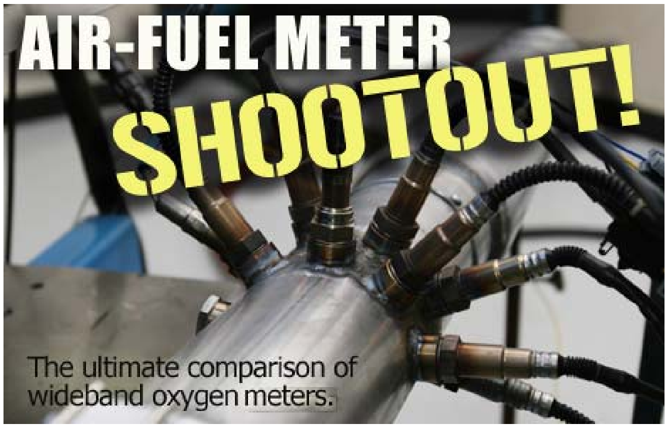


By Mike Kojima

Editor's Note: Since publishing this article, FordMuscle has received a number of questions and comments regarding the test methodology and also how the scores (on page 2) were derived. We have published those comments at the end of this article for your consideration. In addition, note that the the subjective ratings are based on the opinion and experience of the author. Mike Kojima is an engineer by trade, with considerable experience in the import-tuner segment. Mike organized the Wideband Shootout article with help from Westec Performance, Innovate Motorpsorts and EFI University. The opinions within are Mike's, however FordMuscle acknowledges that objectivity could always be improved, particularly through a test in which all manufacturers are present, or invited. We are working on a new comparison in conjunction with many of the manufacturers represented in this article. Stay tuned...

In This Article:
Air-fuel meters are fast becoming an ubiquitous item amongst serious enthusiasts. However, with so many meters on the market how does one begin to select the best one for their needs? We've compared the most popular ones in this article.

Also see:
- Double Vision: FAST AirFuel Meter
- Taking the Guesswork out of Carburetor Tuning
- Super Tuning


From A to Z, we gathered the most popular digital wideband air-fuel meters for comparison. The brands are AEM, Dynojet, FAST, FJO, Innovate, NGK, PLX, Zeitronix.


Part of our analysis was to assess the ease (or difficulty) in getting each unit installed and operating. Wiring up eight units took some time, but fortunately on an engine dyno we didn't need to concern ourselves with a clean installation.

Background

The art of tuning an engine is not new, dating back to the birth of the internal combustion engine over 100 years ago. For a generation or two, methods such as vacuum gauges, CO meters, and the black art of reading spark plugs were the main tools in a tuners arsenal. Due to the lack of accuracy of these methods, tuning was nothing more than subjective analysis and best left to the seasoned professional.

Later, as emissions standards tightened and as racing engines started to produce higher and higher outputs, the need to accurately determine air-fuel ratio became increasingly important. Technology improved and wide band air fuel ratio meters with embedded data logging equipment emerged. For many years this technology was out of reach for all but the most well heeled DIY tuner. The cost of accurate reference level wideband air fuel ratio meters was in the several thousand dollar range.

What is a Wideband sensor?
Standard "narrow band" O2 sensors operate between 0 and 1 volts, and are only capable of accurately measuring a stoichiometric air/fuel ratio (e.g. 14.7:1). A richer or leaner condition results in an abrupt voltage change (see Fig 1.) and thus is only useful for qualitative determination. Modern automobiles use this "switch" like sensing at idle and part throttle to make small compensations in fuel delivery to keep the air/fuel ratio near 14.7:1.

The affordable meters on the market, at the time, used conventional narrow band O2 sensors- the same type of sensors found in most early EFI cars. Such sensors are only accurate around the stoichiometric range, which is an air fuel ratio of 14.7:1. Accuracy in this range is useless for performance tuning where wide-open throttle ratios may drop as low as 11:1, and certainly in the 13:1 range for most naturally-aspirated engines.

The big breakthrough for the performance aftermarket occurred when Bosch made the LSU4 wide band O2 sensor available for a reasonable price, and the aftermarket responded by making affordable wide band air fuel ratio meters using this sensor. This is a boon to the DIY tuner as now there are many wideband air fuel ratio meters available on the market for a reasonable price.

Not All are Equal

Many questions have arisen since the widespread availability of wideband air-fuel meters.

First, since all of these meters use the same Bosch sensor, and since this sensor is factory calibrated, are they all more or less equal? The answer is no. There is significant difference between the controllers and circuitry used in the various meters. How the sensor's heater is controlled and how the pump current is switched and controlled, for instance, are critical for accurate sensor operation. Other questions also can be posed: Which meter is the best performing one? Which meters have the features I need?

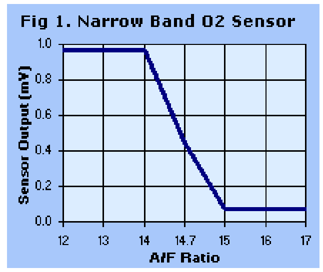
With these question and few subjective answers to be found, we set out to determine which meters were the best. The task was a difficult one but we were determined to find the answers.

Methodology

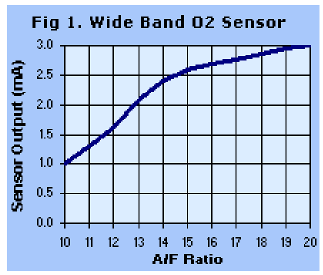
The plan was to take eight popular units and test them right out of the box using calibrated compressed gas. We'd then run them for an hour on a test engine, with leaded race fuel, to simulate wear on the sensor. Finally we'd test them again with calibrated lab gas. The compressed gas is from Scott Specialty Gasses and formulated to SAE standards for .8 lambda and .895 lambda (11.76 AFR and 13.15 AFR respectively). The gas gives us a control with which we can test each sensor without introducing variability - such as a change in rpm if we were to use the test engine's exhaust gas. To further control the study we used Westech's expensive ECM LambdaPro which read dead-on for both of the gas controls.

1 Sensors were tested using laboratory gas specifically formulated to yield 11.76 AFR and 13.15 AFR. This way each sensor sees the exact same "exhaust gas", letting us measure the accuracy and responsiveness of each

2 After testing with lab gas the sensors were run-in for an hour with race fuel, on a test engine (Westech just happened to have a Chevy motor in the dyno room that day.) The run in simulates the wear and tear a sensor



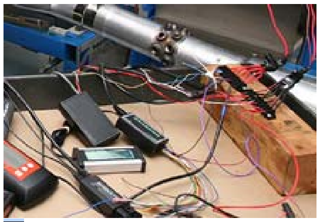
Wide band oxygen sensors utilize a more sophisticated sensing element which enable it to produce precise voltage output in proportion to the oxygen in the exhaust (see Fig 2.) As a result a wide band sensor can measure accurately from as rich as 9.0:1 to as lean as free air. Wide band sensors used to be cost prohibitive, however recently their wide spread use has resulted in lower prices.



meter.

goes through with live fuel and heat conditions.

3 Nine bungs were welded into the exhaust; eight for the sensors under test and one for Westech's own meter. Datalogging was performed during the engine run-in to assess the capabilities of each meter.



4 A common power and ground supplied each meter to ensure no other variables influenced the testing.

During the dyno testing, we also logged data from all of the units. This gave us a chance to configure each unit's analog outputs, and to compare response time (latency) and accuracy under various loads, sweeps, and conditions. We also verified that the logged data matched the values displayed on the various gauges and displays. All the units shared a common and robust power and ground setup.

The chart on the following page summarizes our findings across four categories. Of particular note was the issue of re-calibration. All of the units certainly rely on the factory calibration of the sensor from Bosch. The manufacturers may even perform some sort of a calibration of the sensor to their units during their assembly process. However, as far as we could tell, only two units appeared to be capable of re-calibration to compensate for sensor wear. The Innovate unit is self calibrating, while the NGK requires the user to turn a knob until the display reads "CAL." Both measure the air-fuel ratio of free air to calibrate the sensor.

This raised the obvious question: If a unit is not capable of calibration, how does the user know when the sensor is going bad? We know from the Bosch data that the sensors themselves change as they age.

Continue

Next (Air-Fuel Meter Shootout continued.)
Requires Subscription

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Air-Fuel Meter Shootout (continued)

Quick Ratings Wideband Air/Fuel Ratio Meters

◎ Excellent ◓ Very Good ○ Good ◒ Fair ● Poor

Product	MSRP	Overall score (Poor / Fair / Good / Very Good / Excellent)	Accuracy	Latency	Display	Ease of use	Software
Wideband Products							
Innovate XD-16 Kit	$399.00		◎	◎	◓	◒	◓
AEM All-in-One UEGO Gauge	$349.41		◎	◒	◓	◒	N/A
FAST Air/Fuel Meter	$466.60		○	◒	◓	◓	N/A
FJO Controller, Sensor, & Display	$639.75		○	◎	○	●	◒
PLX M300 Air/Fuel Gauge	$315.00		●	◓	○	◒	N/A
Dynojet Wideband Commander	$529.95		◒	●	◒	◓	◒
Zeitronix ZT-2	$279.00		◒	○	○	◒	◒
NGK/AFX Meter	$295.00		●	○	○	◒	N/A

Legend

Accuracy (Tolerance):
- ◎ +/- .10 AFR
- ◓ +/- .25
- ○ +/- .50
- ◒ +/- .75 AFR
- ● +/- 1.00 AFR

Latency:
- ◎ <100ms
- ◓ <200ms
- ○ <300ms
- ◒ <400ms
- ● <500ms

Display: Subjective, based on readability in direct light and informational content.

Ease of use: Relative difficulty in installing, setting up, and operating. Subjective based on author's experience.

Software: If data-analysis software is included, relative rating on the usefulness and complexity. Units which do not come with software are not rated (N/A).

As previously discussed, air/fuel data is most useful when correlated with other key parameters like throttle position, manifold absolute pressure, and RPM. And this sort of correlation absolutely requires data logging. So, even though all of these units feature useful real-time displays, the most important parameters are response time and the quality of the logging solution. Response time is critical because it's possible to have accurate data, but, due to high latency/delay, the data is essentially in the wrong column of your fuel map.

Results - At a Glance

Listed below, from A to Z, are the eight meters we tested. All use the Bosch LSU4 wideband oxygen sensor. There was a surprising amount of variation between the various units, in terms of both accuracy and response time. We also rated the ease of use, display, and included software. The participants were AEM, Dynojet, FAST, FJO, Innovate, NGK, PLX, and Zeitronix.

AEM
The AEM unit was accurate during our tests, but with no real data logging capability, of limited usefulness for actual tuning. It was average for response time.

AFX (NGK)
The NGK unit exhibited low scores for accuracy, and it was missing the required wire for analog output. It does not have data logging capabilities. Considering NGK makes their own wideband sensors, it is a surprise this unit ships with a Bosch sensor.

Dynojet
The Dynojet unit was hard to set up, and the included logging software was very limited. The Dynojet exhibited the slowest response time tested.

FAST
The FAST unit had internal datalogging, but no separate logging analysis software. This perhaps makes it less useful for complex tuning, but is really "to the point" for those wanting no-frills wideband tuning. Setting up the analog outputs was somewhat difficult. Display is nice and intuitive. More on the FAST unit.

FJO
The FJO unit had tricky wiring for the sensor, the controller, and the analog outputs. It was also difficult to setup the analog outputs with the included configuration software. The included logging software was counterintuitive.

Innovate
The Innovate unit was accurate, exhibited the fastest response time, and included very good analysis software. Innovate claims to be the only truly digital unit, and the high accuracy and low latency seem to support their claims. Setup and wiring was complex and somewhat confusing.

PLX
The PLX M300 does not include logging software, and exhibited accuracy at +/1 AFR (the worst tested). Note that PLX has commented below, and believes we did not wire their unit properly in that we used a common ground for all units.

Zeitronix
The Zeitronix exhibited accuracy of +/- .54 AFR, and gradual lean drift under some conditions. The included logging software was relatively difficult and lacked features. Note that Zeitronix indicated we may have reviewed an outdated unit (see comments below.)

The only regret we have is that we couldn't effectively simulate long-term sensor "aging." Aging is mostly due to oxidation of the sensors internals and fouling of its ceramic elements. Operating conditions and fuel type are big factors in the aging process. Exposure to lead in race gas, metallic elements in octane booster additives, oil or carbon fouling and really high operating temperatures contribute to rapid aging, and a resulting loss of sensor accurancy. Because of aging it is important to have an air fuel ratio meter that can be calibrated. The common type of calibration is called a free air calibration. This is when the meter compares the output of the sensor to what it should be when exposed to a know oxygen content gas, air. If an air fuel ratio meter is lacking the ability to calibrate, the sensor should be replace at regular intervals. The trouble is when should the sensor be replaced? It takes some experience to know when this is appropriate.

We did try to emulate this idea using a variety of old and damaged sensors we had laying around. With one of these sensors, the Innovate XD-16 would show an error code

Contacts:

AEM

NGK

Dynojet

FAST (Fuel Air Spark Technologies)

FJO

Innovate

PLX

Zeitronix

Westech Performance Group

indicating that the sensor was bad. However, when we connected the same damaged sensor to any of the analog gauges they read as much as 3 AFR off. Again, the obvious question is: If your gauge can't tell you when a sensor is bad, how could you ever trust it?

Optimizing Wideband Sensor Usage
Other things to keep in mind to ensure proper sensor function and longevity are exhaust back pressure, rich mixtures, and under/over heating.

A high exhaust backpressure forces more exhaust into the sensors pump cell which can cause an air fuel ratio meter to read richer than what the engines really running. Turbo engines run a relatively high amount of backpressure in the exhaust manifold before the turbine, making them a poor place to locate the sensor.

Missfires due to a malfunctioning or underpowered ignition or an extremely rich mixture can cause false lean readings because unburned liquid fuel in droplets block the small hole leading to the sensors pump cell.

A wideband sensor should not be placed in the exhaust stream and left unheated. The hole to the pump cell can quickly become clogged and contaminated by exhaust byproducts, especially during a start cycle from a cold engine. The sensor can also be damaged by exposing it to temperatures above 700 degrees C, like those typically before the turbine in turbo engines. You never want to place a sensor there anyway due to the aforementioned issues with sensor accuracy and backpressure. Lastly you don't want to place the sensor so far away from the engine that its 10 watt internal heater cannot keep the sensor hot enough. FORDMUSCLE

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Posted by **ZephyrZ7**, 06/27/07 06:02pm:
sweet! Glad I've got an Innovate!

Posted by **10SecS4**, 06/28/07 12:54am:
What is an NTK AFX Meter? I think you guys mean NGK! I have this wideband and am very happy with it. In fact, it reads pretty darn close to my narrowbands at WOT. Oh and I paid $209 shipped for it after Summit price matched an "old" price from back in February. One thing you guys didn't test is RELIABILITY of these wideband 02 sensor systems. I have several friends who had nothing but problems with the AEM UEGO gauges crapping out.

Posted by **chopsuey**, 06/29/07 09:49am:
I have the AEM unit and I love it. I've used it on multiple cars to tune and they are pretty easy to setup once you get used to it. The software is pretty hard to use but you just got to fiddle with it. I would highly reccomend the AEM unit to anyone looking for a wideband setup. Very accurate system with a very good price.

Posted by **Teratum**, 06/29/07 03:16pm:
I am skeptical about the accuracy of the accuracy test iamong these sensors. I think the accuravy data will be credible if all the sensors read the calibrated gas from the same test chamber at the same time and then AFR

readings for each one is compared to the supposed reading of the calibrated gas. The picture 1 in the article shows each sensor is held in free-air at the end of the gas cylinder. I'm not sure if I can believe the test result to be accuarate for all these sensors.

Posted by **Megascott**, 06/30/07 09:42am:
I'm not sure of the value of the logging software on most of these meters, maybe you need it when running a carb, but for EFI most, if not all, of the aftermarket EFI controllers support Datalogging of the analog signal. Certainly Megasquirt EFI does, and I've compared the digital signal of my innovate LC-1 to what the Megasquirt reads and it's spot on.

Posted by **rcamp**, 07/02/07 07:44pm:
Quote: In fact, it reads pretty darn close to my narrowbands at WOT. I love it, using a narrowband sensor to validate the accuracy of a wideband. Why even bother with the wideband if a narrowband is acceptable.

Posted by **chopsuey**, 07/03/07 08:33am:
"In fact, it reads pretty darn close to my narrowbands at WOT." I would never take my car to a tuner that uses a narrowband to tune.

Posted by **10SecS4**, 07/03/07 07:31pm:
The point is that if neither were accurate, I somehow doubt they'd both be inaccurate to the point where they read exactly the same. Who cares about accuracy of A/Fs anyway? I'm going to tune for max. power, so it doesn't matter if the engine makes max. power at an indicated 13:1 or 14:1. All that matters is that the "magic number" is consistent.

Posted by **admin**, 07/04/07 07:02pm:
Some response from PLX:
http://www.plxdevices.com/forum/viewtopic.php?t=1312

Posted by **Helmantel**, 07/05/07 08:23am:
I work in an engine lab and work with emission measurements and engine testing on a daily basis. I must agree with Teratum. The method of holding the sensor in front of a bottle of calibration gas is not a good one. There is a significant risk that atmospheric air dilutes the gas.

Posted by **mikekojima**, 07/06/07 03:01pm:
Our testing suggested that calibrated gas velocity was sufficient to completely fill the sensor's measurement chamber, and exclude any free air. This appeared to be confirmed by the fact that Westec's expensive ECM LambdaPro matched the exact lambda values of the calibrated gasses. We used 2 bottles of 1% tolerance calibrated lab gas from Scott Specialty Gasses. These were formulated to SAE standards for .8 lambda and .895 lambda (11.76 AFR and 13.15 AFR respectively). As an added data point, we used Westec's LambdaPro during every round of testing (and it always matched the SAE gasses). There's always room for improvement, but we believe that our methodology was a good and practical balance, and more precise than any tests we've seen in the past. Having said that, perhaps we should put together another comparison. As stated in the article, the question of accuracy over the life of the sensor is still open. I don't know if I'm the guy for the next one, but if all of the manufacturer's agree to share the cost, I'm sure we can come up with an agreeable

plan.

Posted by **4iFordGeek**, 07/06/07 04:36pm:

I have to disagree with Helmantel and Teratum. I routinely use a butane lighter to saturate the sensor on my PLX unit. Even with the relatively low gas pressure, it is easy to bottom out the sensor to a reasonable value. I actually do this because there is no way to adjust the unit for non standard partial pressure. So, when I tune at home I start with a new sensor and get a base value from the butane. Then when I am at the course I can use the butane to calculate a fudge factor for the change in partial pressure. I then tune back to the fudged number and generally get very repeatable results. I really do not understand the commotion at the PLX site. I would have thought that they have used lighters and stuff like me. Once you have used a butane lighter to send the sensor to a value (which it basically holds until you blow on the sensor to clear its test chamber) I don't think you would have any doubt about gas roaring out of a big pressurized tank. Ambient air just doesn't seem like an issue. Neither does puff to puff consistancy from the tanks. This is very similiar to how a 5 gas analyzer is calibrated. Two things that might be an issue are cooling and gas pressure. Depending on the gas there might be a venturi effect right by the valve. If I understand the Bosch specification correctly the sensor only gives accurate readings at a specific temperature. So if there is cooling from the gas the heater control circuit will have to overcome it. However that seems like an even more accurate scenario. On big bore engines it is often a problem to keep sensors hot enough for the catalytic action used for the measurements to occur. Gas pressure is another matter. The Bosch specification shows some additional gas pressure related errors. If the sensor was stuffed into the end of the valve too tightly the readings may have been less accurate than with the lower pressure flow of a high performance exhaust system. But since the same sensor is used for all the instruments I would expect similiar results using the same techniques. I suppose part of the reason I am no worked up is that I truly am a geek. I am not surprised to see my unit rated as a .5 AFR unit because that is very reasonable based on Bosch's documentation. In the datasheet I have (sorry, I could not find an online version to link to) the LSU 4.2 sensor is rated to be +/- .01 lambda with .8 lambda gas when the sensor is brand new. That means that brand new my readings could be off by about .15 AFR in either direction and still be working perfectly. After 500h Bosch only promises +/- .02 lambda. So in short order being off by .3 AFR in either direction is normal. By 2000h they only promise .04 lambda. All this is under optimum conditions. When you consider that the calibration resistor from Bosch is from standard partial pressure and temperature (that is why I do the butane test at different locations) being a .5 AFR instrument with an artificially aged sensor seems perfectly reasonable to me.

Posted by **mikekojima**, 07/15/07 10:00pm:

Some question have come up to me about the test methdology, some of which was edited out for clarity. Here is here is the main part that was editied out. Test Methodology On the dyno we hooked all of the control unit’s power and ground wires to the battery and the battery to the dyno's 150 amp power supply. The battery would act like a filter to help smooth and rectify the power to the control boxes and act as a very solid ground to avoid ground loop voltage differentials between the boxes. During the dyno testing, we logged data from all of the units. This gave us a chance to configure each unit's analog outputs for data logging in the same way a customer would, and to compare response time (latency) and accuracy under various loads, sweeps, and conditions. We also verified that the logged data matched the values displayed on the various gauges and displays. Now I am not an electronics expert nor am I an EE but I think I could call myself an educated consumer and I ran the test using the equipment as a consumer might. It has been brought to my attention that there were several places that errors could have skewed the test results. The first being differenentials in ground loops. Although I tried to eliminate this by placing a battery between the power supply and the units themselfs, I have been told by several manufactures that this is not enough and that all units should have individual grounds and power with the same resistance in every units ground. I am reporting this complaint as it was brought to my attention by several companies who make these units. The second is that by using units analog outputs, the accuracy is only going to be as good as the interpolation between the points is going to be as well as an A to D conversion error. Now I am not smart enough in the field of electronic deisgn to argue for or against these points but more than one manufacture mentioned this to me and to be fair I must report this. I hope this clarifies some of these results and allows the more educated readers to more accurately draw conclusions to how good this test is. Mike

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Posted by **admin**, 07/23/07 02:14pm:

I am writing in response to the article "Air-Fuel Meter Shootout!" by Mike Kojima, published on the Fordmuscle.com web site. First of all, I want to express to you that Fordmuscle.com and PLX Devices both share common objectives in educating our customers, enthusiasts, and readers in order for them to become well informed consumers. PLX Devices is always in full support of any product performance comparison published by Fordmuscle.com as well as other publications. However, PLX Devices has reviewed your article and strongly believe that your test methodology and test setup is unsatisfactory according to the standards of the engineering and scientific community. We believe that this lead to the misrepresentation of our M-300 as well as other products reviewed. With reference to picture 1 in your article, holding each sensor against the gas canister at an angle like the picture shown is highly susceptible to external variables which influence the accuracy of the measured results. With reference to picture 4, the power connections which share a common power and ground with 7 other products, without proper filtering can introduce coupling and unwanted noise created from the switching behavior of the 7 other oxygen sensor heater circuits. This can introduce errors in the analog output interpretation of each product. Throughout all the tests that are being conducted in the article, there was no mention on the number of test iterations for each sensor, its average value, range, and standard deviation for both results obtained from the digital display as well as the captured analog output signal. To properly perform a comparison test, all the sensors must measure the same gas, at the same time in a sealed enclosure, with equivalent temperature and pressure. The gas must then be allowed to settle and equalize in the enclosure before taking any measurements. The experiment must then be repeated with the sensor positions inside the enclosure randomized as well the sensor controller combination to obtain several data points. To properly connect power to each controller, a low pass filter should be introduced to isolate the effects of the switching behavior introduced from the 7 other products tested. With the M-300, we've included noise filtering capacitors (0.1uF) which is recommended to be connected near the input of your data logger. This helps filter high frequency noise coupled from switching electronics in such a setup like this. The average value, range, and standard deviation must be collected to derive accurate and true results for both the digital display as well as the captured analog output signal. PLX Devices is looking forward to seeing the tests re-conducted and re-published to acceptable industry standard as described above. In PLX's view, accuracy is the most important criteria for doing this test. We believe that testing conducted in a controlled environment will yield very different results from the one published in your story. Sincerely, Paul Lowchareonkul President and CEO PLX Devices Inc.

Posted by **marc99**, 07/25/07 10:09am:

rcamp is pretty much correct - In the range that most tuners work in, a narrowband works well enough - as long as we keep in mind that whatever the supposed "AFR" is - it's ONLY a rough clue of the real AFR and even if it was the "correct" AFR reading - you really don't know exactly what the engine wants - you MUST tweak fuel up and down to get Best Power to do good tuning. Marc Salvisberg www.factorypro.com 415 491 5920

Posted by **tdw6974**, 09/23/07 04:35am:

looks like none of units tested are good????

Write your own comment:

Comments:

Rating: out of 5.

Submit Comment