Tesla model 3 monitoring with the “scan my tesla” application

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Abstract
Experiments using the scan my tesla application are reported here along with basic information about the car and energy efficiency. These experiments were done with my Tesla Model 3 long-range/dual-motor purchased in 2021.

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Introduction

I had the good fortune to have 0.6 Bitcoin left over from a purchase in 2013. I sold them in May 2021. That paid for half of my 2021 red Tesla Model 3 with the long-range/dual-motor option. This write-up is primarily about my experiments with the scan my tesla application to monitor the car's performance. I am also reporting other information about the design of the car and energy efficiency that I have gathered for my own education.

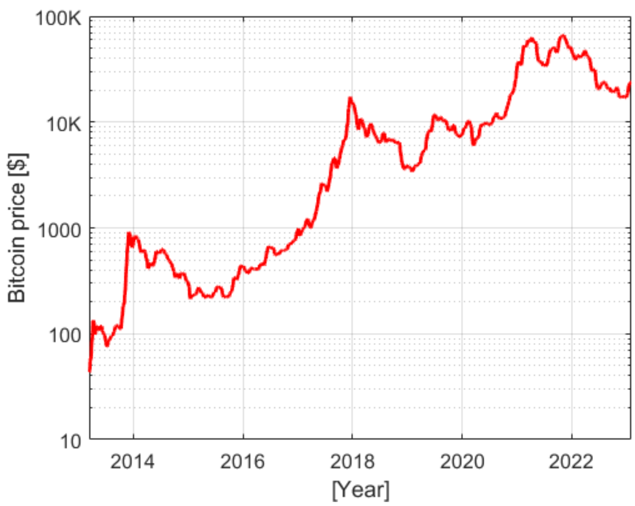

Figure 1. Bitcoin price history

The car is fun to drive. It is very nimble with its low center of gravity from the heavy battery pack mounted in the floor. The acceleration is phenomenal, peaking out at almost 0.7 g. I admire the clean physical design. However, that aesthetic comes with a cost. The car would be virtually undrivable without voice recognition and control, even for such simple actions as turning on the windshield wipers. I amuse people by commanding “open the glove box” since there is no hand latch. I understand that a hand latch lever would spoil the design. I have yet to figure out how to open the box through the touchscreen display. That is a problem because the voice control is dependent on the cell-phone network. One day I may get stranded in a remote area without cellular service. Another issue is that Tesla can abruptly change the control layout through a software download. That is a safety issue if you need to hunt through unfamiliar submenus at highway speeds.

Battery pack

The battery specifications in the table are for the 2021 long-range Model 3. The battery pack is made of 4416 type 2170 lithium-ion rechargeable battery cells. The 2170, as the model number suggests, is 21mm in diameter and 70 mm in length. The layout of the cells is shown in Fig. 2.

Each group of 46 cells is connected in parallel. The voltage of each group can be read with the scan my tesla application and registers around 4 volts, depending on the state of charge. 96 groups are connected in series to create a 384-volt composite battery. There are two such composite batteries, one on the left side of the car and one on the right.

Battery capacity	82 kWh
Total voltage	384V
Type 2170 battery cells	4416
Cell groups	96
Cells per group	46
Group voltage	4V
Battery weight	480 kg (1060 lbs)

The battery weight is considerable and is housed in the

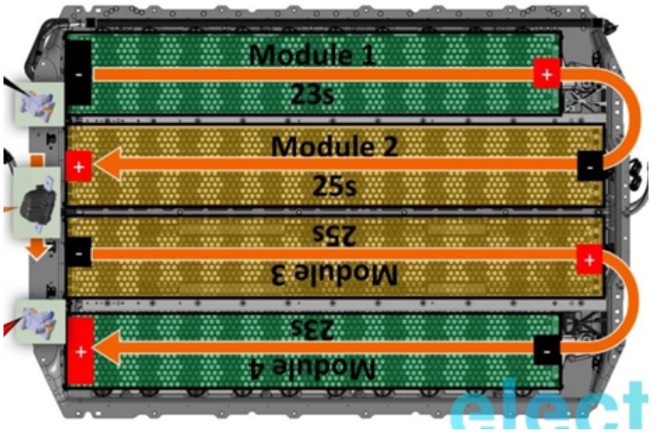

Figure 2. Battery layout in the Tesla Model 3 long range[1].

floor of the car giving it a low center of gravity. As a result, the car corners well and has good traction. The 82 kWh battery allows 358 miles of range. The top speed is 145 mph.

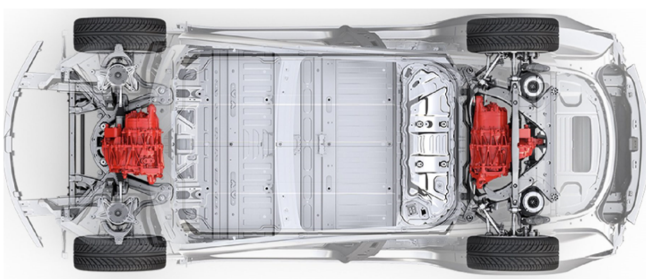

Figure 3. Front and rear motors in the Tesla Model 3 long range[2].

The rear motor is an AC permanent magnet synchronous motor, liquid-cooled, with variable frequency drive. The front motor is an AC induction motor, liquid-cooled, with variable frequency drive. The permanent magnet motor is especially efficient [3] and was seen to be used for most of the propulsion and regenerative breaking in our tests.

“scan my tesla” application

The scan my tesla application was written by Norwegian developer, Amund Børsand. The results presented here were taken with Android version 1.9.12. It logs 247 parameters at a rate of over 1000 data packets per second. The data were saved as a csv file to the “Download” directory of my cell phone. Not every parameter is logged in every packet. However, the application can supply real-time data on the state of charge, power usage, and torque, to name a few. Quickly changing parameters are reported more frequently. A full list of the parameters is presented in Fig. 7.

Figure 4 shows that the packet rates are very high with a spacing of less than 21 ms for 99% of the packets. Since the data of interest does not exist on every packet, the actual data rates are less. However, the data samples are still dense with 99% of the torque data coming within 74 ms and 99% of the speed values within 103 ms.

The physical installation requires a cable to tap into the CAN bus and an OBD-II adapter that has a Bluetooth interface. The products I used are shown in Fig. 5 and the physical installation in my car is shown in Fig. 6.

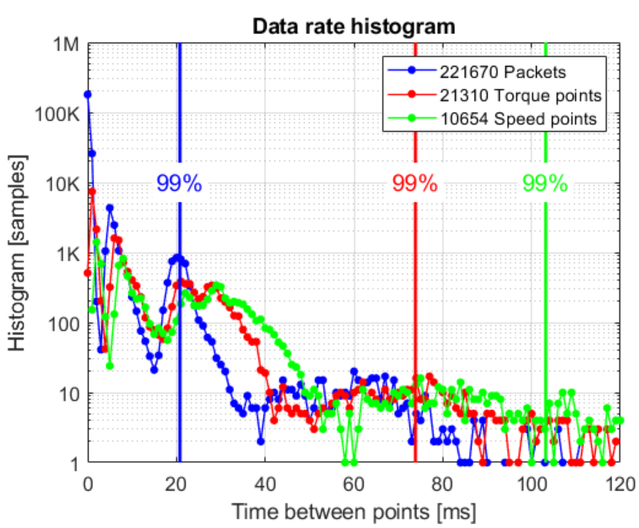

Figure 4. Data rate histogram showing delay times between information packet types.

Figure 5. CAN bus cable and the OBD-II adapter with Bluetooth interface to my Android cellphone.

Figure 6. Installation behind the center console of my car.

1	Time [ms]	63	Rear oil temp [°C]	125	Sleep current [mA]	187	Cell 36 voltage [V]
2	Packets per second [#/s]	64	F Inverter PCB temp [°C]	126	Left headlamp Fan [0/1]	188	Cell 37 voltage [V]
3	Signals received	65	F Inverter temp [°C]	127	Right headlamp Fan [0/1]	189	Cell 38 voltage [V]
4	Battery voltage [V]	66	F Stator temp [°C]	128	Left headlamp position [pos]	190	Cell 39 voltage [V]
5	Battery current [A]	67	F heatsink temp [°C]	129	Right headlamp position [pos	191	Cell 40 voltage [V]
6	Series/Parallel [%]	68	R Inverter PCB temp [°C]	130	Front ride height [mm]	192	Cell 41 voltage [V]
7	Battery power [kW]	69	R Inverter temp [°C]	131	Rear ride height [mm]	193	Cell 42 voltage [V]
8	Radiator fan target [RPM]	70	R Stator temp [°C]	132	DC-DC output voltage [V]	194	Cell 43 voltage [V]
9	Five way valve angle [Deg]	71	R heat sink [°C]	133	DC-DC output current [A]	195	Cell 44 voltage [V]
10	F power [kW]	72	Cell temp max [°C]	134	DC-DC output power [W]	196	Cell 45 voltage [V]
11	Radiator bypass [%]	73	Cell temp mid [°C]	135	FL brake est [°C]	197	Cell 46 voltage [V]
12	R power [kW]	74	Cell temp min [°C]	136	FR brake est [°C]	198	Cell 47 voltage [V]
13	F torque [N-m]	75	Cell volt max [V]	137	RL brake est [°C]	199	Cell 48 voltage [V]
14	R torque [N-m]	76	Cell volt mid [V]	138	RR brake est [°C]	200	Cell 49 voltage [V]
15	F torque 186 [N-m]	77	Cell volt min [V]	139	Rated range [km]	201	Cell 50 voltage [V]
16	Front oil flow [lpm]	78	Cell imbalance [mV]	140	Ideal range [km]	202	Cell 51 voltage [V]
17	F RPM [RPM]	79	CAC min [Ah]	141	Full rated range [km]	203	Cell 52 voltage [V]
18	Rear oil flow [lpm]	80	CAC avg [Ah]	142	Full ideal range [km]	204	Cell 53 voltage [V]
19	R torque 108 [N-m]	81	CAC max [Ah]	143	Speed [km/h]	205	Cell 54 voltage [V]
20	R RPM [RPM]	82	Last cell block updated [xb]	144	0-50	206	Cell 55 voltage [V]
21	Max discharge power [kW]	83	Battery inlet [°C]	145	0-60	207	Cell 56 voltage [V]
22	Max regen power [kW]	84	Powertrain inlet [°C]	146	Cell 1 voltage [V]	208	Cell 57 voltage [V]
23	Max pack voltage [V]	85	Outside temp [°C]	147	0-100	209	Cell 58 voltage [V]
24	Min pack voltage [V]	86	Outside temp filtered [°C]	148	Cell 2 voltage [V]	210	Cell 59 voltage [V]
25	Max discharge current [A]	87	Target PT ActiveCool [°C]	149	0-130	211	Cell 60 voltage [V]
26	Max charge current [A]	88	Target PT Passive [°C]	150	Cell 3 voltage [V]	212	Cell 61 voltage [V]
27	Max charge power [kW]	89	Target bat ActiveCool [°C]	151	0-160	213	Cell 62 voltage [V]
28	Steering Angle [Deg]	90	Target bat Passive [°C]	152	Cell 4 voltage [V]	214	Cell 63 voltage [V]
29	Steering Speed [Deg/s]	91	Target bat ActiveHeat [°C]	153	0-200	215	Cell 64 voltage [V]
30	Accelerator Pedal [%]	92	Wiper cycles [#]	154	Cell 5 voltage [V]	216	Cell 65 voltage [V]
31	Brake Pedal [on/off]	93	Headlamp L blade [°C]	155	60-100	217	Cell 66 voltage [V]
32	Accuracy [s]	94	Headlamp L diffuse [°C]	156	Cell 6 voltage [V]	218	Cell 67 voltage [V]
33	Consumption [kWh/km]	95	Headlamp L high beam [°C]	157	80-120	219	Cell 68 voltage [V]
34	DC Charge total [kWh]	96	Headlamp L low beam [°C]	158	Cell 7 voltage [V]	220	Cell 69 voltage [V]
35	AC Charge total [kWh]	97	Headlamp L turn [°C]	159	Cell 8 voltage [V]	221	Cell 70 voltage [V]
36	DC Charge [kWh]	98	Headlamp R blade [°C]	160	Cell 9 voltage [V]	222	Cell 71 voltage [V]
37	AC Charge [kWh]	99	Headlamp R diffuse [°C]	161	Cell 10 voltage [V]	223	Cell 72 voltage [V]
38	Regen total [kWh]	100	Headlamp R high beam [°C]	162	Cell 11 voltage [V]	224	Cell 73 voltage [V]
39	Drive total [kWh]	101	Headlamp R low beam [°C]	163	Cell 12 voltage [V]	225	Cell 74 voltage [V]
40	Regenerated [kWh]	102	Headlamp R turn [°C]	164	Cell 13 voltage [V]	226	Cell 75 voltage [V]
41	Energy [kWh]	103	Charge total [kWh]	165	Cell 14 voltage [V]	227	Cell 76 voltage [V]
42	Regen % [%]	104	Discharge total [kWh]	166	Cell 15 voltage [V]	228	Cell 77 voltage [V]
43	Odometer [km]	105	Discharge cycles [x]	167	Cell 16 voltage [V]	229	Cell 78 voltage [V]
44	Distance [km]	106	Charge cycles [x]	168	Cell 17 voltage [V]	230	Cell 79 voltage [V]
45	Avg consumption [kWh/km]	107	Discharge [kWh]	169	Cell 18 voltage [V]	231	Cell 80 voltage [V]
46	Nominal full pack [kWh]	108	Charge [kWh]	170	Cell 19 voltage [V]	232	Cell 81 voltage [V]
47	Nominal remaining [kWh]	109	Stationary [kWh]	171	Cell 20 voltage [V]	233	Cell 82 voltage [V]
48	Expected remaining [kWh]	110	Blower speed target [RPM]	172	Cell 21 voltage [V]	234	Cell 83 voltage [V]
49	Ideal remaining [kWh]	111	Evap enabled [0/1]	173	Cell 22 voltage [V]	235	Cell 84 voltage [V]
50	To charge complete [kWh]	112	Evap temp [°C]	174	Cell 23 voltage [V]	236	Cell 85 voltage [V]
51	Energy buffer [kWh]	113	Evap target [°C]	175	Cell 24 voltage [V]	237	Cell 86 voltage [V]
52	SOC [%]	114	Evap demand [W]	176	Cell 25 voltage [V]	238	Cell 87 voltage [V]
53	SOC expected [%]	115	A/C compressor duty	177	Cell 26 voltage [V]	239	Cell 88 voltage [V]
54	Usable remaining [kWh]	116	PTC input voltage	178	Cell 27 voltage [V]	240	Cell 89 voltage [V]
55	Full pack when new [kWh]	117	PTC heater left	179	Cell 28 voltage [V]	241	Cell 90 voltage [V]
56	SOC UI [%]	118	PTC heater right	180	Cell 29 voltage [V]	242	Cell 91 voltage [V]
57	SOC Min [%]	119	PTC heater total	181	Cell 30 voltage [V]	243	Cell 92 voltage [V]
58	SOC Max [%]	120	Duct left est [°C]	182	Cell 31 voltage [V]	244	Cell 93 voltage [V]
59	SOC Avg [%]	121	Duct right est [°C]	183	Cell 32 voltage [V]	245	Cell 94 voltage [V]
60	Battery flow [lpm]	122	Cabin temp probe [°C]	184	Cell 33 voltage [V]	246	Cell 95 voltage [V]
61	Powertrain flow [lpm]	123	Cabin temp mid [°C]	185	Cell 34 voltage [V]	247	Cell 96 voltage [V]
62	Front oil temp [°C]	124	Cabin temp deep [°C]	186	Cell 35 voltage [V]		

Figure 7. List of parameters reported by the scan my tesla application.

Performance on the highway

The drag on the car determines most of the energy usage at highway speeds. The two components of drag are rolling resistance and air resistance. The rolling resistance power loss is

$$P_{rr} = C_{rr}\, m\, g\, v \qquad (1)$$

where C_{rr} is the rolling resistance coefficient, m is the mass of the car and passengers, g the acceleration of gravity, and v the velocity. The rolling resistance is due to the energy loss in compressing and releasing the rubber in the tires. For low rolling resistance, the tires should be inflated to a relatively high 42 PSI.

The air resistance power loss is

$$P_{ar} = \frac{1}{2}\rho\, C_d\, A\, v^3 \qquad (2)$$

where ρ is the density of air, v the velocity, A the frontal area of the car, and C_d is the drag coefficient. The Model 3 has a very low C_d for a production car[4]. The aero wheel covers on my car can increase range by several percent [5] by reducing air resistance.

Both the rolling and air resistance powers are plotted in Fig. 8 as a function of speed. At 80 mph you would expect to achieve 3.6 miles/kWh. That would be a maximum figure that neglects motor efficiency, lights and electronics, heating and air conditioning.

scan my tesla data for a trip on Interstate 495 in Massachusetts under adaptive cruise control is presented in Fig. 9. The car held to 80 mph very well except when the adaptive cruise control slowed for a car ahead. The accelerator depression was zero while on cruise control. The road was fairly straight as evidenced by the low steering wheel angles. The car was propelled mostly by the rear permanent magnet motor. The motor power and torque responded to the slight hills on the route, throttling back to almost zero on one of the steeper downhill segments. Most of the battery power goes to the motors. The bottom plot shows the instantaneous "mileage" that averaged out to 3.4 miles/kWh.

Battery weight	480 kg (1060 lbs)
Mass of car	1830 kg
Mass of car and driver, m	1920 kg
Rolling resistance coefficient, C_{rr}	0.011
Model 3 drag coefficient, C_d	0.23
Density of air, ρ	1.3 kg/m^3
Model 3 frontal area	2.22 m^2
0.62 miles	1 km
1 horsepower	0.746 kW
Acceleration of gravity, g	9.8 m/s^2

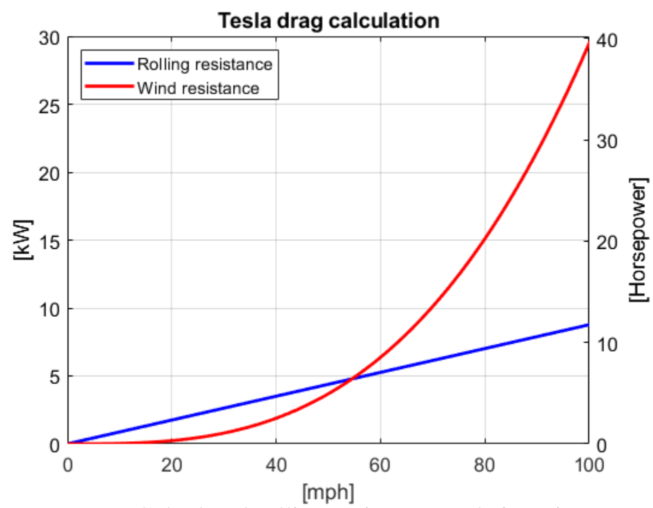

Figure 8. Calculated rolling resistance and air resistance.

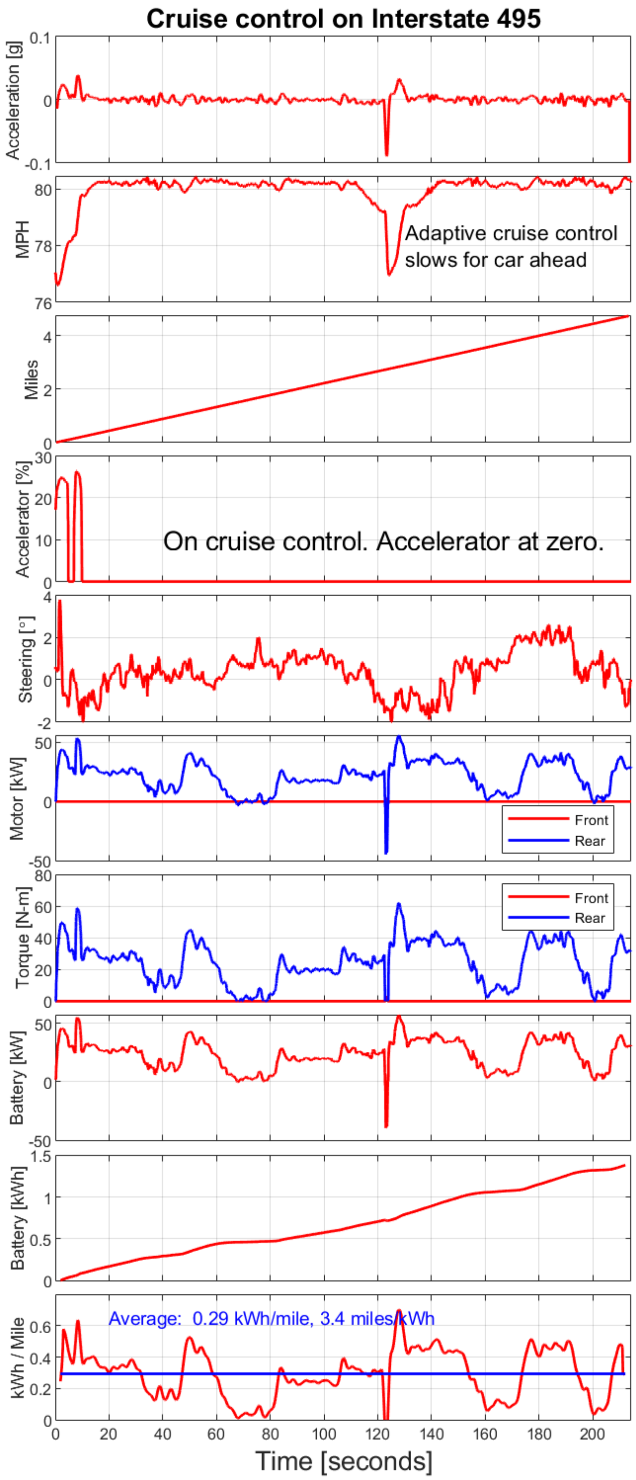

Figure 9. Data logged while traveling under adaptive cruise control on Interstate 495 in Massachusetts.

Performance during high acceleration

The data plotted in Fig. 11 show a right turn off Concord Road to a downhill entrance ramp onto Route 3. The accelerator was “floored” for several seconds. The peak acceleration was about 0.7 g. Theoretically, scan my tesla is supposed to log brake pedal depression, however, there was no change in that data stream. The friction brake was applied briefly around 60 seconds. The motor torque and power curves show interesting choreography between the front and rear motors. The rear motor is a permanent magnet motor and is more efficient. It is the primary motor used for most of the acceleration and regenerative braking. The front motor acts as a significant, but secondary, assist during high acceleration. The maximum drive power is 300 kW occurring when the accelerator was depressed to the floor. Shortly thereafter, regenerative braking of 50 kW was observed when the accelerator was returned to zero depression.

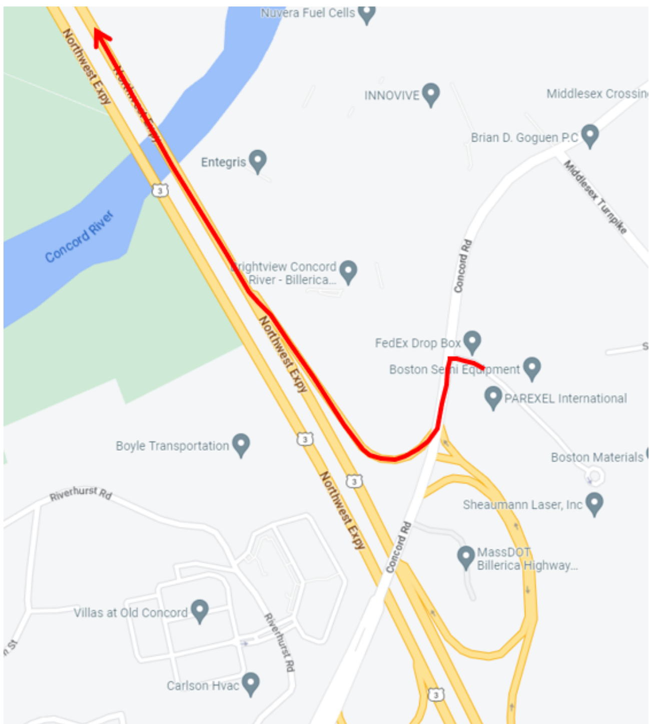

Figure 10. Map of Concord Road entrance to the freeway.

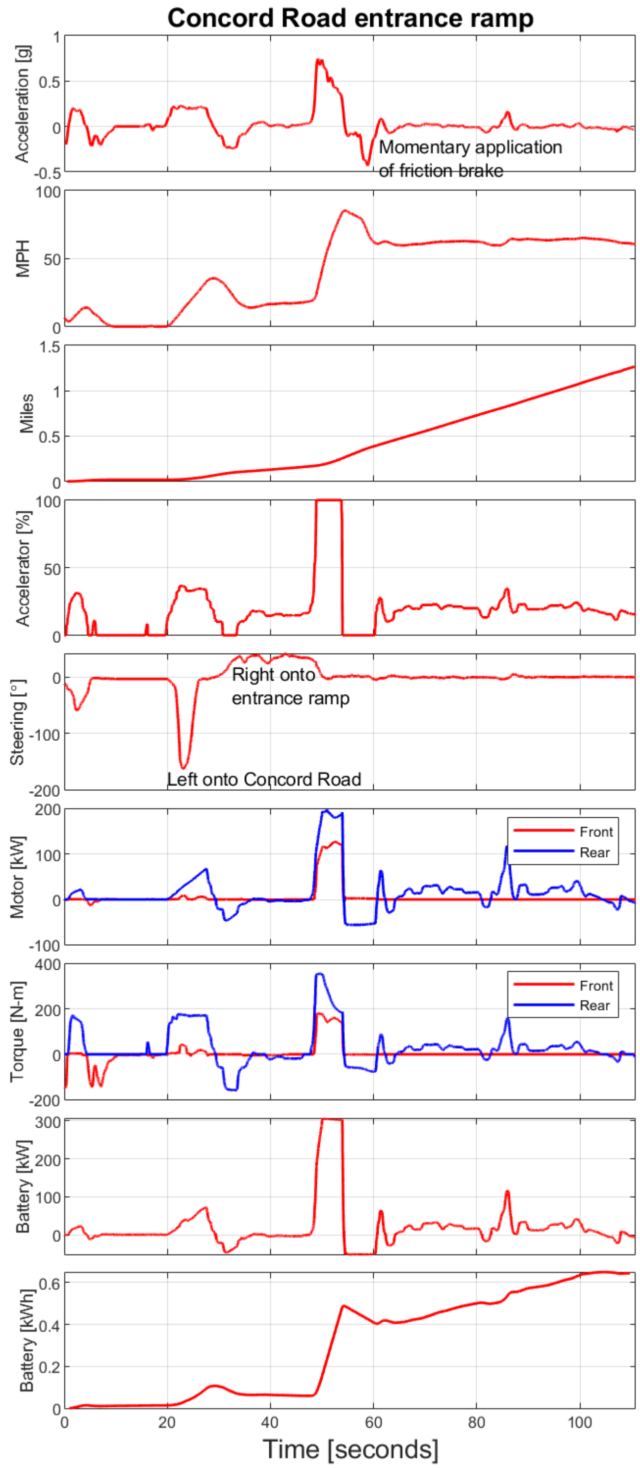

Figure 11. High acceleration data on the entrance to the freeway.

Figure 12 compares acceleration computed from

$$\frac{a}{g} = \frac{1}{g}\frac{dv}{dt} \tag{3}$$

with

$$\frac{a}{g} = \frac{\tau R}{m r g}. \tag{4}$$

where the numeric parameters are listed in the following table.

Acceleration, a	m/s^2
Gravitational acceleration, g	9.8 m/s^2
Car velocity, v	m/s
Torque, τ	N-m
Gear ratio, R	9
Car and driver mass, m	1920 kg
Tire radius, r	0.34 m

The curves nearly match. However a little extra torque is required going uphill and a little less downhill. Also a little more is required to overcome rolling and air resistance at higher speeds. There is also a dip in acceleration at about 60 seconds where the friction brakes were applied. In that case, the torque-based computation did not follow.

The electric motors are geared down to the wheels by a ratio of 9. The torque to the wheels is therefore 9$\times$ that at the motors. That means that the motors rotate very fast. At the maximum speed of 145 mph, the motors spin at 16400 rpm.

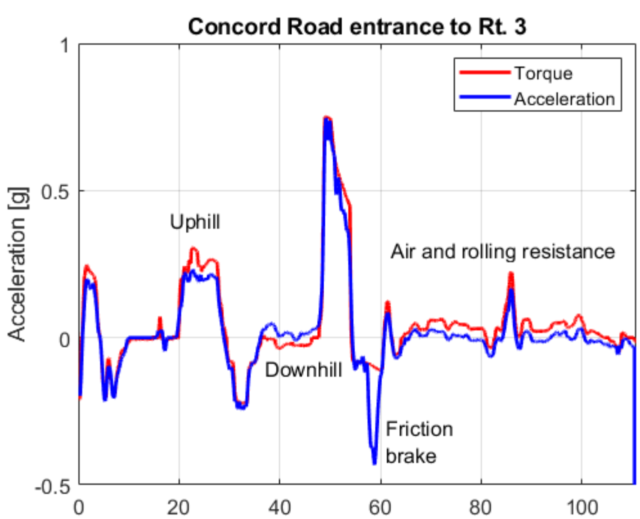

Figure 12. Acceleration computed from torque.

Accessory power draw

The accessories were turned on one at a time to measure the power draw. The lights, wipers, and heaters were a simple electrical draw. The climate control and front defroster ran the heat pump and consumed much more power. There was also a turn-on transient for the electric motor driving the heat pump. The climate control was set to 70°F and the outside air temperature was 37°F.

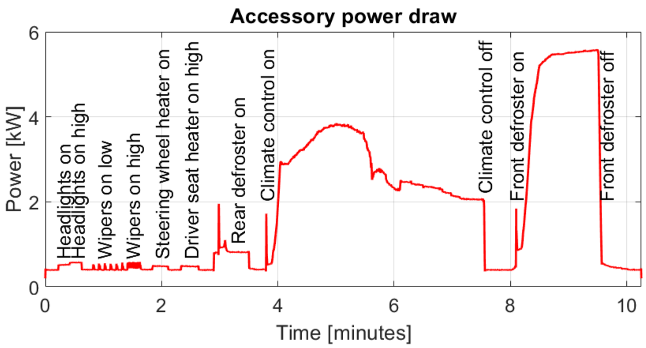

Figure 13. Power draw of accessories turned on one at a time.

Baseline draw	400W
Headlights low	120W
Headlights high	180W
Windshield wiper peak	140W
Steering wheel heater	90W
Driver seat heater on high	90W
Rear defroster	410W

Cumulative data

There are some interesting cumulative data that are recorded. If the total charge and discharge number are accurate, the system is 96% efficient in converting stored energy to released energy. The DC and AC charge numbers indicate I do 87% of my charging at home. I recover about 23% of my energy through regenerative braking. My “mileage” is 3.6 miles/kWh.

Charge total [kWh]	12030 kWh
Discharge total [kWh]	11549 kWh
DC Charge total [kWh]	1220 kWh
AC Charge total [kWh]	8463 kWh
Regen total [kWh]	2350 kWh
Drive total [kWh]	8760 kWh
Regen %	23%
Odometer	34700 miles

Charging

Figure 14 shows data from a supercharging experiment. On a cold day, I drove from home to a supercharging station in Lynnfield, MA. I used the navigation system to guide me to the supercharger so the car would automatically “precondition” the battery, that is, heat it up. I charged from 41% to 90% of capacity and then drove into work. In response, the battery was heated during preconditioning and in the initial phases of the charge. On the way to work, the battery was cooled.

The battery voltage [V], charge rate [kW], and state of charge [%] are shown in the first three graphs. The discharge rate and rate of charge in miles per hour are found by differentiating the state of charge curve.

Apparently current can be run through the motors without turning them. The motor powers are driven up during the first minutes [31-48] of charging. This significantly raises the stator, inverter, and heat sink temperatures creating heat that is pumped to the battery by the coolant loop in the thermal management system. The result is that the battery gets quite hot by the end of the charge and needs to be cooled down while driving.

The thermal management system can be run in series or parallel mode. In series mode, the battery and power train coolant flows are the same. Heat is pumped from the power train into the battery. In parallel mode, the cooling loops can separate. Tesla’s thermal management system is quite complex. Reference [6] has a very good analysis of the system put together from patents and other public sources.

The last few graphs show the logic of the thermal management system as it switches into various modes of operation: Series to parallel, radiator bypassed or not, and radiator fan settings. The capture of all these signals was made possible by a dedicated group of hobbyists who reverse-engineered the Tesla CAN bus data stream. All of these signals are subject to change with the model year as the design evolves. Also, frequent software updates can change packet structures and break particular data streams.

I am still curious about all these signals and am still learning. The thermal management system may be as impressive an achievement as electrifying the car in the first place.

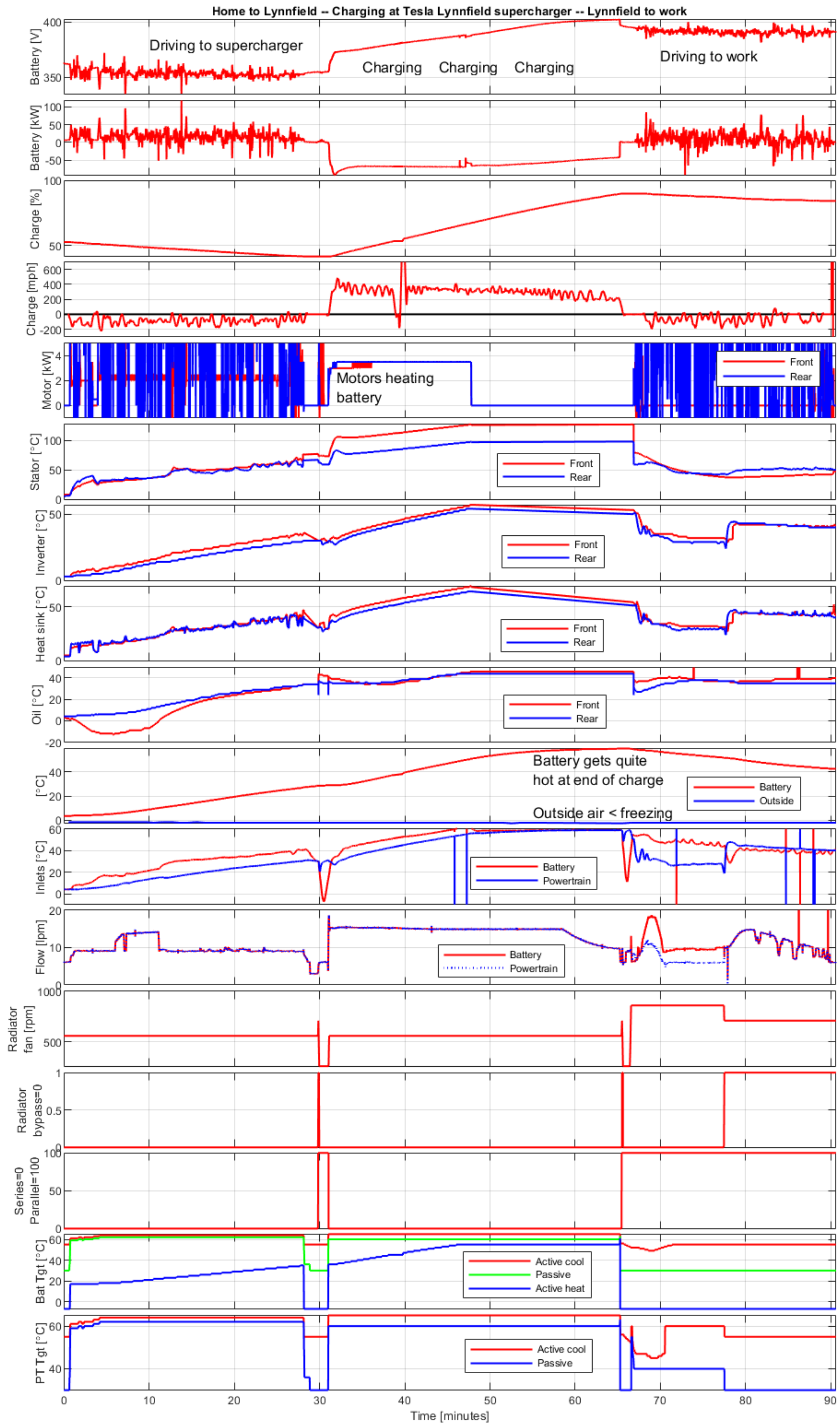

Figure 14. Topping off the battery at a Tesla supercharger.

Drag race

I wanted to explore the extreme performance of the Tesla Model 3 dual motor. In order to stay legal, I took my Tesla to New England Dragway in Epping, New Hampshire. They have “Street Night” on Wednesdays and Fridays. It was my first time racing and I needed to purchase a Snell-2015-rated helmet and a SFI Spec 3.2A/1 fire jacket.

Figure 15. Me in my Snell-2015-rated helmet and SFI Spec 3.2A/1 fire jacket.

I was never a fan of drag racing, so I knew little of the procedures. It showed in my first race. The quarter-mile track is followed by a 0.45-mile straightaway for slowing down. Unmindful of my high speed, I needed every bit of the straightaway on the first race. In subsequent races, I got on the friction brake right away after the quarter-mile mark.

I ran five races in total. My times are in the table. My reaction times got better with experience but were still quite slow. Note that the reaction times do not count in the 1/4-mile time. Those times are from start-of-roll. Of course, reaction time is very important in match racing with other cars. My times grouped closely showing that they are limited by the performance of the car rather than the driver. I made a video of drag race 1.

Race	RT [sec]	1/4-mile [sec]	1/4-mile [mph]
1	1.214	12.392	111.43
2	0.867	12.447	111.18
3	0.575	12.399	111.28
4	0.368	12.433	111.01
5	0.417	12.422	112.57

Zero on the time axis is start of roll. RT is the reaction time. Initially, the Tesla accelerates very quickly at 0.7g due to the 400 ft·lb (550 N·m) of torque. Above 50 mph the motors switch from constant torque to constant power and the car accelerates more slowly under a steady 425 horsepower (317 kW). The run ends at 111.43 mph and 12.392 sec. The rear permanent-magnet motor contributes more than the front induction motor, both to acceleration and to regenerative braking.

Figure 16. Map of New England Dragway.

Regenerative braking recovered 37% of the charge expended in the run, however, it did not slow the car by much. I had to strongly apply the friction brakes and the end of the run to keep from crashing into the gravel pit. The brake temperatures rise abruptly at the end of the run just before a hard right turn. The 1/4-mile race expended about 1 kWh of energy. The normal highway mileage for the Tesla is 3.6 miles/kWh. The car expended energy at 16× the normal rate during the 1/4-mile.

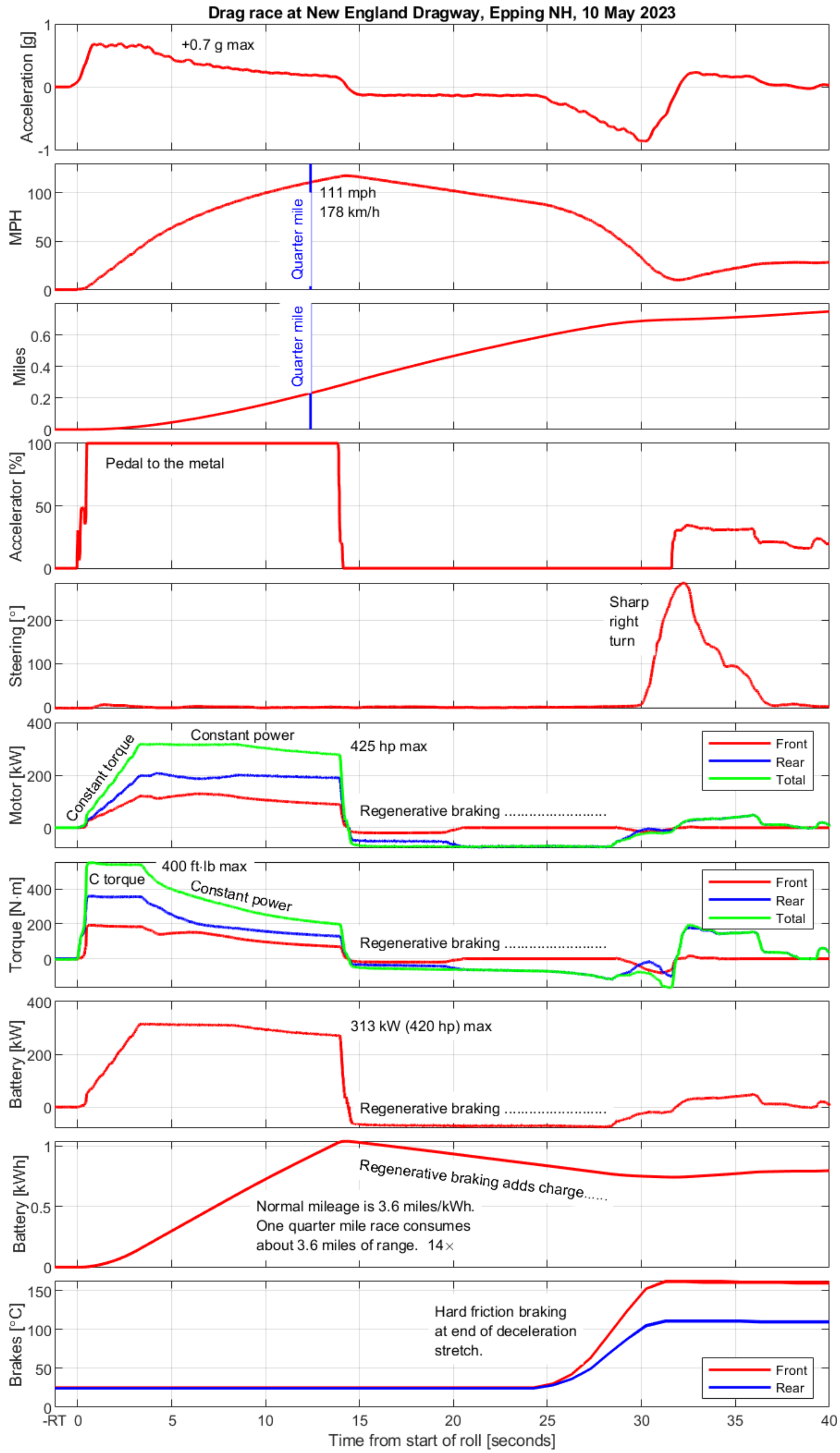

Figure 17. Drag race 1 data.Video.

Summary

Using the scan my tesla application was a revelation to me. It was very easy to set up and use. It prompted me to research the Tesla Model 3 and I gained insight into the engineering involved in building an electric car. As an electrical engineer, I was very impressed with the choices Tesla made. This project was an exercise in basic mechanics from first-year physics. I had not been there in a while.

Amund Børsand could charge more for the scan my tesla application in my opinion. He only collects $8.99 whereas the total cost of doing these measurements includes the price of the cable ($29.95) and the OBD-II scanner ($148.70). The cost of the application is incidental.

Amund thanks the people who contributed to the decoding the Tesla CAN bus codes on his home page:
https://www.scanmytesla.com/

Biography of the author

Bart Johnson was born in 1956 and raised in Edina, Minnesota. He holds a BEE from the University of Minnesota and a PhD from MIT in electrical engineering. He has held engineering positions at MIT Lincoln Laboratory, AT&T Bell Laboratories, and McDonnell Douglas/Boeing. Since 2000 he has been employed at several Boston-area startups and is currently Director of Electro-Optics Systems Engineering at Axsun Technologies. In his work as a laser engineer at Axsun, he has done theoretical modeling of wavelength-swept lasers for Optical Coherence Tomography (OCT). He is currently helping to develop a swept VCSEL for advanced OCT applications. Bart is the author of the book *Can't Be Trusted* about mental health in aviation. It is available on Amazon.com. Website: https://cantbetrusted.org/

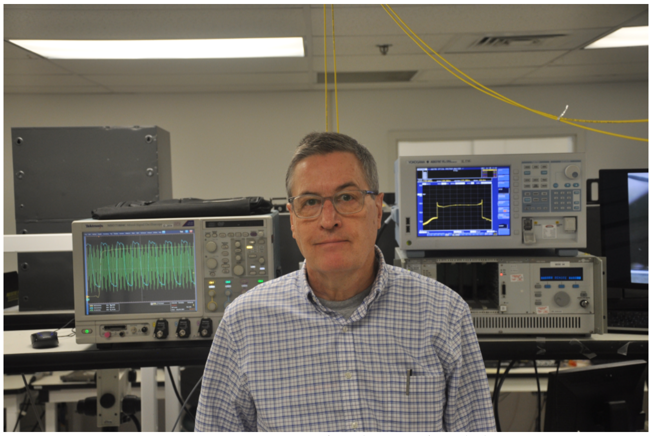

Figure 18. Bart in the optics lab.

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