TRANSMISSION TYPES EXAMINED

In the first place, why must a 4x4 have a transmission at all? You don't see gearboxes hanging off Jumbo jet engines or on steam trains. We're so used to living with the internal combustion engine, be it petrol, diesel or gas-fuelled, that we've come to accept its shortcomings without much thought.

For instance, we accept that an engine has to keep running when it's not actually doing anything: the process is appropriately called 'idling'. Another concession we make readily is the need for a multi-ratio transmission behind the internal combustion engine. However, if steam or electricity had won the early 1900s’ automotive engine contest we wouldn't have idling engines or the need for multi-ratio transmissions, because these engines provide instant starting torque and don’t need to be spinning before they can handle a load.
(Steam, it would seem, is finished as an automotive powerplant possibility, but electricity is on the way back in.)

Since the internal combustion engine needs to be spinning before it produces any torque it must be equipped with a device that can disengage it from the load – the weight of the vehicle and its resistance to rolling - until the engine has worked up some speed.

The only way such an engine can work in an automotive application is with a clutch, or fluid coupling, to engage the load at lift-off. The internal combustion engine also needs a multi-ratio transmission to regulate engine revolutions through different load and road-speed conditions.

A transmission is simply a torque multiplier, magnifying the torque the engine is producing when the vehicle is moving from rest and then progressively reducing the magnification to zero in direct gear. In 'overdrive' the transmission actually reduces the torque produced by the engine, dropping engine revs in the process and improving economy.

Manual and Automatic Transmissions

A manual transmission is fitted with three or more principal shafts, on which gears are mounted in such a way that the shafts are constantly ‘meshed’ together. The gear ratios are ‘stepped’ along the shafts, so that there’s a progressive lessening in engine speed reduction as the box is upshifted and a progressive increase in engine speed reduction as the box downshifts.

Gear changes are done by splined hubs sliding back and forth on a mainshaft, locking and unlocking gears which are otherwise free to spin in constant mesh with fixed, mating gears on a countershaft (also known as a ‘cluster’ gear). A synchroniser assembly equalises gear speed as the selector hub moves into engagement.
(The 'grunch' you hear if you mistime a shift or if your foot slips off the clutch isn't the reduction gears clashing, because they're in constant mesh: the noise comes from the selector teeth grinding against the engagement teeth as they try to lock the desired gear to the selector hub.)

Most automatics use ‘planetary’ gear sets - named after the rotation of the planets around the sun – where a combination of sun, ring and pinion gears are locked and unlocked to vary the ratio spread. If you look at the typical ratio range in a 4x4 manual transmission you’ll find a first gear of around 5:1, a progression to 1:1 fourth gear and one or more overdrive gears, between 0.9:1 and 0.8:1.

In contrast, an automatic transmission usually has less ratio ‘depth’, starting off with a first gear around 4:1 and extending to a taller overdrive that can be as much as 0.6:1. The reason autos have less gear reduction than manuals is that an auto comes with a torque converter, fluid coupling. The torque converter does exactly that: it increases engine torque, by a factor that’s called its ‘stall ratio’ and that is usually at least 2:1.

In a torque converter, fluid is pushed from the engine-drive side of the coupling to the transmission side, rotating the transmission. Torque multiplication is at its greatest at lift off and progressively decreases as vehicle speed rises.

A torque converter contains three major elements, impeller, stator and turbine, while the mechanical part of the transmission consists of planetary gear sets. Ratio changes are done by wet-plate clutches and brakes, locking and unlocking the different elements of the planetary gear sets.

The modern automatic transmission has an automatically-functioning clutch on its torque converter, to lock it up when fluid torque multiplication isn't necessary. This lock-up facility overcomes the fuel consumption penalty which exists if the torque converter is 'slipping' slightly all the time.

You can pick the point of torque converter lock-up when you're driving an auto, because you'll see the tachometer drop down a couple of hundred revs without any drop in road speed. Conversely you can see the lock-up clutch disengage when you press the accelerator lightly while cruising in overdrive: the tacho needle will flick up without any change in road speed.

Automatics have benefited from the use of electronic controls and on-board computers. Typical electronic control applications include torque converter lock-up clutch action, shifting parameters, shift action modulation and prevention of incorrect ratio selection.

Manual or Automatic

Around two thirds of new recreational 4x4s sold today are fitted with automatic transmissions and many new models don't come with a manual transmission choice.

Automatic transmissions have the advantage of torque multiplication at lift-off and single pedal control in awkward circumstances, like hill starts on very steep or slippery grades. While heavier on fuel in stop-start conditions than a manual box, a modern auto doesn't give anything away in cruise, when the torque converter is locked, giving mechanical drive.

A significant advantage of an automatic transmission over a manual box is the 'P' position, which mechanically locks the transmission, even while the engine is running, making an effective parking brake when the rear-wheel, drum-in-disc parking brake gives up the ghost through water entry or lack of adjustment.

The drawbacks with autos are a propensity to get hot if used for extended periods in soft sand or with heavy loads; reduced engine braking when compared with a manual box; and the inability to start the engine if the only battery or the starter motor packs up.

The reduction in engine braking with an automatic transmission has a twofold cause: the fluid coupling between engine and transmission and the lower numerical ratio reduction in an auto compared with a manual transmission. Many late-model 4x4s overcome the auto’s engine braking problem with electronic hill descent control that applies selective wheel braking to maintain a set downhill speed.

Manual transmissions in 4x4s haven't changed much in recent years. The design is synchromesh on all forward gears, and in reverse as well on heavier vehicles. The principal recent advances are multi-cone synchronisers, to improve the durability of these hard-worked components.

The advantages of a manual transmission over an auto are simplicity of design, lower first cost, easy tow-starting and stronger engine braking.

The drawbacks include the obvious one of having to shift each gear manually; the need for a clutch; and the fact that the engine can stall on steep grades and then require a stall-recovery technique to get going again.
(Some 4x4 drivers think they're smart by being able to shift a synchromesh transmission without using the clutch – like truckies do with Roadranger non-synchro boxes. A synchromesh-equipped transmission must never be shifted without full clutch action that eliminates transmission torque during the shift, or the synchromesh units will be damaged.)

Transfer Case

Where a two-wheel drive vehicle has only a main transmission, a 4x4 has an auxiliary transmission, to distribute or 'transfer' engine torque to front and rear axles – hence the term 'transfer case'.
In the case of a 'soft-roader' 4x4 there's only single-stage or no reduction gearing in the transfer case, but with a 'real' 4x4 there is two-speed gearing in the transfer case. The latter transfer fulfils a double purpose: torque transfer front and rear, and additional torque multiplication.
It's easy to see why 4x4s need more torque multiplication than road-bound cars. All you have to do is put your front wheels against a steep rock shelf to find out that you need more torque than is available through a road-going transmission. Low-range gearing varies in ratio, but 'real' off-road vehicles have a minimum 2:1 low range reduction, thus at least doubling the torque available. North America's love of rock-crawling has resulted in some Yank transfer cases with ratios of 4:1.
Although the principal requirement for a transmission is torque multiplication there's a bonus in the case of 4x4s: speed limitation. There are many instances in off-road situations where you select low range, but use hardly any, or no, accelerator pressure. In these walking-pace conditions the low-speed gearing provides powered control, where a vehicle without low range would need constant in-out clutch action, or, in the case of an automatic, wheel brake action and torque converter 'slip'.
Low-range gearing works on the 'overrun' as well. Engine braking power is magnified when descending steep grades in low gears, because engine speed is forced up by the gear reduction, enhancing the engine compression effect.
In most low-range vehicles it's necessary to stop the vehicle before low range can be selected, because most transfer cases have simple dog-clutch low-range engagement. However, some 4x4s have low-range selection 'on the fly', with electronically-controlled selection while the vehicle is moving at low speed.

Final Drive

Every 4x4 has a pair of final-drive reduction gear sets. The primary function of a final drive is to send torque to the wheels, but a secondary function is another step in the gearing process. Typically a 4x4 final drive ratio is in the 3:1 to 5:1 zone, reducing propeller shaft speed by that factor and multiplying engine torque – already magnified by the main transmission and transfer case – still further.
It's theoretically possible for all the gear reduction work to be done in the main transmission and have a 1:1 final drive ratio, but that would mean a much heavier transmission and it would still be necessary to have final drive gearing to split driveline torque to the axle half shafts.
Vehicle designers have opted for optimum main transmission, transfer case and final drive sizes.

Overall Gearing

'Overall gearing' describes the reduction from engine revs in each gear. In the case of a vehicle without low range there's one set of overall reductions, calculated by multiplying the reduction in each transmission gear by the final drive ratio in the axles. In the case of a 4x4 with low range gearing there are two sets of overall gearing numbers: one set for high range and one for low range. Low range overall gearing is found by multiplying each transmission ratio by the low range reduction ratio and the final drive ratio.

The most significant overall gearing figure is low range first gear, which gives a picture of the vehicle's crawling, hill climbing and hill descending ability.

Overall mechanical gearing tells only part of the gear-reduction story in the case of automatic transmission 4x4s, because the gearing calculations need to be multiplied by the torque converter stall ratio as well. Importantly, the auto's overall gearing when climbing is different from when it's descending, because the torque converter works 'one way' only: uphill effective overall reduction can be at least twice that of downhill reduction.

Continuously Variable Transmission

DAF, the Dutch car and truck maker, patented the first production continuously variable transmission (CVT) and van Doorne Transmissie still licenses pulley-type CVTs to an increasing number of global vehicle makers.

The early CVTs used a rubber belt running between variable-diameter 'vee' slots in two pulleys. As the pulleys changed their effective diameters, the gearing changed, steplessly. One pulley was connected to the engine and the other to the driveline. As one pulley became effectively larger in diameter the other became correspondingly smaller and this varied the gear ratio between input and output pulleys.

The main problem with rubber-band CVT's was the torque limit the belt could endure.

Later CVT developments use a steel link-plate chain instead of a rubber band, increasing torque capacity up to over 300Nm and with hydraulic pulley diameter control to eradicate 'slipping clutch syndrome'.

Steel-belt CVTs reverse the rubber-band CVT rotation direction, with the drive pulley pushing rather than pulling the belt. The 'push' chain becomes virtually a steel rod when under compression between the pulleys.

A variation of the two-pulley CVT is the Anderson design that features floating sprocket bars on the insides of the pulley sheaves that match grooves in the drive chain. Thus, the chain drive is positive, rather than by friction between the sheaves and the chain.

A variation of the Anderson CVT is a pair of parallel cones instead of pulleys, with floating sprocket bars mounted in longitudinal grooves on the outsides of the cones. The drive chain is free to run back and forth along the cones, thus changing the gearing.

However, even a steel chain has its limitations and higher-torque CVTs have moved away from the pulley design to a 'toroid' concept.

The NSK-made Extroid unit, used principally by Nissan in performance cars and in the 4x4 Murano, relies on the same variability principle as a pulley-type CVT, but looks quite different.

This half-toroid CVT has a pair of dished, facing cones that don't touch, but are connected by contact with the wear faces on four hemispherical rollers, in much the same way that pinion gears 'connect' the side gears in a differential. One of the cones couples to the engine, via a clutch or torque converter, and the other to the drive system.

The rollers can be tilted fore and aft, varying the contact positions on the two cones and this action varies the gearing.

Another variation on the toroidal theme is the Torotrak design, which has an additional double-ended central cone and twice the number of hemispherical rollers, for greater gearing reduction. Unlike the Extroid unit the Torotrak doesn't need a clutch or a torque converter in the input cone. This unit is aimed at the heavy 4x4 and light truck markets.

The future of CVTs looks bright and they might well have moved into racing circles as well, were it not for a decisive block by the FIA in 1994, following spectacular times clocked by David Coulthard in an experimental CVT-equipped Williams.

The Ideal 4x4 Transmission

Despite the size of the world 4x4 market, no maker has yet come up with a commercially-available, purpose-designed 4x4 transmission – manual or automatic.
You only have to play around with a calculator and your 4x4's transmission and transfer case ratios to see that there's overlap in the gearing. In the case of a five-speed 4x4 transmission bolted to a two-speed transfer case you have 10 forward ratios: five in high and five in low range - in theory. In practice, 'overlap' between the ranges means that there are really only six or seven useful ratios. So, a seven-speed manual or automatic box, with two progressive 'crawl' gears, could do the job nicely, while eliminating the two-speed transfer case.

