WHITE PAPER

TRIMBLE MS980—A NEW, RUGGED SMART ANTENNA GPS RECEIVER FOR THE CONSTRUCTION GRADE CONTROL SYSTEMS

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Overview: Trimble has designed and tested a combined GPS receiver and antenna specifically for the rugged machine guidance market. This paper describes why this strategy was chosen and the results.

INTRODUCTION

The Trimble® MS980 is a new smart antenna GPS receiver designed to be a modular component in the new GCS family of Grade Control Systems. It is designed as a 'smart antenna' to deliver a number of frequently requested operator benefits. Its rugged design includes features to maximize the upcoming modernized GPS signal structure.

Previous to the Trimble MS980, external GPS antennae were connected to a GPS receiver located in the cab. Only Trimble, with extensive experience in 3D machine control systems, could solve the many design challenges in making a system that both meets user needs and is able to work in the most extreme construction environments. This paper describes why the integrated receiver / antenna strategy was chosen, the testing program, and the results that ensued.

WHAT IS IT?

The Trimble MS980 is a rugged, integrated GPS receiver and antenna that is termed a 'smart antenna'. It is designed specifically for installation as close as possible to the cutting surface for greatest accuracy in machine guidance and grade control. The Trimble MS980 contains the GPS receiver, GPS antenna and isolation system all in a single housing, similar to laser receivers, sonic tracers and ATS targets, making it the first truly modular GPS positioning sensor for sensor-independent machine control.

As the GPS system is currently being modernized to transmit new GPS signals, the Trimble MS980 was built with Trimble's latest core GPS technology to provide tracking of the new L2C signal for more robust operation. The Trimble MS980 is the only commercially available machine control receiver that supports the new GPS signals.

Building on 10 years experience in blade-mounted GPS operation, the Trimble MS980 has a new advanced tracking system that maintains lock on satellites under even harsher operation than formerly possible for maximum high- accuracy production. This increases the hours of high- accuracy operation available for users working in tough conditions.

Figure 1: The new Trimble MS980. Combined antenna, GPS receiver, rugged isolation system, quick mount.

WHY A SMART ANTENNA DESIGN?

Some of the main reasons for building the Trimble MS980 were to increase system reliability, increase user flexibility and reduce the cost and complexity of installation. An integrated design delivers those benefits and more.

The Trimble MS980 increases system reliability by reducing the number of components in a dual GPS system from 13 to 6. The receiver replaces the coaxial antenna cables with the more robust CAN cables that are common to all the other sensors used in modern machine control systems. The elimination of the coaxial cables improves GPS signal strength and ensures greater positioning uptime. Additionally, the cable that connects from the front of the machine to the mast-mounted component now is a simple CAN cable; this simplifies servicing and diagnosing cable damage and failure and employs common methods used for all other positioning sensors in the system. No specialized Radio Frequency (RF) service tools are required for checking cable reliability.

The initial installation of the Trimble MS980 smart antenna is significantly easier than other machine control systems because it eliminates the need to run RF cables from the front of the machine, through the machine body, to the GPS receiver. For customers who remove their equipment on a daily basis, the Trimble MS980 is faster and easier to remove than other systems because both the receiver and antenna are combined into a single component that mounts with a simple locking handle – no tools required.

During the design phase of the Trimble MS980, Trimble ensured it was 'future-proofed' and included the latest Trimble core GPS technology to provide tracking of the new L2C signals (first launch is scheduled in March 2005, with a total of five launches scheduled for 2005). The L2C feature allows more robust GPS operation and improves productivity due to the following features:

- Increased signal-to-noise on L2 ratios for L2C satellites
- Maximum multipath error reduction on L2
- Superior low-elevation tracking on L2

While offering this new L2C capability, the Trimble MS980 still optimally supports legacy satellites.

A common practice with current systems is to install the GPS receiver in the machine cab. The Trimble MS980 does not require a receiver in the cab; this leaves all the cab compartments available for other uses.

Other important reasons for selecting a Smart Antenna design include:

- Rugged
- Portable
- Flexible
- Versatile
- Scalable
- Performance
- Serviceable
- Longevity

Figure 2: MS980s on antenna mounts. The Trimble MS980 has a simple, quick release cable and ratchet.

RUGGED

Operating conditions on earth-moving machinery are extreme. Both man and machine are subject to high vibration and shock for long hours. The Trimble MS980 smart antenna was designed to survive and operate effectively in these conditions. The testing program is highlighted in the section below (Performance Proven in Extensive Testing).

PORTABLE, FLEXIBLE, VERSATILE

The single, smart antenna unit is lightweight (3 kgs / 6 lbs) and quick to remove, making it easy to move between different machines or to provide a fast upgrade path from the Trimble GCS300/GCS400 laser system. The antenna ratchet mount means no field tools are needed to mount or remove the Trimble MS980. Figure 1 shows the Trimble MS980 with the quick release ratchet lever. Additionally, since there is no separate receiver unit mounted in the cab, it is faster to move the GPS system around your fleet.

The Trimble MS980 smart antenna has been designed for sensor independence. This refers to the ability to take a given machine and quickly swap from one sensor to another. A classic example would be swapping sensors on a bulldozer – using the GPS for rough earthworks then swapping it out for a laser receiver for finished grading. Within a few minutes, you simply unplug the Trimble MS980 cable, disconnect the antenna from the antenna mount, then mount and connect the laser sensor.

SCALABILITY

The Trimble MS980 modular configuration is designed as part of the Trimble GCS Grade Control System. The Trimble GCS family allows customers to start with a single antenna/receiver and/or tilt-sensor system and then upgrade to Trimble's industry-leading dual antenna/receiver method for optimal performance under high dynamics.

The modular design also allows contractors to equip multiple machines with installation and automatic hydraulic kits and configure their machines based on the applications; a contractor would use one Trimble MS980 per machine for simple building pad applications, then reconfigure to the dual antenna/GPS mode for complex surface work.

PERFORMANCE PROVEN IN EXTENSIVE TESTING

To validate the design, an extensive laboratory and field testing program was initiated.

Initial Trimble MS980 testing was carried out on a 'shake table', a standard tool used by mechanical test engineers. Figure 3 shows the Trimble MS980 on a mast bolted to the shake table that was subject to extreme vibration. Vibration testing was done for extended periods on all three primary axes at 20G RMS using a wide range of frequencies, including those typical for a bulldozer.

The copper coils to the left of the unit (Figure 3) allow the temperature to be cycled past its operating temperature range of -40°C (-40°F) to +70°C (158°F). During this exercise, GPS satellite signals are tracked and data collected to ensure they not only remain tracking but also exhibit superior tracking to previous designs. At the end of each testing cycle, the Trimble MS980 is checked for mechanical damage.

Figure 3: Trimble MS980 and installation mast on the shake table with temperature cycling tubes in the background

However, since the forces exerted on equipment are even more extreme when tested in the "real world," a testing program that included the smallest to the largest bulldozers, motor graders and excavators was conducted. To cover a broad range of operational environments, testing was carried out at Trimble field test facilities, as well as at actual operating sites. Additionally, testing was geographically extensive to cover the extremes of temperature and material types – from snow-covered mountain sites in New Zealand to Tucson, Arizona desert heat, and from a roading project in Belgium, to a landfill site in Canton, Ohio, USA where the equipment was used in all four seasons. This real-world testing accumulated a total of 30,000 hours of use on machines.

Figure 4: Field testing on hard rock pushed the Trimble MS980s past their expected operating conditions. High-accuracy RTK was maintained under these conditions.

The “blade-drop” test was conducted to prove the ruggedness of the Trimble MS980 smart antenna while delivering centimeter accurate positions. In this test, the bulldozer blade is lifted up as high as possible and allowed to free fall onto a rock surface. This is regarded as one of the most severe tests and the procedure can damage the machine itself. The Trimble MS980 survived this test which was repeated at many of the test sites.

To quantify the Trimble MS980’s high performance, data was recorded while the bulldozer was stationary to get a baseline reading. The Trimble MS980 was then subjected to the 'bedrock' test sequence in 2nd & 3rd gear. The bedrock test involves driving the blade of the bulldozer over a rock surface at maximum speed. Again, this demanding test sequence is potentially more extreme than would occur on a typical work site. Data collected from a field trial is plotted in Figure 5. This shows the Trimble MS980 tracking satellite signals with no loss of lock and minimal signal degradation compared with the static base station. The data values are based on the Signal-to-Noise ratio which has been normalized to a static Trimble MS980 acting as a base station. Another commonly used GPS receiver (Competitive Receiver), located next to the rover MS980, shows a 3dB drop, as well as a greater variation of Signal to Noise. A 3dB drop indicates a 140% decrease in the Signal-to-Noise level. Although Competitive Receiver has been an effective machine guidance GPS sensor, the Trimble MS980 performs better. With this improved performance, the Trimble MS980 will track GPS signals more effectively under more adverse conditions for more accurate positioning and increased productivity. With the Trimble MS980’s L2CS capability the improvements in tracking will be even more on the L2 Frequency.

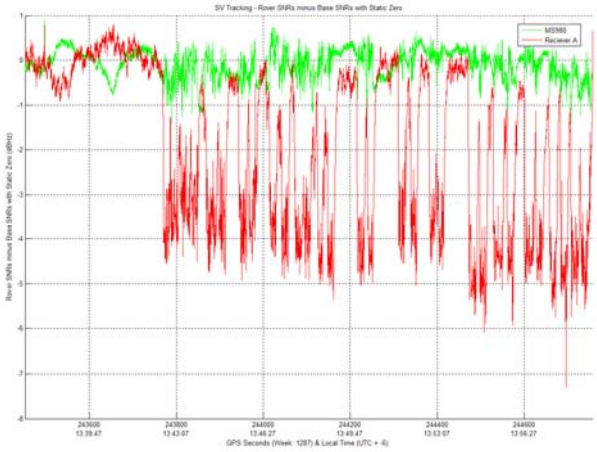

Figure 5: Trimble MS980 tracks GPS signals more effectively than Receiver A while being field tested.

Throughout this testing, Trimble MS980 smart antennae were exposed to vibration as high as 170G RMS[1] while on bulldozers. These forces were in the mechanically harmful lower frequency ranges up to 400Hz.

Extreme shock loadings in excess of 650Gs were measured during the test program. We believe this

[1] G RMS is a way a specifying an average of random vibration across a frequency range. In the case of heavy equipment moving across any terrain, the vibration created during that movement is random in nature, different G forces at different frequencies occur simultaneously. A simple way to define this is to specify a frequency range, 1-400 Hz, then look at the vibration forces (g-forces) at each frequency, and produce a weighted average which describes this energy. That figure is the G RMS. value. Machine manufacturers’ design specification for their machines is typically 25 G RMS across the frequency range of 24 to 2000 Hz.

program is the most extensive field testing performed on any GPS receiver.

The Trimble MS980, designed for the machine guidance market and tested in these harsh conditions, maintained accuracy throughout the testing process. The Trimble MS980 smart antenna is the ideal sensor to help the operator improve construction cycle productivity.

Figure 6: Worldwide testing was done in all four seasons. Over 25,000 hours of field testing were conducted.

DESIGNED FOR THE CONSTRUCTION ENVIRONMENT

In the past, if the GPS antenna was damaged, it usually had to be replaced.

Current GPS receivers and GPS antennas utilize rubber isolation systems that require periodic maintenance. The Trimble MS980 receiver has an integrated isolation system designed to last for the life of the product, eliminating the need for maintenance. This system is so innovative that it is being patented, and is able to function across a wide operating temperature range of -40°C (-40°F) to +70°C (158°F) and for a minimum design life of 40,000 hours.

The Trimble MS980 has simplified diagnostics featuring a 3- light panel to allow the machine operator to confirm at a glance whether the unit:

- has power connected and is operating.
- is tracking sufficient satellites (5 or more) for high-accuracy GPS operation.
- is receiving GPS corrections from the base station.

When the Trimble MS980 is mounted on the blade, the operator can confirm the operational status of the receiver at a glance.

The Trimble MS980 was designed as a serviceable part. Its modular design allows faster parts replacement during repair and helps reduce associated labor costs. In the past if the GPS antenna was damaged, it had to be replaced. The Trimble MS980 can be repaired. Figure 7 shows an MS980 that suffered a 4 m (12 ft) drop from a mast onto the blade of a bulldozer. Although the radome was damaged, the unit still performed to specification. The repair only involved replacing the radome. Generally, the Trimble MS980 design enables quick repair with replacement parts.

Figure 7: Damage from 4m drop onto blade. Radome repair was fast and inexpensive

SUMMARY

The innovative approach to produce a smart antenna GPS receiver delivers significant operator benefits. Trimble has developed and proven through extensive testing that the Trimble MS980 is the GPS sensor choice for use on machines in construction market.

Table 1. MS980 Smart Antenna GPS receiver

Characteristic	Description
Size	147 mm (height) x 231.9 mm (width) x 251.1 mm (depth) (5.8” x 9.1” x 9.9”)
Weight	3.04 (6.6 lbs) ± 0.04 kg without bracket 3.76 (8 lbs) ± 0.04 kg with bracket
Operating temperature	-40 °C to +70°C (-40 °F to +158 °F)
Storage temperature	-50 °C to +85°C (-67 °F to +185 °F)
Input voltage	9 VDC to 32 VDC
Power Consumption	5 watts steady-state (1.5 Amps peak)
Accuracy	20 mm + 2 ppm (times baseline) horizontal 30 mm + 2 ppm (times baseline) vertical
Initialization	Automatic
Range	Up to 20 km from the base station
Start-up	<2 min
Upper LED	Power on
Middle LED	Radio signal received
Lower LED	GPS signal received

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