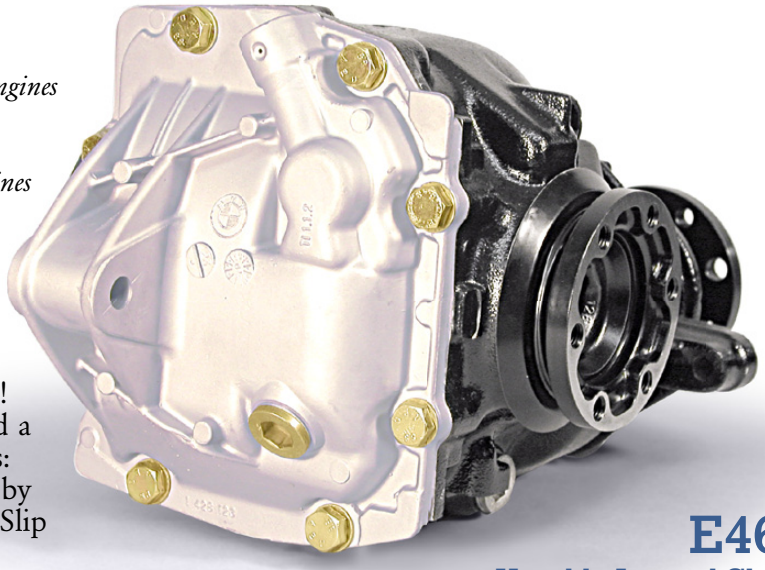
Metric Mechanic's Differentials

Metric Mechanic's Line of Differential Rebuilds

General Differential Description

BMW Differentials come in three sizes which are classified by the ring gear outside diameter measured in millimeters. An overview of their use follows:

Small Differential 168 mm
Generally used behind 4 Cylinder engines
Medium Differentials 188 mm
Generally used behind Small and Big Six engines
Large Differentials 210 mm
Generally used behind early M5, M6, V8, V12, some early 7 Series and E 46 M3 engines



The inherent reliability of BMW Differentials is very sound. For instance, bearing failure is extremely rare. So what are the vast majority of our customers looking for in a differential rebuild? Performance gains! This means a re-engineered Limited Slip and a Ring and Pinion Gear Change. The result is:
1) Increased Cornering Speed achieved by incorporating our 20% Variable Limited Slip with a 30° ramp angle & 3 discs.
2) Optimizing Acceleration by changing out the rear gear ratio to increase torque to the rear wheels.

E46
Variable Limited Slip with 3 Discs and a 3.46 Gear Ratio

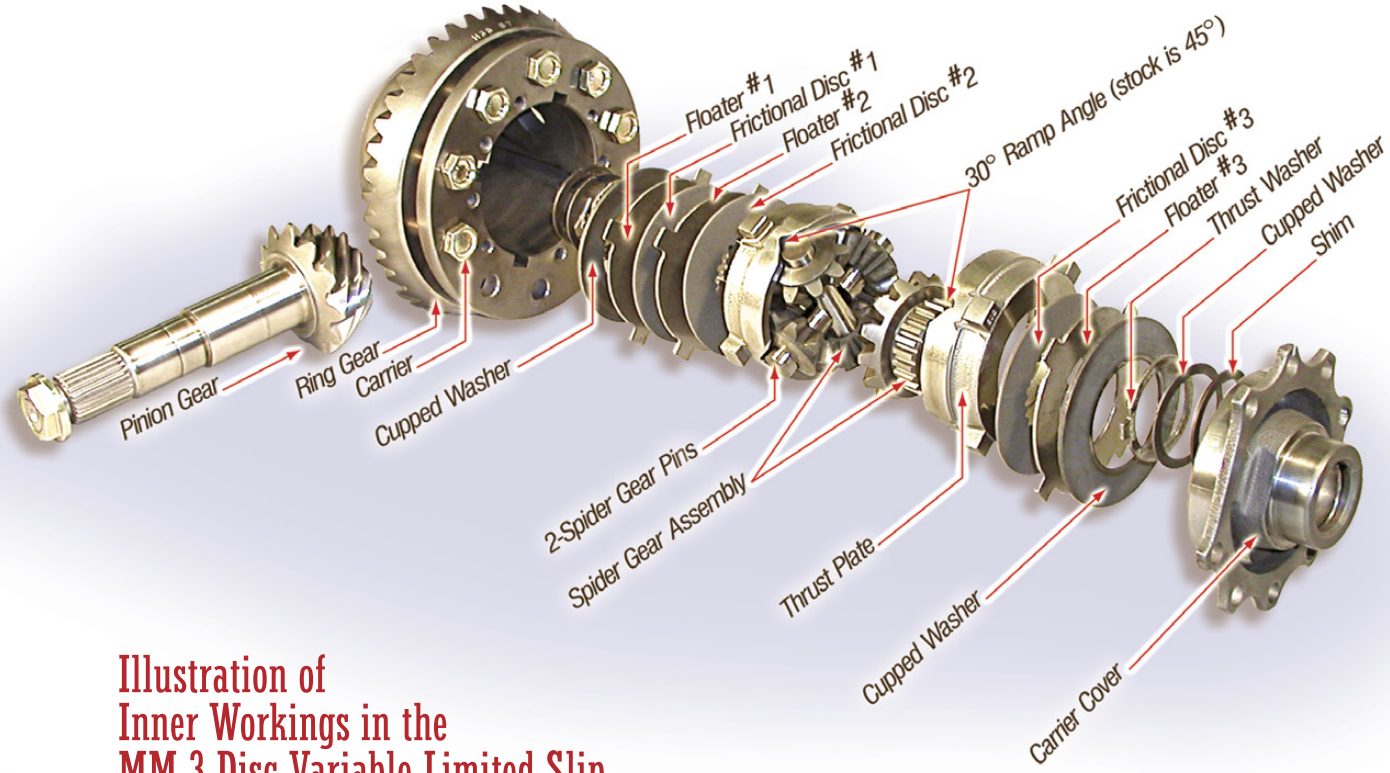


Illustration of Inner Workings in the MM 3 Disc Variable Limited Slip

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Increasing Cornering Speed

We've re-engineered BMW's friction disc limited slip to maximize cornering speed, acceleration, and braking by developing a Variable Limited Slip - varies from 20% to full lock-up, and by adding friction discs to increase LS life and smooth-out its operation. Before cornering, brake while driving in a straight line.

1 With our MM Variable Limited Slip, the lock-up increases with braking but

2 once entering the corner, it drops off to 20%.

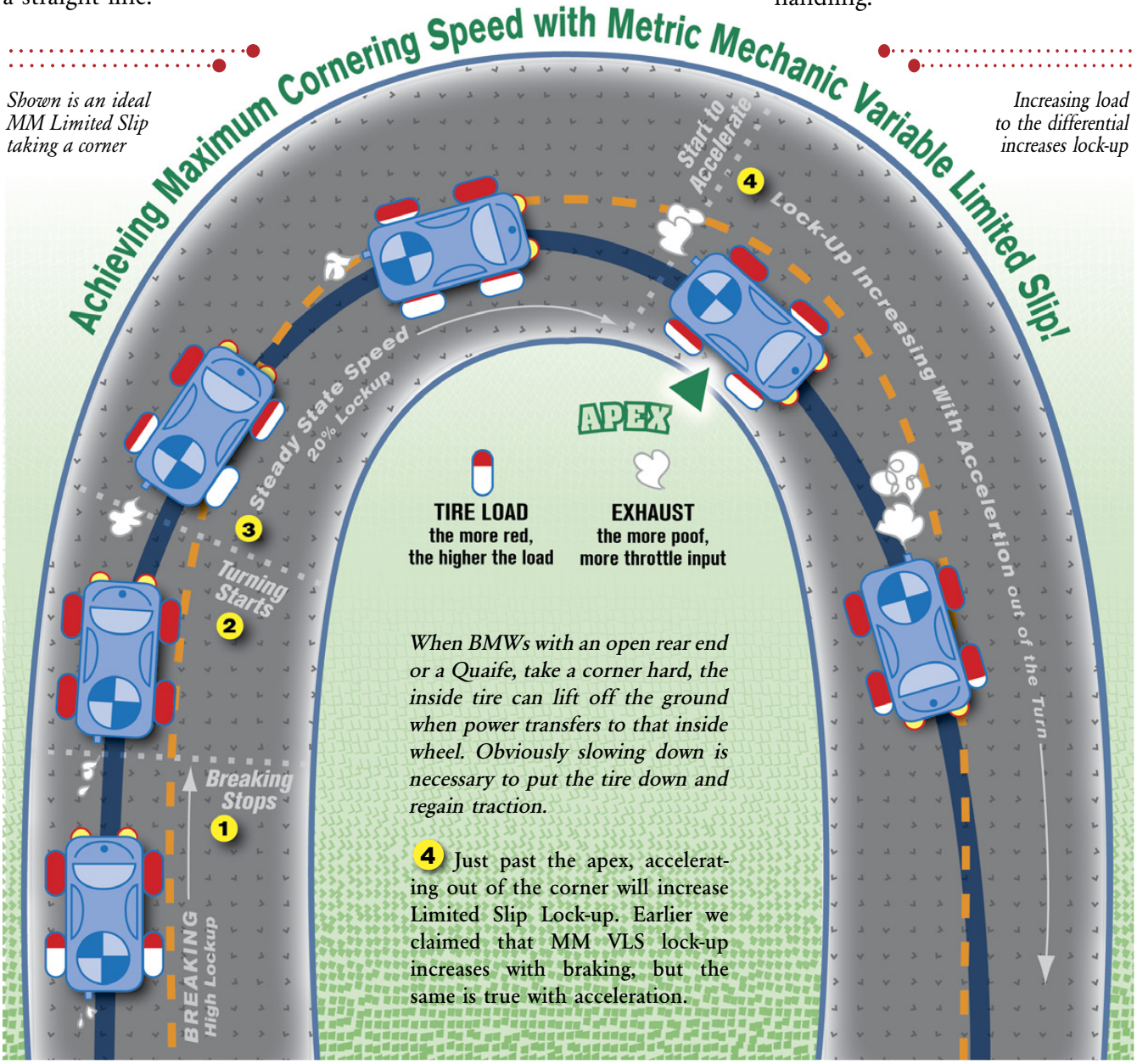
Over the years our understanding of the actual effects of increasing limited slip have evolved. We don't recommend a high lock-up at the rear wheels during the initial turn-in because this will compel the car to go straight, further inducing understear or cause the car to plow. To correct this, slow down.

Maintain a fairly steady speed through the corner to just past the apex.

3 Under hard cornering, the inside rear tire will have limited traction or actually lift off the ground. If lift occurs with our differential, the 20% lock-up keeps the rear wheels turning at the same speed, so when the inside tire connects with the ground again, it won't upset the car's handling.

Shown is an ideal MM Limited Slip taking a corner

Increasing load to the differential increases lock-up



When BMWs with an open rear end or a Quaife, take a corner hard, the inside tire can lift off the ground when power transfers to that inside wheel. Obviously slowing down is necessary to put the tire down and regain traction.

4 Just past the apex, accelerating out of the corner will increase Limited Slip Lock-up. Earlier we claimed that MM VLS lock-up increases with braking, but the same is true with acceleration.

Optimizing Acceleration With Gearing

In the drivetrain (engine, transmission and differential) the differential is the last multiplier of torque before power is delivered to the rear wheels. The percentage of gear change equals torque gains to the rear axle. For example, consider an E36 325i or M3 with a 3.15 gear, switching to a 3.45 LTC (Low Tooth Contact) gear. This change would be an 8.7% gear change which would increase torque to the rear wheels by 8.7%. To state this in terms of engine power; because torque is directly related to engine displacement, it would take approximately an 8.7% increase in engine displacement to gain the same acceleration. For example, an M3 with a 3200 cc engine would have to be increased to 3475 cc to gain the same acceleration from an 8.7% gear change.

When calculating the optimal gearing, we consider the following:

1) **Driving style:**
   moderate, hard, very aggressive
2) **Intended use of the car:**
   daily, drivers school, autocrosses, racing, etc.
3) **Engine:**
   engine size (torque output) power band, stroke (piston speed)
4) **Transmission:**
   4 speed, 5 speed, 6 speed, manual, 3 speed, 4 speed, 5 speed automatic or close ratio.

Gearing Math

Often we're asked hypothetical questions about the effect of differential gear change percentages on speed and rpm. We use the following formulas.

Calculating Gear Change %

$$\text{Gear Change \%} = 1.00 - \frac{\text{Original Gear Ratio}}{\text{New MM Gear Ratio}} \times 100$$

Calculating Speed Change %

$$\text{Speed Change \%} = \frac{\text{Original Gear Ratio}}{\text{New MM Gear Ratio}} \times 100$$

Calculating RPM Change %

$$\text{RPM Change \%} = \text{Gear Change \%} + 100\ \%$$

Gearing Example

The E46 330i equipped with a 6 Speed ZF S6 - 37 and a 2.93 or 3.07 BMW Sport Package is, in our opinion, geared numerically too low. Acceleration can be greatly enhanced by changing to an MM 3.46 Variable Limited Slip. Let's fill in the formulas with real numbers:

Calculating Gear Change % from a 2.93 to a 3.46 Gear

$$\text{Gear Change of 15.3 \%} = 1.00 - \frac{2.93}{3.46} \times 100$$

Using 6000 rpms as a shift point, the 330i will do the following in each gear. See Graph Below. MPH were determined using the **Calculating Speed %** formula. For example, in switching from a 2.93 gear to a 3.46, 2.93 divided by 3.46 is .847 x 100 = 84.7%. A 330i at 6000 rpms runs 122.5 mph in fourth gear. Take 122.5 x .847 = 104 mph. Notice that in each gear, the speed (MPH) of the 3.46 Gear Ratio is reduced by 15.3%. But 15.3% more torque is going to the rear wheels - making the 330i acellerate much faster. So, with the 2.93 differential, 6000 rpm in 5th gear can reach 150 mph. Switching to our MM 3.46, using the same 6000 rpm, the driver can now reach 150 miles in 6th gear meaning the driver has 6 gears in which to acellerate to this point - whereas before (with the 2.93) they had only 5. At 75 mph (half of 150) one would still be turning an aggressive yet fairly relaxed 3,000 rpm (not working the engine hard) with our MM 3.46 rather than about 2550 (a more laboring rpm) with the 2.93.

Differential Gear Ratios		1	2	3
Gear	Transmission Gear Ratios	2.93	3.07	3.46
1st	4.35	35.5	34.0	28.5
2nd	2.50	59.5	57.0	50.5
3rd	1.67	88.5	84.5	75.0
4th	1.23	122.5	117.0	104.0
5th	1.00	150.0	143.0	127.0
6th	.85	176.5	168.0	150.0

Miles Per Hour

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Differentials that Make a Difference!

Differential Gearing for BMW's with Automatic Transmissions

Changing a differential gear to a numerically higher gear will do more for the acceleration of a BMW with the automatic transmission than any other bolt-on modification. 5 Series E39, 7 Series E38 and 8 Series E31 with V8 or V12 engines came with large 210 differentials using 2.81 or 2.93 rear gears with 20% overdrive automatics. These BMW's can greatly increase their acceleration with a 3.46, 3.64 or 3.91 gear change.

Turbo Power Versus Gearing

In order to load a Turbo engine to pull boost, normal procedure is to go down numerically on gearing. Gear ratios in the range of 2.93 to 2.95 are common choices for a boosted engine.

Complementing Traction Control

The Limited Slip option was dropped when BMW added traction control on the following models: E46 3 Series, E39 5 Series, E38 7 Series and the Z4. Exceptions were the M3 and M5 performance models, in which Limited Slip came standard with traction control which kicks in when one tire turns at a greater speed than the others.

For example, when accelerating hard from a stop which breaks the rear tires loose, traction control activates and slows down the car. This is accomplished by closing down the throttle opening, retarding the ignition timing or adding braking to the spinning wheels.

Also, when cornering hard, if the inside rear tire lifts spinning off the ground, traction control will again slow down the car.

In both cases, the traction control is limiting the acceleration or cornering speed - for safety. By adding an MM Variable Limited Slip with a gear change, both cornering speed and acceleration can be increased.

Hot Drivetrain for the E30 325i

We offer a CR 5 Speed Conversion for the E30 325i using the Getrag 250 transmission. When this is combined with one our 2900 or 3200 Baby Six engines, the hot differential is a 3.25 or 293 gear.

Cool Looking - Cool Functioning Covers

Adding a finned rear cover to an MM Variable LS Differential is necessary only for extended track use. The following differentials can be fitted with finned OEM rear covers sourced from the models shown.

The E46 Differential on the Left has a 3.38 Variable Limited Slip with 3 Discs and a Standard Rear Cover. To the Right is a 3.64 Variable Limited Slip with 4 Discs and a Finned rear Cover. The Nylon Spacers in the foreground are used to shim up the rear trailing arms to minimize the torque steer on the rear wheels.

Model	Finned Cover Origin
2002	1975 & 76 2002's
E30 325e/i	Z3 M-Coupe/Roadster
E36 325i, 328i	E36 M3
323i, 325i, 328i, 330i	Z4 with 3.0L

Gearing for Reduced Parasitic Loss in the E36 M3, 325i and 328i

Many M3 owners are inclined towards the 3.46 gear ratio. We offer a 3.45 gear ratio that has a low tooth contact or LTC. The 3.45 ring gear is 5 mm narrower than the 3.46 with 38 teeth while the 3.46 has 45 wider teeth. And the 3.45 pinion has 2 less teeth than the 3.46 pinion. These differences account for for reduced drag against the ring gear.

The 3.45 Low Tooth Contact LTC gear set has 11 pinion teeth and 38 ring gear teeth with a ring gear tooth width of 25mm

The 3.46 gear set has 13 pinion teeth and 45 ring gear teeth with a ring gear tooth width of 30mm.

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Reducing Differential Drivetrain Loss

A Monumental Jump

Most customers are familiar with gearing changes and switching from an open rear end to a limited slip but actually removing their differential and replacing it with a smaller one, may sound like a radical change. Following, is our rationale.

The Case for a Smaller Differential

In a differential, the ring and pinion turn at right angles to one another. This unavoidably causes some drag resulting in parasitic loss. Power is wasted. We believe that going down a differential size not only reduces the weight of the differential by about 20 lbs. but also reduces the normal drivetrain loss of 20-25% by about 3-5%. By studying the MM Torque Ratings for Small, Medium and Large BMW differentials *(see graphs in this article)*, you'll notice that their load rating is over engineered by 200 - 300%. Going to a lighter smaller differential can make the performance difference for a sedate street screamer, weekend Driver's School vehicle, Autocrosser or Racer.

Many variables are included in the formula that equals a margin of victory. To us, reducing differential drivetrain loss through a lighter rear end, is one of them. Here are some case studies.

Case #1 - M5 E28, M6 E24
When going to a larger 3900 Metric Mechanic M Engine, going to a 3.73 medium sized rear end will give you the same acceleration as you would get from a 3.90 larger rear end (due to the parasitic loss of the larger ring and pinion). The results will be the engine will be more relaxed at high speeds, increased engine life and fuel mileage.

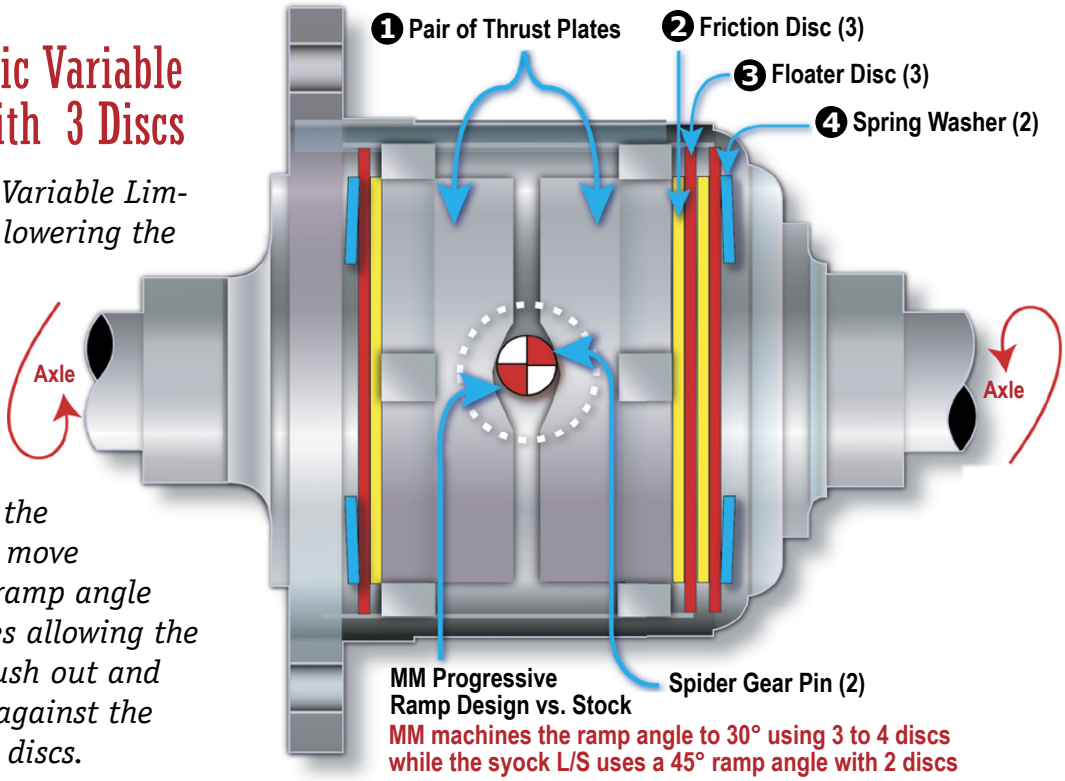
Case #2 - M3 E30
The E30 M3 has a great deal of overkill in it's drive train. It uses a big 6 rear end and transmission. Going to a smaller rear end such as a 3.90 or a 4.11 LS can be a hot replacement rear end even with one of our 2500 stroker engines.

Case #3 - 325i E30
The 3.64 and 3.90 Ring and Pinion is very common in a small 168 differential but it is quite difficult to find in the medium 188 differential, These are nice gear ratios to run behind our 2.9 "Baby" six engine.

Case #4 - M3 E36, 325 E36. Many M3 owners go to a 3.46 gear ratio. We offer a 3.45 gear ratio that has a LTC (low tooth contact). This reduces the parasitic loss of the ring and pinion.

Metric Mechanic Variable Limited Slip with 3 Discs

Metric Mechanic's Variable Limited Slip works by lowering the limited slip down to 20% from 25% and decreasing the ramp angle to 30° from 45°. These reductions make it easier for the spider gear pin to move up and down the ramp angle of the thrust plates allowing the thrust plates to push out and increase the load against the limited slip clutch discs.



MM machines the ramp angle to 30° using 3 to 4 discs while the syock L/S uses a 45° ramp angle with 2 discs

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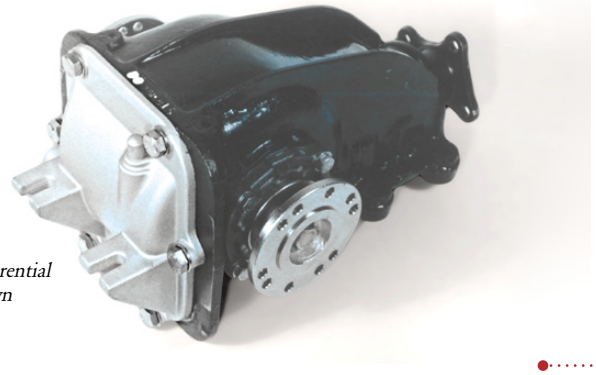
Small 168 Differentials

2002, 320i, 318i & All 4 Cylinder BMWs from 1969 on E21, E30 & E36



Differential Shown 2002

Gear Ratios	MM Torque Rating
3.25	300 ft. lbs.
3.45	280 ft. lbs.
3.64	260 ft. lbs.
3.90	240 ft. lbs.
4.10	220 ft. lbs.
4.27	200 ft. lbs.

Weight - 49 lbs.
Ring Gear Diameter - 168 mm
Friction Disc Diameter:
42 mm ID x 76 mm OD

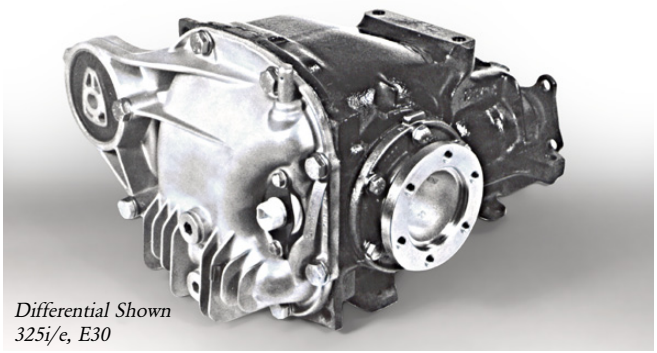
Specifications for Small 168 Differentials

Description	MM Sport	MM Rally	Stock
Number of Discs	3 Disc	4 Disc	2 Disc
Friction Disc Area	189 sq. cm.	252 sq. cm	126 sq. cm
Increase in Disc Life	4.25 times	10 times	1 time
Initial Lockup	20%	20%	25%
Initial Breakaway Torque	35 ft. lbs.	35 ft. lbs.	44 ft. lbs.
Rapid Angle	30° Angle	30° Angle	45° Angle

Medium 188 Differentials

3, 5, 6, 7 Series (some), M3 (E30), Z3 (Roadsters & Coupes) with 6 Cylinder Engines

E30, E36, E28, E34, E24, E23 & Z Cars



Differential Shown 325i/e, E30

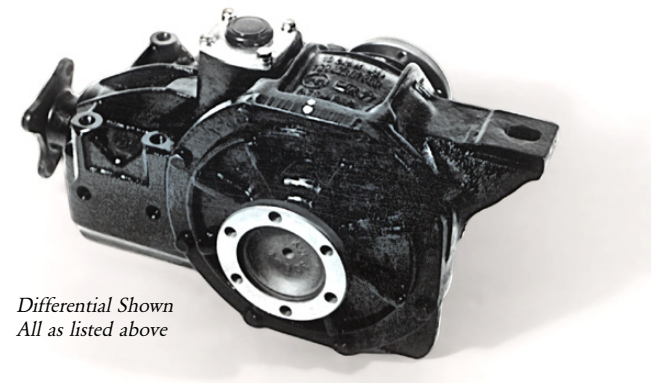
Gear Ratios	MM Torque Rating
2.79	500 ft. lbs.
2.93	480 ft. lbs.
3.15	460 ft. lbs.
3.25	440 ft. lbs.
3.45 LTC	350 ft. lbs.
3.46	420 ft. lbs.
3.73	400 ft. lbs.
3.90	380 ft. lbs.
4.11	360 ft. lbs.
4.27	200 ft. lbs.

Weight - 83 lbs.
Ring Gear Diameter - 188 mm
Friction Disc Diameter:
48 mm ID x 88.25 mm OD

Specifications for Medium 188 Differentials

Description	MM Sport	MM Rally	MM Race	Stock
Number of Discs	3 Disc	4 Disc	5 Disc	2 Disc
Friction Disc Area	258 sq. cm.	344 sq. cm	430 sq. cm	172 sq. cm
Increase in Disc Life	4.25 times	10 times	19.5 times	1 time
Initial Lockup	20%	20%	20%	25%
Initial Breakaway Torque	45 ft. lbs.	45 ft. lbs.	45 ft. lbs.	58 ft. lbs.
Rapid Angle	30° Angle	30° Angle	30° Angle	45° Angle

3.0cs, 3.0, 3.0si, Bavaria, 5 & 6 Series up to '82



Differential Shown All as listed above

Gear Ratios	MM Torque Rating
3.07	350 ft. lbs.
3.45	325 ft. lbs.
3.64	300 ft. lbs.

Weight - 75 lbs.
Ring Gear Diameter - 188 mm
Friction Disc Diameter:
48 mm ID x 88.25 mm OD

Specifications for Medium 188 Differentials

Description	MM Sport	MM Rally	Stock
Number of Discs	3 Disc	4 Disc	2 Disc
Friction Disc Area	258 sq. cm.	344 sq. cm	172 sq. cm
Increase in Disc Life	4.25 times	10 times	1 time
Initial Lockup	20%	20%	25%
Initial Breakaway Torque	45 ft. lbs.	45 ft. lbs.	58 ft. lbs.
Rapid Angle	30° Angle	30° Angle	45° Angle

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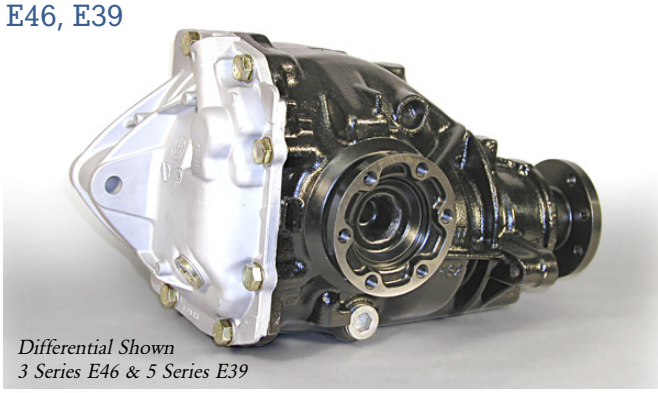
Medium 188 Differentials

323, 325, 328, 330, 528i, 530i for '99 on

E46, E39



Differential Shown
3 Series E46 & 5 Series E39

Gear Ratios	MM Torque Rating
2.93	450 ft. lbs.
3.07	425 ft. lbs.
3.15	400 ft. lbs.
3.38	375 ft. lbs.
3.46	350 ft. lbs.

Weight - 61 lbs.
Ring Gear Diameter - 188 mm
Friction Disc Diameter:
48 mm ID x 88.25 mm OD

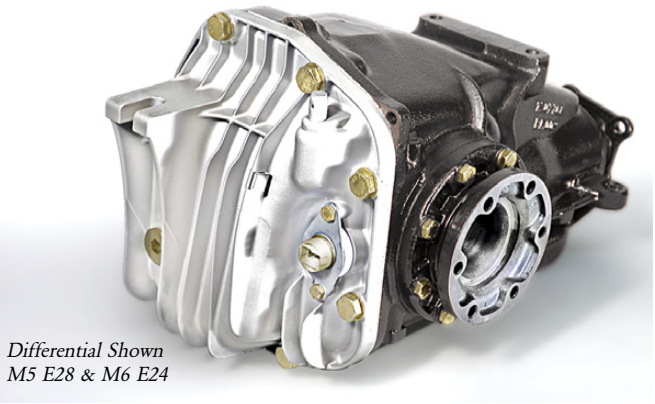
Specifications for Medium 188 Differentials

Description	MM Sport	MM Rally	MM Race	Stock
Number of Discs	3 Disc	4 Disc	5 Disc	None
Friction Disc Area	258 sq. cm.	344 sq. cm	430 sq. cm	None
Increase in Disc Life	4.25 times	10 times	19.5 times	None
Initial Lockup	20%	20%	20%	None
Initial Breakaway Torque	45 ft. lbs.	45 ft. lbs.	45 ft. lbs.	None
Rapid Angle	30° Angle	30° Angle	30° Angle	None

Large 210 Differentials

M5, M5 (6 Cyl. DOHC) 7 Series (some), 540, 740, 840, M5 for V8s, 750, 850 for V12s

E28, E34, E24, E39, E23, E31, E32, E38, E46 M3



Differential Shown
M5 E28 & M6 E24

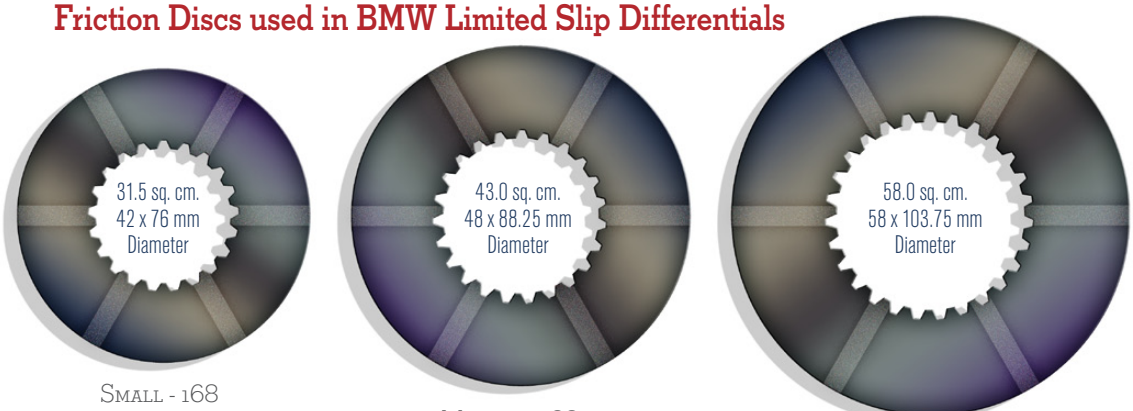
Gear Ratios	MM Torque Rating
2.81	675 ft. lbs.
2.93	650 ft. lbs.
3.15	625 ft. lbs.
3.25	600 ft. lbs.
3.46	575 ft. lbs.
3.64	550 ft. lbs.
3.73	525 ft. lbs.
3.90	500 ft. lbs.

Weight - 96 lbs.
Ring Gear Diameter - 210 mm
Friction Disc Diameter:
58 mm ID x 103.75 mm OD

Specifications for Large 210 Differentials

Description	MM Sport	MM Rally	MM Race	Stock
Number of Discs	2 Disc	3 Disc	4 Disc	2 Disc
Friction Disc Area	232 sq. cm.	348 sq. cm	564 sq. cm	232 sq. cm
Increase in Disc Life	1.50 times	4.25 times	10 times	1.0
Initial Lockup	20%	20%	20%	25%
Initial Breakaway Torque	85 ft. lbs.	85 ft. lbs.	85 ft. lbs.	105 ft. lbs.
Rapid Angle	30° Angle	30° Angle	30° Angle	45° Angle

Friction Discs used in BMW Limited Slip Differentials



Small - 168 | Medium - 188 | Large - 210

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Metric Mechanic's Differentials

Metric Mechanic's Line of Differential Rebuilds

Differentials Made to Last

In the past 15 years, Metric Mechanic has enjoyed a perfect track record with differential rebuilds - not one single failure. Two factors contributed to this.
1) Meticulous measuring and fitting by extremely qualified technicians and
2) A differential, unlike an engine or a transmission, is almost impossible to abuse.

Meticulous Measuring and Fitting

Rebuilding a differential correctly, requires the ability to preload a set of pinion bearings and a carrier bearing with a rolling torque gauge. This is critical to bearing life because too much preloading will burn up the bearings in short order and too little will cause them to skid on the races and create flat areas on the rollers. Either extreme drastically shortens the longevity of the differential.

Pinion bearings are separated by a "boa neck" crush collar that must be collapsed first in order to preload the bearings for 14 to 16 inch pounds of rolling torque. Preload specs for the carrier bearings are 9 -11 inch pounds of rolling torque. This is accomplished with shims that are installed between the differential case and the carrier bearing housing. They also "shim-up" the back-lash on the ring and pinion.

Because factory shims come in .002" increments, they can be problematic when it comes to setting up the ideal backlash of .003" to .0035". We get around this by manufacturing our own shims in smaller .001" increments, allowing us tighter tolerances.

As for bearings, our choice is Timken Roller Bearings. We've fabricated special tools for installing the bearing races and seals so that they are always seated squarely and properly.

Some units require unique attention such as the E46 Variable LS. Their carrier bearings are pre-loaded with a set of precision ground snap rings used for shimming.

We've developed a method for expanding the case so these bearing can be shimmed and pre-loaded to the proper 9 to 11 inch pounds of rolling torque and still be able to set the back-lash on the ring and pinion to .0030" - .0035".

Building the MM Variable LS Carrier

Special machining inside the carrier allows us to reduce the breakaway torque from 25% down to 20%. With a jig fixture, we surface grind Thrust Plate ramp angles to 30°. Machining is also required for the addition of extra discs and floaters. Once the carrier assembly is complete, we check the break-away torque one final time.

The Importance of Correct Drive Flanges

Up to the mid 90's, flanges were fairly standard but after that, variations emerged. Installing an incorrect drive flange can be a disaster to the point of destroying the pinion bearing and crush collar and necessitating redoing the rebuild. To be absolutely sure we are using the correct style, we may require the original differential up front. Once received, we can rebuild it in 3-5 days. This is the cleanest route. When this is impossible, very careful communication can solve the puzzle. It is a critical issue.

Shown in the background are later flange styles.
Foreground Left: Flange used on all Medium 188 and small 168 Differentials up to and including E30, E28 and E24.
Foreground Right: Flange from E36 and E34 except M models.

We Measure and Properly Set Pinion and Carrier Bearings' Rolling Torque, then Measure and Shim Backlash for the Ring and Pinion. The result is a Blue Printed Differential that's MADE to LAST!

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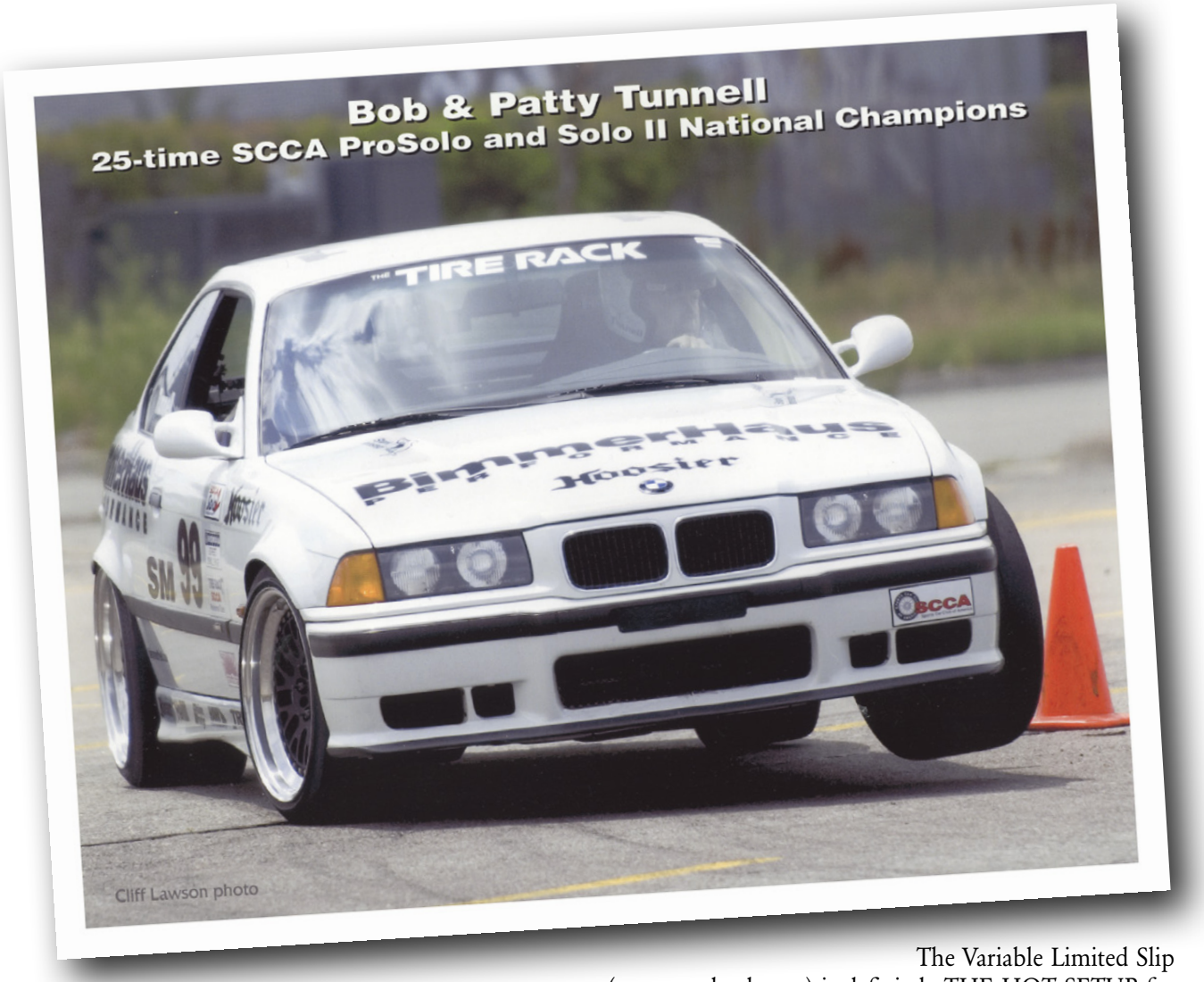

The Variable Limited Slip (ramp angle change) is definitely THE HOT SETUP for high-powered cars in autocross or road racing. It acts like an open diff as you enter a corner, but like a locker as you accelerate out. If your budget depends on your results, this mod is a no-brainer. *Bob Tunnell*

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