Differential ....Theory

We need a differential because (a) there is a distance between the left and right rear wheels and (b) the left and right rear wheels are physically connected. When going round a corner, the wheel on the outside must travel a greater distance than the wheel in the inside, and therefore must rotate faster. The smaller the radius of the corner (or the greater the distance between the wheels) the greater this 'differential action'.

On the front (non-driven) wheels, this makes no difference as the left and right wheels are not connected, so their rotational speeds are independent. However, at the rear, the wheels are connected to the same power source.

Suppose we had a solid rear axle ('spool') with no differential. Since, in a corner, the outside wheel will be the more heavily loaded (and thus have more stick) it will be the one that dictates the speed of the axle. The inside wheel will be forced to rotate faster than it 'wants' to, so it will spin, overheating itself and wasting both thrust and rubber.

On the other hand, a fully 'open' differential will not do the job well either; they are so designed that they distribute the torque evenly between the wheels. This is fine until one wheel starts to slip or spin, at which point the total drive force available will be just twice the force available from the tire with the least grip. (Ever tried to drive a rear-wheel drive car with an open differential out of a snow drift? †) With a fully open differential, the torque delivered to both rear wheels is limited by the traction limit on the most lightly loaded wheel.

What you need is a device that limits wheel spin of the unladen wheel under torque loading (i.e. accelerating out of a corner), but which allows 'differential action' of the wheels at low torque loads (i.e. mid-corner). There are several different types available, ranging from the one designed by Dr Ferdinand Porsche in 1934, to the electronically controlled examples in modern Formula 1 cars.

<http://website.lineone.net/%7Erichardn/img/diff.gif>

The cars in GPL all have a design which is basically an open differential with some extra angled 'ramp' gears and a series of friction discs (clutches).

The angle at which these gears meet determines how hard the clutches are locked together (it's yet another leverage thing). The harder the clutches are locked together, or the more clutches there are (or the more preload (springing) is applied to the clutches), the more the differential functions as a 'spool'. Conversely, the less hard the clutches are pushed together, the more the differential functions as an open differential.

If the gears meet at a high angle, for example 85° (90° isn't used because it chips the teeth), only a small amount of leverage is applied to the clutches, so they are not pushed together much. When the gears meet at a lower angle (e.g. 30°), more leverage is exerted and so the clutches are pushed together harder, giving more locking.

There are two pairs of these gears in the differential; one pair comes into play when torque (driving force) is applied, and the other when torque is released. 'Power on' and 'coast'. Usually expressed in that order, for example 45°/85°.

Automotive Learning Online has some animations and descriptions of the workings of both open and limited slip differentials.
Application to GPL

The differential setting has a huge effect on the handling of the cars in GPL, perhaps more so than any other parameter. The differential settings directly affect the way in which the throttle is used to steer the car.

The differential settings you see commonly used in GPL differ from those used in 1967. In a realcar™, ramp angles of 45/85 and a minimal number of clutches would be normal (Carroll Smith - "I cannot see a reason to have anything other than 85 on the coast side"); in GPL, 85/30 or 85/45 with a medium to high number of clutches is normal.

A near opposite. Why?

The answer is, I think, that the 'typical' GPL differential mutes a lot of the behaviour of the car, making it unrealistically easy to drive. The high power-on ramp angle means that the throttle can be used very roughly, and the high number of clutches 'stiffens' the rear of the car up a lot, making it easier to drive but wasting energy in the turns by limiting the differential action.

To go back to basics for a moment, what you want from a the differential in your GPL car is:

1. Good differential action in the corners, so that the car turns easily and energy of the car is preserved by minimizing tire scrubbing;
2. Good lock up under power;
3. Smooth transition between open and locked up states.

You are not going to achieve (1) by having a lot of clutches.

You can almost achieve (2) by having a lot of clutches and relatively little power-on lock up, but that interferes with (1).

So, to achieve (1) and (2), you want very few clutches and a positive lock-up action.

Carroll Smith: “The most common misconception with these units is that the amount of preload on the clutch plates is a primary determining factor of the amount of lock up. It can be, but things are a lot better if it is not. The spreading force of the bevel gears is an order of magnitude greater than any conceivable preload. To my mind, minimum preload should be used only to ensure that ... the unit will limit slip when one wheel is completely unloaded”. (That reflects something Tifosi once told me, which was to think of the ramp angles as the 'big number' and the number of clutches as the 'small number'. For example, 85/45+1 could be written as 85.1/45.1; the smaller the number the harder and faster the diff locks up.)

Therefore, it seems a 'realistic' differential for GPL would be (for example) 45/85+1. I found that making the transition from the 'old style' (e.g. 85/30+3) to the 'realistic' required climbing quite a learning curve; I would recommend transitioning though the available bevel gear angles. However, the net result has been well worth it; driving the car is now much more enjoyable, my driving has improved, setting up the car is easier and my lap times are certainly faster.

<http://website.lineone.net/%7Erichardn/img/New.gif> I now use the power side angle to control the amount of power-on oversteer; a higher angle = less power-on oversteer, a lower angle = more power-on oversteer. (You always want some power-on oversteer - it's how these cars were designed to be driven.)

Likewise, I use the coast side angle to control the power-off understeer/oversteer balance; a higher coast angle = more dropped throttle oversteer, a lower coast angle = less dropped throttle oversteer.

With minimal clutches in the differential, the back of the car now rotates much more freely. If you just suddenly lift off the throttle and try to turn into a corner, the car will probably spin through 180°. Instead, you have to ease off the throttle, ease onto the brake and steer the car into the corner by modulating pressure on the brake. Also, the extra lock-up on the power-on side means that the car can oversteer-spin very easily when coming out of the slower corners. (This is authentic behaviour for a single-seat open-wheeler; standing at the exit of a hairpin and watching the less-experienced drivers pirouette is a hobby of mine.) So, when coming out of slow corners, you have to progressively apply the throttle as you progressively straighten the steering wheel (forcing you to stay on the edge of the friction circle). Entirely reasonable for a 400 horsepower car weighing 500 kgs, no? The upside is that the car responds very well to the throttle; when drifting in a corner, you can lock the rear axle and stop a potential oversteer-spin just by applying a little more power. Fabulous.