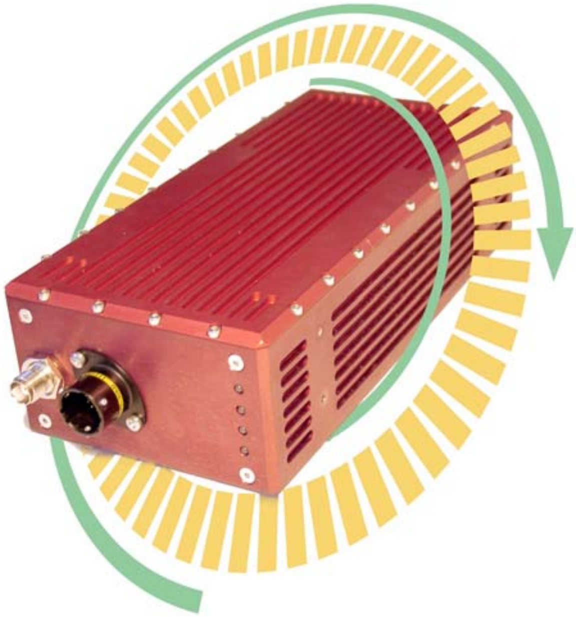
RT3000

Inertial and GPS Measurement System

Oxford Technical Solutions
77 Heyford Park
Upper Heyford
Oxfordshire
OX25 5HD
Tel: +44 1869 238 015
Fax: +44 1869 238 016
http://www.oxts.co.uk
mailto:info@oxts.com



Advanced Slip

Accurate Slip Angle Measurement

using RT3000 products

Confidently. Accurately.

Legal Notice

Information furnished is believed to be accurate and reliable. However, Oxford Technical Solutions Limited assumes no responsibility for the consequences of use of such information nor for any infringement of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Oxford Technical Solutions Limited. Specifications mentioned in this publication are subject to change without notice and do not represent a commitment on the part of Oxford Technical Solutions Limited. This publication supersedes and replaces all information previously supplied. Oxford Technical Solutions Limited products are not authorised for use as critical components in life support devices or systems without express written approval of Oxford Technical Solutions Limited.

All brand names are trademarks of their respective holders.

Copyright Notice

Revision

Document Revision: 030925

Contact Details

Oxford Technical Solutions Limited
77 Heyford Park
Upper Heyford
Oxfordshire
OX25 5HD

Tel: 01869 238 015
Fax: 01869 238 016

http://www.oxts.co.uk
mailto:info@oxts.co.uk

Table of Contents

Introduction

Our Advanced Slip program took three months to improve and qualify the Slip Angle performance of the RT3000. We have been very pleased with the results, they have surpassed our expectations and now the precision of Slip Angle measured by the RT3000 product range is second to none.

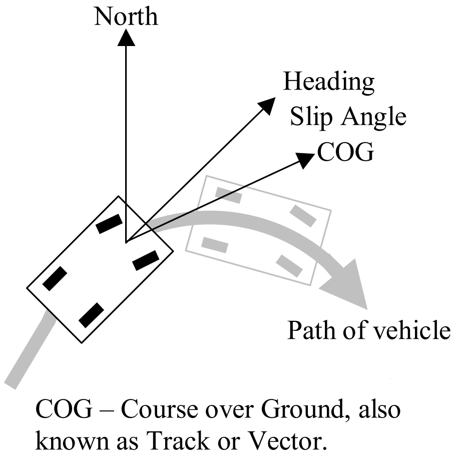
The purpose of the Advanced Slip program was to get accurate Slip Angle data from single-antenna RT3000 systems in all dynamic conditions. Previously the Slip Angle information from the single-antenna systems as accurate during races or ride/handling circuits, but now it is accurate for all testing. Dual-antenna systems still have a role to play, but for the majority of vehicle testing a single-antenna system will be perfectly accurate.

We have tested the algorithm on hours of test data to verify that it works correctly. In fact the testing took far longer than the development since we wanted to make sure that the algorithms worked in all circumstances. We have not found any situations where the Advanced Slip did not work correctly.

Definition of Slip Angle

The RT3000 measures Slip Angle by comparing the angle of the velocity vector (*Course over Ground)* to the *Heading*. For example, on an aircraft in a cross-wind there is a clear difference between the *Heading* of the aircraft (which way it is pointing) and the *Course over Ground* (which way it is travelling). The *Course over Ground* is the angle of the velocity vector and it is measured from True North (the direction to the north pole over the surface of the earth). The difference is the Slip Angle.

Figure 1. Heading, Slip Angle and Course Over Ground (COG)



Benefits

The RT3000 has many advantages over traditional measurement systems for measuring Slip Angle.

The RT3000 is mounted internally, close to the Centre of Gravity. This is the point where most simulation systems want Slip Angle to be reported. By mounting the RT3000 at or close to the Centre of Gravity it is not necessary to compensate the Slip Angle measurement (the Slip Angle changes with position in the vehicle, with the front having a larger Slip Angle than the rear). Furthermore, the RT3000 includes a yaw rate measurement that can be used to move the Slip Angle to another point in the vehicle. An option in the software allows the RT3000 to output its measurements at a remote point if it is mounted away from the Centre of Gravity.

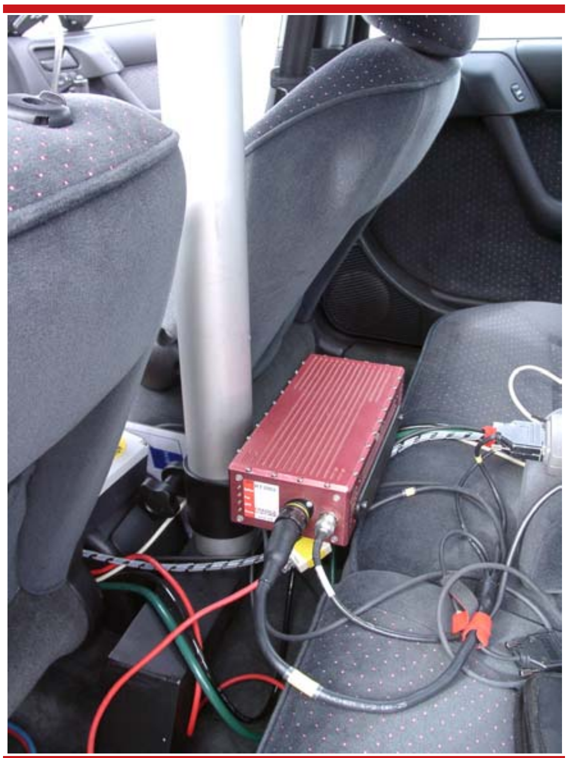
The RT3000 has a high bandwidth. Most vehicles respond to steering input up to about 2.5Hz, with few effects remaining at 5Hz. Optical based sensors tend to have a similar bandwidth, so the phase and amplitude responses were not accurate at the higher frequencies. The RT3000 can measure up to 50Hz, with phase and amplitude errors not becoming significant until 30 or 40Hz; this is way beyond the bandwidth required for car testing.

The RT3000 can be installed *very* quickly. The optional Mounting Strut can be fitted in minutes and provides excellent yaw stiffness. It is quick to swap from one vehicle to the next so multiple vehicles can be tested in a short period of time. It can take a considerable time to fully instrument a vehicle with all the sensors that a single RT3000 offers.

The RT3000 includes many additional measurements that are critical to the tests. These include Acceleration; Roll angle; Velocity and Yaw rate, all critical for many vehicle tests. This can add to the timesaving since these sensors all take time to install in a vehicle.

Changes to the road surface texture have no effect on the RT3000's output. The RT3000 makes its measurements using GPS

Figure 2. RT3100 Installed on Mounting Strut close to Centre of Gravity.



and Inertial sensors. These are not affected by surface water, changes in road surface or any other properties of the road.

The RT3000 is not affected by road camber although the effect on the vehicle itself is part of the measurement. The RT3000 works equally well on inclined planes, banked circuits and even upside down. A single axis gyro system cannot perform accurately on inclined roads or tilted vehicles, even when compensated by GPS.

The RT3000 does not require regular calibration every 20 to 30 minutes. The use of GPS keeps the measurements of the RT3000 accurate all day long, with no need to restart or realign the system regularly.

The RT3000 can be used on Motorbikes. Up to now measuring the slip angle of a motorbike has been virtually impossible. The RT3000 works equally well on motorbikes as it does on cars opening up a whole new branch of measurements in the future.

The RT3000 has many interfaces including CAN bus, RS232 and Ethernet. We have an external module for converting the CAN bus signals to analogue voltages. We have interfaced the RT3000 to National Instruments, Ipetronik, Argus, MicroLab, MultiData, 2D and several custom acquisition systems. In most cases it takes less than one hour to fully configure the acquisition system software to connect to the RT3000.

Advanced Slip Results

Here we present some results of the RT3000 during some tests where the Slip Angle performance in critical. In each case there is some discussion on the test, the RT3000's performance and the results.

There are four tests presented here. These are:

- Lane Change
- Frequency Analysis
- Step Steer
- Steady-State Circles

Although the emphasis here has been on Slip Angle, readers might be interested to note the stability of other quantities in the RT3000. The use of GPS aiding allows the RT3000 to stabilize other channels such as the Roll Angle. Unaided Inertial Navigation Systems it difficult to keep roll stable for long periods of time.

All the results presented here are from single-antenna RT3000 systems. Graphs of Velocity, Slip Angle, Lateral Velocity, Lateral Acceleration and Roll Angle are presented, all measured from the RT3000 system.

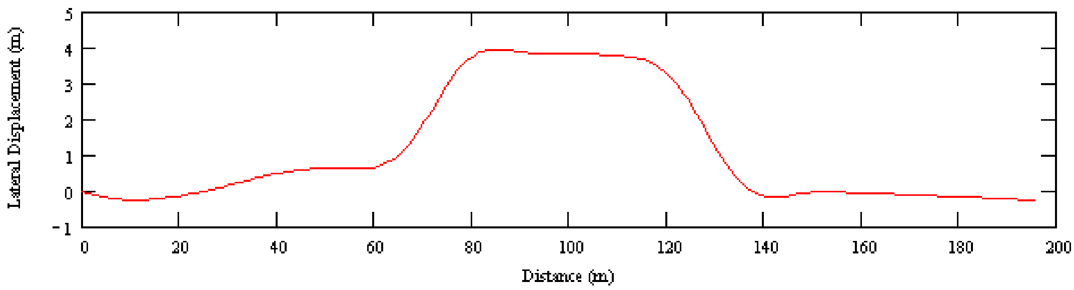
The data is available in Excel form on our web-site if further analysis is required.

Lane Change

The dynamics of Lane Changes have always been important, especially when they are extended to include Elk or Roll-Over testing. This is an area that benefits from the Advanced Slip features of the RT3000. Traditionally the d.c. stability meant that the Slip Angle at the start and at the end were not necessarily at the same value. Advanced Slip fixes this, giving very repeatable results.

For this set of data the system was mounted in a Citroen Xantia. The position of the vehicle was measured using an RT3002, so is accurate to 2cm. The graph below shows the lateral displacement of the vehicle during the test.

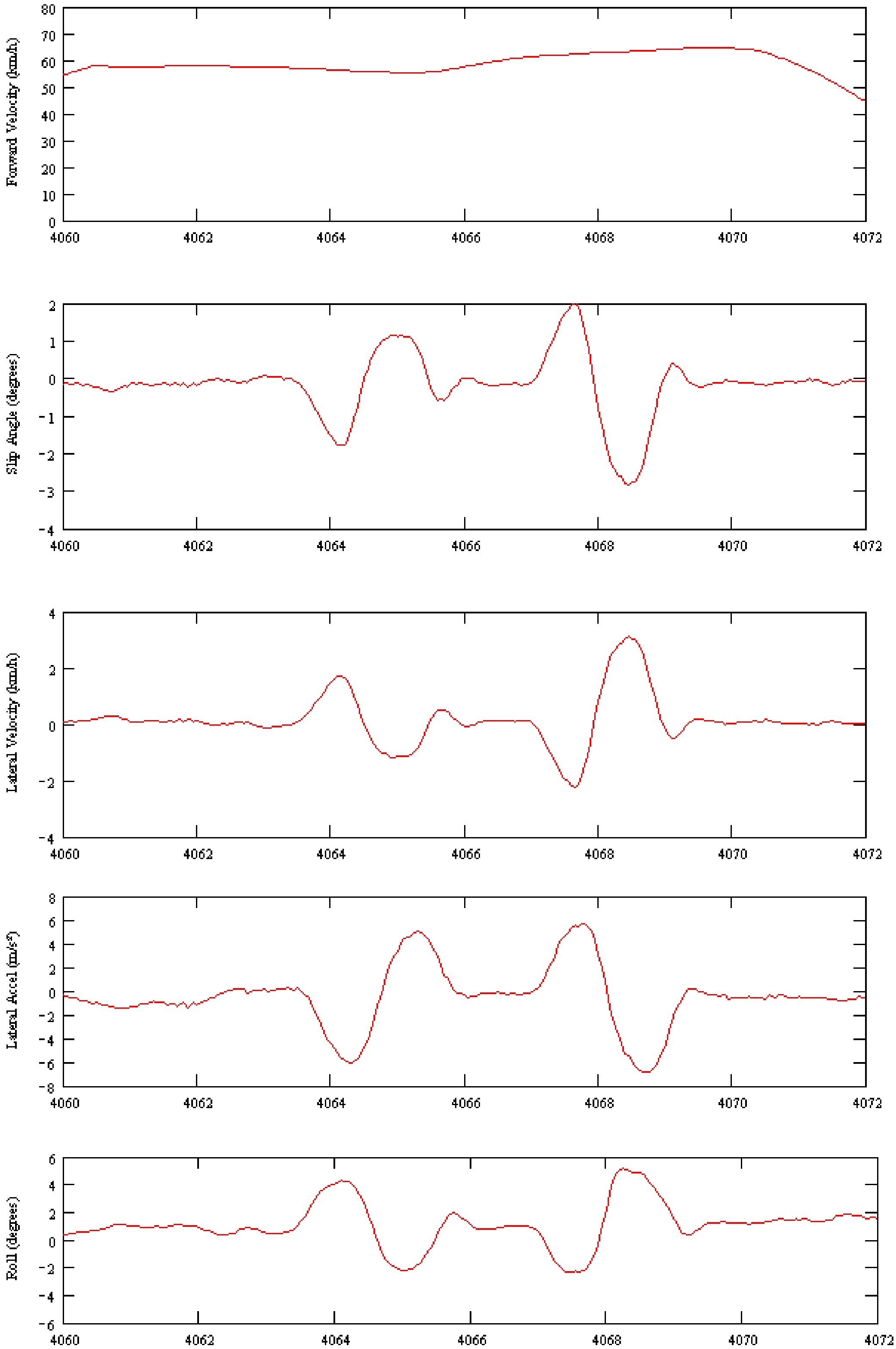
Figure 3. Position of the vehicle during the Lane Change



This test was driven by an Anthony Best Dynamics Path Following robot. A 4m Lane Change was chosen. The overshoot and undershoot of the system is remarkably good considering that the vehicle has up to 0.6G of lateral acceleration. The lead-in to the test may not be straight, but this is a feature of how the robot lines the vehicle up at the start of the test; also the Y-axis is very enlarged so small lateral deviations can be seen clearly.

The following graphs show the measurements made by the RT3000 for this test.

Figure 4. Lane Change



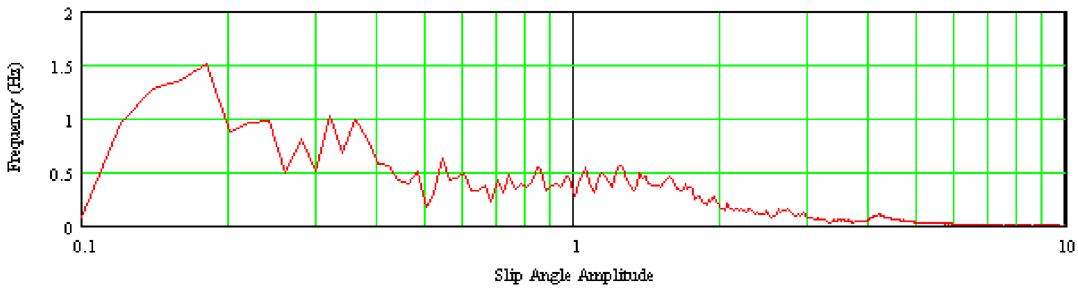
Frequency Analysis

In this area the RT3000 has always performed well because of the high bandwidth. The Advanced Slip algorithm helps stabilize the Slip Angle before and after the tests, giving excellent results continuously.

The wide bandwidth and accurate phase response means that the frequency response of the car up to and beyond 5Hz can be obtained. The RT3000 has a wide bandwidth, with little amplitude error or phase error at 30Hz, so measurements up to and beyond 5Hz range pose no problems. At the other end of the spectrum, engineers rarely look at the data below 0.1Hz. This would be of interest to steady-state testing instead.

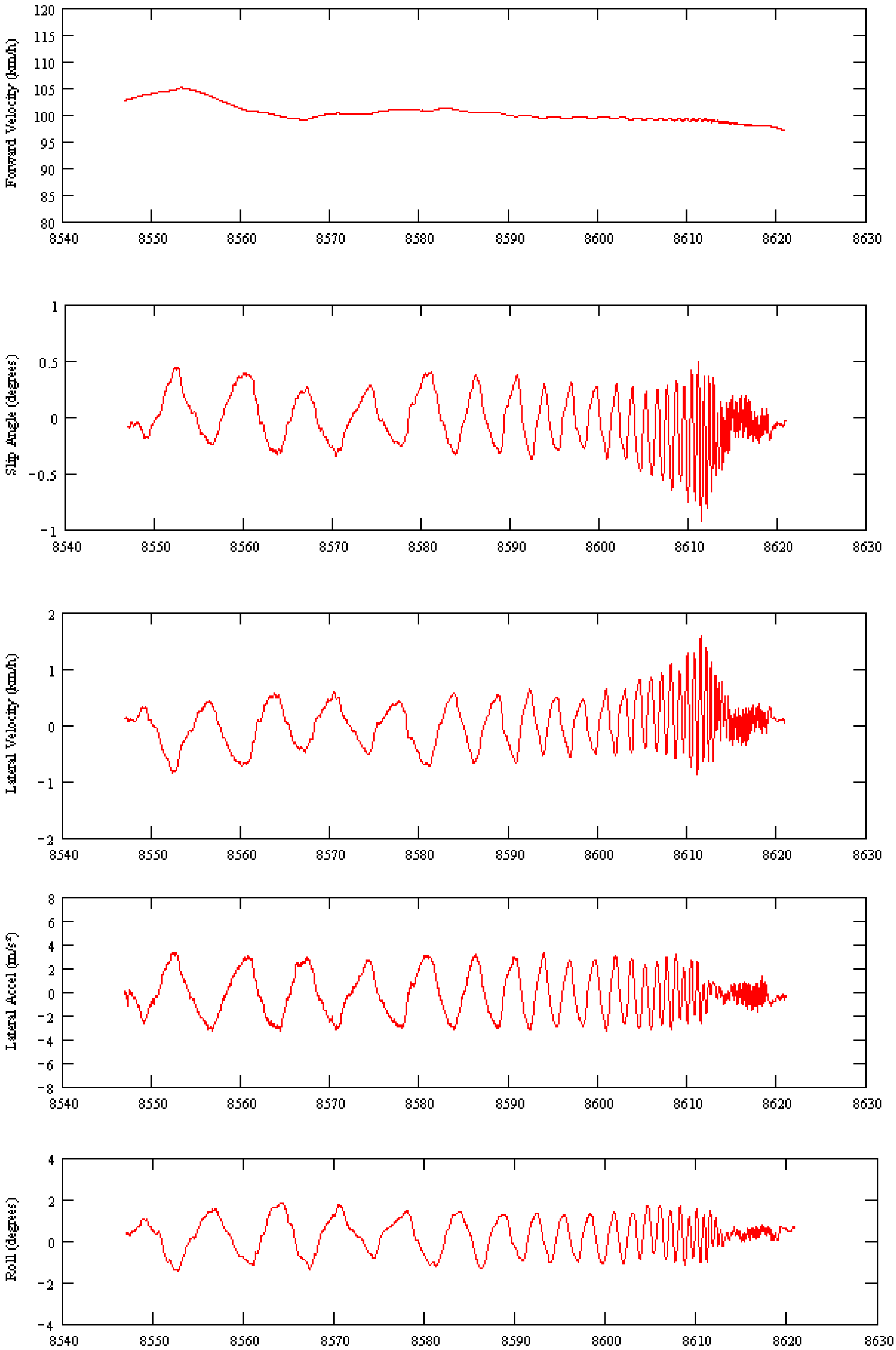
The FFT for the Slip Angle for one test is shown below. Normally this would be compared to the FFT of the input steering angle, but this was not available during this test.

Figure 5. FFT of Slip Angle



During one test it is very hard for a human driver to give equal input energies across the whole spectrum, this is one reason why the FFT appears noisy. It is customary to perform many tests and average the results; this has not been done here, instead the FFT of only one run has been computed.

Figure 6. Frequency Analysis



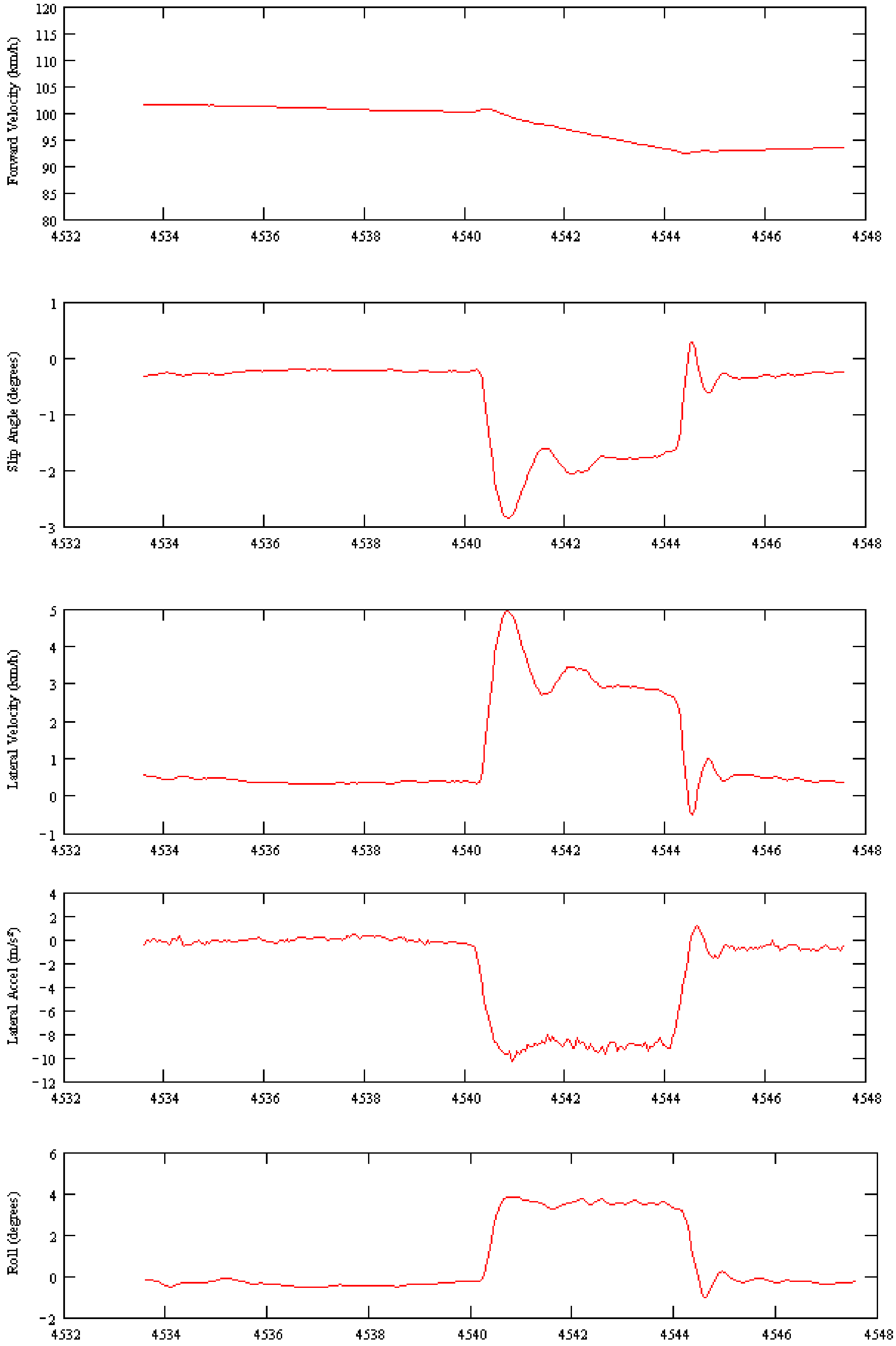
Step Steer

The Step Steer test shows the transient response of the vehicle to a sudden step change to the steering wheel angle. This is the test that benefits the most from the Advanced Slip features of the RT3000.

During the straight lead-in to the test it is very hard to estimate slip angle correctly, since there is no acceleration. During the test the slip angle can be estimated accurately and after the test it is normally correct.

Using the Advanced Slip feature the slip angle is correct throughout the whole of the test. The d.c. level of the slip angle is the same before and after the test.

Figure 7. Step Steer

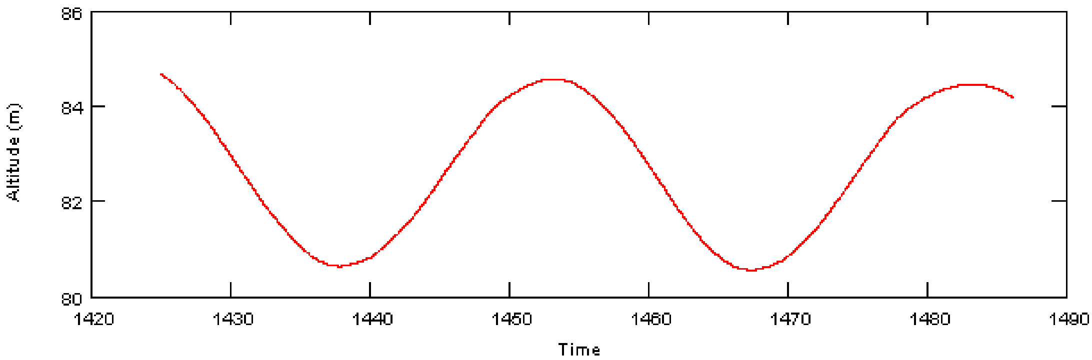


100m Radius Circle with Increasing Speed

For a GPS-aided Inertial Navigation System like the RT3000, constant acceleration is very useful for stabilizing heading. Testing on a circle leads to good results even without the Advanced Slip algorithms. In this example the RT3000 was mounted above the Centre of Gravity in a Volkswagen Passat. Unfortunately the track used was not flat and one side of the circle is 4.0m higher than the other side to allow for rainwater to flow off. Proper test tracks are invariably flat or conical in shape for accurate vehicle testing.

To show the incline of the track, the Altitude of the vehicle during two circles is shown in the graph below. The 4.0m displacement on a 200m distance corresponds to an incline of 1.15 degrees, so the roll and pitch angles have a 2.3 degree sine-like change on them during the test. This can be compensated for by pre-surveying the track.

Figure 8. Altitude change during the circle



Having a non-flat track also affects the quality of the slip angle that is measured. Although the lateral acceleration is the same, the force seen by the tyres has an 8% change in load during the circle. (The acceleration due to gravity coupled by the incline of the track gives an extra 0.4m/s² acceleration, i.e. 8% of the 5m/s² seen in this test).

The second set of graphs shows many circles, at two different speeds. The effect of the incline on the slip angle is clearly shown. Note the stability of the slip angle; gyro drift in a motion pack would normally lead the slip angle to change its d.c. level with time but the GPS-aiding of the inertial navigation system leads to stable results, even over this 8 minute test.

This second set of graphs aims to show that the measurement equipment is not the only critical component to vehicle testing. A flat test track is essential too.

Figure 9. 100m Circle with Increasing Speed

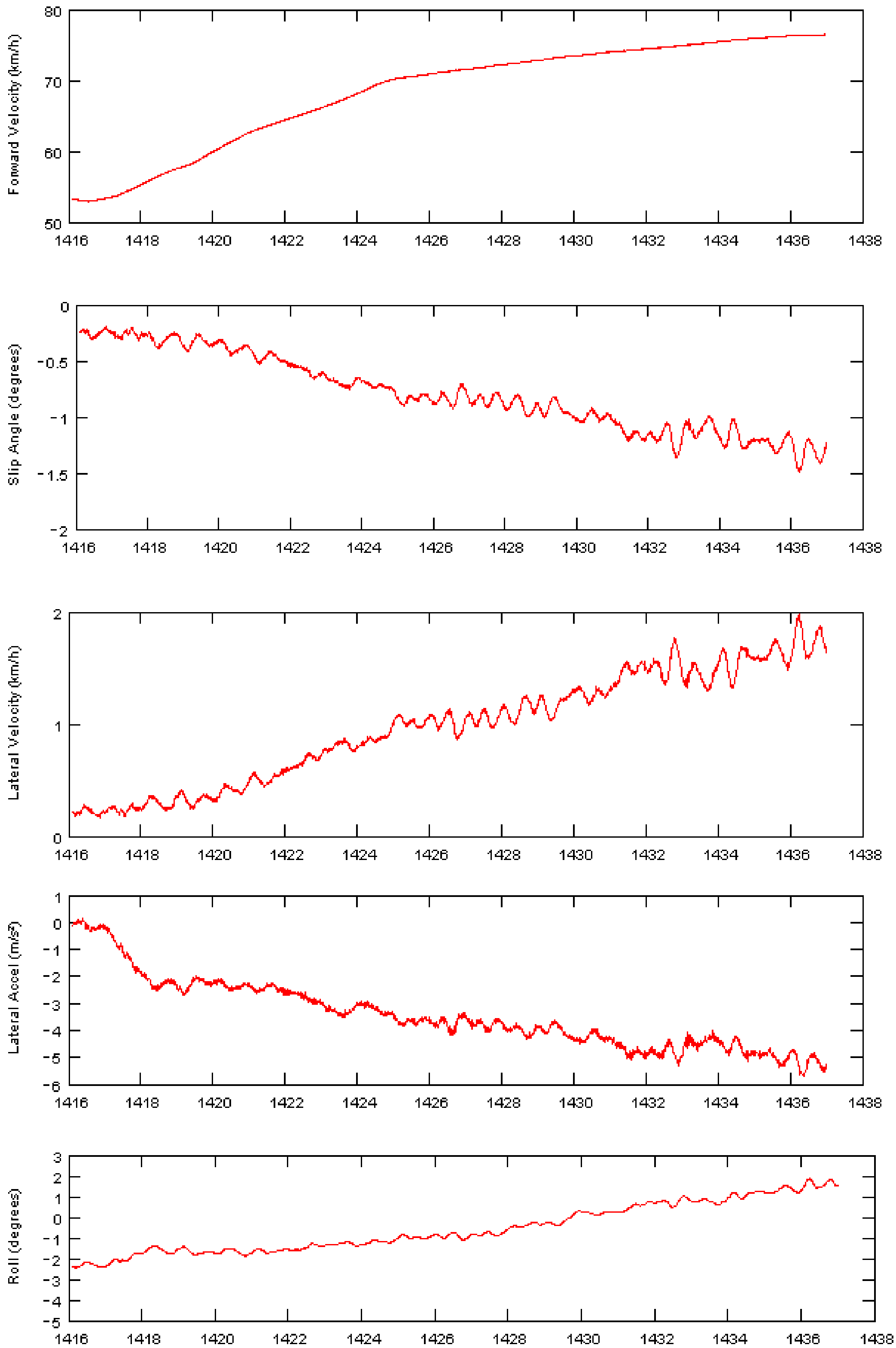
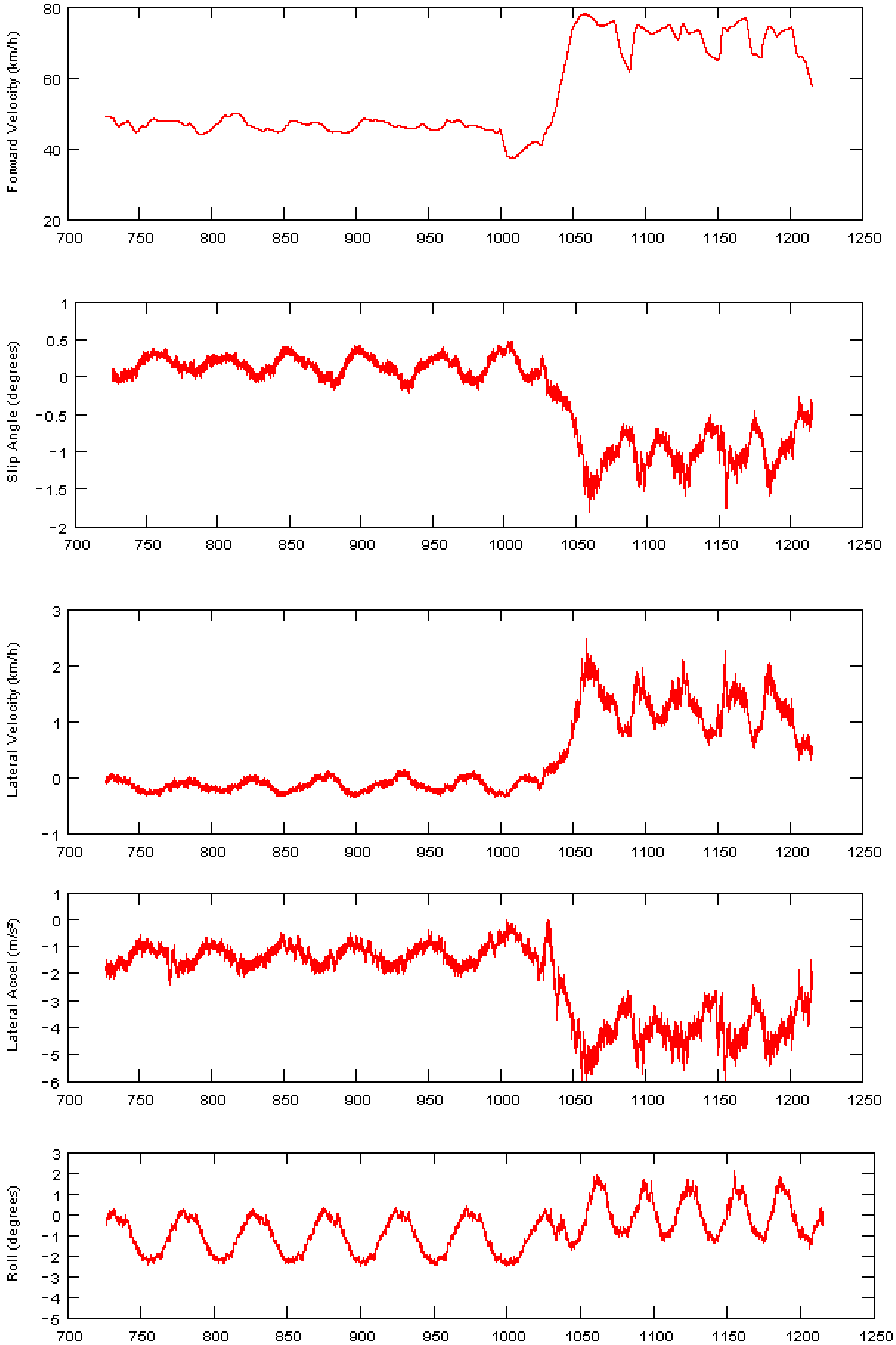


Figure 10. 100m Circles showing effect of an Inclined track on Slip Angle



Conclusions

The data presented here shows that the RT3000 can be used for reliable measurements of slip angle. The Advanced Slip feature of the RT3000 enables the d.c. level of the slip angle to be stabilized at the correct level, even when the acceleration level is low. The RT3000 is also able to make many other measurements, some of them are presented here.

The RT3000 is a versatile, quickly installed product that is suitable for all types of vehicle testing.