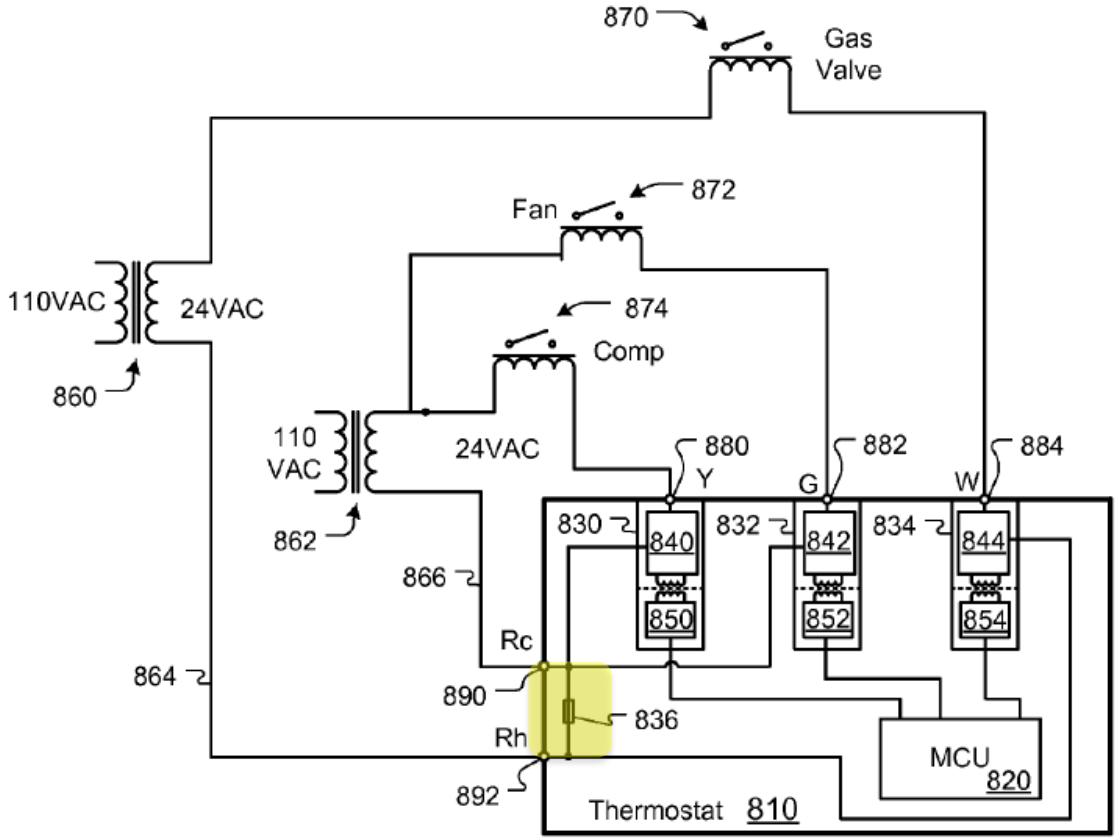
KEY FUNCTIONS

Accommodation of Single and Dual Transformer Installations





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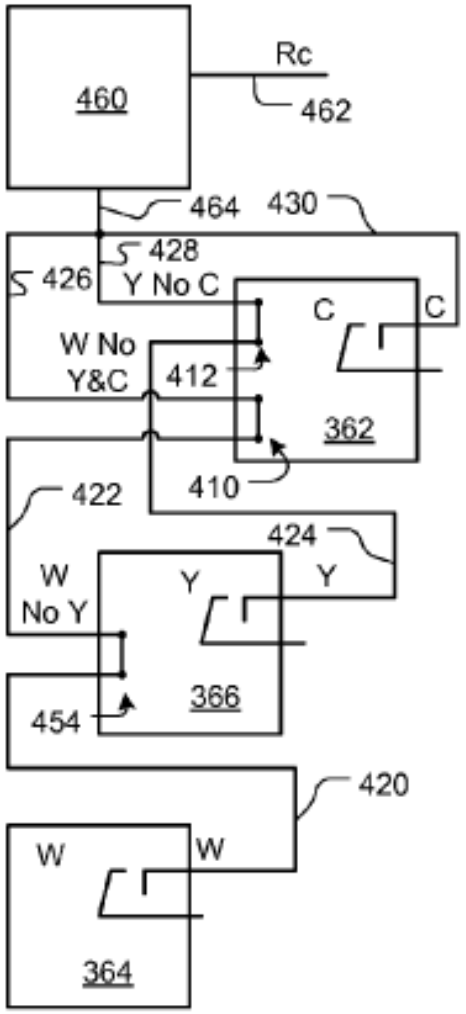
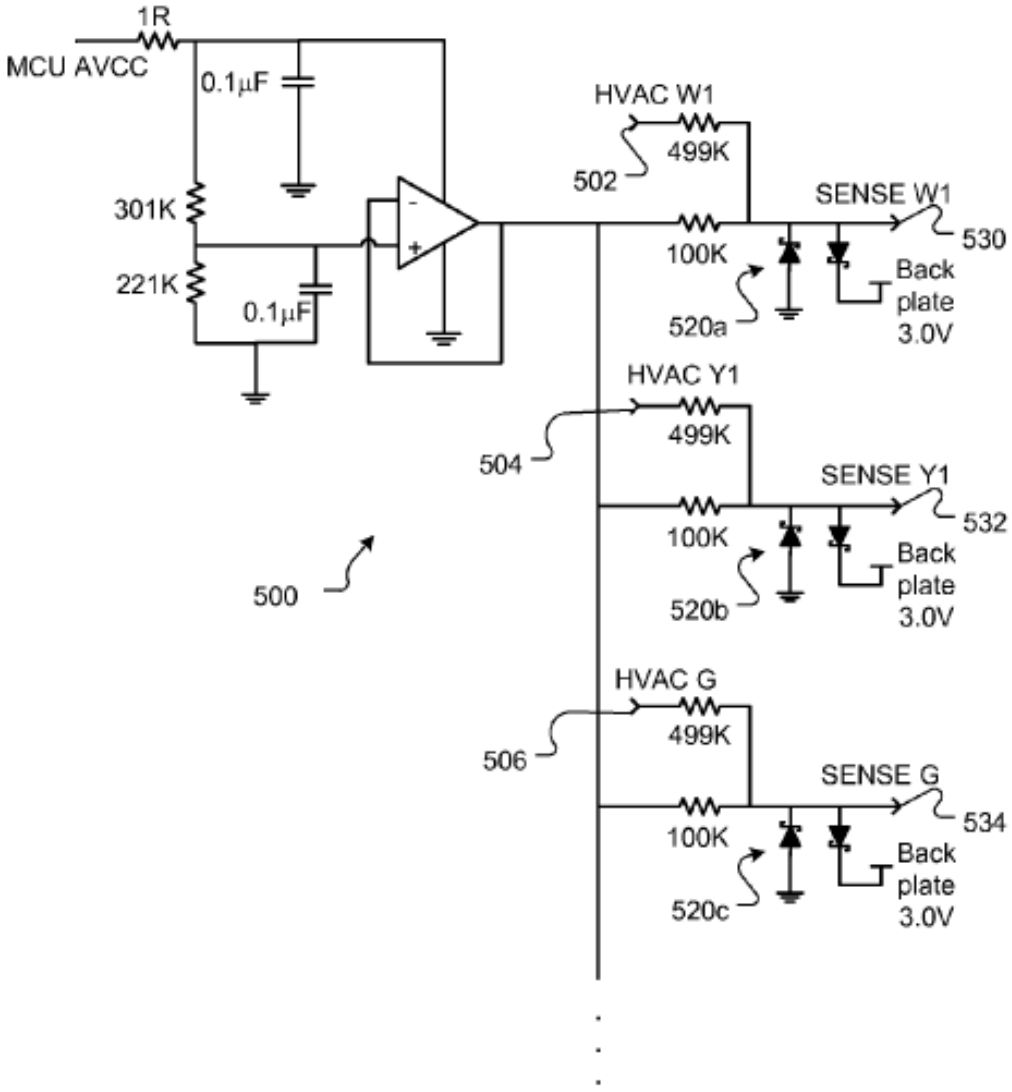
SCHEMATIC DETAILS

Connection Sensing Mechanism

Use of auto-switching connectors for automatically selecting a source for power harvesting





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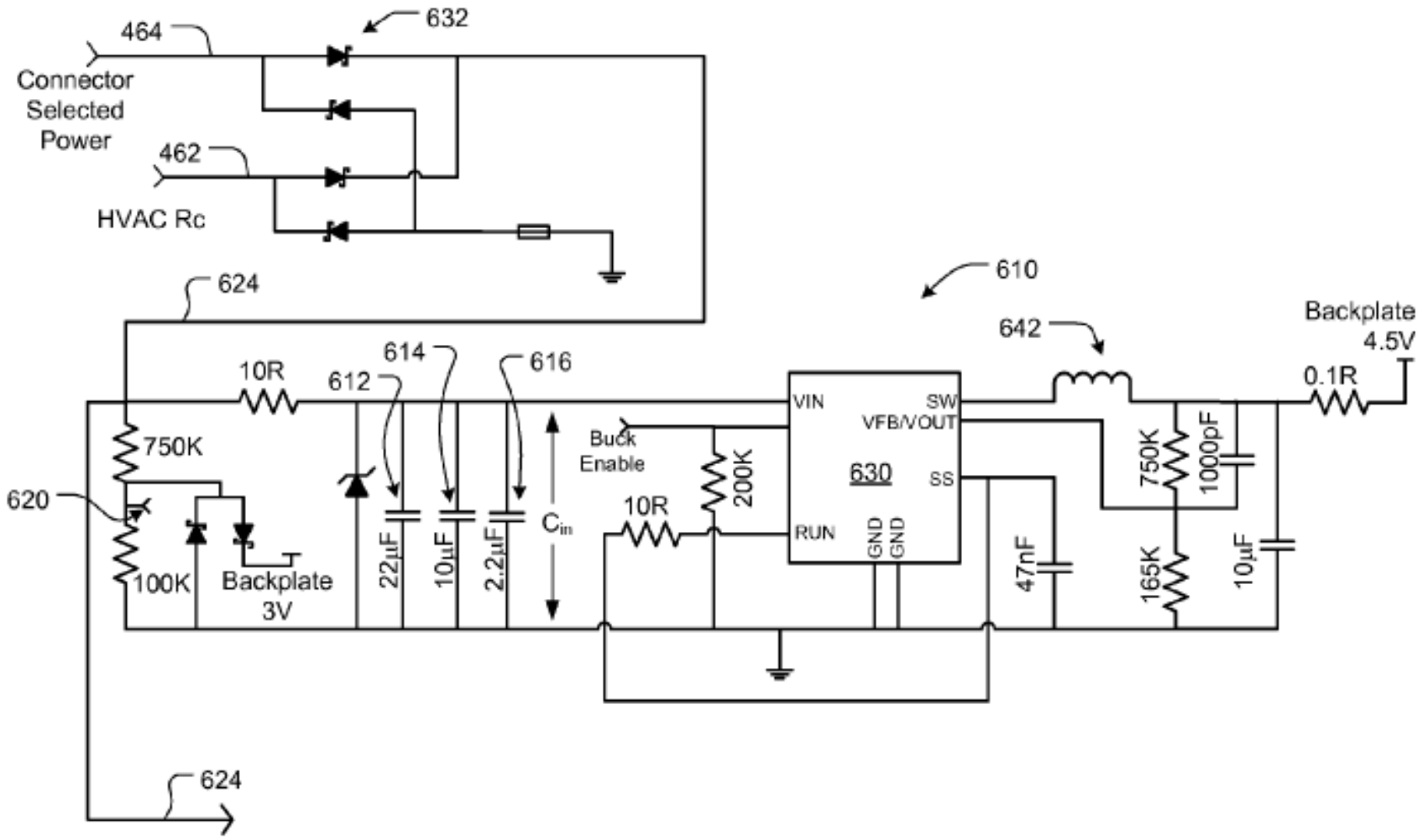
SCHEMATIC DETAILS

Power Supply - 1

"high voltage" buck converter



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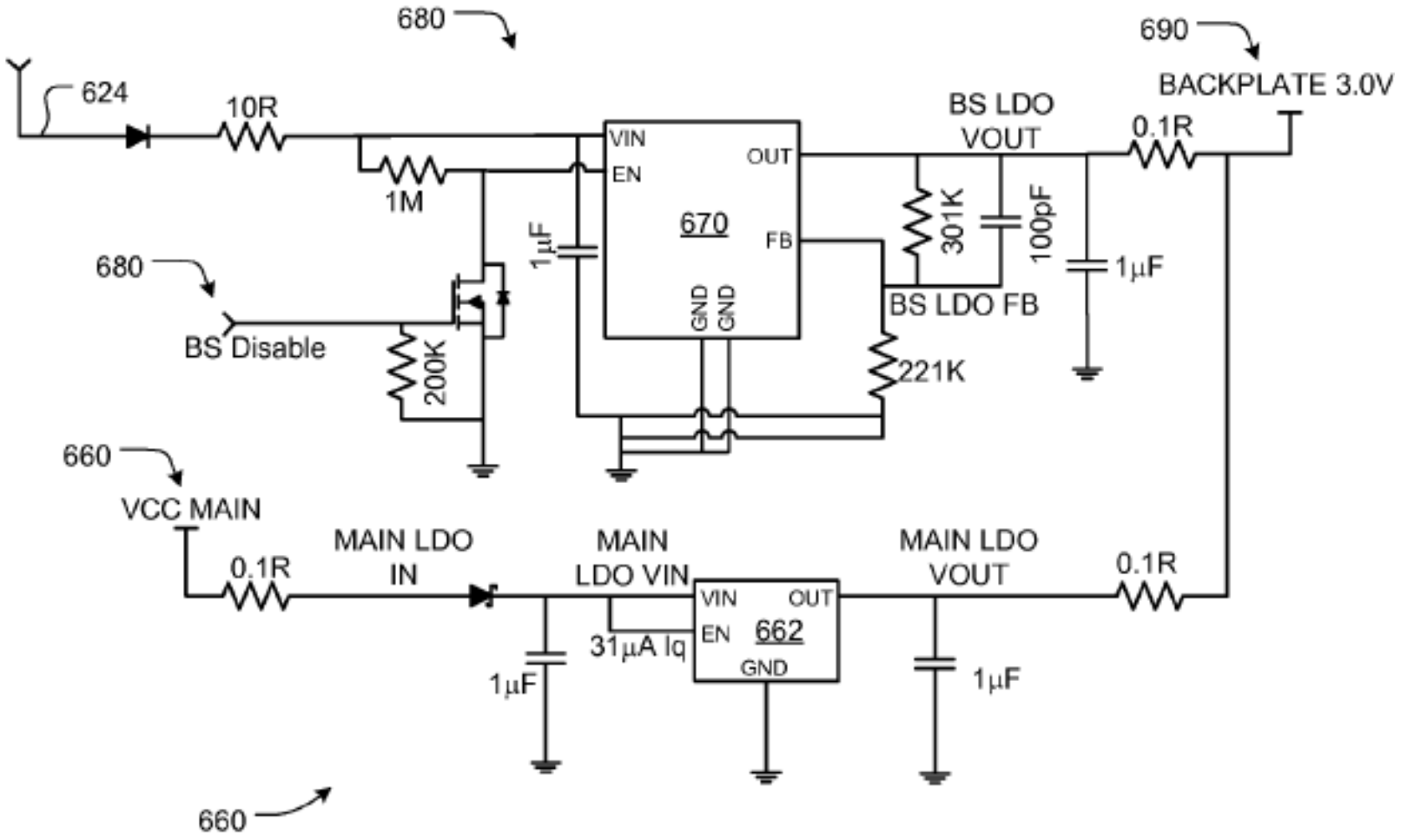
SCHEMATIC DETAILS

Power Supply - 2

Bootstrap LDO



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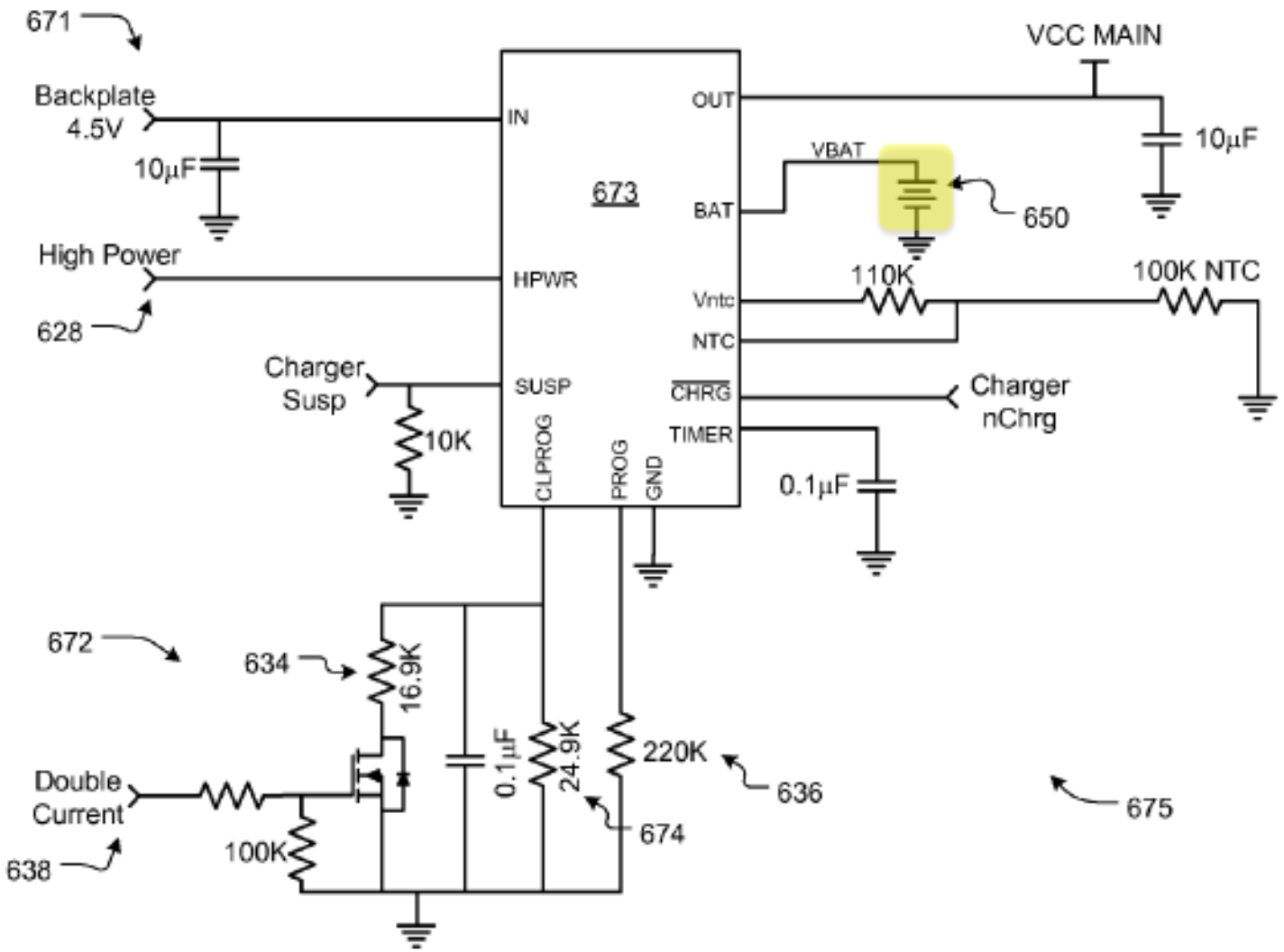
SCHEMATIC DETAILS

Power Supply - 3

Battery LDO and charging circuitry



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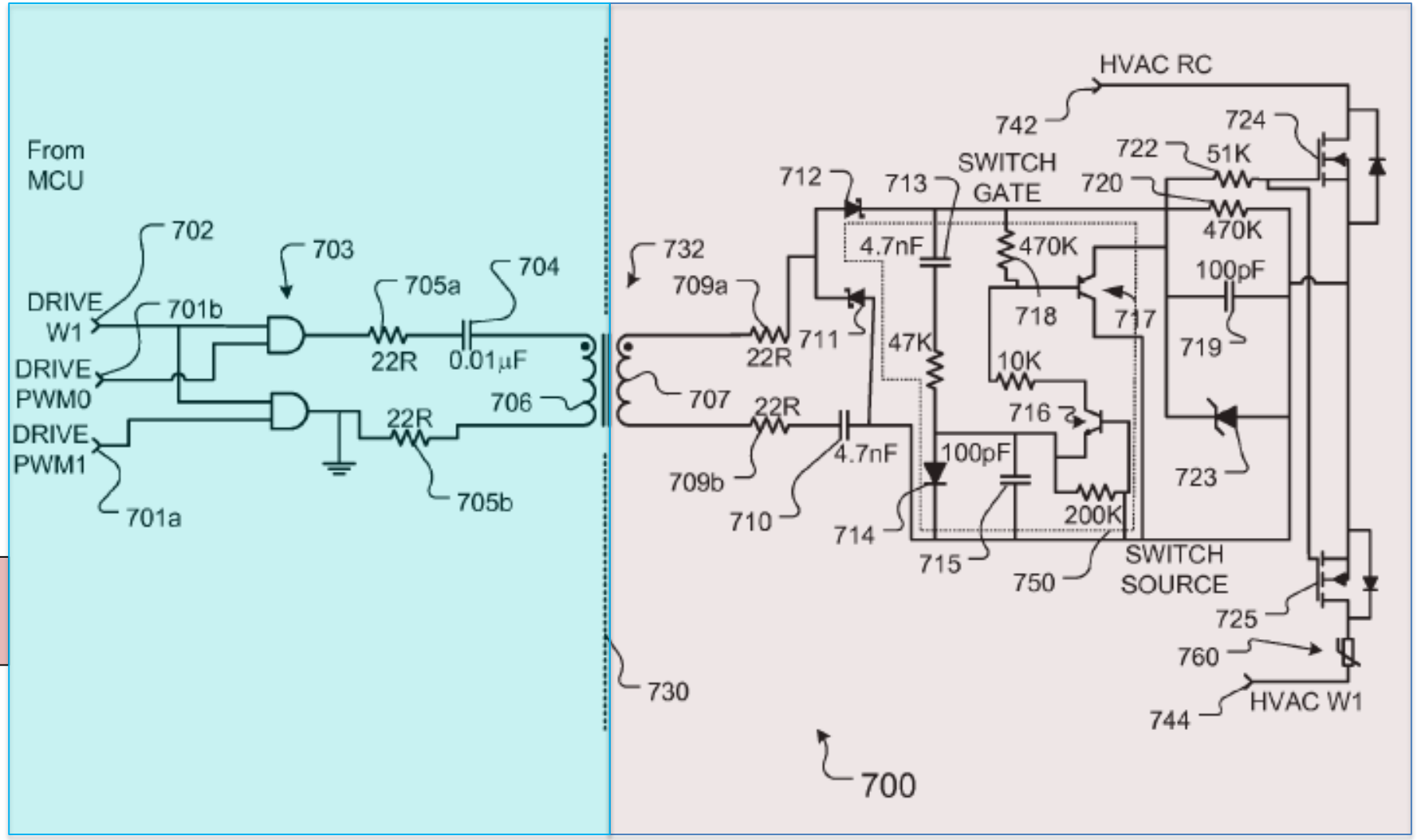
SCHEMATIC DETAILS

Output Drive for Connection Between RC and W (or Y / G)

*Most electronic thermostats accomplish this function (switching 24 VAC signals) using a **latching relay** or an (optically isolated) **thyristor (triac or SCR)** – why is such a complicated circuit used by the Nest Thermostat to perform essentially the same task?*

Why is a transformer required? Why is PWM used?

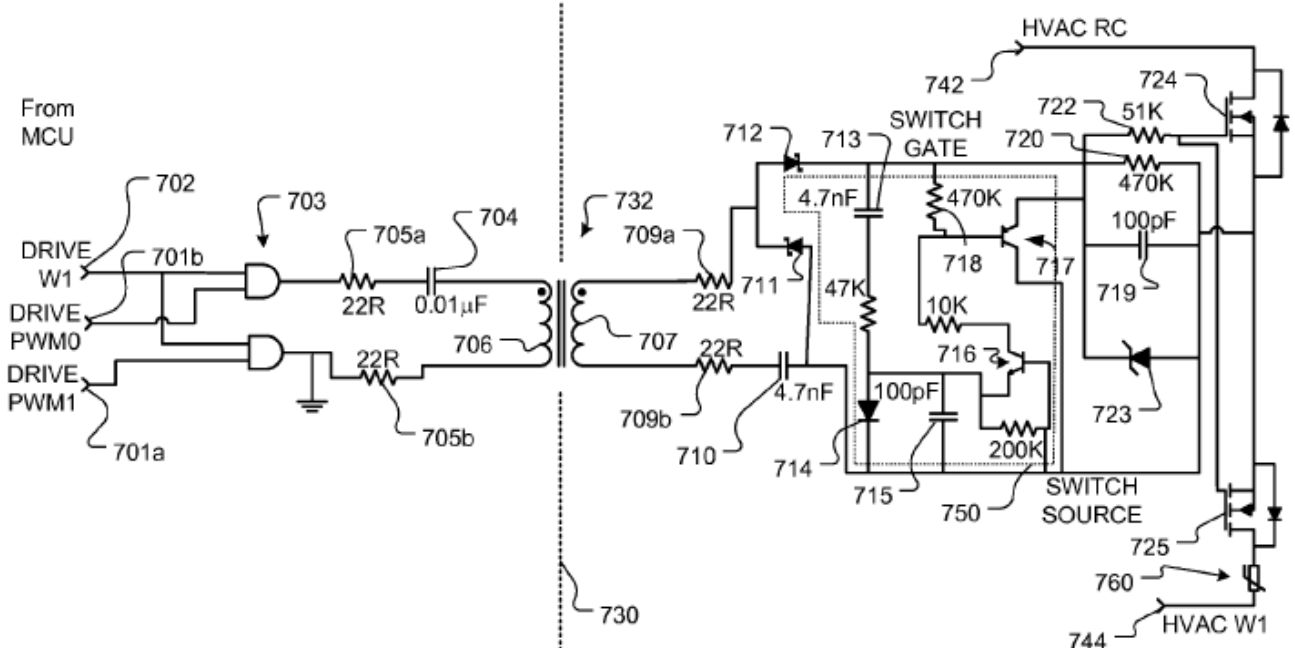


CLICKER QUIZ

Question 4

Based on the preferred embodiment published in the patents, a fairly complicated circuit is used to provide essentially a "contact closure" between two terminals (like R_C and W_1 to control cooling). The reason given in the patent disclosure for using this circuit in place of a much simpler device (like a relay or SCR) is:

A. to increase reliability
B. to enable energy harvesting while the control contact is "closed"
C. to enable energy harvesting while the control contact is "open"
D. to eliminate the annoying "click" associated with relays
E. none of the above



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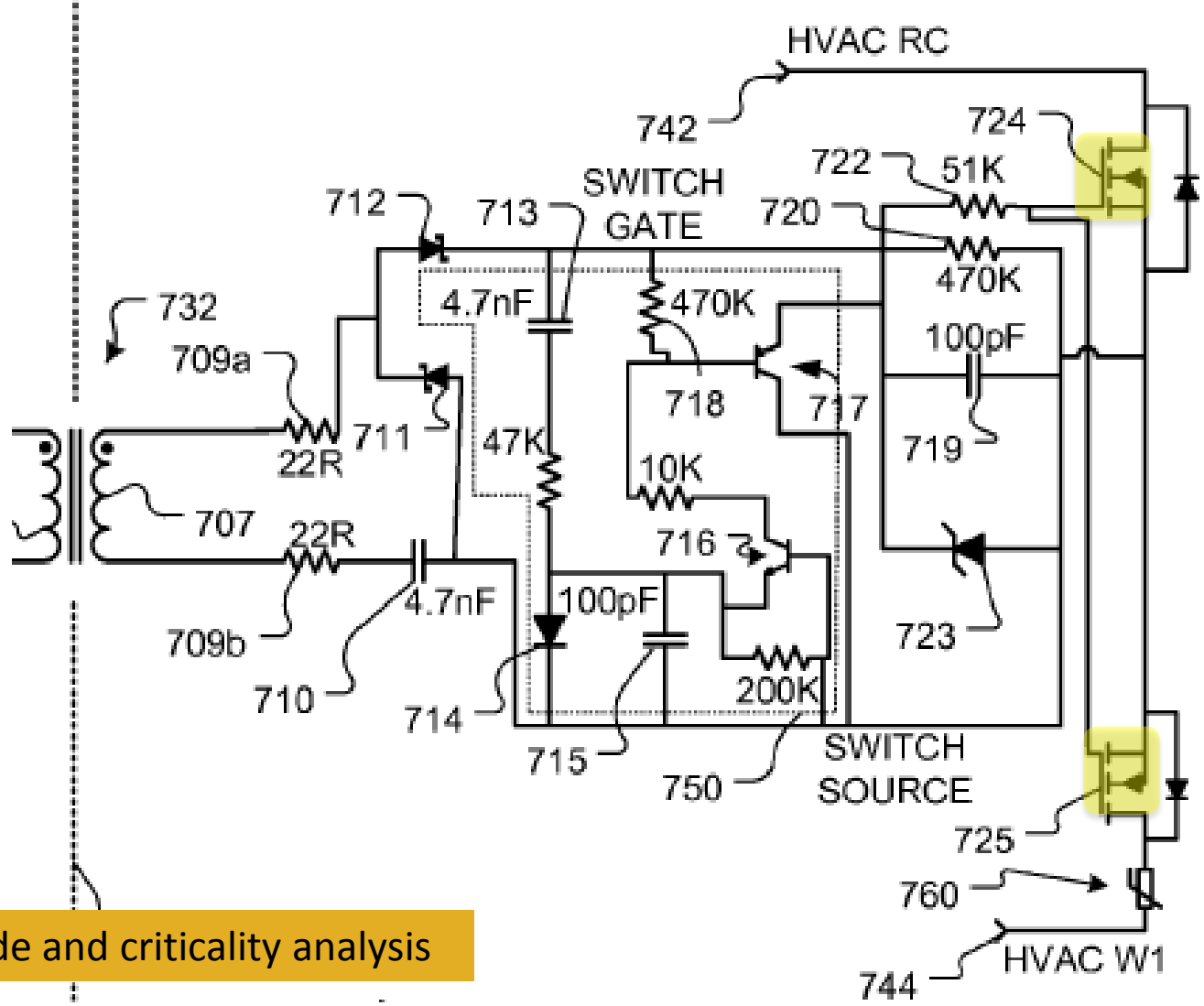
RELIABILITY & SAFETY

FEMCA* of Power MOSFETs

Questions:

1. What happens if the MOSFETs heat up (even just a few degrees above ambient)?
2. What is the most likely cause of power MOSFET failure?
3. What happens if either or both MOSFETs fail open?
4. What happens if either or both MOSFETs fail shorted?
5. What is the criticality level of either of these failure modes?



*failure effects mode and criticality analysis

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LEGAL

Patent Infringement

- February 2012 - Honeywell filed a lawsuit claiming that some of its patents had been infringed by Nest (e.g., US 7,476,988 “Power Stealing Control Devices”)
- May 2013 – Allure Energy filed lawsuit against Nest for newly issued patent US 8,442,695 “Auto-Adaptable Energy Management Apparatus” (filed November 2011)

Kevin Imes, president and CEO of Allure Energy, first began developing a smart thermostat in 2009, filing its patent application in 2010, to manage home temperature and energy usage. Allure Energy also developed and patented “Proximity Control Technology” that instantly adapts to a user’s daily schedule to provide automatic comfort and energy savings at home based on the distance a user may be from a residence.

“With our own capital, we created a smart and original thermostat control that also syncs music, reports local weather and offers energy tips, and filed all the required patent documentation well before Nest Labs launched its products.”

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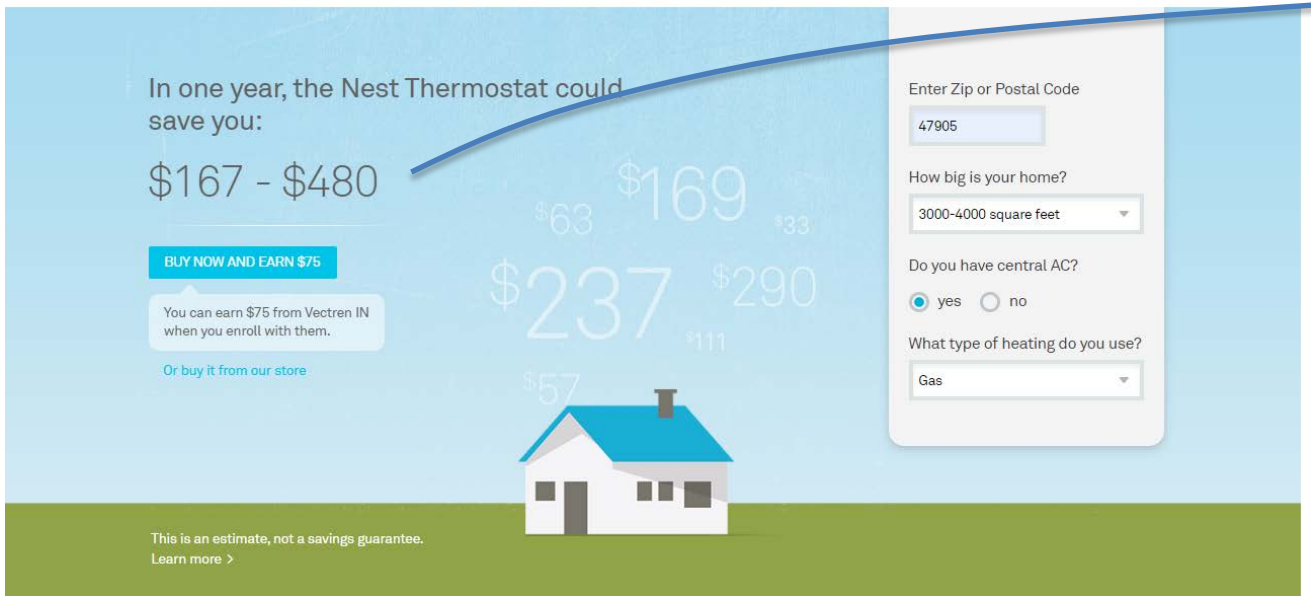
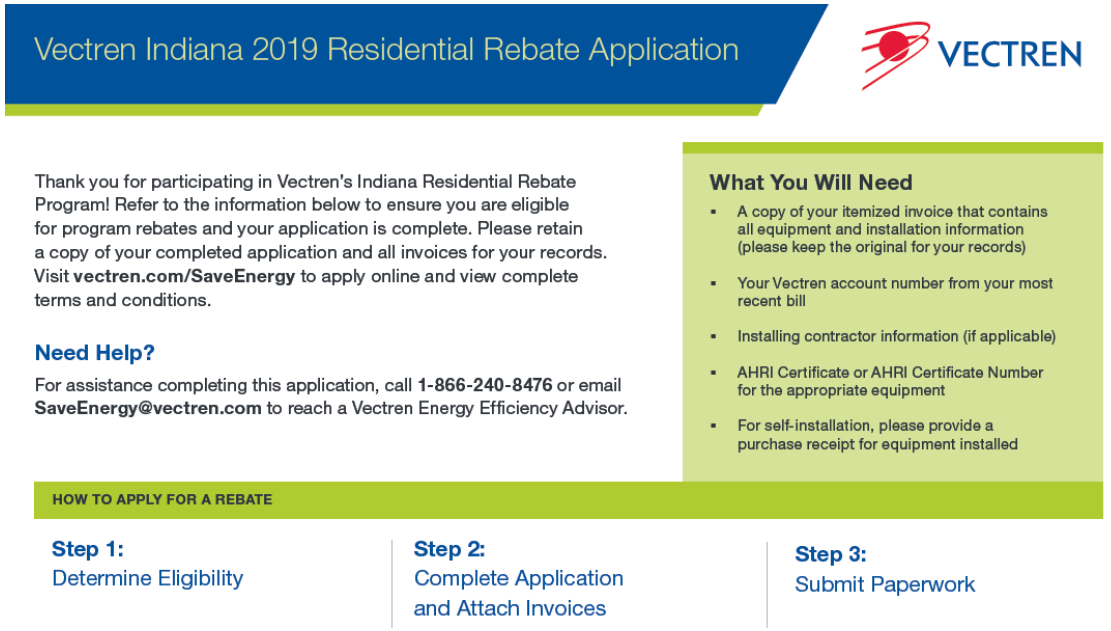
ENVIRONMENTAL & REGULATORY

Nest Learning Thermostat Energy Savings Claims





Vectren Indiana 2019 Residential Rebate Application

VECTREN

Thank you for participating in Vectren's Indiana Residential Rebate Program! Refer to the information below to ensure you are eligible for program rebates and your application is complete. Please retain a copy of your completed application and all invoices for your records. Visit **vectren.com/SaveEnergy** to apply online and view complete terms and conditions.

Need Help?

For assistance completing this application, call **1-866-240-8476** or email **SaveEnergy@vectren.com** to reach a Vectren Energy Efficiency Advisor.

What You Will Need

- A copy of your itemized invoice that contains all equipment and installation information (please keep the original for your records)
- Your Vectren account number from your most recent bill
- Installing contractor information (if applicable)
- AHRI Certificate or AHRI Certificate Number for the appropriate equipment
- For self-installation, please provide a purchase receipt for equipment installed

HOW TO APPLY FOR A REBATE

Step 1: Determine Eligibility

Step 2: Complete Application and Attach Invoices

Step 3: Submit Paperwork

☐ **THERMOSTATS**

Equipment specifications (please ✓)	Unit controlled (please ✓)		
☐ Wi-Fi thermostat $50 rebate ☐ Smart thermostat $75 rebate	☐ Central air source heat pump ☐ Gas furnace/boiler with A/C	☐ Electric furnace with A/C ☐ Gas furnace/boiler no A/C	☐ Electric furnace no A/C

Manufacturer	Model number	Serial number	Date installed
Manufacturer	Model number	Serial number	Date installed

- **Homes must have Vectren natural gas or Vectren electric as the primary heat source to be eligible for this rebate. Dual fuel systems are not eligible.**
- Rebate available for existing homes only; new construction is not eligible. If replacing existing (non Wi-Fi) thermostat in newly constructed home, thermostat is eligible.
- Must be Wi-Fi capable without the use of additional equipment and connected to the internet for programming and adjusting remotely.
- Serial number is preferred, but not required.
- Must be ENERGY STAR® certified smart thermostat to be eligible for $75 incentive.
- Household limit is two thermostat rebates.

- Homes using Vectren natural gas or Vectren electric as the primary heat source are eligible for this rebate. Dual fuel systems are not eligible.
- Rebate available for existing homes only; new construction is not eligible.
- *"Smart" thermostat*: Must be Wi-Fi capable and connected to the home. Must be ENERGY STAR certified as "Smart." Limit of two thermostats per home ("Wi-Fi" and/or "Smart").
- *Wi-Fi enabled thermostat*: The product must be Wi-Fi capable and connected to the internet for programming and adjusting remotely. Limit of two Wi-Fi enabled thermostats per home ("Wi-Fi" and/or "Smart").

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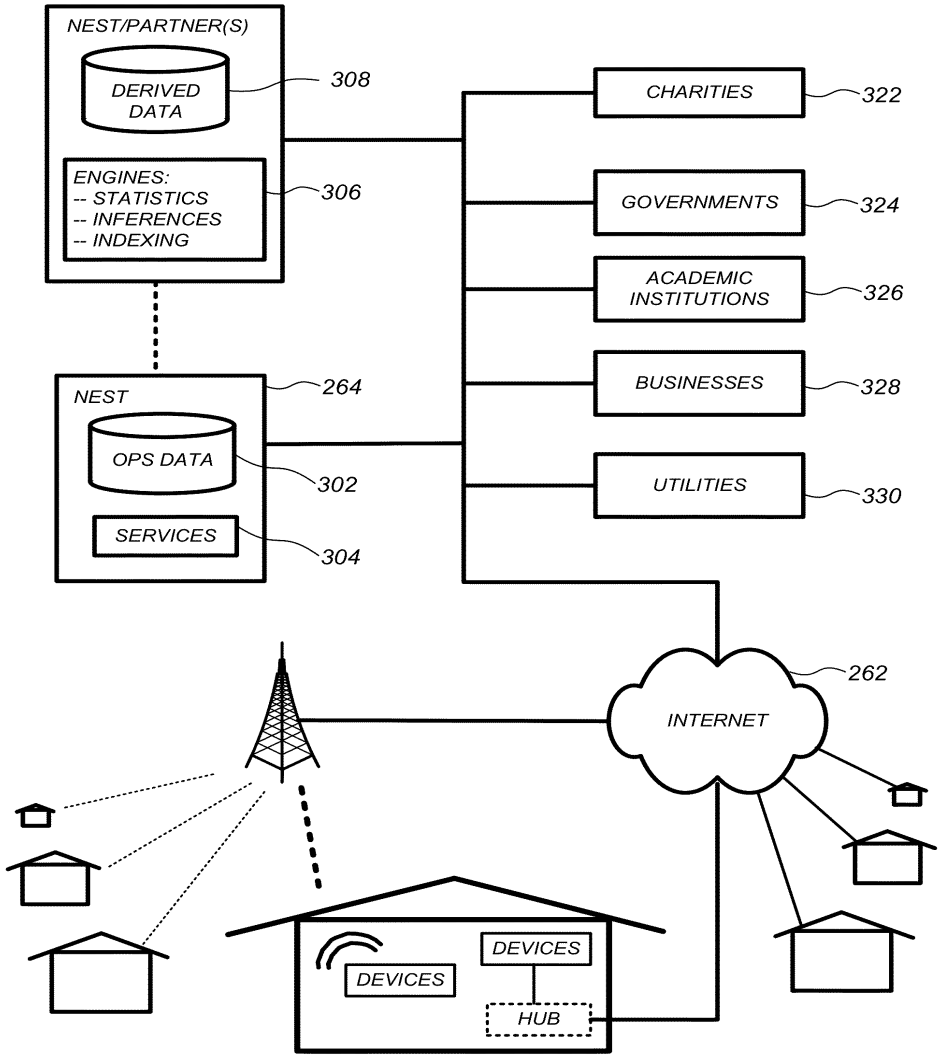
ETHICS & PUBLIC POLICY

Security of Personal Data

- Energy use profiles could be collected by devices like Nest and sold by data mining companies such as Google
- No “consent clause” on use of this personal data is currently included with purchase agreement
- Potential for abuse?



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