Power Transmission Systems

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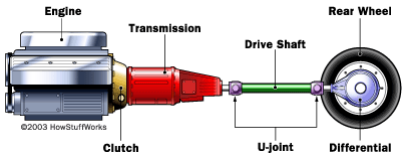
Introduction

Power Transmission System is the next and final stage of the engine generated power before it hits the wheels.

The whole system is responsible to couple engine and wheels, driving and adapting the output shaft rotation to a desired speed/torque ratio, allowing a wider range of speed and better performance as the engine has its own RPM limit (redline) and maximum performance value.



Block diagram

Power Transmission Systems are divided in three major blocks:

- Clutch
- Gearbox (Transmission)
- Differential

Each of them has a specific role transmitting power from the engine to the wheels ensuring correct rotation speed and torque.

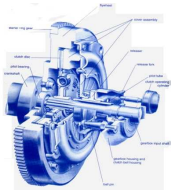
Let's start exploring each of them…

The Clutch

- Clutch is basically a system that many systems use, to connect and disconnect one (sub-)system that produce torque to other (sub-)system that will use that torque to produce work;
- The first sub-system could be, for instance, an engine, and the second one a transmission (as in a car);
- Multiplies or desmultiplies the torque;
- There are lots of other systems that use clutches like drills, chain saws, some yo-yos…;
- This might not be just mechanicals, can be electrical too.

The Clutch

- In automotive-systems we need a clutch because they have a engine that spins all the time (when it is on), but the car are not always in movement. When we need our car start there movement, when we need to push a more height that the usually (in manual transmission), when we need to stop the car… just with motor, gearbox and differential there were not possible.
- Besides this the clutch provides a smooth start of the car.
- To do this we need a connection (on/off) between the motor and the gearbox.



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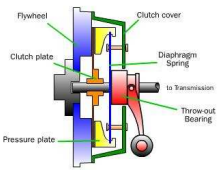
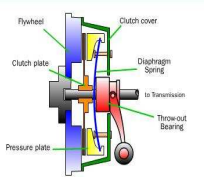
The Clutch

Operation method of a clutch:





- The on and off of clutch is done by a pedal that is present under the instrumental panel.
- When the pedal is not pressed it means that the clutch is engaged; when we press the pedal the clutch is not connected, that means that the motor are disengaged of gearbox.

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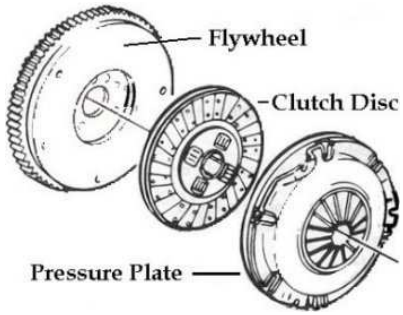
The Clutch

- The clutch has two fixed elements to the motor and other connected to the transmission. When the pedal is totally down, the engine could work even with one speed engaged that the car will not has traction.
- The clutch allows us to engage a spinning engine to a non-spinning transmission by controlling the slippage between them. It works because of the friction between clutch plate (that is the output of the system) and a flywheel (that is the input of the system). The friction is possible because the plate of clutch is done by brake pads there are connected to the engine, and the clutch plate connects to the transmission; when we press the clutch pedal, a cable or hydraulic piston pushes on the release fork, which presses the throw-out bearing against the middle of the diaphragm spring.

The Clutch

As the middle of the diaphragm spring is pushed in, a series of pins near the outside of the spring cause the spring to pull the pressure plate away from the clutch disc. This releases the clutch from the spinning engine. then the engine is locked to the transmission input shaft, causing them to spin at the same speed.



The Clutch - Dual Clutch

- This kind of transmission does the work of two clutch's, like the name says.
- When one clutch is working, the other is waiting and when the first disengages the second engages. This is useful for high performances, because the time between up shifts or down shifts is insignificant.
- It works like 2 gearboxes in 1, because we have one clutch connected to the odd gears and to the reverse gear, and other connected to the even gears by 2 axles; one of them spins internally and other externally.

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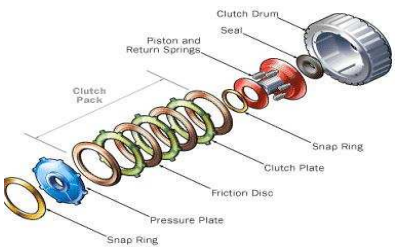
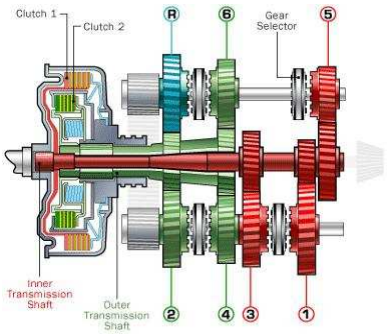
The Clutch - Dual Clutch

This clutch consisting in a wet multi-plate clutch there is one that baths components in a fluid to reduce friction and limits the production of heat.





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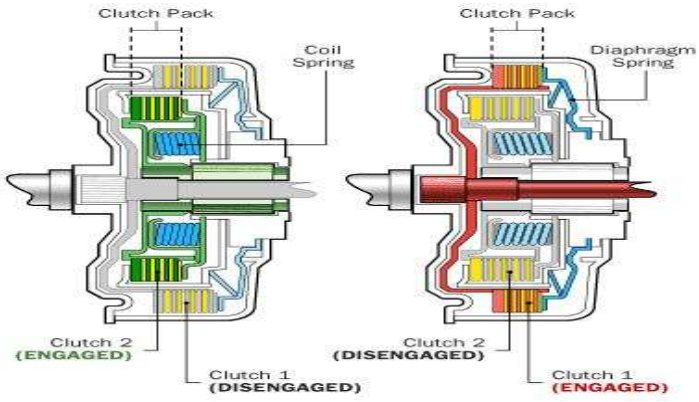
The Clutch - Dual Clutch

Wet multi-plate clutches use hydraulic pressure to drive the gears. The fluid does its work inside the clutch piston. When the clutch is engaged, hydraulic pressure inside the piston forces a set of coil springs part, which pushes a series of stacked clutch plates and friction discs against a fixed pressure plate. The friction discs have internal teeth that are sized and shaped to mesh with spines on the clutch drum. In turn, the drum is connected to the gear-set that will receive the transfer force.

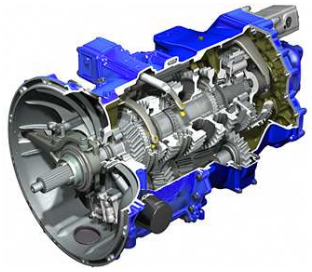
The Clutch - Dual Clutch



This mechanism is similar with a torque converter used in automatics transmission.

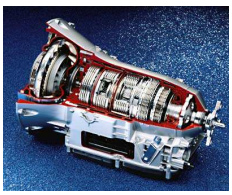
The Transmission

- Cars need a transmission (gearbox) because the engines binary itself isn't capable of create different relations of velocity and binary. The engine has a rotation limit (redline) that cannot be passed for the good of the engine.
- So, we need to create a way of using the available rotation of the engine, creating different relationships between engine and the wheels.

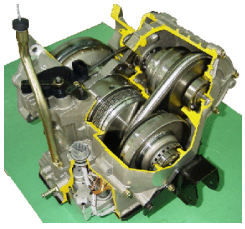


The Transmission

There are 4 big types of transmissions:

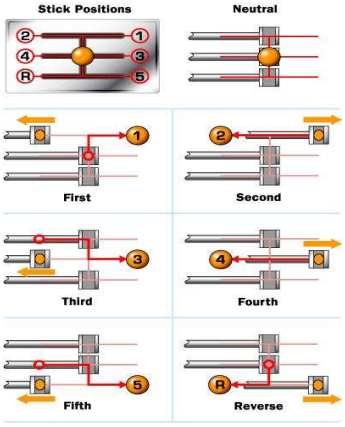


- Manual Gear box
- Dual-clutch transmission (DCT)
- Continuous Variable transmission (CVT)
- Automatic transmission



The Transmission – Manual Transmission

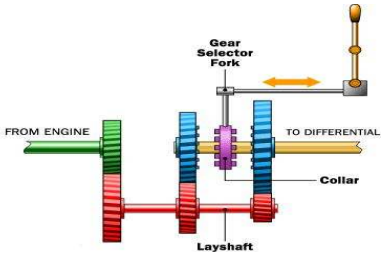
- Manual transmission in cars is usually controlled by an “H” pattern lever. This has this name because it has H architecture, I mean the gear lever works like an H, how we explain in the following diagrams:



The Transmission – Manual Transmission

This looks with the actual 5 gear-boxes, it works with the same principle as next diagram:

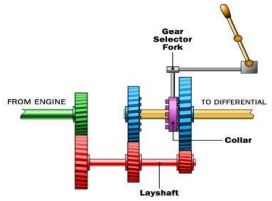
- The green shaft comes from the engine through the clutch;
- The red shaft and gears are called the layshaft. These are also connected as a single piece, so all of the gears on the layshaft and the layshaft itself spin as one unit. The green shaft and the red shaft are directly connected through their meshed gears so that if the green shaft is spinning, so is the red shaft. In this way, the layshaft receives its power directly from the engine whenever the clutch is engaged.



The Transmission – Manual Transmission

- The yellow shaft connects directly to the drive shaft through the differential to the drive wheels of the car. If the wheels are spinning, the yellow shaft is spinning too.
- The blue gears ride on bearings, so they spin on the yellow shaft. If the engine is off but the car is coasting, the yellow shaft can turn inside the blue gears while the blue gears and the layshaft are motionless.
- The purpose of the collar is to connect one of the two blue gears to the yellow drive shaft. The collar is connected, through the spines, directly to the yellow shaft and spins with the yellow shaft. However, the collar can slide left or right along the yellow shaft to engage either of the blue gears. Teeth on the collar, called dog teeth, fit into holes on the sides of the blue gears to engage them.

The Transmission – Manual Transmission



- To we engage the 1st gear, we move the lever like in the last image, and the gear selected fork will engage the collar in the 1st spur gear (blue);

- To we engage the 2nd gear, we move the lever like in the last image, and the gear selected fork will engage the collar in the 2nd spur gear (blue).

And the same principle applies to the other gears. When the collar engages in the any spur gear, there will be a transfer of rotation between spur and differential, and now we have rotation in wells. The reverse gear works like the others, but has one more spur that promotes the rotation in the reverse way that the others gears. The next video animation shows who manual gearbox works.

The Transmission – Manual Transmission

Manual transmissions in modern passenger cars use synchronizers to eliminate the need for double-clutching. A synchro's purpose is to allow the collar and the gear to make frictional contact before the dog teeth make contact. This lets the collar and the gear synchronizer their speeds before the teeth need to engage, like this:

The Transmission – Manual Transmission

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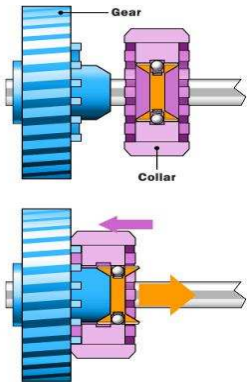
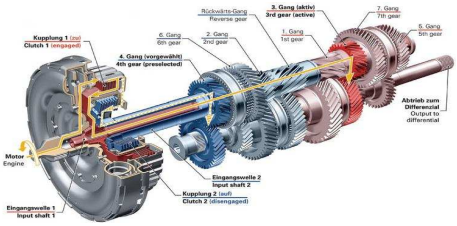


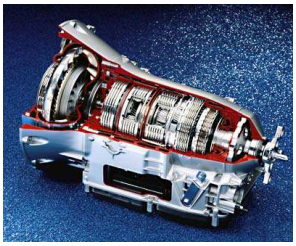
The Transmission – Dual Clutch



The Transmission – Dual Clutch

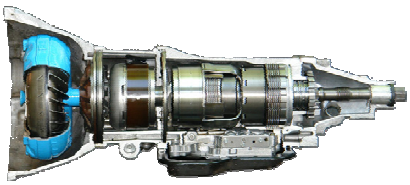
- This type of transmission is used in races since 1985 used for audi and Porsche. This kind of transmission gave to both victories in some Championships.
- The main advantage of this transmission is her capability to work sequentially with 2 clutches. One of them is connected to the odd gears and to the reverse gear, and other connected to the even gears.
- This fact enable the vehicle of have the possibility to change gears very quickly, promotes lowers consumptions and a longer live than the other transmissions.
- The synchronizers of this gearboxes are done with a more abrasive material of friction to get very lower synchronization times and to allow down shifts like 6^{th} to 2^{nd}. In other car this isn't possible.

The Transmission – Automatic Transmission



Automatic transmission was invented in order to transfer the need of shifting gears from the driver to the car, allowing an easy and more fluid driving experience to all passengers, as well as the same objective of all the other types of transmission: convert the narrow range of engine speeds into a wide range to the output.

Therefore, if the car would need to shift gear it should be able to press the clutch pedal autonomously first. Well, that's not like that... Automatic transmission cars doesn't have clutch at all.



The Transmission – Automatic Transmission

However, if in a manual transmission system there is a need to use a clutch in order to keep the engine running while the wheels are stopped, in automatic transmission there is the same need, thus, another device was created to act the same way, but now automatically.

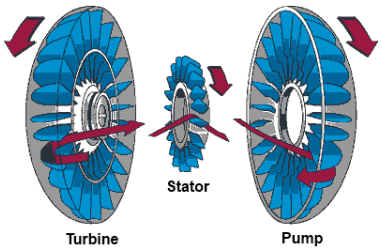
Torque Converter is the device that will do that job and its operation method is based on fluid movement.

Next we'll see how it works…

The Transmission – Automatic Transmission

This device has three major parts:

- Turbine
- Stator
- Pump



Turbine is directly connected to the engine flywheel, so it spins at the same speed. The stator is the middle part that will redirect the fluid from the turbine to the pump, forcing this one to rotate nearly at the same speed as the turbine that will transmit the movement forward as it's directly connected to the transmission. In low engine rpm's the force of the fluid is so low that almost no rotation will be generated in the pump.

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The Transmission – Automatic Transmission

Unlike manual transmissions, an automatic transmission only works with one set of gears that produces all of the different gear ratios. This set of gears is called Planetary Gearset and consists in the ring gear, planet gears and sun gear. Combining witch of these parts will stay stationary, act as input and output, it's possible to produce all the gear ratios available in the car. It has some clutches to hold desired parts stationary and can be also seen in electric screwdrivers.

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The Transmission – Automatic Transmission

However, in cars it's used a Compound Planetary Gearset. This has an extra sun gear with a different diameter allowing to create more gear ratios than with one.

Although, that's not everything an automatic transmission needs to do its job. It's necessary some kind of intelligence in order to respond correctly to driver orders. For instance, if he accelerates gently, shifts will occur at lower speeds than if he accelerates at full throttle; if he pushes the gas pedal all the way down, the transmission will downshift to the next lower gear; etc…

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The Transmission – Automatic Transmission

This is actually the brain of the automatic transmission, managing all of these functions and more. The passageways route the fluid to all the different components in the transmission. Passageways molded into the metal are an efficient way to route the fluid; without them, many hoses would be needed to connect the various parts of the transmission.

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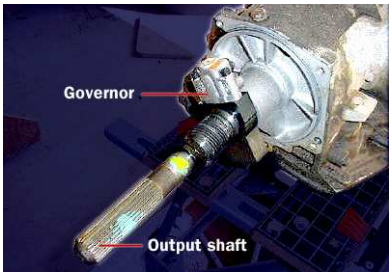
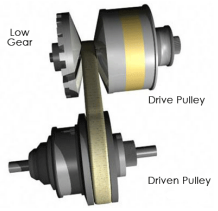
The Transmission – Automatic Transmission

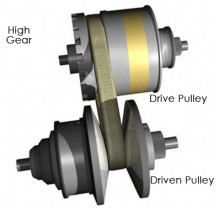
The governor is a clever valve that tells the transmission how fast the car is going. It is connected to the output shaft, so the faster the car moves, the faster the governor spins. Inside the governor is a spring-loaded valve that opens in proportion to how fast the governor is spinning. The faster the car goes, the more the governor valve opens and the higher the pressure of the fluid it lets through.



The Transmission – Continuous Variable Transmission

Unlike other transmission systems, Continuous Variable Transmission is a type of transmission witch can generate infinite gear ratios without any kind of gears, instead of that it uses a pair of pulleys capable of changes its diameter, thus, changing gear ratio and allowing an infinite variability between highest and lowest gears without discrete steps or shifts while it doesn't have to lock toothed wheels.





It was conceptualized by Leonardo DaVinci in 1490 but since then it has been modified in order to improve some relevant questions including material witch the belt is made.

The Transmission – Continuous Variable Transmission

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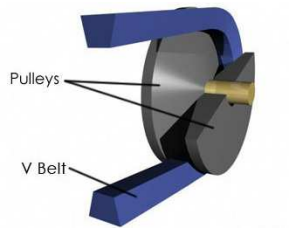
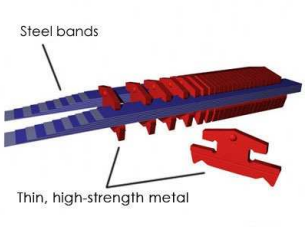
Pulleys are made of two 20-degree cones facing each other varying its distance, where a belt adjusts its position generating a continuous gear ratio. Is preferred this belt is made from rubber and is V-shaped allowing to increase frictional grip.





The belt is an essential component of the CVT transmission system as it holds all the torque transferred by the engine to the wheels. Now-a-days it's made of nine to twelve bands of steel combined with steel pieces making this a very strong although flexible belt.

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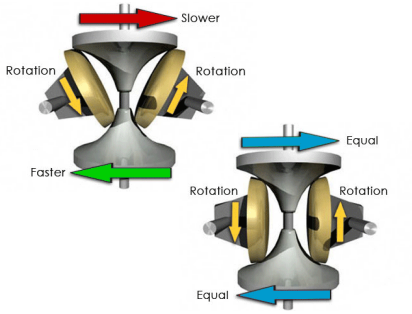
The Transmission – Continuous Variable Transmission

Sistemas Automóveis

There are, however, some types of CVT transmission systems. A Toroidal CVT works in the same principle of standard CTV but don't uses diameter-variable-cones and a belt to change gear ratios, instead of that it connects the input and output shafts through a adjustable surface. On the left a simple toroidal CVT, on the right the NuVinci bicycle CVT.



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The Transmission – Continuous Variable Transmission

Most of all CVT has lots of advantages:

- Smoother drive – constant and stepless acceleration;
- Improved fuel efficiency – always keeps the car in optimum power range;
- No gear shifting – great response to changing conditions (speed, throttle…);
- Better acceleration – less power loss than in a typical automatic transmission;
- Better control over emissions - better control of engine's speed range.

The Transmission – Continuous Variable Transmission

Sistemas Automóveis

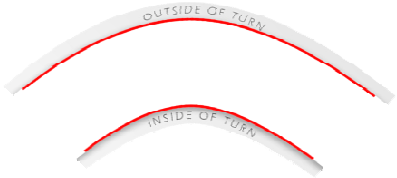
Although it has some disadvantages too:

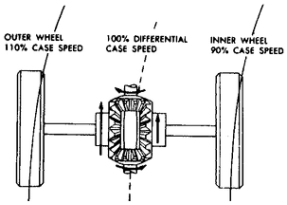
- Some CVT's in production vehicles have seen premature failures;
- In vehicles, without intervening electronics, a CVT will go to high rmp on wide throttle opening, producing a disquieting noise;
- CVT's aren't as capable of handling torque as other transmission systems.

Nevertheless they are a very reliable system, being increasingly used in economic cars.

The Differential

Differential was invented to solve a problem: allow each driven wheel to travel at different speed at the same time the power is applied to them, this especially happens when making a turn.



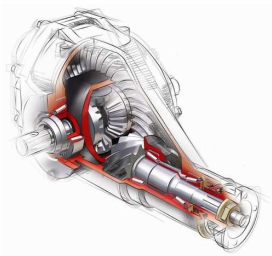


As you can see in figures above, when a car does a turn, inner wheels travel a different distance from outer wheels, forcing each ones to spin at different speeds. Since speed is equal to distance divided by the time, inner wheels will spin slower then outside wheels.

The Differential

Non-driven wheels are physically disconnected, so they spin independently. But not the driven wheels. Those must be linked together in order to a single engine and transmission can spin both ones.

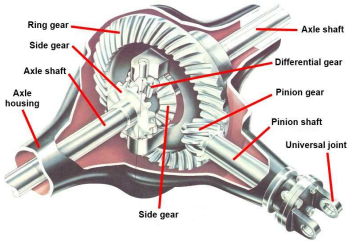
The differential is the device that solves this paradox.



The Differential

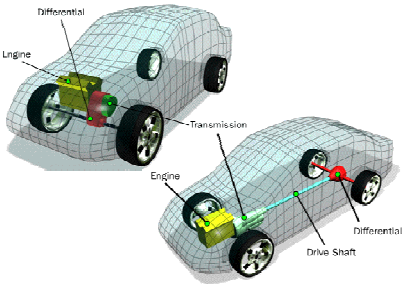
If differential doesn't exist it would be very hard to make a turn as one of the wheels tend to slip, and with modern tires and concrete roads that force will overstrain all the axle. It's the last stage of the power before it hits the wheels and it's inside a housing filled with differential fluid allowing to gears spin easier. So, as we already saw, it's jobs are:

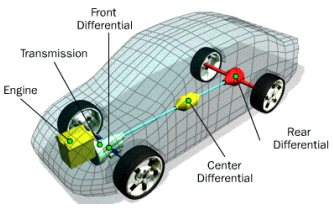
- To aim the engine power at the wheels;
- To act as final gear reduction, slowing the rotational speed of the transmission one last time;
- To transmit the power to the wheels while allowing them to rotate at different speeds (the reason it earned the differential name).



The Differential

Its location varies according to the type of traction the car is. In a 2WD front-wheel-drive car, differential its located in the front axle; in a 2WD rear-wheel-drive car its located in the rear axle (on the right).





There are, although, other types of car traction like all-wheel-drive (AWD) and full-time four-wheel-drive car (full-time 4WD) that need an extra differential isolating front and rear axis (on the left).

The Differential

Notice, however, that part-time 4WD cars (the ones that allow switching between 2WD and 4WD) don´t have a differential between front and rear axis, that's the reason they are hard to turn on concrete.

When in 4WD both axis are locked together in the transfer case (on the right) so they have to spin at the same average speed. That's the same situation of two wheels in an axle if it wasn't used a simple differential between them.

The Differential

Type	WD types available	Number of Differentials
2WD	2WD	1 (motion axle)
part-time 4WD	2WD low 4WD high 4WD	2 (front and rear axles) In 4WD both are connected in transfer case
full-time 4WD	low 4WD high 4WD	3 (front, rear and centre) In some cases centre differential can be locked acting as none
AWD	high 4WD	3 (front, rear and centre)
auto AWD	2WD AWD	2 (front and rear axles)

The Differential

There are some types of differentials:

- Open differential;
- Clutch-type Limited Slip Differential;
- Viscous Coupling;
- Locking and Torsen.

The Differential

The open differential is the one we have been presenting, a differential with standard features, found in most cars.

Clutch-type limited slip differential is a differential that are equipped with a clutch allowing to connect or disconnect both axles in some situations.

The Differential

The viscous coupling differential works without any kind of physical connection between both axles actuating the input one on a viscous fluid dragging the output, allowing differences in speed.

Locking/Torsen differential is very useful for serious off-road vehicles. That's because it allows to lock both axles whenever driver wants. On the left a locking differential, on the right a open and a Torsen one.

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