

# CASE STUDY: NEST LEARNING THERMOSTAT

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**PURDUE**  
UNIVERSITY

# BACKGROUND

## Nest Labs Company History

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- 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 product is Nest Protect (Smoke and Carbon Monoxide detector with voice alerts)

# 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.



#### Temperature sensors

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



#### Humidity sensor

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



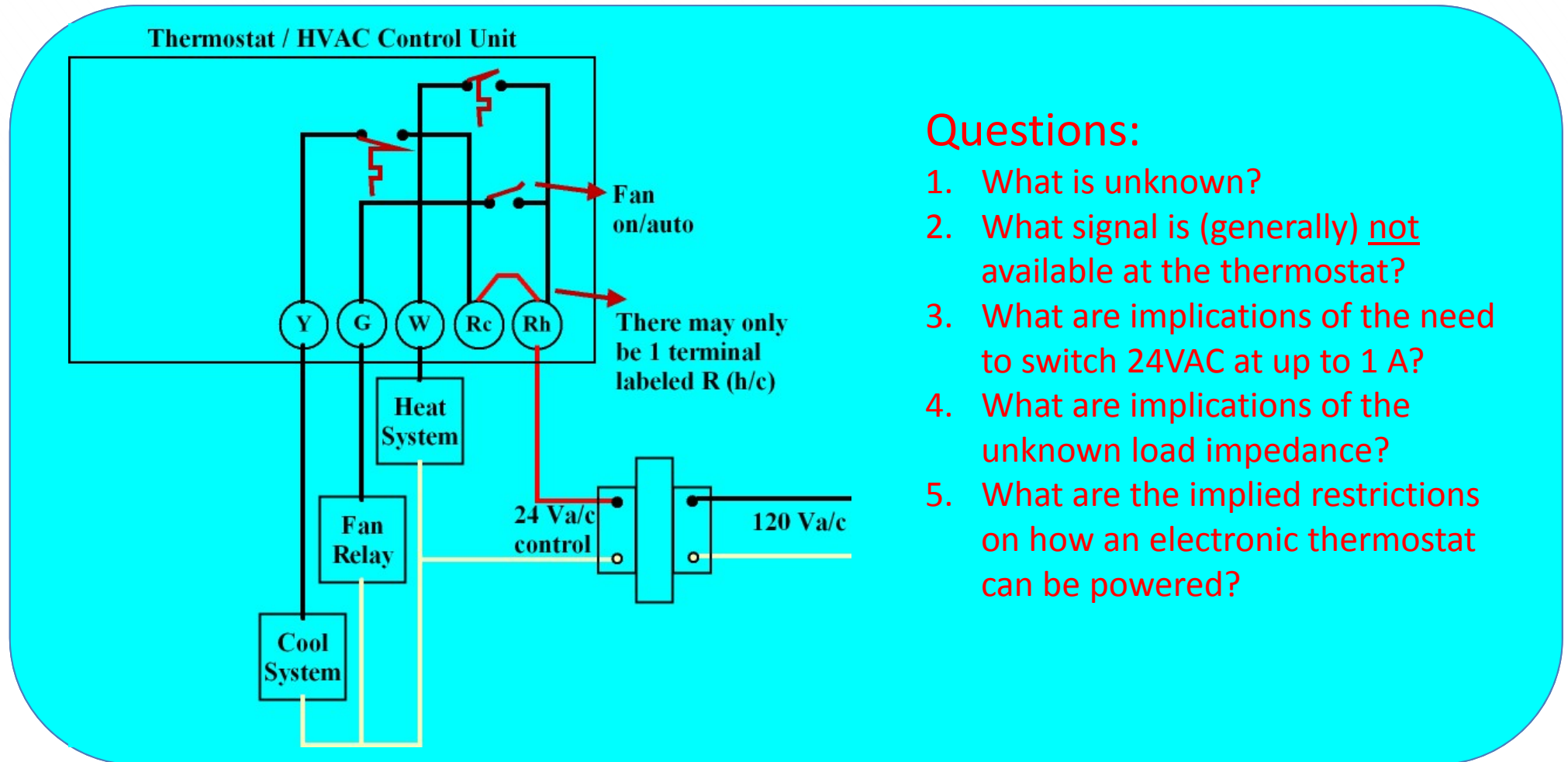
#### Weather aware

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.



# BACKGROUND

## Basic 4-Wire Circuit Thermostat Circuit





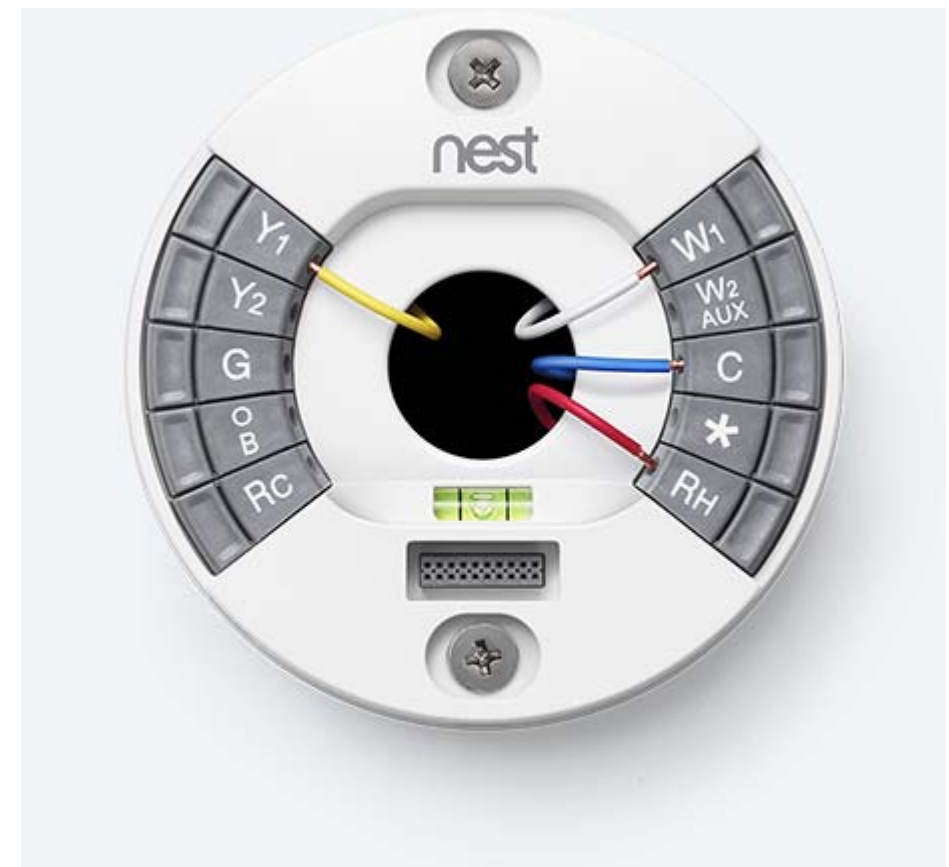
# PATENTS

## 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.



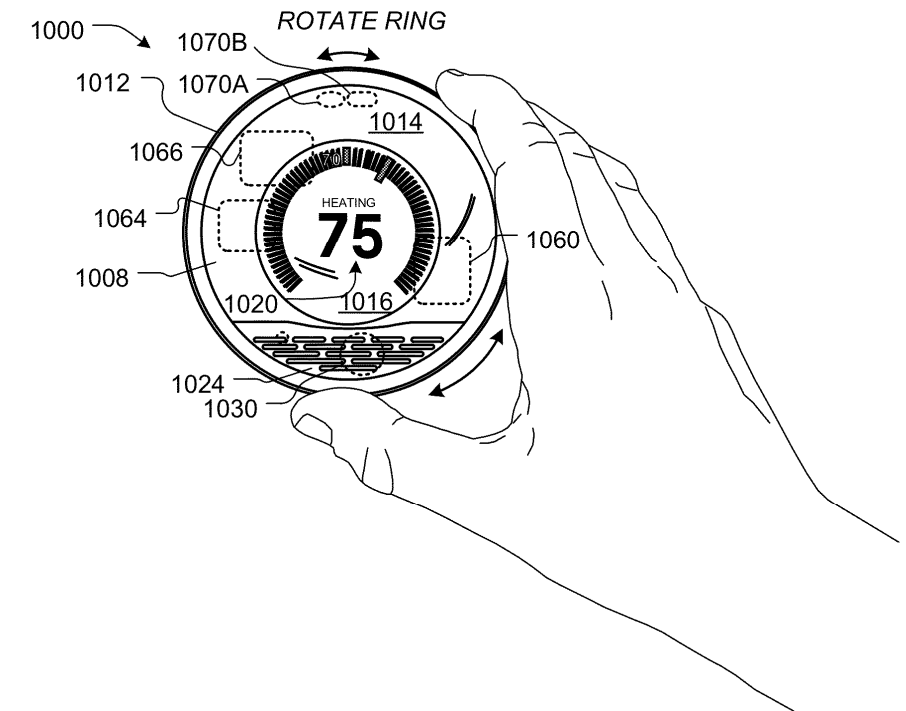
# PATENTS

## Event Forecasting System

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

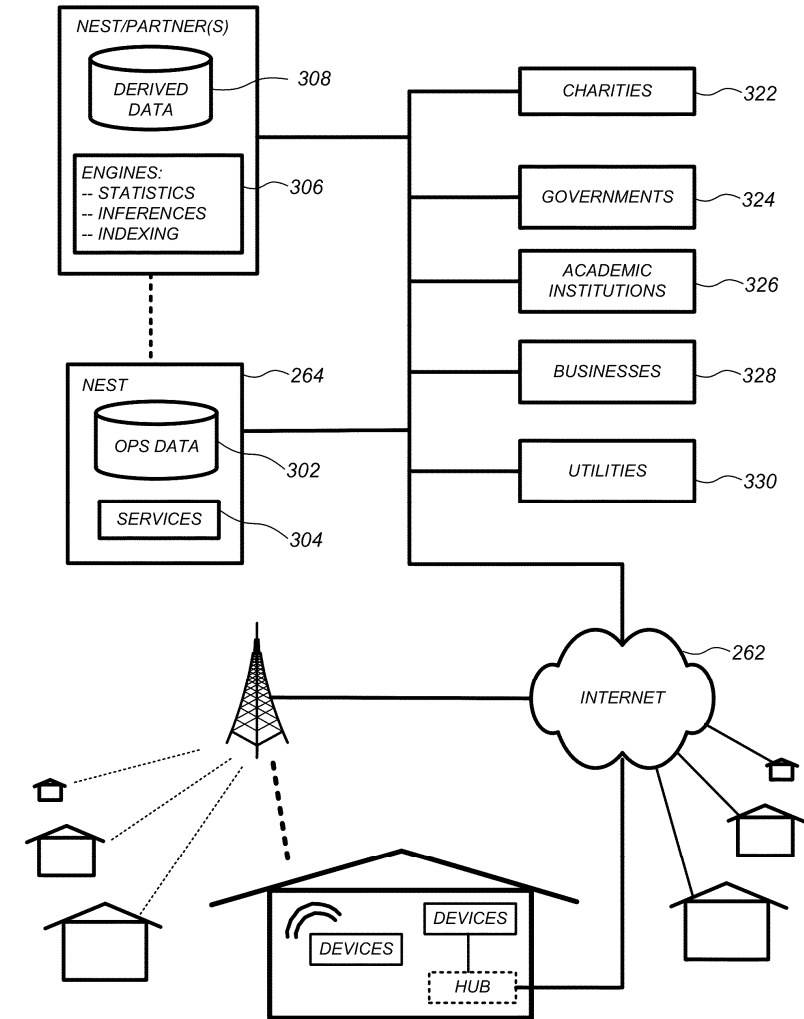
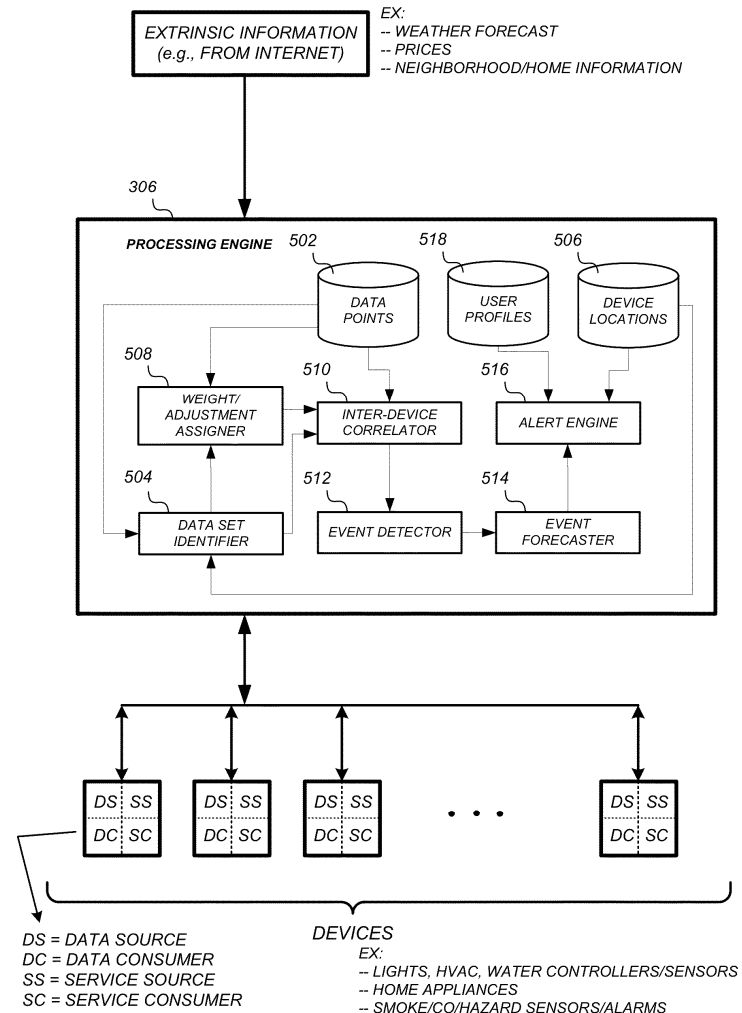
### *DYNAMIC DISTRIBUTED-SENSOR THERMOSTAT NETWORK FOR FORECASTING EXTERNAL EVENTS*

**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.



# PATENTS

## Event Forecasting System is Key Patent Claim



# 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.

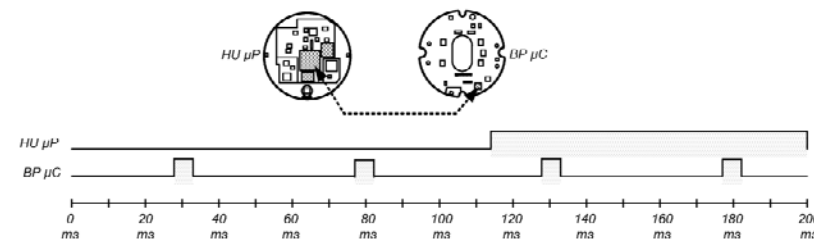


FIG. 17A

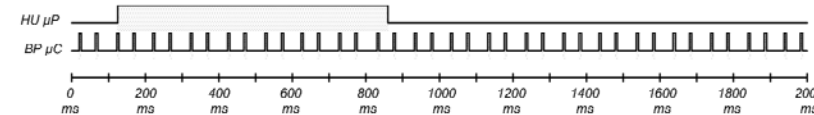


FIG. 17B

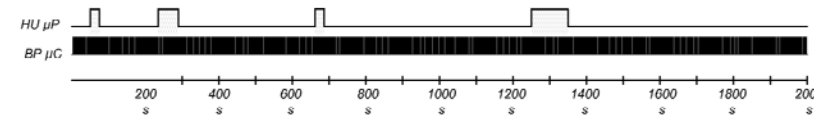
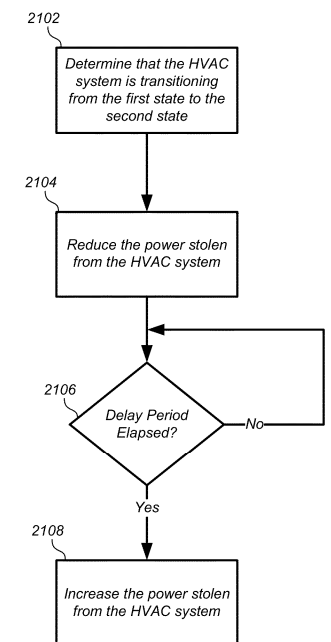


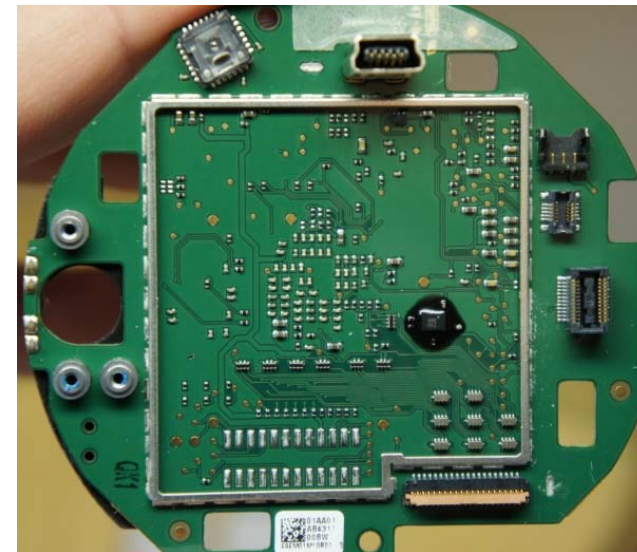
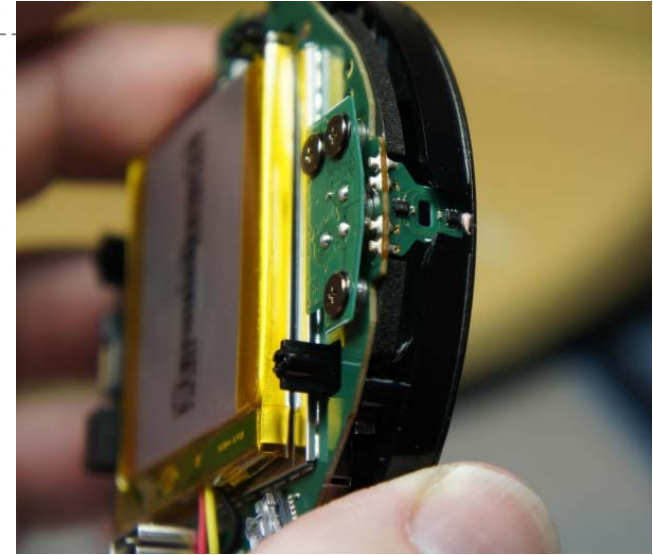
FIG. 17C





# INTRODUCTION

## What's Inside



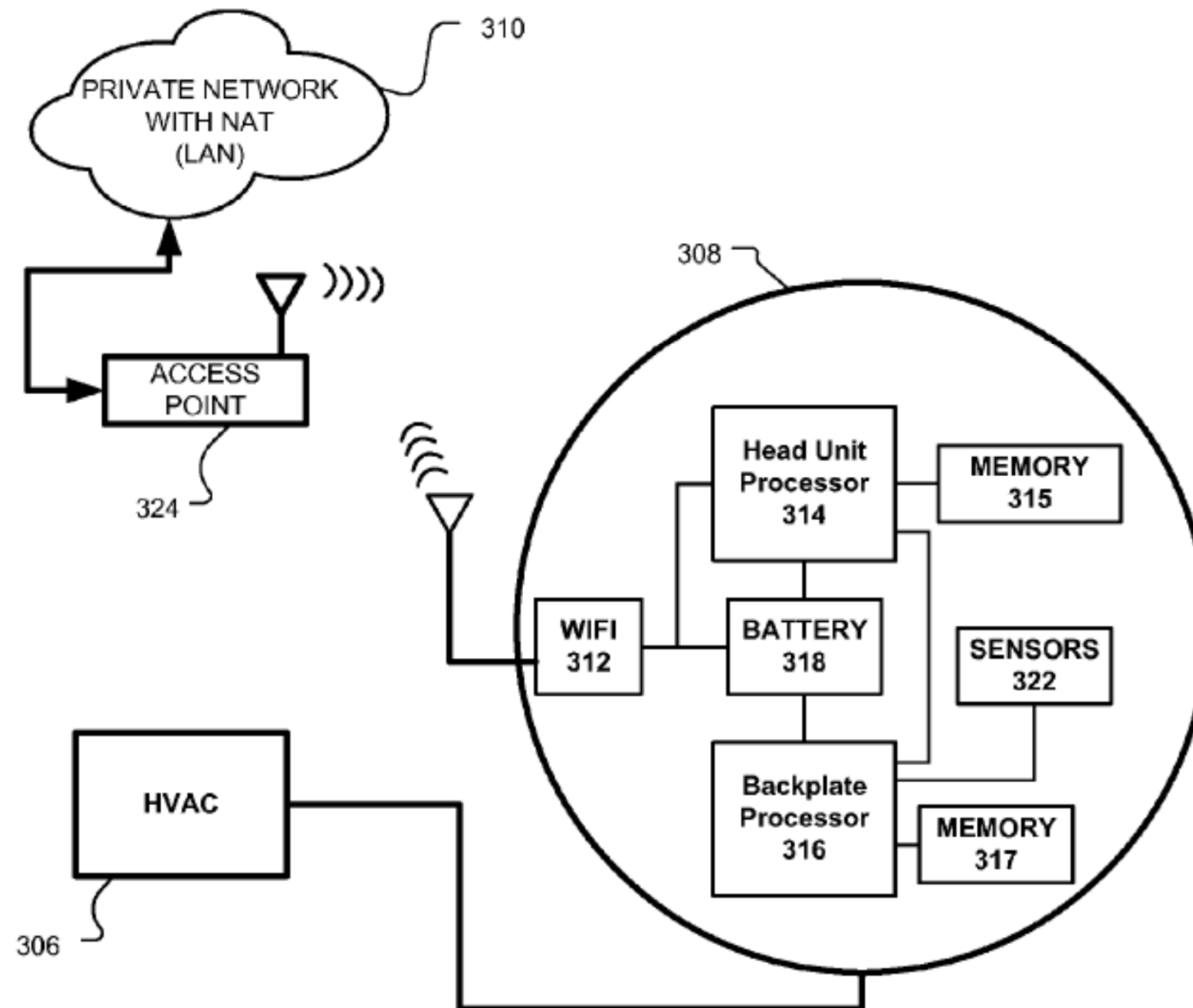
# INTRODUCTION

## What's Inside



# INTRODUCTION

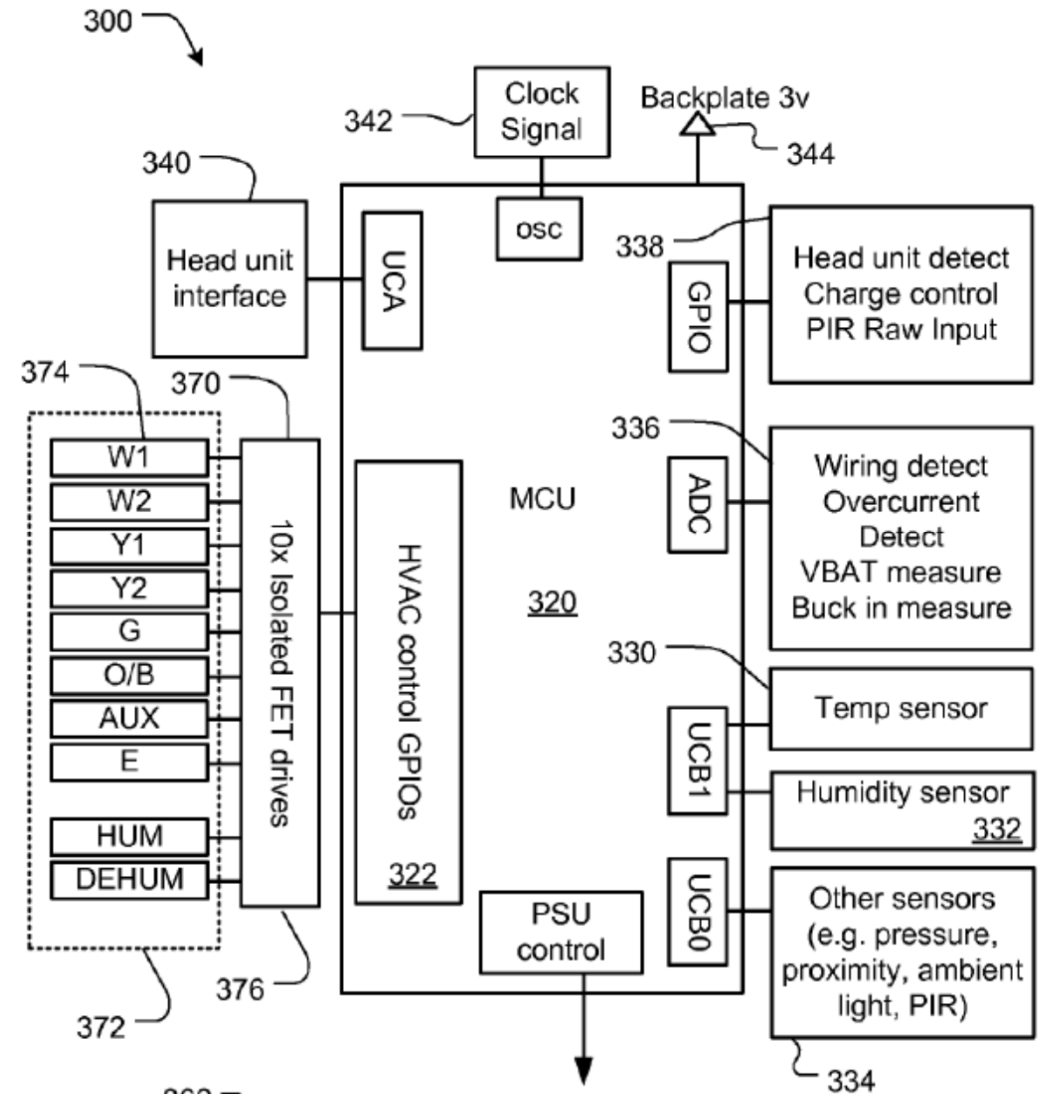
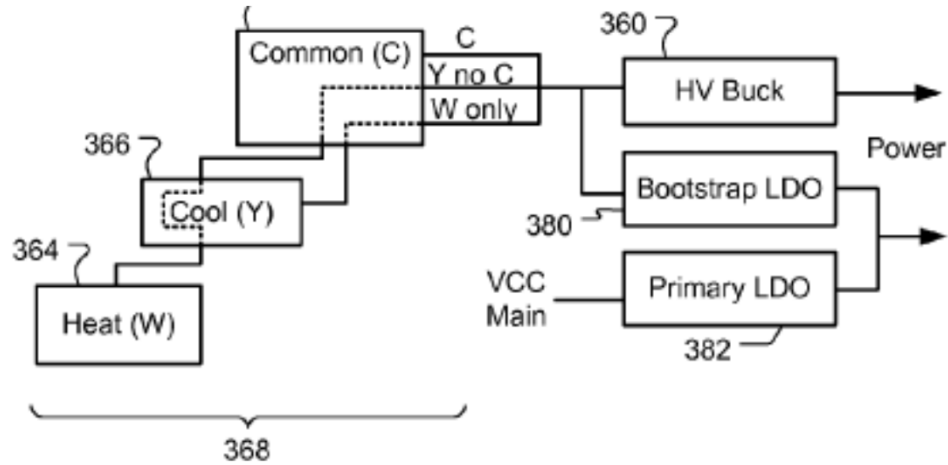
## Conceptual Block Diagram





# INTRODUCTION

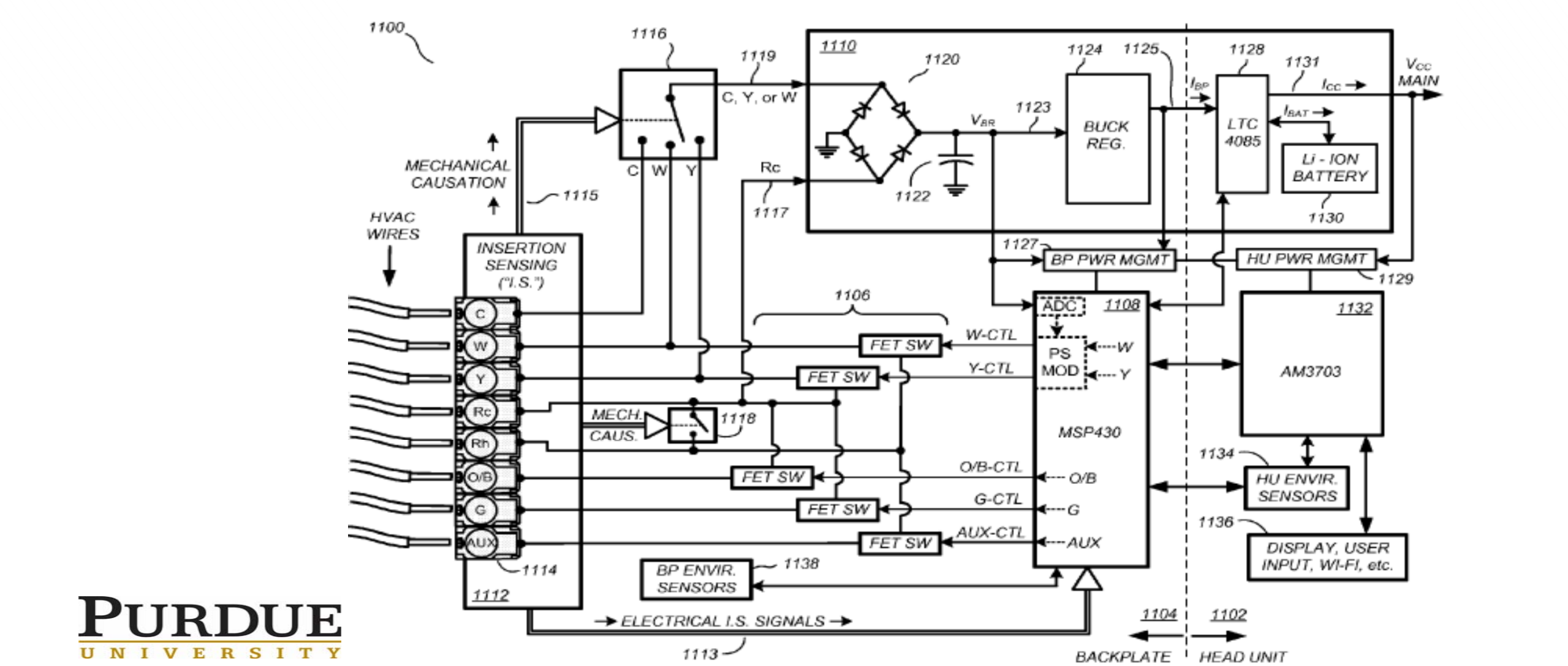
## Block Diagram





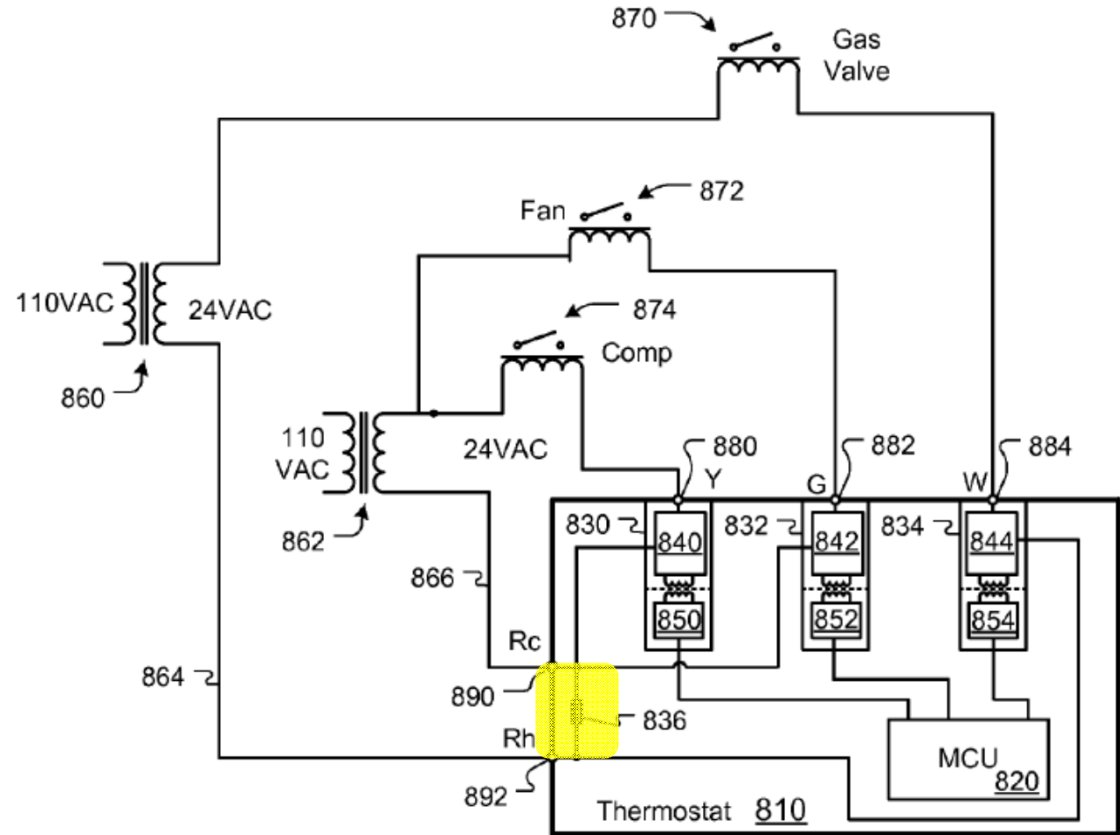
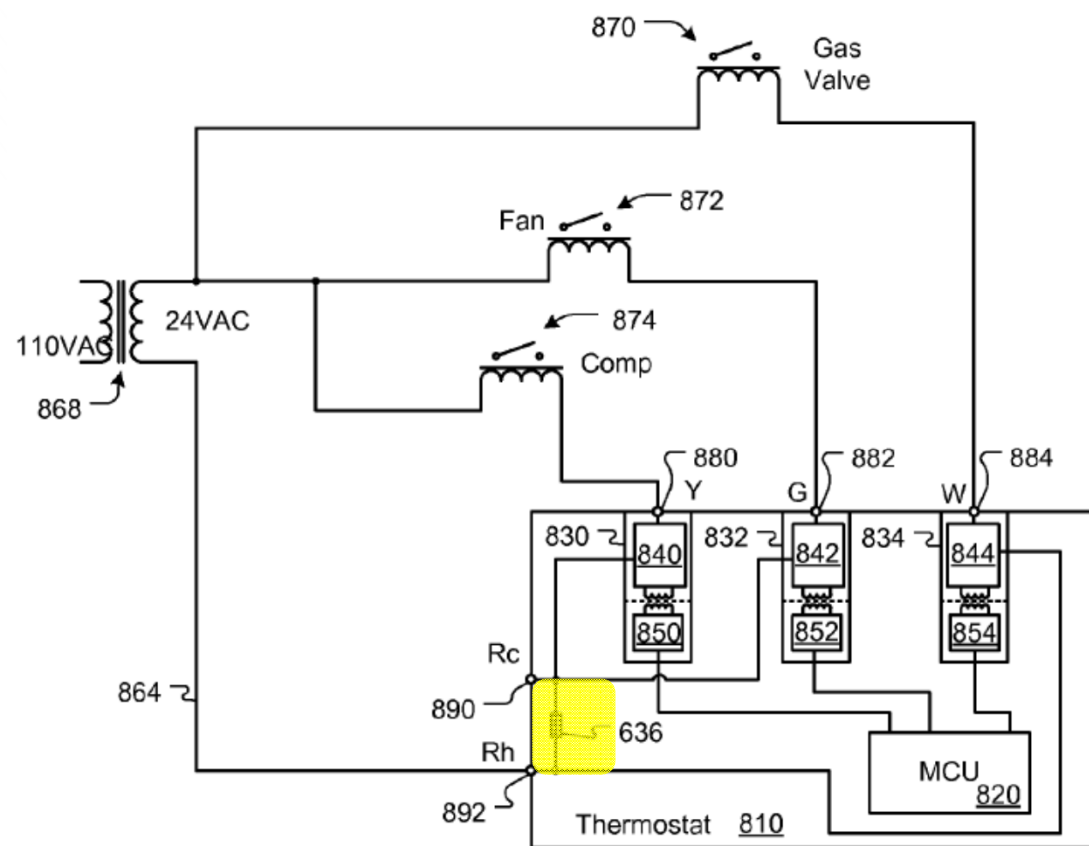
## KEY FUNCTIONS

## Mechanical Evaluation of Floor Slab Connecting Organs



# KEY FUNCTIONS

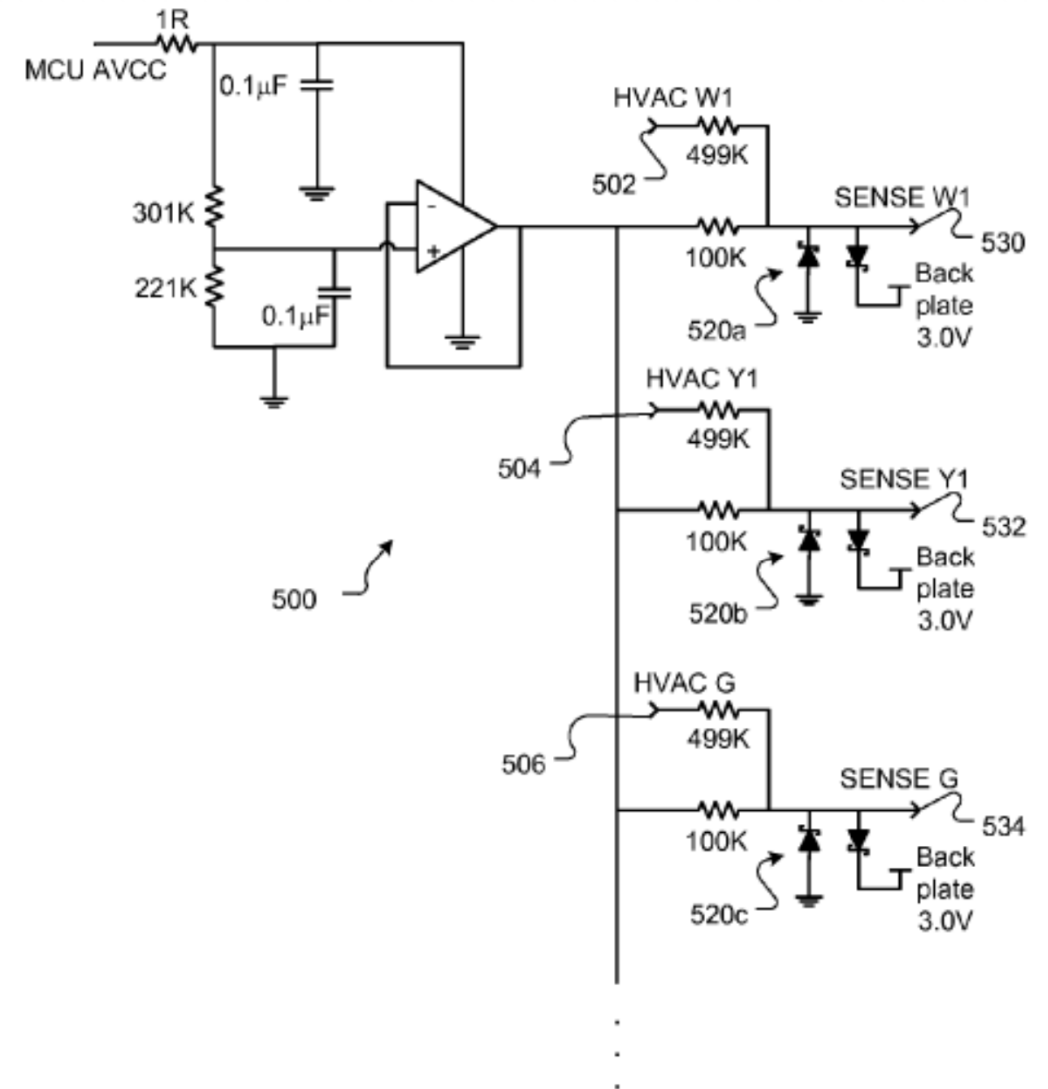
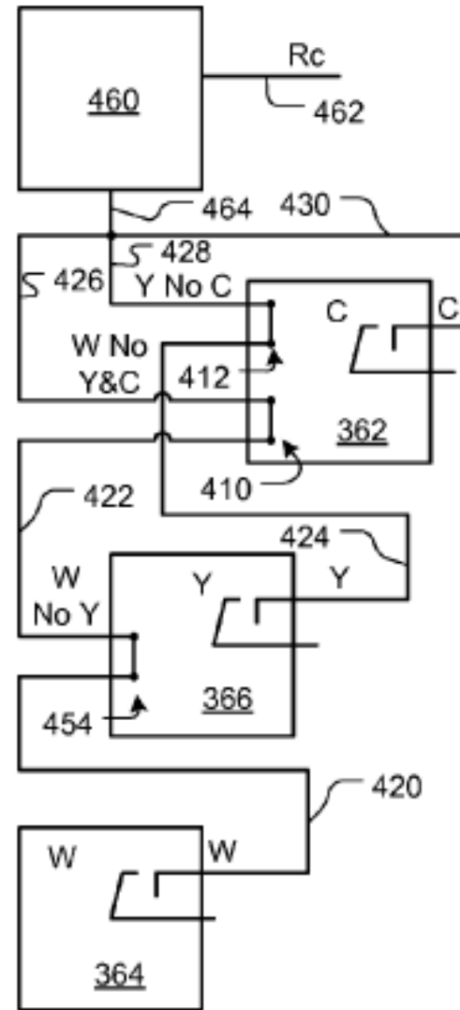
## Accommodation of Single and Dual Transformer Installations



# SCHEMATIC DETAILS

## Connection Sensing Mechanism

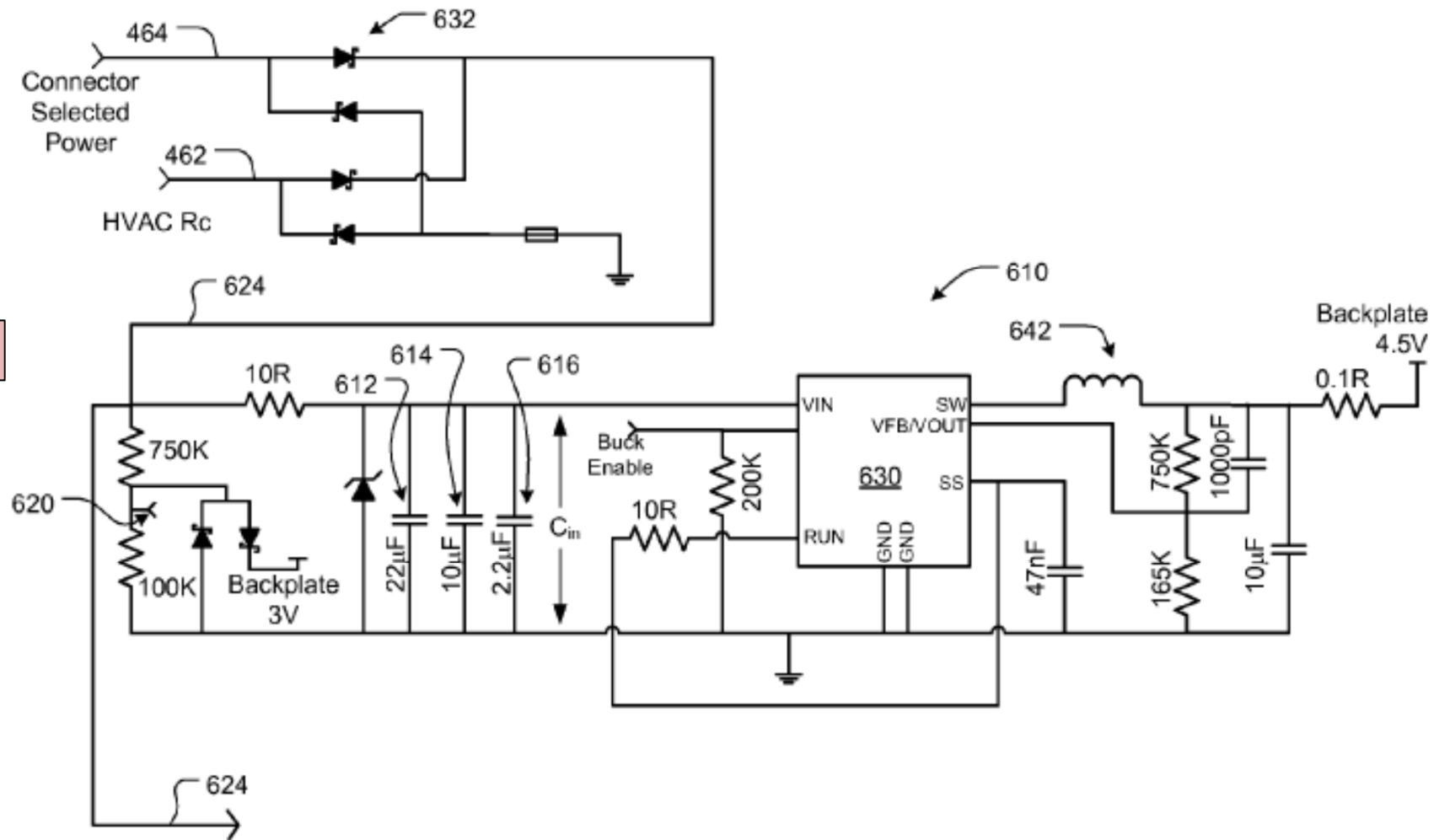
*Use of auto-switching connectors for automatically selecting a source for power harvesting*



# SCHEMATIC DETAILS

## Power Supply - 1

*"high voltage" buck converter*

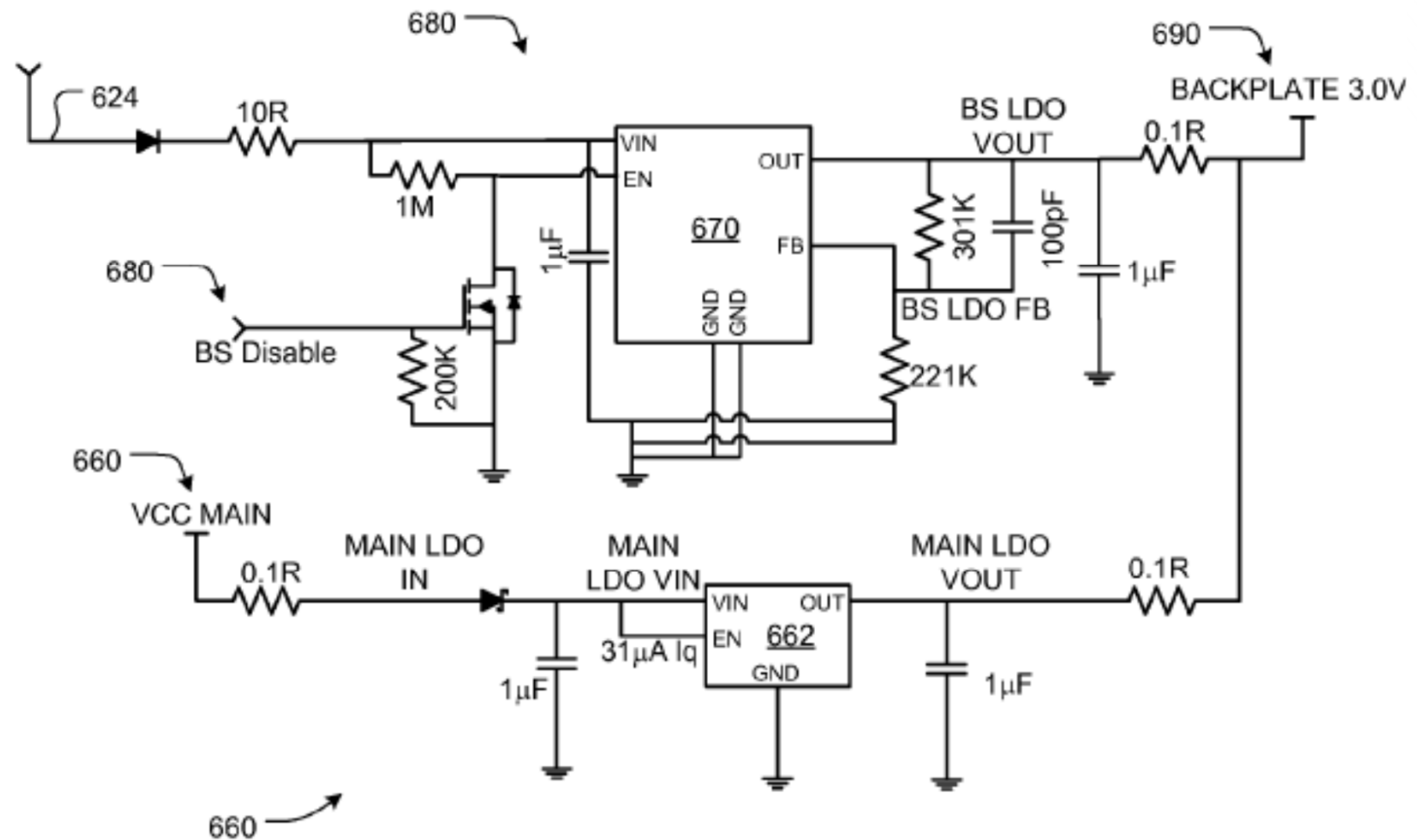




# SCHEMATIC DETAILS

## Power Supply - 2

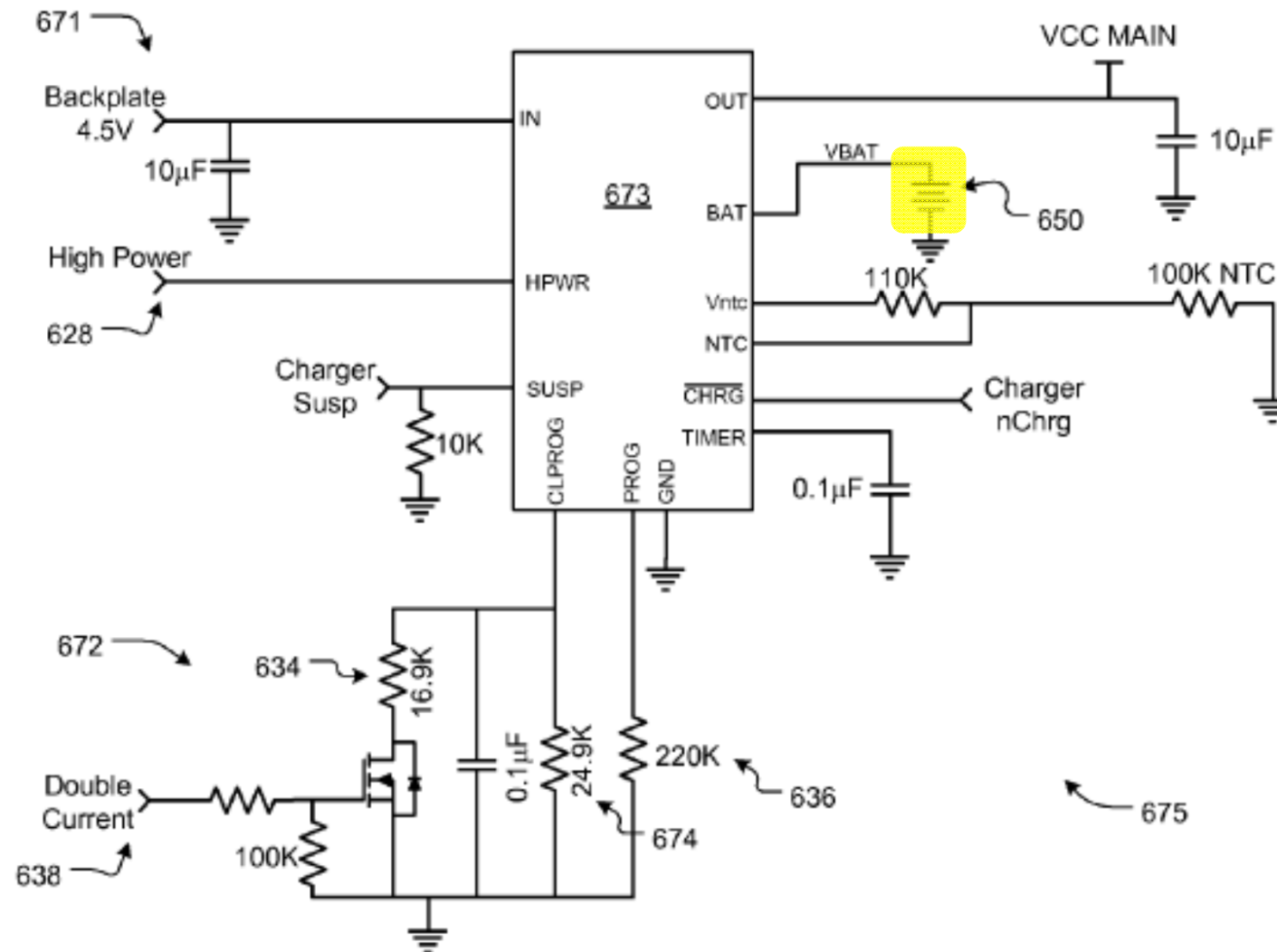
Bootstrap LDO



# SCHEMATIC DETAILS

## Power Supply - 3

Battery LDO and  
charging circuitry

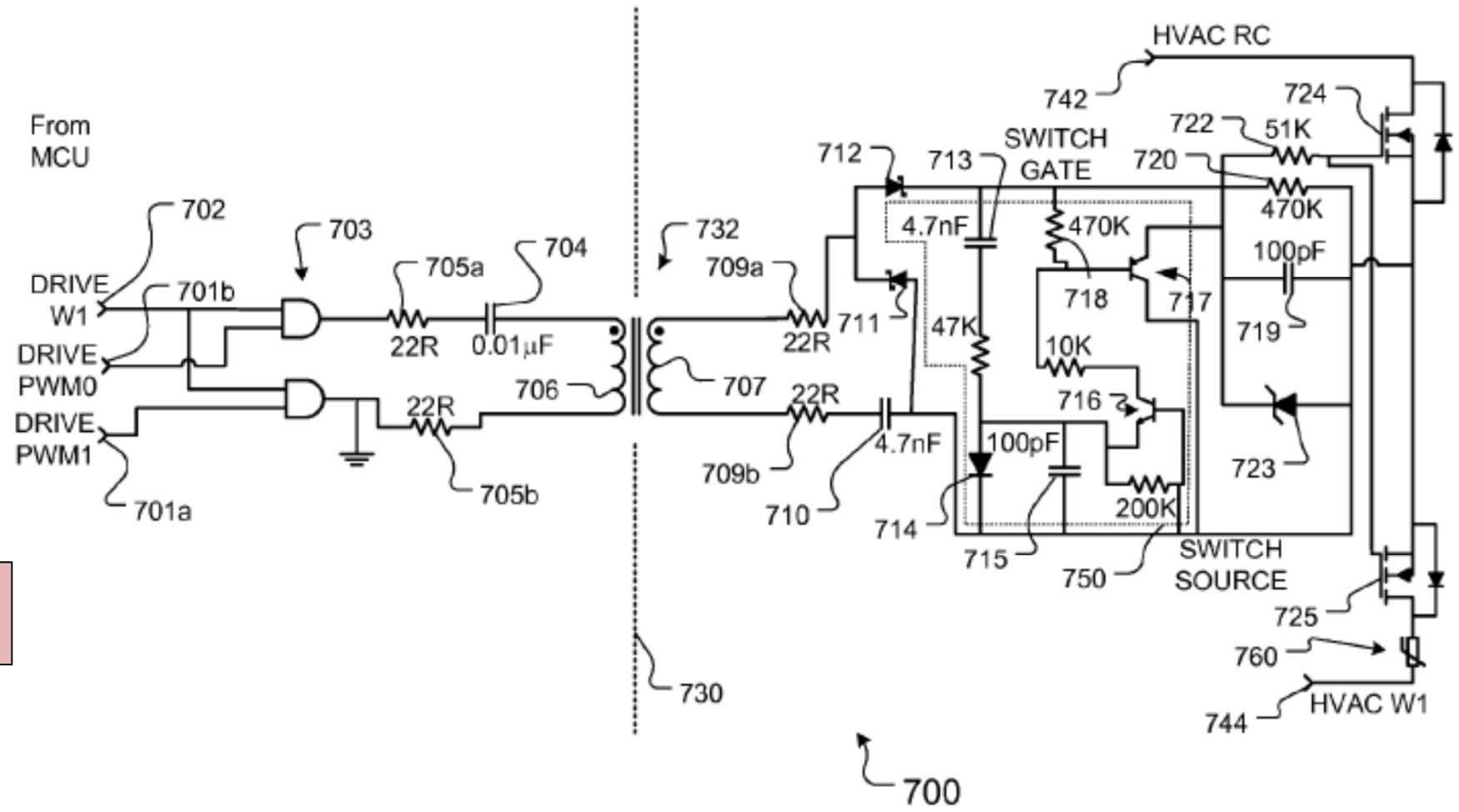


# SCHEMATIC DETAILS

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

Most electronic thermostats accomplish this function (switching AC signals) using a **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?

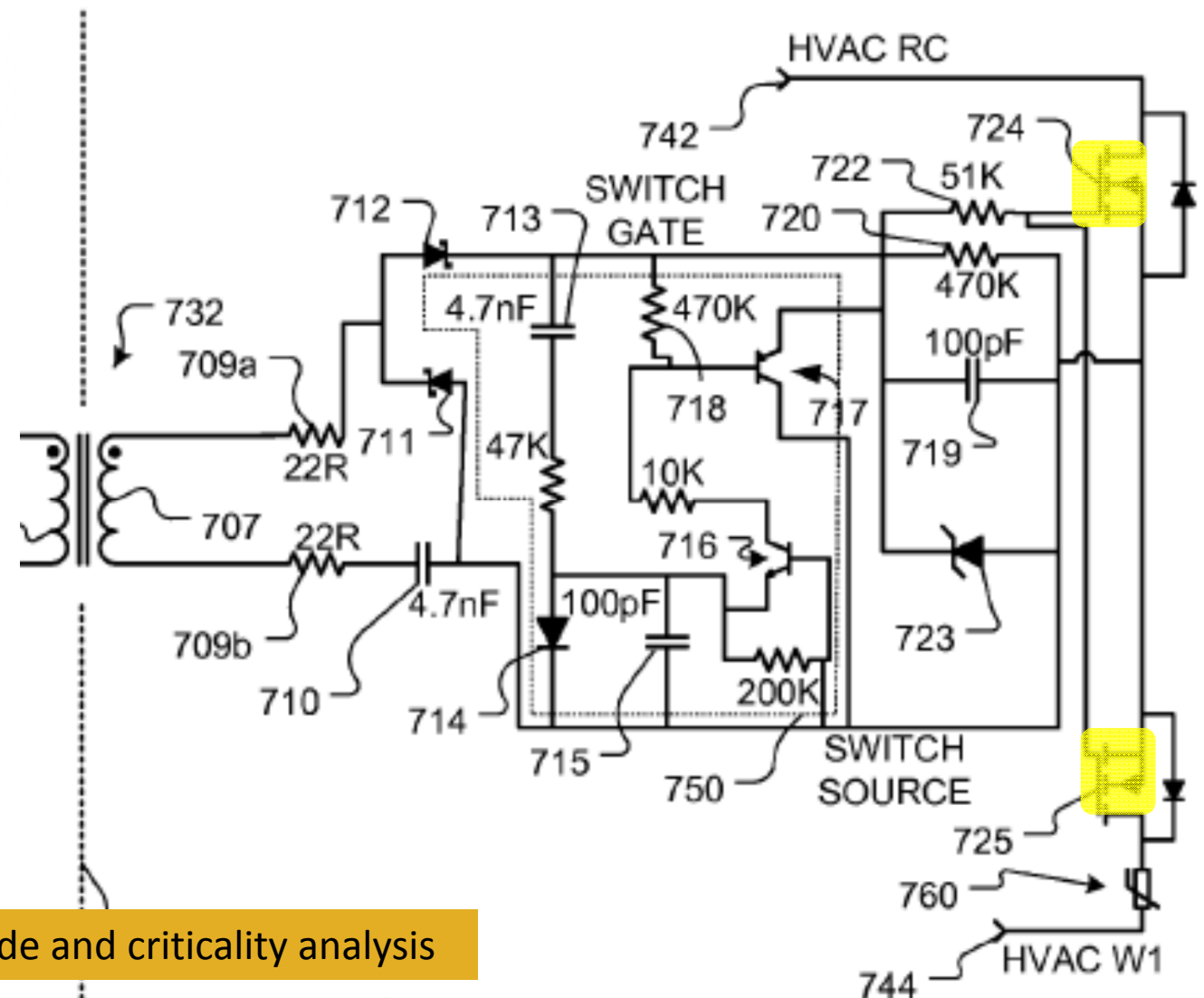
Why is a transformer required?  
Why is PWM used?



## RELIABILITY & SAFETY

## 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?





# RELIABILITY & SAFETY

## Customer Complaints Documenting That Critical Failures Can and Do Occur

- I can't even begin to say how upset I am to have to title the Nest Learning Thermostat as "The Worst Thermostat EVER." For the "cool" factor and appearance it was in "A" in my book. I installed it in November 2014 and it worked like a charm... for 4 weeks. Then we came home to a house that was 80+ degrees in winter (in Buffalo no less) and found "the base unit was malfunctioning" preventing the nest from shutting off. The "overnight" FedEx replacement arrived in 2 days which meant I had to manually turn on and off the furnace from the circuit breaker. The new nest worked great... for 3 weeks before it did the same thing. Another call to nest with their crazy long wait customer service stated this was a known issue and another unit would be sent... "overnight." Four (4) days later FedEx showed with my third unit in the same number of months and it worked again...well. Yesterday, after only 2 1/2 weeks from install, the Nest again malfunctioned and my phone call to their customer support agent and "senior" agent finally concluded my energy efficient Heil forced air gas furnace was "incompatible" to the nest. What?!?!? I have finally had it and went straight to Home Depot and purchased a Honeywell Smart Thermostat as a replacement. My last Honeywell thermostat lasted over 20 years and I'm just hopeful this one will last longer than the Nest's.*

# RELIABILITY & SAFETY

## Customer Complaints Documenting That Critical Failures Can and Do Occur

- *The NEST product was an interesting and fun gadget for a year and a half ... until control of it was taken away by someone during one of the coldest days of the year. As the house got colder and colder I worked through the NEST website looking for tech support to no avail. Finally Googling "NEST help" got me a contact number. During three hours of troubleshooting I found out that this thermostat was part of an energy savings program. NEST thought the thermostat was controlled by my local utility. I contract my local utility and they had no idea what I was talking about. I then went back to NEST and they still had no idea who was controlling the thermostat or how low the "Controller" whoever that was would let the temp fall. I worked with them a little longer in an attempt to opt out of this energy saving program and after three hours I told them thank you very much, but your time is up. I then replaced this thermostat with a conventional programmable thermostat. The NEST product is not ready for prime time.*
- *WOWWW The coldest day of the year, this is the second time NEST shut down heating system and said it wanted us to call nest service to come fix heating system. I had to reconnect old thermostat which corrected the issue. what a scam .;. im wondering who had control of my house ???*

# 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.”*

# LEGAL

## Patent Infringement

- September 2013 – Nest announced patent license agreement with Intellectual Ventures, and acquired several patents (unclear how many)
- November 2013 – BRK (First Alert) filed a lawsuit against Nest alleging infringement on six of its patents (e.g., location warning voice alerts)

The location warning system, BRK says, was laid out in a series of patents that cover using pre-recorded voice alerts to "describe the type of environmental condition detected or the location" of the detector that senses it. That "exclusive" technology was first used in a 2003 smoke detector, and the company says it's sold 1.8 million units with voice and location alarm systems since then.





# LEGAL

## Class Action Lawsuit

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- Claim (filed March 2014) – Faulty temperature readings actually cause an increase in energy cost, due to faceplate and base heating up by as much as 10° F
- Complaint seeks \$5M in damages, alleging Nest has violated warranty and consumer protection laws

“...customer reports and Defendant’s own admissions show that Nest is so defective it cannot correctly gauge ambient temperature.”

# 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

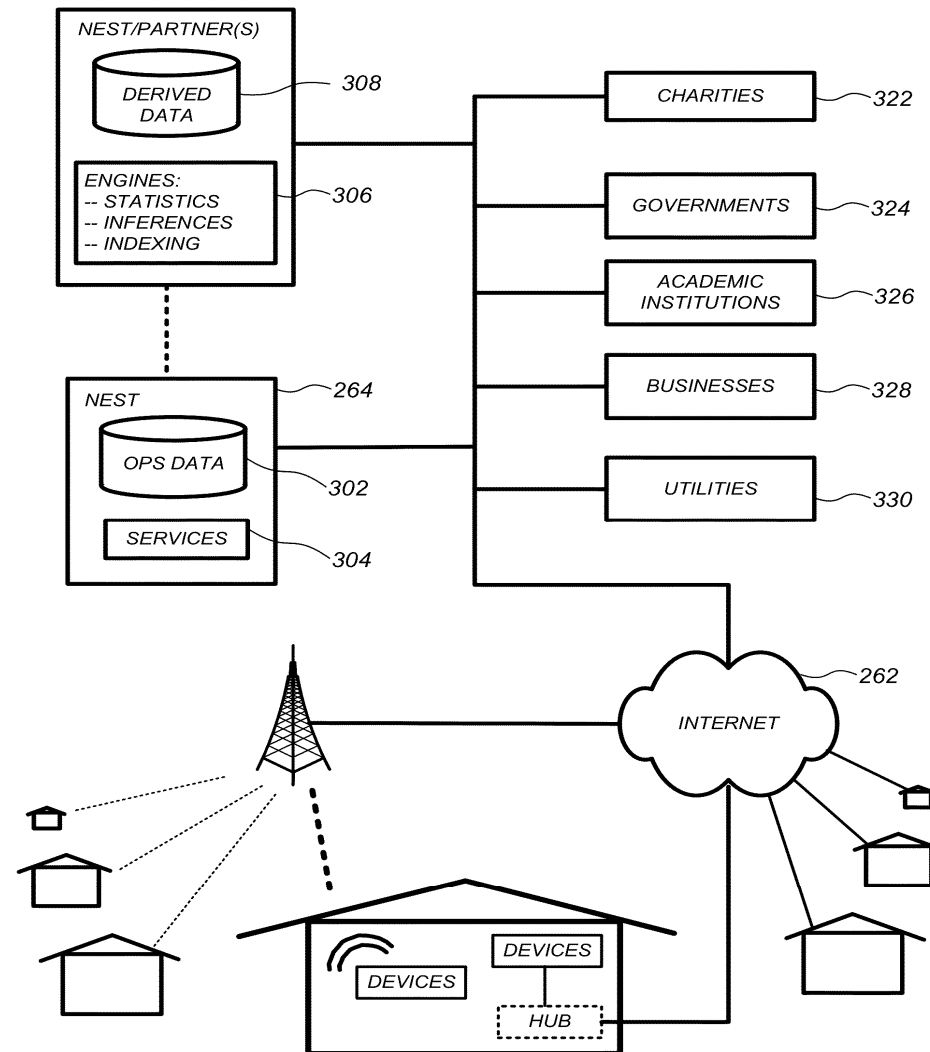
One of the largest retail energy suppliers in North America, [Direct Energy](#), has announced a partnership with [Nest](#), the smart thermostat. The deal is designed to encourage adoption of Direct Energy's service as well as the [smart home](#) device in the U.S. The partnership will focus on offering incentives to customers who purchase Direct Energy utility services, an arrangement similar to the one launched in Alberta, Canada, earlier this year.

Nest's ability to penetrate the U.S. home market will likely get a boost from large scale partnerships like the one with Direct Energy, a dynamic that could make "smart homes" a more common phenomenon [sooner than some might expect.](#)

# ETHICS / PUBLIC POLICY

## Security of Personal Data

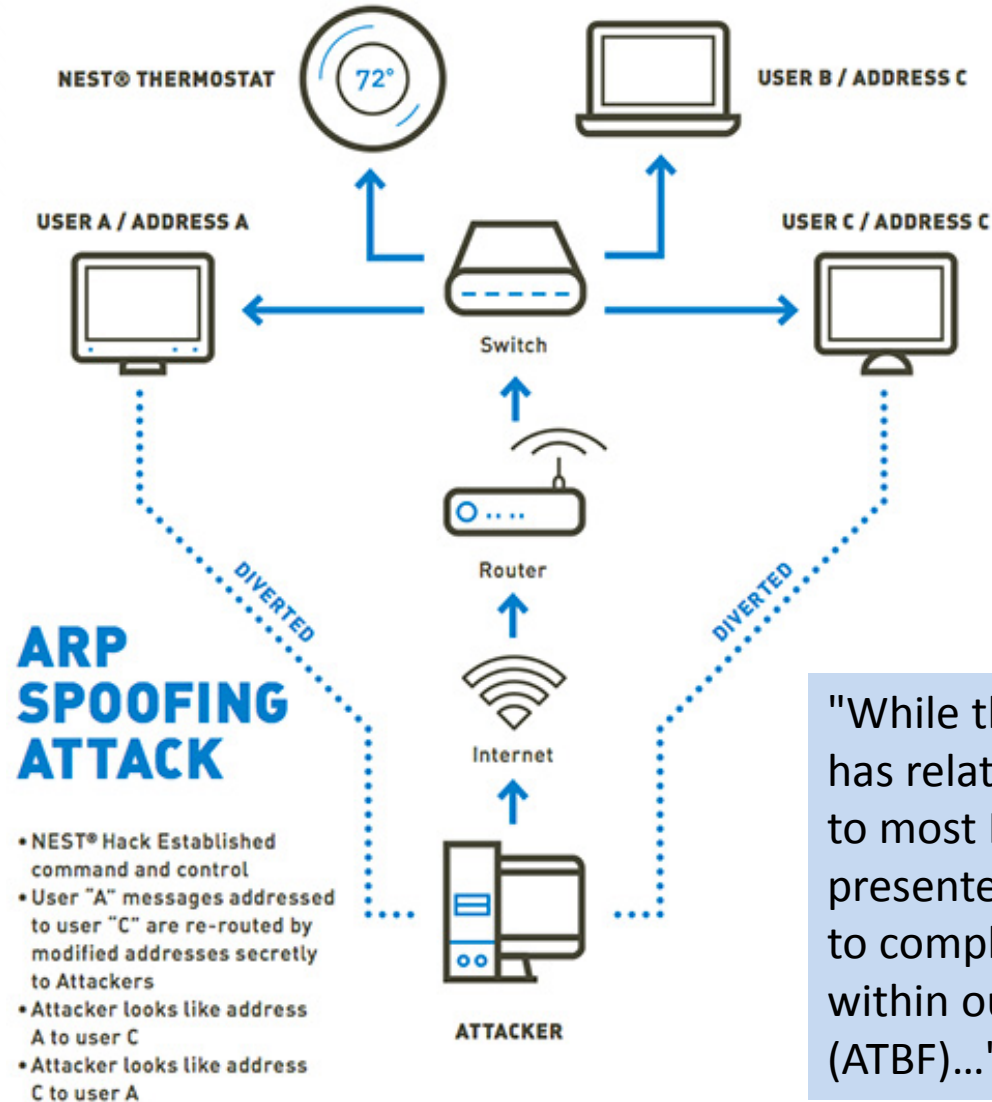
- Potential for abuse?



# ETHICS / PUBLIC POLICY

## Hacking Vulnerability

TrapX confirmed the design flaws discovered in the Nest Learning Thermostat. They validated the attack vector presented at the Black Hat 2014 Conference by compromising the device and an entire home network.



"While the Nest Learning Thermostat has relatively robust security compared to most IoT devices, the attack vectors presented at Black Hat enabled our lab to completely compromise the device within our Advanced Test Bed Facility (ATBF)..."