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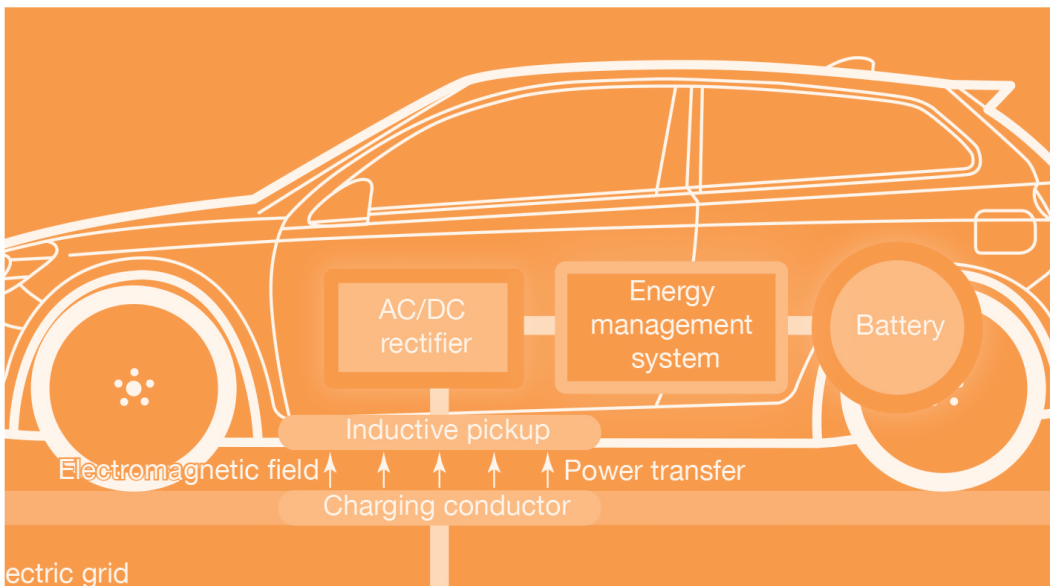
electronic design
power electronics

ENGINEERING PRINCIPLES

That make things work!



Dear Festival Attendee:

We are excited to be partnering with the *USA Science and Engineering Festival* this year to help showcase STEM! Penton's Design Engineering & Sourcing group is a collection of industry-leading brands that brings the most up-to-date technical content to engineers and purchasing professionals in industries such as automotive, electronics, microwaves, medical, power, and much more. As editors and engineers, we too were once bitten by the technology bug and continue to be intrigued with the science of how things work. This handout is designed to help students (young and old) see the basic engineering principles of things they use, play with, drive, or enjoy in their daily lives. We hope you find it helpful. We also hope you will continue your journey in STEM and one day become part of our loyal audiences!

Have fun!

Nancy Friedrich and
the Content Team

Alan Hitchcox, Leah Scully, Editors—HYDRAULICS & PNEUMATICS
Bill Wong, Maria Guerra, James Morra, Editors—ELECTRONIC DESIGN
Steve Mraz, Jeff Kerns, Carlos Gonzalez, Leah Scully, Editors—MACHINE DESIGN
Chris DeMartino, Jack Browne, James Morra, Editors—MICROWAVES & RF
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Top 5 Engineering Principles Behind an Electric Car

An electric car is propelled by one or more electric motors, using electrical energy stored in rechargeable batteries or another energy storage device.

LET'S LOOK AT SOME of the characteristics of an electric car and identify some of the electrical principles or concepts related to it.

1. Energy storage: Electric cars get power from dozens of rechargeable batteries stored inside the car that are controlled by a battery management system (BMS) for better performance. Depending on battery performance, the car can run for many miles or not.

2. Charging the batteries: The process of charging the batteries of an electric car is not much different from charging another electronic device. Depending on the car's model, you can use a special 110-240 volt charger or a 208-480 volt fast-charger.

Capacity rating and electric charge are the concepts used for the first and second characteristics of electric cars. The most common battery rating is the Amp-Hour rating. Ah (Ampere hour) is a capacity rating that measures how much current a battery will discharge over a specified period of time. An ampere-hour or amp-hour (SI symbol A·h or A h; also denoted Ah) is a unit of electric charge, equal to the charge transferred by a steady current of one ampere flowing for one hour, or 3,600 coulombs.

The coulomb (unit symbol: C) is the International System of Units' (SI) unit of electric charge. It is the charge transported by a constant current of one ampere in one second.

3. Wireless-charging the batteries: There is a new cable-free option to charge batteries by just parking the car over a special spot. It is based on magnetic resonance and electromagnetic induction power transfer technologies; just imagine invisible magnetic waves traveling a very short distance through the air transmitting power to the batteries.

The concepts applied to this third characteristic are called alternating magnetic fields, magnetic resonance, and electromagnetic induction power transfer technologies. Magnetic field is produced by electric currents moving within an electrical conductor.

In electromagnetic induction, a current circulates through a transmitter coil (transmitter antenna); it generates a magnetic field that induces a voltage in the receiver coil (receiver antenna). Electromagnetic induction has several advantages, such as the simplicity of its circuit scheme and its cost-effectiveness. Major disadvantages include the limited charging distance and the necessity for precise alignment between the transmitter and receivers.

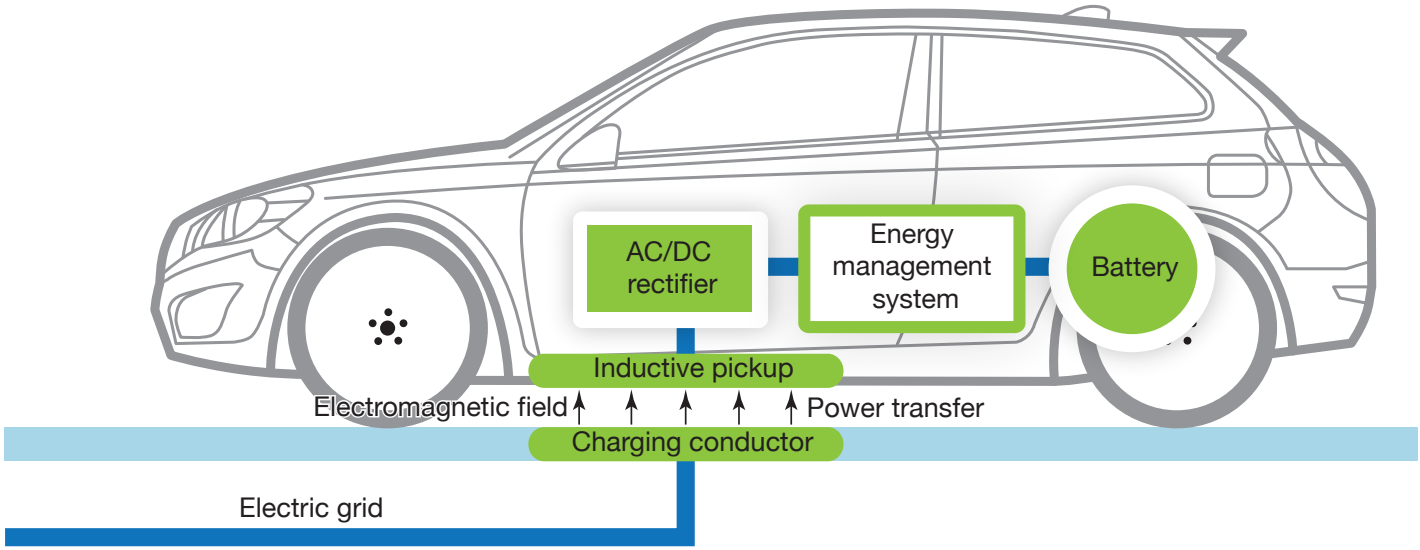
Magnetic resonance transmits power wirelessly over a space utilizing a resonance phenomenon based on the same principle as electromagnetic induction. The transmitter and receiver coils oscillate (or resonate) at the same frequency, which is determined by the material and shape of the coil. The main advantage of magnetic resonance is its ability to transmit electrical energy over a relatively long distance without precise alignment between transmitters.

4. Regenerative braking: There is a second brake system that when the cars brake it can recapture the car's kinetic energy and convert it to electricity to recharge the batteries. The electric motor reverses direction, becoming a generator or dynamo.

The concepts applied in this case are kinetic energy and electrical energy. Kinetic energy is the movement energy of an object. And in this particular case, regenerative braking is an energy recovery mechanism that converts kinetic energy into electric energy that is then stored in the batteries.

5. Power electronic components: Some equipment in the car works with direct voltage and some works with alternate voltage. For example, the battery is charged with direct voltage that comes from the alternator. The alternator receives alternating voltage that is transformed into direct voltage before sending it to the battery. Some electronics components like dc/dc converters or dc/ac inverters are able to do the transformations.

The concepts in this characteristic are alternate voltage and direct voltage. A direct voltage maintains the same polarity at all times. In an alternating voltage, the polarity reverses direction periodically.



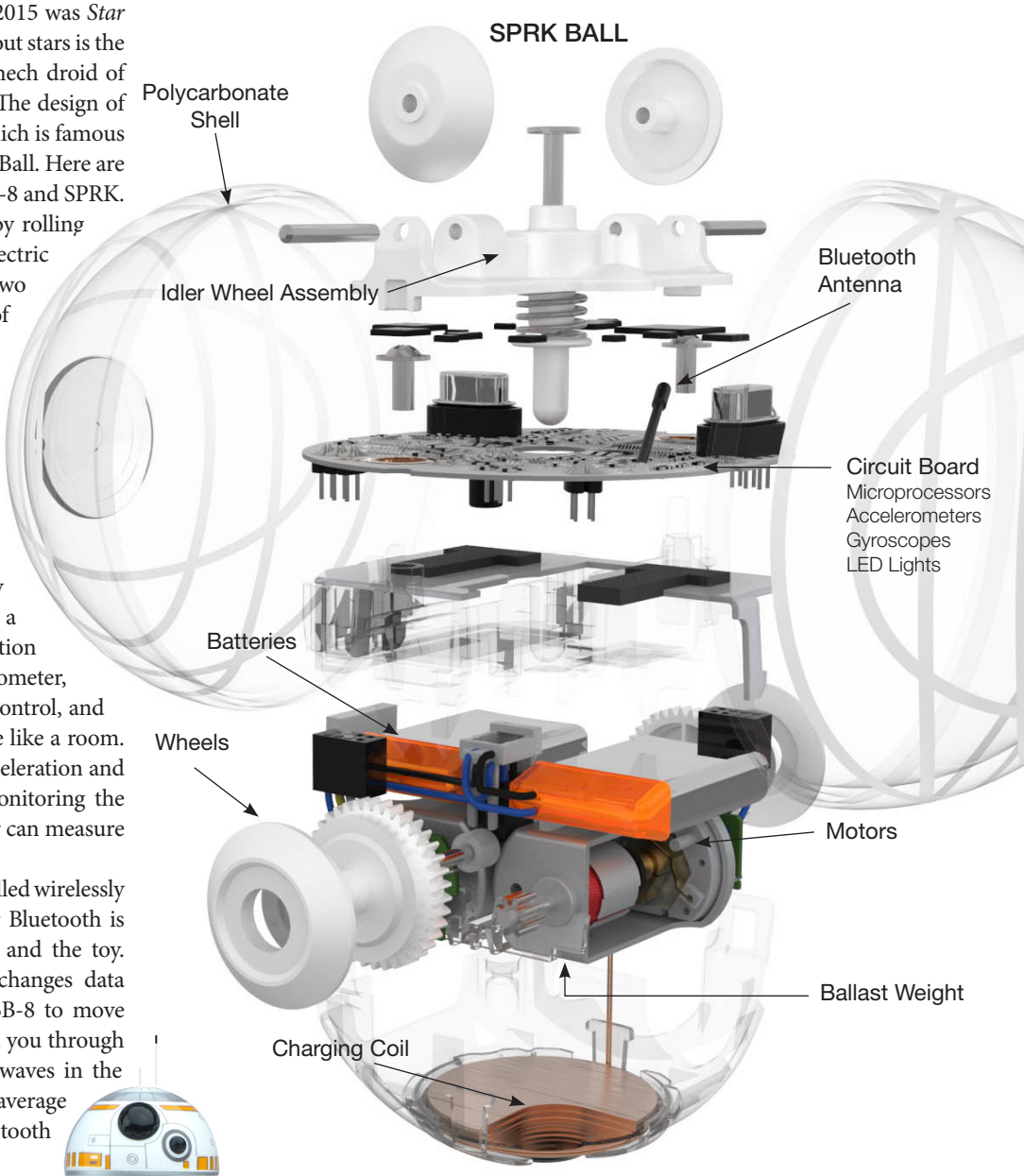
Top 5 Engineering Principles Behind the Toy: BB-8 by Sphero

ONE OF THE MOST POPULAR MOVIES in 2015 was *Star Wars: The Force Awakens* and one of its breakout stars is the new droid BB-8. BB-8 is the sidekick astromech droid of pilot Poe Dameron (played by Oscar Issac). The design of BB-8 came from the toy company Sphero, which is famous for its similarly designed toy called the SPRK Ball. Here are the top five engineering principals behind BB-8 and SPRK.

1. Motors and Wheels: BB-8 gets around by rolling its body. This function is performed by two electric motors that are housed inside the ball. The two motors spin the geared wheels on the side of main motor chassis. These wheels spin against the inside of the protective polycarbonate shell and create the rotating motion of BB-8.

2. Gyroscopes and Accelerometers: The parts found on the circuit board include the microprocessor, LED lights, gyroscopes, and accelerometers. A gyroscope is a spinning wheel or disc where the axis of rotation is free to assume any orientation by itself. The SPRK breakdown here includes a digital gyroscope that calculates the orientation and rotation of the ball. Paired with an accelerometer, this allows for BB-8 to have better balance, control, and to recognize its movement within a 3D space like a room. The accelerometer is used to measure the acceleration and orientation of the ball. It can do this by monitoring the direction of weight change. An accelerometer can measure vibration, shock, and falling.

3. Bluetooth: BB-8 and SPRK are both controlled wirelessly through a smartphone or tablet. Low-power Bluetooth is used to communicate between your device and the toy. Bluetooth is a wireless technology that exchanges data over short distances. This is how you tell BB-8 to move around, watch the perimeter, or interact with you through its "beeps" and sounds. It uses UHF radio waves in the ISM band from 2.4 to 2.485 GHz. It has an average range of 30 feet before the device is out of Bluetooth range.



4. Wireless Charging: In order for the ball to roll smoothly, the body has no plug-in ports. However, it operates on batteries so it needs to be charged. This is where wireless charging comes into play. Wireless charging uses an electromagnetic field to transfer energy between the two objects. BB-8 sits on its base, which is plugged into an electrical outlet and the induction coil in the charging base creates an altering electromagnetic field. The bottom of the ball is layered with its own induction coil and converts it back into an electric current to charge the battery.

5. Programming: Sphero has handed over control to the user and introduced the SPRK Lighting Lab. The SPRK Lighting Lab is an application for a mobile device (Android, iOS, and other devices) that lets you create custom programs for your BB-8 or SPRK. The app uses block-based programing to create the code and the user can double tap on the block to learn its function. After you finish building your code, the text-based code view lets you see the code and helps you learn more about programming.

Top 5 Microwave Engineering Principles Behind Cellular Phones

CELL PHONES ARE RADIOS, just like the AM and FM radios in the car. The one chief difference that makes it possible to talk on a cell phone is the way that the radio frequency (RF) technologies are used in each type of radio. In a frequency-modulated (FM) radio, frequencies are from 88 to 108 MHz and are divided into channels and a radio station transmits voice and/or music on one frequency, such as 102.7 MHz, and an FM radio that is tuned to that station can receive their programming.

A cell phone uses two frequencies at a time, or duplex operation, with one frequency for transmitting a signal and one for receiving a different signal. This way, two people can talk and listen at the same time. The cell phones don't transmit and receive directly to each other but go through a cellular base station, with a coverage area divided into many cells, each with its own base station. Each base station receives and transmits many different signals within an operating frequency band in support of many cell phone users. It also uses frequencies for control channels for each cell phone, to know where it is and when to switch it to another base station. A base station measures the power levels of each cell phone it communicates with, as well as nearby base stations, and it knows when to transfer a cell phone (also known as a mobile phone) to the next base station while maintaining a continuous communications link with almost imperceptible delays.

FIVE KEY TECHNOLOGIES

1. **IC transceivers**
2. **Amplifiers**
3. **Packaging**
4. **Design Software**
5. **Test Equipment**

Microwave technology makes the marvelous convenience of a cell phone possible. Every cell phone and base station relies on a microwave radios, usually in the form of a transceiver with both the transmitter and receiver built into a single, small circuit. Cell phone handsets rely on radio transceivers designed as integrated circuits (ICs). These are tiny circuits with all their transistors and passive components, such as capacitors and resistors, fabricated by semiconductor processes. Modern microwave IC technology makes it possible to fabricate the entire cellular radio transceiver for a cell phone handset in one chip, making cell phones affordable.

Amplifiers are important components in both cell phones and cellular base stations, boosting signals to the levels needed for reliable operation. The amplifier must provide high signal gain without deviations in performance, a trait typically known as "linearity." Amplifier technology has improved as each generation of cell phone has emerged, so that wireless service providers can offer service to a growing number of customers on a relatively limited number of frequencies.

Another key technology that makes cell phones affordable to so many people is the packaging of RF/microwave components. Modern packaging techniques, including surface-mount-technology (SMT) packages, along with IC technology, have made it possible to fit entire radios, as well as other important components, such as filters and amplifiers, within these miniature packages. The SMT packages can be added to a circuit board by "pick-and-place" machines to reduce manufacturing time and cost.

Circuits such as cell phone transceivers were once designed according to electronic formulas and built as circuits that had to be tested, modified, and rebuilt until they performed as desired. But one technology that has changed the speed and effectiveness in the way that microwave circuits are created is computer-aided-design (CAD) software. Each improved generation of cell phone products can be engineered on a computer without the time-consuming trial-and-error design practices of early cell phones.

Finally, one more essential technology to the development and advancement of cell phones is test and measurement technology. The rapid growth of cellular communications has driven test equipment manufacturers to find new ways to measure minute details, including signals to and from cell phones, from base stations, interference, and even how a cell phone will work in a car or in a building.

Of course, these are just five examples of the many RF/microwave technologies that have contributed to the development and growth of cellular communications with many other technologies, for instance antennas, playing important roles in the successful implementation of cellular telephones.

Top 4 Hydraulic Engineering Principles Behind Roller Coasters

TOP THRILL DRAGSTER is an attraction at Cedar Point, Sandusky, Ohio, that accelerates riders from zero to 120 mph in about four seconds. At that speed, the coaster has just enough kinetic energy to scale its monstrous 400-ft. hill. From there, gravity pulls the coaster down the other side of the hill, where it once again reaches speeds of about 120 mph.

The biggest challenge to this application was finding a technology that could accelerate a 12,000-lb coaster train—plus the weight of 18 passengers—to 120 mph in four seconds. Ride designers initially considered using linear induction motors, but they could not transmit enough power to accelerate the 15,000-lb coaster train to 120 mph in four seconds.

Instead, designers chose hydraulics. The hydraulic launch system transmits about 10,000 hp. This power is needed for only four seconds, which is a big reason why hydraulics was chosen: its inherent ability to store energy and release it rapidly with controlled speed, force, and acceleration. Four key principles are the basis for this system:

1. Motor Power

The launch system uses 16 pairs of motors powered by pressurized hydraulic fluid instead of electricity. Each motor is supplied by its own pump, so the entire launch system consists of 32 pumps and 32 motors. The motors drive an internal ring gear in a setup that somewhat resembles a clock. The big ring gear becomes the clock face, and the motors are positioned where the numbers would be—except there are 16 instead of 12. The two ring gears drive a gearbox, which, in turn, drives a wheel that pulls the coaster's launch cable.

2. Fluids & Flow Rate

The 10,000 hp equates to hydraulic oil flow of about 3,650 gal/min (gpm) at 4,640 psi. Even with 32 pumps, the system would require each pump to deliver more than 100 gpm. Such is not the case. Instead, each pump-motor combination relies on hydraulic accumulators to supply the majority of flow for each four-second launch interval.

3. Accumulators

An accumulator works much like a balloon to store energy. When you blow air into a balloon, you push air out of your lungs and into the balloon. Each time you take a breath, you have to blow harder to push more air into the balloon. That's because the balloon is elastic, so it "wants" to return to its original size and shape. Each additional breath stretches the balloon more, so it squeezes more on (compresses) the air inside. As you continue blowing more air into the balloon, it is storing more compressed air.

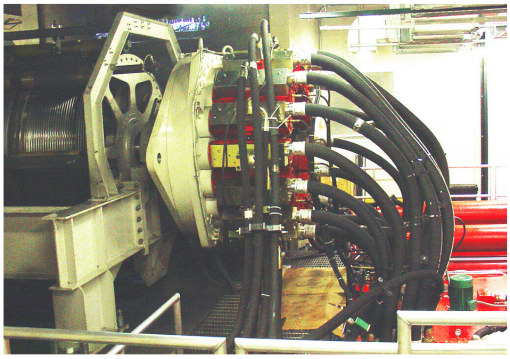
As long as the balloon doesn't break, it will store the compressed air. Letting go of the balloon will cause the air to rush out within a few seconds—much faster than it took to blow it in. The same concept applies to hydraulic accumulators. But unlike a balloon, an accumulator is made of strong steel to hold extremely high pressure. The accumulator has a pocket of gas inside, so pumping hydraulic oil into the accumulator causes the gas inside it to compress—just like with the balloon.

4. Pumps & Pressure

The hydraulic pump rotates at high power thousands of times per minute to rapidly push fluid into the accumulator. But because the accumulator is made of high-strength steel, it does not expand. Instead, all the fluid energy from the pump goes into compressing the gas in the accumulator.

When enough hydraulic oil has been pumped into the accumulators to compress the gas to a prescribed (charge) pressure, the coaster train can be launched. When this happens, large valves open to release all the pressurized hydraulic oil from the accumulators within four seconds. The oil rushes into the hydraulic motors with such speed and power that they accelerate the coaster train up to 120 mph in just four seconds.

The pumps start re-pressurizing the accumulators as soon as a coaster train is launched. It takes a few minutes for the incoming coaster to unload exiting passengers and board incoming passengers. But these few minutes provide just enough time for the pumps to recharge the accumulators for the next group of passengers brave enough to take on Top Thrill Dragster.



One of the hydraulic rooms of Top Thrill Dragster shows 16 hydraulic motors mounted to a ring-gear assembly (top center). At left is the wheel that pulls cable to launch each coaster, and at far right are some of the accumulators (red).

Gravity has pulled this coaster train down a 420-ft. hill. A powerful hydraulic system launched it to the top.

AT OUR BOOTH

Each year, Penton's Design Engineering & Sourcing group conducts a March engineering-related bracket contest that engages and entertains our audience. Last year's contest matched up engineering kits, toys, models, and tools that helped get our audience started in the sciences and engineering. Nominations included the Rubik's Cube, Legos, microscopes, erector sets, and various other games and toys. Festival attendees got to play with and vote on their favorite as well as explore some of the very latest STEM STARTERS like the Dragon City Marbelocity and the BB-astermech droid.

MEET THE TINKINEERS

The Tinkineers are a group of high-school friends who have grown up together in a historically industrial town outside of Boston called Chapin. Their town is laced with old mill buildings and manufacturing outfits, both old and new. If you grew up in Chapin, building, fixing, and/or making runs through your veins. Back in the town's heyday they used to say, "What're they makin' in Chapin!?"

Guided by their oft endearing and ever-quirky neighbor, Buddy, the Tinkineers are always building (or un-building, as is frequently the case) something. Along the way they're learning about engineering and how to channel their creative tinkering into a career path to keep them young at heart!

KELVIN

GOES BY: Kelvin

AGE: 17

SCHOOL YEAR: Senior at Memorial High School

ASTROLOGICAL SIGN: Virgo

FAVORITE COLOR: Blue

LIKES: Baseball, video games, taking things apart and 'fixing' them, guitar, cars

DISLIKES: Peanuts, butterflies, getting up early

PERSONALITY: Responsible, thoughtful, leader, inventive with creative ideas.

MOSFET

GOES BY: Mosfet or Mos

AGE: 16

SCHOOL YEAR: Junior at Memorial High School

ASTROLOGICAL SIGN: Libra

FAVORITE COLOR: Pink

LIKES: Sparkly things, social causes, music, robots

DISLIKES: Tests, meat, lakes

PERSONALITY: Bubbly but a bit snarky, feels things very deeply and is passionate about what she holds dear—an activist.

JOULE

GOES BY: Joule

AGE: 16

SCHOOL YEAR: Junior at Memorial High School

ASTROLOGICAL SIGN: Gemini

FAVORITE COLOR: Purple

LIKES: Basketball, superhero movies, books, running, animals, cooking

DISLIKES: Mean girls, losing, spiders

PERSONALITY: Quick-witted & vocal, sarcastic, impetuous, sensitive with a tough exterior.

IGGY

GOES BY: Iggy

AGE: 17

SCHOOL YEAR: Senior at Memorial High School

ASTROLOGICAL SIGN: Cancer

FAVORITE COLOR: Yellow

LIKES: Video games, watching sports, plays soccer, girls, movies

DISLIKES: Meatheads, poison ivy, cleaning

PERSONALITY: He's the funniest person of the group and perhaps the most popular. Don't let the funny fool you – he's smart.

NEWT

GOES BY: Newt

AGE: 17

SCHOOL YEAR: Senior at Memorial High School

ASTROLOGICAL SIGN: Aquarius

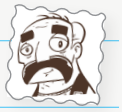
FAVORITE COLOR: Green

LIKES: Repurposing, gadgets, baseball, lizards

DISLIKES: Waste, including wasting time, pushy people

PERSONALITY: Popular, very handsome, a cool dude, and snappy dresser, a little shy but VERY smart.

BUDDY



GOES BY: Buddy—no one knows his real name

AGE: Who knows

PROFESSION: Retired—tinkerer

FAVORITE COLOR: All

LIKES: Everything! Loves building things, experimenting, puttering at the house and around town

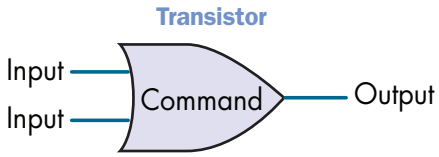
DISLIKES: Boredom, busybodies, neighbors who want him to clean up the yard

PERSONALITY: He's the best neighbor you could imagine. A cross between Doc from *Back to the Future*, Wilson from *Home Improvement*, and MacGyver.

To learn more about our past March Bracket Contests (Movie Madness and STEM Starter) as well as this year's competition matching up Academic Engineering programs at U.S. Colleges and universities, go to: www.electronicdesign.com/

Solve the Integrated Circuit

In an integrated circuit, electricity flows through transistors based on binary code. Each transistor processes binary 1 and 0 values to block current or allow it to flow through different paths in the circuit. Below you can see a simplified transistor with two inputs and a single output. Depending on the command in the transistor, the output will be 1 or 0.



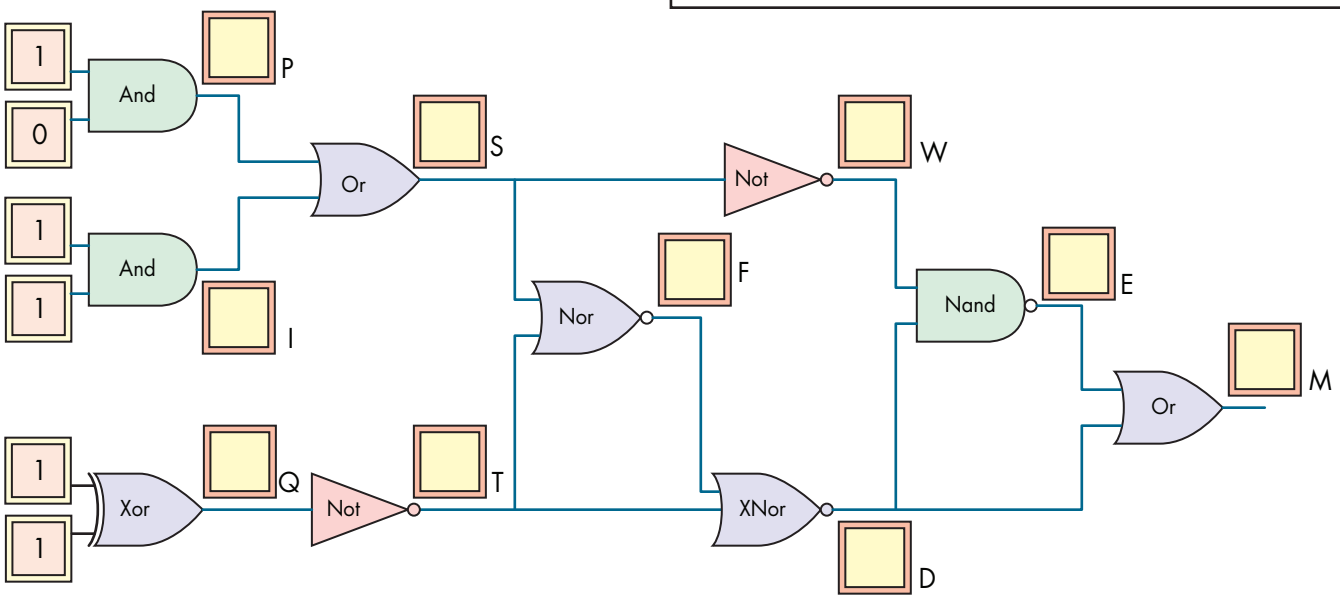
Using the commands listed in the key, can you solve the path of the integrated circuit below? You can write the output values in the ☐ provided next to each transistor.

Also, next to each ☐ is a letter.

For each output value of 1, use the letter in the spaces below to solve the secret message.

KEY

- **And** — "And" means that if both inputs are 1, then so is the output. All other input pairs will give an output of 0.
- **Or** — If either or both inputs are 1, then the output is also 1. If both are 0, the output is 0.
- **Xor** — The "X" means exclusive. So the output is 1 only if both inputs are different.
- **Not** — Also called an inverter, the output will always be the opposite of the input.
- **Nand** — This combines "Not" and "And," so that if both inputs are 1, the output will be the opposite, 0.
- **Nor** — This combines "Not" and "Or" so that if either or both inputs are 1, the output will be the opposite, 0.
- **XNor** — This is an exclusive "Nor." First, if both inputs are the same the output will be the opposite of 0, which is 1. If either inputs are 1, the output will be 0.



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