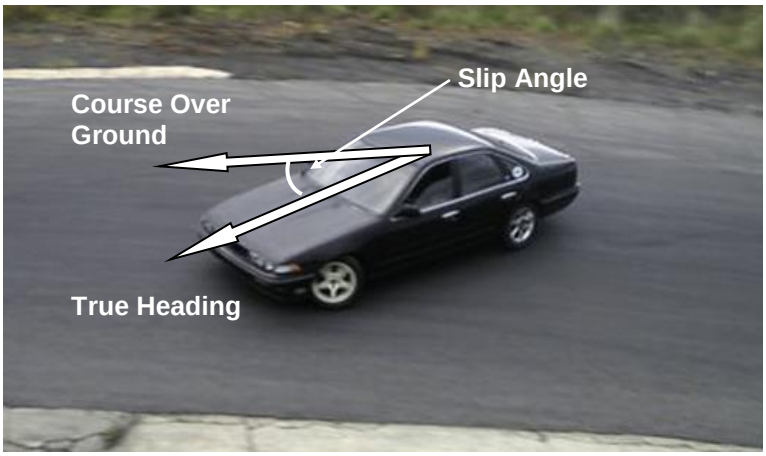
Slip Angle Explained

How to measure vehicle body slip angle using VBOX equipment

Slip Angle – What is it?

In basic terms, slip angle is the difference between the direction a vehicle is travelling (known as heading or course over ground) and the direction that the body of the vehicle is pointing (true heading).

For example, in the picture opposite, we can see that the vehicle is oversteering through the curve and is travelling generally in the direction of the front wheels, but the body of the vehicle is pointing towards the inner radius of the curve.



How does the VBOX measure this?

The VBOX uses two antennas to measure slip angle – one designated as the primary antenna and one designated as the secondary antenna. The antennas are placed on the vehicle at a set distance apart, 2m for example. The VBOX uses the data from both antennas to calculate the true heading (a straight line through the antennas).

The greater the separation between the antennas, the more accurate the measurement of slip angle will be.

Maximum separation is 5m VB20SL; 10m VB3iSL

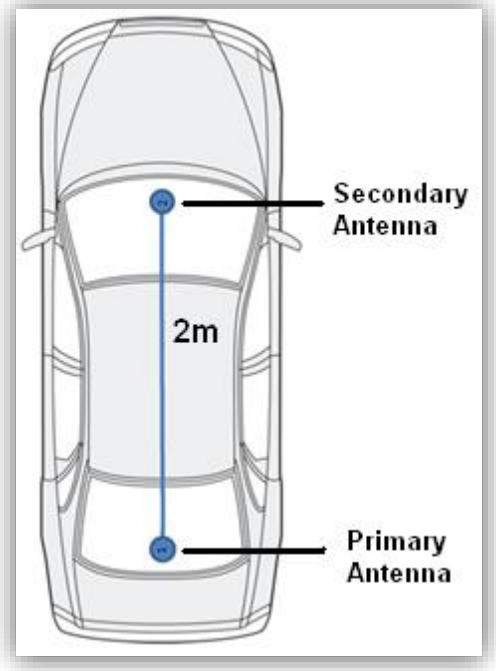
The VBOX also measures the GPS heading at the primary antenna (Course over Ground heading).

Slip angle is then the difference between the True heading and the Course over Ground heading, as shown in the first picture.

But Slip Angle is different at different points on the vehicle!

It is clear that the direction in which the body of vehicle is pointing is the same at all points of the vehicle, unless the vehicle is articulated.

The picture at the top of the page shows a vehicle which has lost traction at the rear wheels and is sliding around the corner – in this instance, the slip angle will be the same wherever it is measured on the vehicle.



However, slip angle does not just occur when traction is lost – any turning manoeuvre will generate a level of slip angle. The vehicle will still have a true heading and a course over ground, but the 'Course over Ground' heading of a vehicle is different depending upon where on the vehicle it is measured. On any vehicle, the 'Course over Ground heading of a point at the front of the vehicle will be different to that at the back of the vehicle during a turning manoeuvre, regardless of whether the vehicle is sliding or not as detailed in the diagram on the following page.

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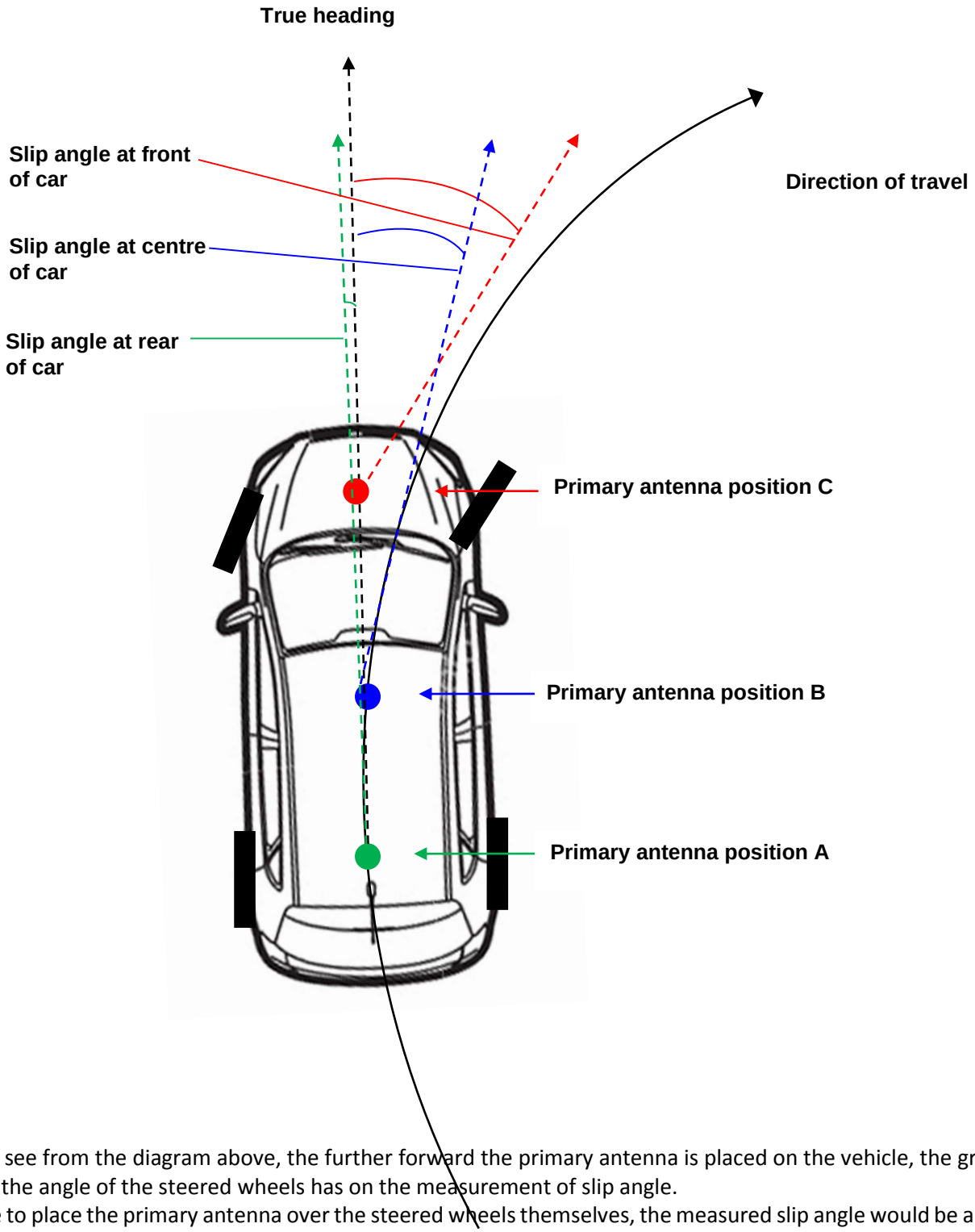
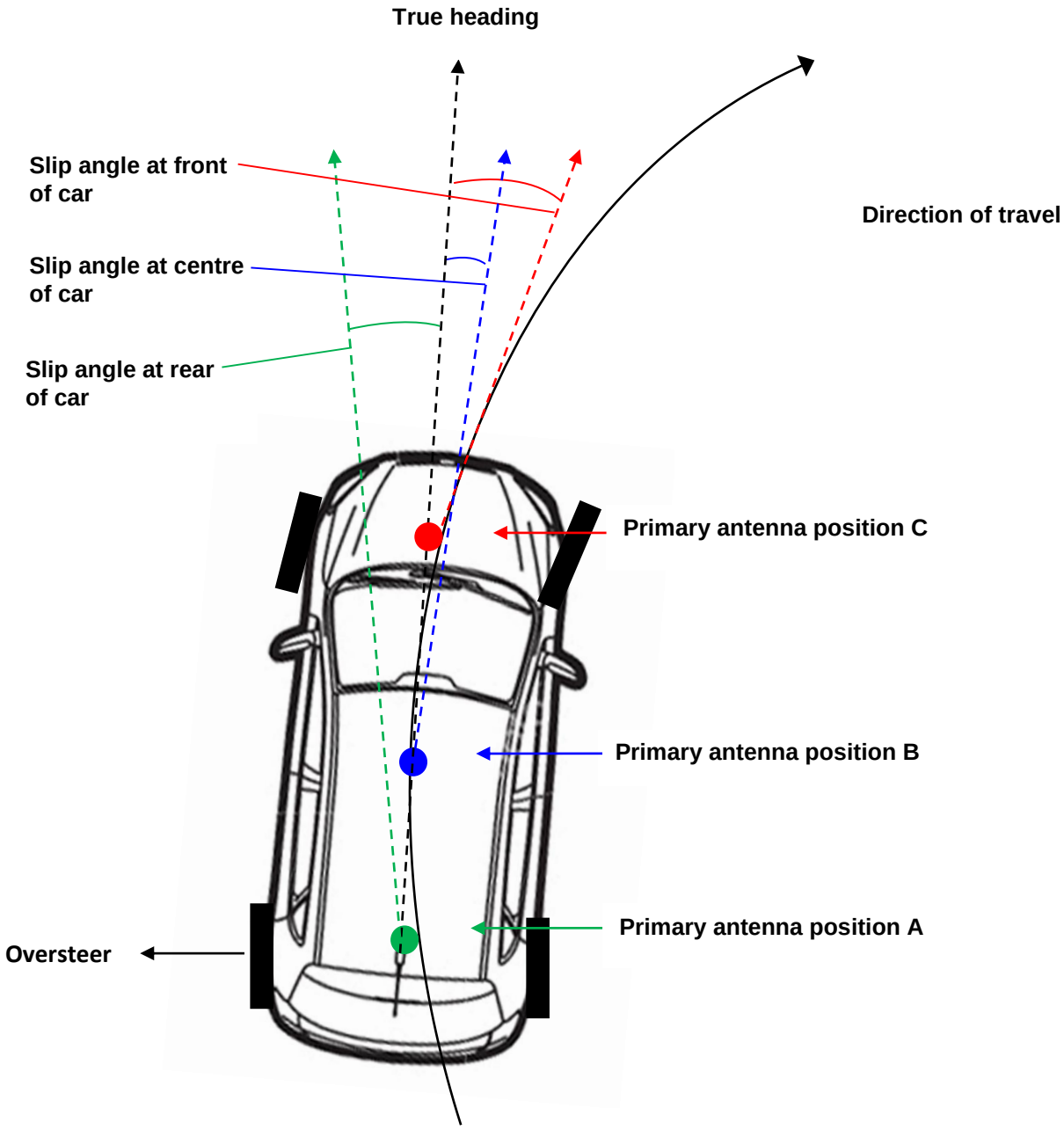
Normal Turning Manoeuvre



As we can see from the diagram above, the further forward the primary antenna is placed on the vehicle, the greater the effect the angle of the steered wheels has on the measurement of slip angle.
If we were to place the primary antenna over the steered wheels themselves, the measured slip angle would be almost identical to the wheels steering angles, less a small amount of tyre slip.

However, the steered wheels would need to be measured independently, due to the effects of Ackerman steering.

Turning Manoeuvre With Oversteer



As we can see from the diagram above, the slip angle measured at the rear of the car is now showing a larger slip angle corresponding to the fact that the vehicle is now oversteering. The slip angles measured at the middle and front of the car in this case are now reduced, but still affected by the angle of the steered wheels.

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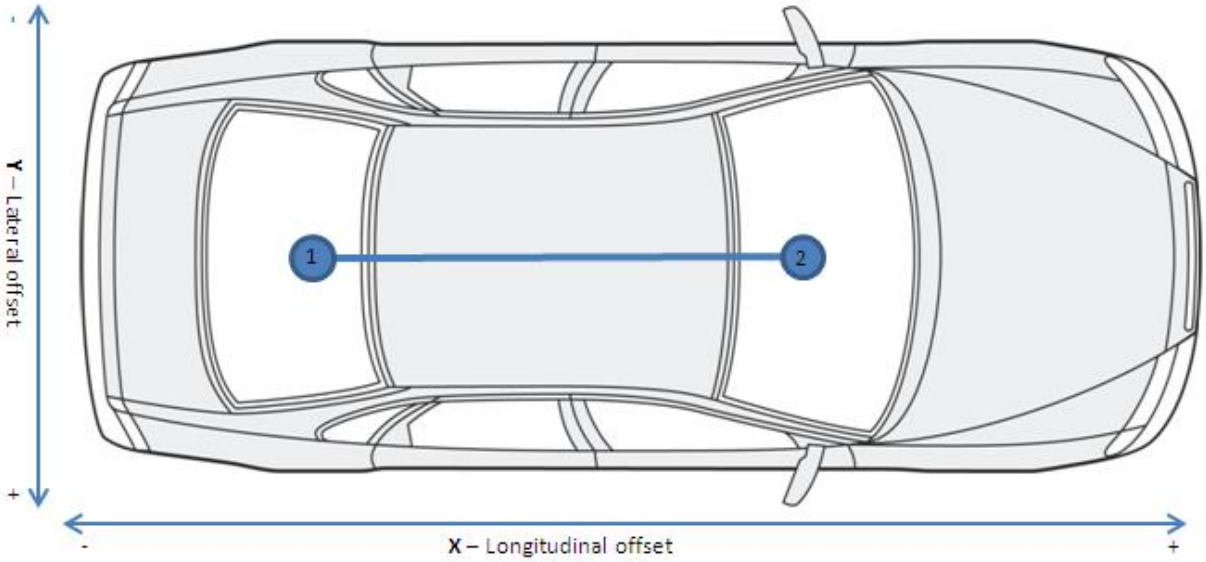
Translating Slip Angle to other locations on Vehicle

It is often the case that the Slip angle measurement is required at set locations on the vehicle, i.e. above the CofG point or directly over the centre contact patch of a Tire.

The Racelogic twin or triple antenna Slip angle VBOXs will measure Slip angle at the location of the reference/primary GPS antenna, shown as Antenna 1 below.



1. Primary Antennae
2. Secondary Antennae

Translation procedure

1) Measure the longitudinal distance, with reference to the vehicle, from the Primary antenna to the nominated translation point.
    a. If the translated point is forward of the Reference antenna then the value should be recorded as positive.
    b. If the translated point is to the rear of the Reference antenna then the value should be recorded as negative.
2) Measure the lateral distance, with reference to the vehicle, from the Primary antenna to the nominated translation point.
    a. If the translated point is to the right of the Reference antenna then the value should be recorded as positive.
    b. If the translated point is to the left of the Reference antenna then the value should be recorded as negative.

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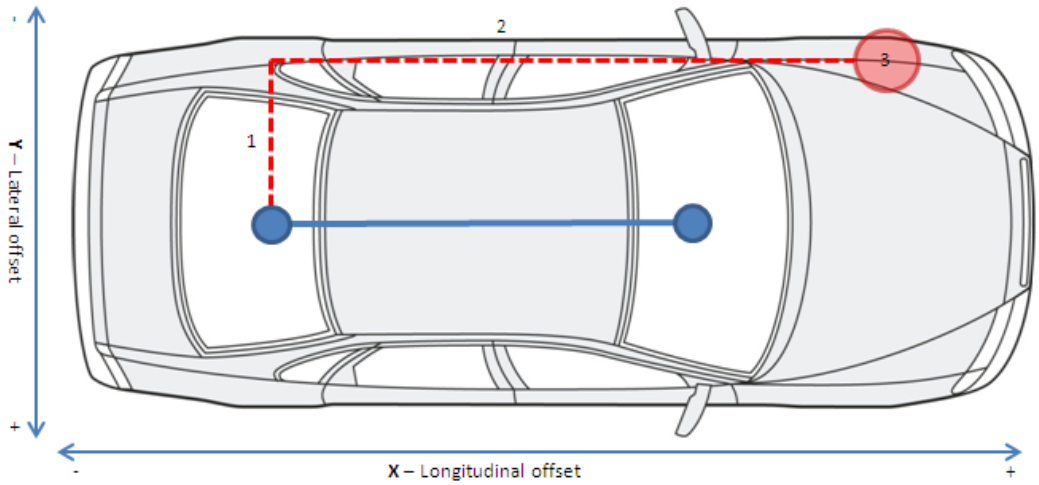
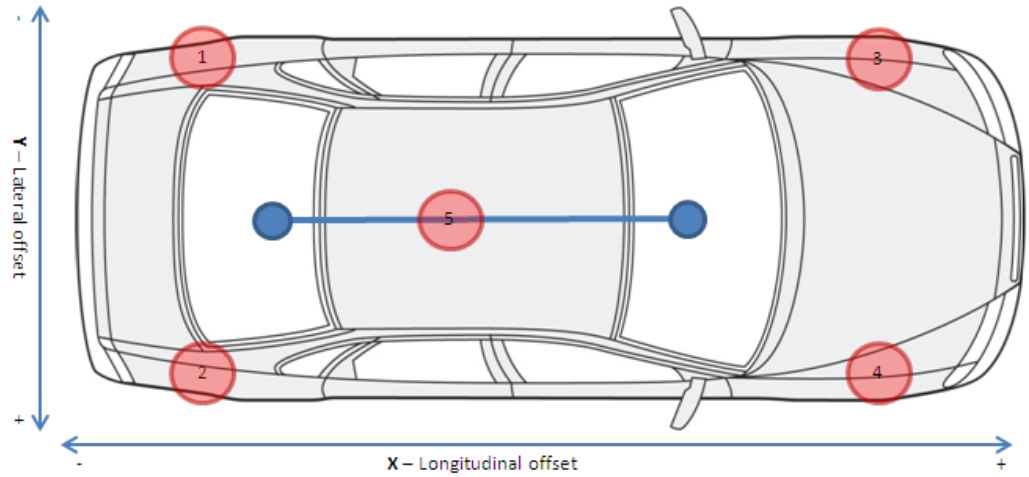


1. Lateral offset **Y** (example -0.45m)
2. Longitudinal offset **X** (example +3.50m)
3. FL (Front Left) translated slip position

Repeat this measurement for all projected translation points on the vehicle, as shown below.



Translated slip points

1. RL (Rear Left)
2. RR (Rear Right)
3. FL (Front Left)
4. FR (Front Right)
5. COG (Centre of gravity)

Translation Calculation

Before the main calculation can be performed the following two procedures should be done.

Calculate Lateral and Longitudinal components of Velocity

$$V_x = \frac{Speed\ (km/h)}{3.6} * COS\ Slip\ Ang°$$

$$V_y = \frac{Speed\ (km/h)}{3.6} * SIN\ Slip\ Ang$$

$$V_x = Vel\ Long\ (m/s)$$

$$V_y = Vel\ Lateral\ (m/s)$$

Convert YAW rate to Radians/sec

$$YAW\ rate\ \left(\frac{rad}{s}\right) = YAW\ rate\ \left(\frac{deg}{s}\right) * \frac{\pi}{180}$$

Calculate interim components

$$t_1 = V_y - YAW\ rate * b$$

$$t_2 = V_x - YAW\ rate * a$$

Where a = lateral offset (m)
Where b = longitudinal offset (m)

Main Translation Math Function

$$New\ Slip\ angle = ARCTAN\left(\frac{t_1}{t_2}\right)$$

Repeat for each slip translation location.

Note for best results use YAW rate from Racelogic IMU or YAW rate sensor.

The following screen shot shows slip angle translated from the reference antenna position at the back of the car to the four corners of the car and to the CofG.

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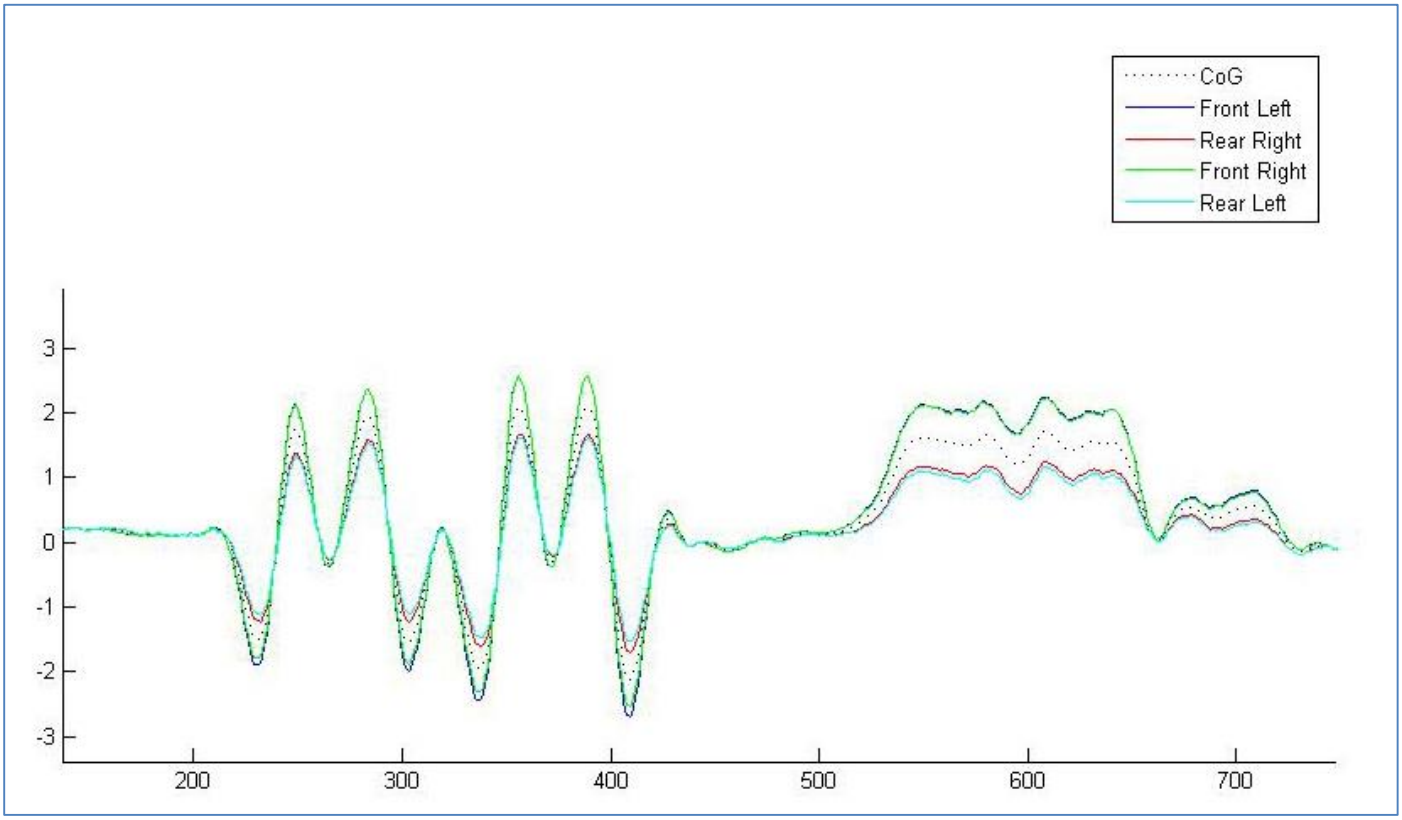

Why Translate Slip angle to different positions on the car?

1) It is often the case that engineers require the Slip angle to be measured at the C of G on the car because it is a consistent point with which to base calculations.
2) Translating the slip angle after measurement, means that the largest possible antenna separation can be used on the vehicle to maximise data accuracy

Slip angle and steering angle – Tyre slip angle

Assuming grip is maintained, the body of vehicle will tend to follow the direction the steered tyres are pointing in but momentum of the vehicle will mean that there will always be a level of tyre slip, however minimal this may be. The tyre will deform slightly as it makes contact with the road and this deformation may also need to be considered. This can be calculated by measuring the slip angle over the wheel and the actual wheel steering angle (which can be obtained via CAN), then subtracting the slip angle from the wheel steering angle – the result is the tyre slip angle. Note that wheel steering angle will need to be measured at each wheel, due to the effects of Ackerman steering.

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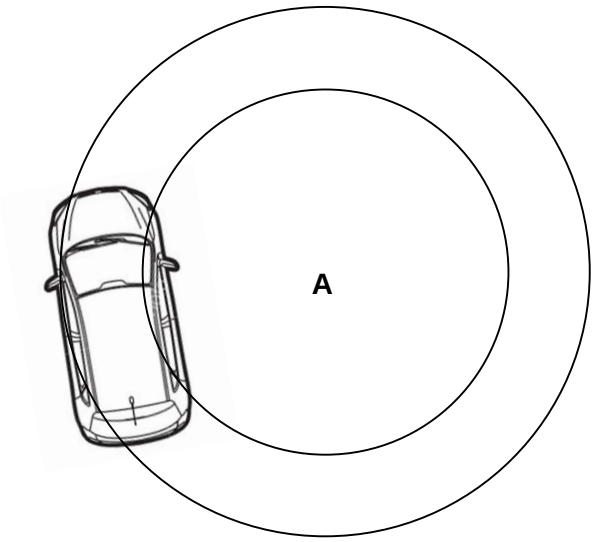
Ackerman steering

Imagine a vehicle travelling clockwise in a circle around a centre point A; the width of the vehicle will cause the inner wheels to be travelling in a circle of a smaller radius than the outer wheels, therefore the inner wheels will need to turn more than the outer wheels.



Why is VBOX good for Slip angle measurement?

- Measurements of true heading and course over ground are made directly via GPS - GPS does not suffer calculation errors associated with gyro drift
- Antennas can be easily mounted on the roof of the car and using the Racelogic roof mount pole, maximum antenna separation can be achieved on virtually any vehicle roof.
- Slip angle translation function means you can measure slip angle at any point on the vehicle (such as over each wheel), even though the two antennas are in a set position on the roof
- No lengthy calibration procedure is required after setup.
- Changes in pitch do not affect slip angle.