Appendix 1. Inrush Current Waveforms

1. Overview

Table 1. Types of inrush currents. In a motor vehicle, these currents all draw current from the battery and produce negative voltage spikes

<table>
<thead>
<tr>
<th>Load</th>
<th>Examples</th>
<th>Typical Current Waveform</th>
<th>Inrush Current (X = Steady State current)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistive</td>
<td>Heating elements, rear window defroster</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Inductive</td>
<td>Solenoids, relays, clutches, ignition coils</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Capacitive</td>
<td>Filter caps in ECU’s (e.g., PWM, ABS, air bag ECU’s)</td>
<td></td>
<td>~5X</td>
</tr>
<tr>
<td>Incandescent Lamp</td>
<td>Headlamps, tail lamps, flashers</td>
<td></td>
<td>~5X</td>
</tr>
<tr>
<td>Motor</td>
<td>Pumps, fans, blowers</td>
<td></td>
<td>5X to 10X</td>
</tr>
</tbody>
</table>

Typical Motor Current Waveform:

Fig 1. Current drawn by a 150W (12 amp) DC motor showing how the steady state current varies with rotational speed, reducing to the stall current when completely stopped or seized
1. Types of Lamps in Vehicles
2. Lamp Load Current Waveform
3. H1 55watt Lamp Current Waveform
4. H4 55 watt Lamp Current Waveform
5. H4 Lamp Inrush Current Versus Temperature
6. Current Waveforms for Several Lamp Types
7. Tail Light Current Waveform
8. 1157 Dual Filament Lamp Current Waveforms
9. Halogen vs High Intensity Discharge (HID) Lamp Current Waveforms
10. Fuel Pump Currents
11. Door Lock Motor Current Waveform
12. Windshield Washer Motor Current Waveform
13. Windshield Wiper Motor Current Waveform 1
14. Windshield Wiper Motor Current Waveform 2
15. Power Window Motor Current Waveforms
16. Radiator Cooling Fan Motor Waveforms
17. Toyota Avalon Dual Cooling Fan
18. Lincoln Mark 8 Cooling Fan Current Waveform
19. Blower Fan Current Waveforms
20. Blower Fan Inrush Current vs Speed
21. Brake Light Current Waveform
22. Throttle Motor Inrush and Steady State Current
23. JBL Speaker Currents
24. Rear Defroster Heater Current Waveform
25. ABS Brake Currents and Voltages
26. ABS Pump Motor Current
27. Starter Motor Current Waveform
28. Starter Motor Current Waveform 2
29. Starter Voltage Waveform with Different Battery Internal Resistances
30. Table with Various ECU Currents
31. Fuel Injector Current Waveform
32. Fuel Injector Current Waveform 2
33. Starter Motor Current Waveform 3
34. Starter Motor Current Waveforms and Discussion
35. ABS Pump Current Waveform

Figure 2. Typical incandescent lamp, solenoid, and stepper motor load current waveforms

Fig 3. Typical solenoid voltage and current waveforms
Based on a car with 2 head lights you are drawing 10.83 amps. Typical headlamp is 55 watt low and 65 watt high beam load. 65 watts/12 volts = 10.83 amps
Figure 4. Estimate H4-55W Lamp Inrush Current over Initial Lamp Temperature

Figure 5. Measured and simulation current responses of an H4 lamp to a 0V to 12V voltage step
Tail light from http://www.motor.com/magazine/pdfs/082007_05.pdf

Figure 6 shows a typical inrush event at 25°C for the STOP filament of a type-1157 dual-filament (stop/tail) bulb.

Figure 7 shows a typical inrush event at 25°C for the TAIL filament of a type-1157 dual filament (stop/tail) bulb.

Note the droop on VA in this example is due to limiting in the power supply source.

<table>
<thead>
<tr>
<th>Bulb Number</th>
<th>Voltage</th>
<th>Amperage</th>
<th>Life in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1156</td>
<td>12.8</td>
<td>2.1</td>
<td>1,200</td>
</tr>
<tr>
<td>1157 (2 filaments)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— tail</td>
<td>12.8</td>
<td>2.10</td>
<td>1,200</td>
</tr>
<tr>
<td>— signal</td>
<td>14.0</td>
<td>0.59</td>
<td>1,500</td>
</tr>
</tbody>
</table>
1. LED Rear tail and break light - BMW R1200GS Forum : R1200 GS Forums

Door Lock Motor


Power Window Motor
An Electronic Cause of Sudden Unintended Acceleration

R. Belt
18 March 2012

10

Prius cooling fans draw 20 amps.

From: Lincoln Mk 8 fan draws 33A with a 100A inrush current

I have tested several of these fans over 30+amps continuous on the car. Most are about 36 amps@13.5volts. And, about 100 amps peak inrush/startup at about 20msec duration. In the post above...if you are measuring the "startup" current with a good digital or analog meter as opposed to a scope...you will not see the correct inrush or startup current figure. Both animals are too slow to pick it up and do not sample fast enough.

And to further corroborate my findings I offer this experienced site which is a boon of information on this very subject at http://www.geocities.com/smithmonte/...rkVIII_Fan.htm which they warn... [b]"Note: The Lincoln Mark VIII fan will draw continuous currents of 33A@12.0V & 42A@14.4V, and has a starting current in excess of 100A!"

From: Large cooling fan causes surge when turned on. Waveforms 2011_May_07_11-23-38
7-(1). Electrical life test (Motor free)  
Sample: CBA1-H-12V, 3pcs.  
Load: Inrush current: 64A/Steady current: 35A  
Fan motor actual load (motor free) 12V DC  
Switching frequency: (ON:OFF = 3:7)  
Ambient temperature: Room temperature  
Circuit

7-(1). Electrical life test (Motor load)  
Sample: CBA1a-12V-C, 3pcs.  
Load: Inrush current: 63A, steady current: 23A  
Blower fan motor actual load (motor free)  
Switching frequency: (ON:OFF = 2:3s)  
Ambient temperature: Room temperature  
Load current waveform  
Inrush current 64A, Steady current: 35A

From: Scope waveforms of inrush Currents 122007_09

3. Electrical life test (Blower fan)  
Sample: CBA1X-0-12V, 3pcs.  
Load: Blower fan load 28V DC  
Inrush current: 39 A/Steady current: 10 A  
Switching frequency: (ON:OFF = 3s:3s)  
Switching cycle: 10s  
Ambient temperature: 65°C  
Coil protective element: Diode  
Circuit

Load current waveform  
Inrush current 39 A, Steady current: 10 A

Brake Lights:  
From: Thesis with current loads
An Electronic Cause of Sudden Unintended Acceleration

R. Belt

18 March 2012

Figure 3.2: Current waveform of 21W light bulb
(Current scale: 2A/div; Time scale: 500ms/div)

Throttle motor: From: Visteon Modeling 08.08110307


Figure 12. Measurement of the motor inrush and steady state current.

Red line is JBL speakers on Prius, Lexus, and Camry’s before 2012
Green line is JBL speakers on Prius, Lexus, and Camry’s after 2012 with improved power amp and smaller speakers. (eliminates cooling fan)
Rear Defroster:
From: Scope waveforms of inrush Currents 122007_09

**Fig. 10** A sharp vertical rise in a current waveform is characteristic of a shorted component, a high current consumer like a motor starting up or, in this case, a rear-defrost heater grid that’s been switched on.

ABS brakes:
From: test bench for automotive power nets ABS waveforms

From: ABS pump motor over 300 watts solenoids draw 2A each

The ABS brake pump motor power can vary depending on application, but is typically above 300W
Pump Motor Driver

Since hydraulic fluid is diverted to the dump accumulator during an ABS event, the fluid must be returned to the master cylinder/high pressure side of the hydraulic system. After each DUMP cycle, the pump motor is used to recycle hydraulic fluid to the high side of the ISO valve. The pump motor requires significant current with start-up surge currents as high as 200 Amps (for ~20 ms) and steady state currents of 10 to 30 Amps.

Starter Motor:
From: p50 p61 Intelligent Automotive Battery with Start Waveforms CYBOX GOOD

The Intelligent Automotive Battery, "CYBOX™"
Keizo Yamadaa, Yoshifumi Yamadab, Koji Otsc, Yoshiaki Machiyamaa, Akihiko Emorid, Taturo Okoshie

a Advanced Battery Development Center, Shin-Kobe Electric Machinery Co., Ltd., 2260 Oka Fukaya Saitama 360-0297, Japan
b Hitachi Research Laboratory, Hitachi Ltd, Japan
c 7-1-1 Omika Hitachi Ibaraki 319-1293, Japan
d 3-1-7 Iitami, Itami City, Hyogo, 664-8502, Japan
From: Scope waveforms of inrush Currents 122007_09

Fig. 1 This scope trace shows starter current draw for a relative compression test on a 2005 Scion xB 1.5L. With a peak of over 1950 amps of current when the starter begins to turn, at curve 2, and with an average current of about 150 amps, it’s clear that voltage supply must be adequate. The general uniformity of the waveform once cranking is well underway indicating an engine with relatively even compression. Cursor 1 highlights the beginning of the solenoid’s “pintle hump.”

From: Start waveform with different internal resistances and IR vs time

Fig. 3. Battery voltage during engine cranking for a battery with various levels of grid corrosion resistance
An Electronic Cause of Sudden Unintended Acceleration

by

Bob Stasonis
Marketing Manager
GenRad, Inc.
From: Scope waveforms of inrush Currents 122007_09

Fig. 2 Channel A (red trace) displays the voltage signal measured on the PCM side of this conventional fuel injector. The supply voltage through the injector windings appears steady at an appropriate level (14.4 volts) prior to turn-on at 74.4 μs into the picture. The circuit is then grounded by the PCM, to be released 2.3ms later. Note that current, shown on channel B (yellow trace), begins to rise immediately after turn-on, reaching a maximum value of 1 amp after 2.3ms. This is a good example of voltage leading current. This capture was made at idle on a known-good car (the same Scion) with a low-amp probe set at 10mV/amp.

From: Current Ramping Complete PDF Doc Chapter 69781428399969_ch06

Figure 6–31 Voltage and current (ampere) waveforms for a standard fuel injector.

Start Waveforms
After a few emails, I thought it might be worth spending some more time on just how you can use your scope to perform a complete test of the battery/starting/charging system. The example I’m going to share is from a recent customer’s 2004 VW GTI, with the 1.8 turbocharged powerplant and manual transmission.

Before starting, I set my scope on "single trigger" mode so I don't waste buffer space recording the time it takes me to walk from the scope to the car to start it. I use the channel I have the amp probe attached to as the trigger, and set it to start tracing when it sees 10 amps or more. I have the amp clamp oriented so that a discharge current will read positive on the scope screen...and that's why you see the current spiking upward instead of downward. Battery voltage is being measured on the blue channel, and this connection is the same as connecting your multimeter. The time divisions are set to 500ms per division, and the trigger starts on the first one, so I have a total test time of 4.5 seconds on the screen.

The voltage scale is on the left side of the image, and the current scale is on the right. If you click on the image above, it will take you to the photo file I uploaded. There, and just below the image, is a selection for viewing a larger size. When the scope is armed, it will trace to the trigger point and that saves me the static readings for the battery and current level. At this current setting, though, I can't make an accurate parasitic drain measurement. That is best done separately...just be sure all the modules go to sleep! The starting battery voltage shows a battery with a decent static voltage of 12.25v or so as I begin the test.

Notice anything?

The engine sure does take a long time to start...about a second and a half. It's also taking some time to get up to speed...see the humps? Those humps are the same you would see when performing a relative compression test. **The starter, however, peaked at about 300 amps and quickly dropped to an even lower level.** Not likely the slow starting is a fault in the starter itself. However, this abuse (as Mac mentioned in his feature) is hard on both the
starter and the battery. Drawing a line over from the 200-220 amp level over to the pattern, then going vertical to see where that lines up with the voltage trace will give me a pretty good idea of the system's loaded voltage, so I do that next.

![Image](image1.png)

Under 7.0v...this battery is not long for this earth. That explains the slow cranking speed you see initially. The starter isn't going to work as well with only half the voltage it needs getting to it! Once it starts moving, though, the current demand is less and the battery starts to recover. Next question then is why the battery is weak...age/internal failure or is there a problem in recharging it afterwards?

![Image](image2.png)

Once the engine the engine rpm picks up, the charging output picks up. Charging voltage as shown at the end of the trace is roughly 14.0v and charging current is a positive 30 amps (remember, the current probe is oriented to show a discharge as a positive reading...the -30 amps shown on the screen is actually positive current flow into the battery). See the upward ramp on the voltage trace, right dead in the middle of the window I've drawn in? That's the ramp Mac referred to as the best place to see problems in the alternator diodes. Here the trace is relatively smooth, so I didn't bother on this car. For comparison, though, here is the one I shared earlier that did have a diode problem (excessive AC ripple).

![Image](image3.png)
See the difference? This was an extreme example, but checking it is easy enough. With the capture saved, just close in on the voltage trace or alter your time base to 10ms per division, in order to see this...

Take a moment to compare the engine cranking section of these two. In the second, the engine got up to speed just fine.

As for the VW...all it needs is a battery. But what a way to sell it to the customer!

**A Closer Look At Scope Battery Testing**

Tuesday, July 06, 2010, 8:22:33 PM | Peter

After a few emails, I thought it might be worth spending some more time on just how you can use your scope to perform a complete test of the battery/starting/charging system. The example I'm going to share is from a recent customer's 2004 VW GTI, with the 1.8 turbocharged power plant and manual transmission. Before starting, I set my scope on "single trigger" mode so I don't waste buffer space recording the time it takes me to walk from the scope to the car to start it. I use the channel I have the amp probe attached to as the trigger, and set it to start tracing when it sees 10 amps or more. I have the amp clamp oriented so that a discharge current will read positive on the scope screen...and that's why you see the current spiking upward instead of downward. Battery voltage is being measured on the blue channel, and this connection is the same as connecting your multimeter. The time divisions are set to 500ms per division, and the trigger starts on the first one, so I have a total test time of 4.5 seconds on the screen. [image] The voltage scale is on the left side of the image, and the current scale is on the right. If you click on the image above, it will take you to the photo file I uploaded. There, and just below the image, is a selection for viewing a larger size. When the scope is armed, it will trace to the trigger point and that saves me the static readings for the battery and current level. At this current setting, though, I can't make an accurate parasitic drain measurement. That is best done separately...just be sure all the modules go to sleep! The starting battery voltage shows a battery with a decent static voltage of 12.25v or so as I begin the test. Notice anything? [image] The engine sure does take a long time to start...about a second and a half. It's also taking some time to get up to speed...see the humps? Those humps are the same you would see when performing a relative compression test. The starter, however, peaked at about 300 amps and quickly dropped to an even lower level. Not likely the slow starting is a fault in the starter itself. However, this abuse (as Mac mentioned in his feature) is hard on both the starter and the battery. Drawing a line over from the 200-220 amp level over to the pattern, then going vertical to see where that lines up with the voltage trace will give me a pretty good idea of the system's loaded voltage, so I do that next. [image] Under 7.0v...this battery is not long for this earth. That explains the slow cranking speed you see initially. The starter isn't going to work as well with only half the voltage it needs getting to it! Once it starts moving, though, the current demand is less and the battery starts to recover. Next question then is why the battery is weak...age/internal failure or is there a problem in recharging it afterwards? [image] Once the engine the engine rpm picks up, the charging output picks up. Charging voltage as shown at the end of the trace is roughly 14.0v and charging current is a positive 30 amps (remember, the current probe is oriented to show a discharge as a positive reading...the -30 amps shown on the screen is actually positive current flow into the battery). See the upward ramp on the voltage trace, right dead in the middle of the window I've drawn in? That's the ramp Mac referred to as the best place to see problems in the alternator diodes. Here the trace is relatively smooth, so I didn't bother on this car. For comparison, though, here is the one I shared earlier that did have a diode problem (excessive AC ripple). [image] See the difference? This was an extreme example, but checking it is easy enough. With the capture saved, just close in on the voltage trace or alter your time base to 10ms per division, in order to see this... [image] Take a moment to compare the engine cranking section of...
these two. In the second, the engine got up to speed just fine. As for the VW...all it needs is a battery. But what a way to sell it to the customer!

**Following Mac's Advice: Battery/Starting/Charging Test With A Scope**

In this month's issue of *Motor Age*, we showed you how to test the battery/starting/charging system in under 5 seconds using your scope. I recently applied what Mac taught in his article on a 2006 Dodge Stratus, with a 2.4 liter four cylinder and a complaint of an intermittent battery warning light illumination. I hooked up my scope, and started the engine. The time base on this pattern is 500 ms per division, with a total of 5 seconds captured. Can you apply the lessons Mac shared?

![Scope Pattern](image)

First, it's pretty obvious something's wrong. This doesn't look anything like Mac's illustrations in the magazine! The blue, voltage, trace looks like a smear instead of a straight line and the red, current, trace ranges from a 60 amp draw to a 45 amp charge! However, the starter got up to speed in just about 0.5 seconds and starter draw is normal. Tracing a line from the point where the current draw is about 200 amps and intersecting that with the blue voltage trace shows a battery loaded voltage of 10.9 volts...and that's just dandy. **So, the starter appears OK as does the battery.**

By using the zoom function of the scope, I decide to home in on the blue smear to see what's really hiding there. Here's the close up:

![Zoomed Close-up](image)

Looks like AC ripple, doesn't it? But is it too much? **Measured, it's over 1.0 volt** and the key is in the amplitude and shape of this ripple wave. Let's take a look at it and a known good AC ripple pattern to compare:
No question, there’s a diode failure in this alternator...in this case, more than one has failed. Do I care if it’s shorted or open? No, I just know it’s bad and a replacement alternator is installed. Here’s the pattern after the repair:

Much better. And much faster!
Thanks, Mac!