Manufacturing Threshold Modeling

Abstract

This analysis documents my analysis of the SOC range implications of assuming a VHA threshold equal to 1.2146. The concern was that the SOC range will be excessive (>10%). I am using a Monte Carlo analysis here to estimate the actual SOC range based on the sampling the empirical distribution of the HPM10 ratio error.

I am guessing at the distribution of the A/D converter errors. I have seen data that indicates something in the range of 5 mV to 10 mV with a normal distribution. Note that I am ignoring random quantization errors because those can be minimized by averaging.

In [127…

```
# Load in libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import scipy.interpolate

VHA=1.2146 # This value is too low. It probably should be 1.24 V
```

Read in the Z22A SOC Curve

This SOC curve assumes a minimum operating voltage for the Z22A based on the wireless circuit.

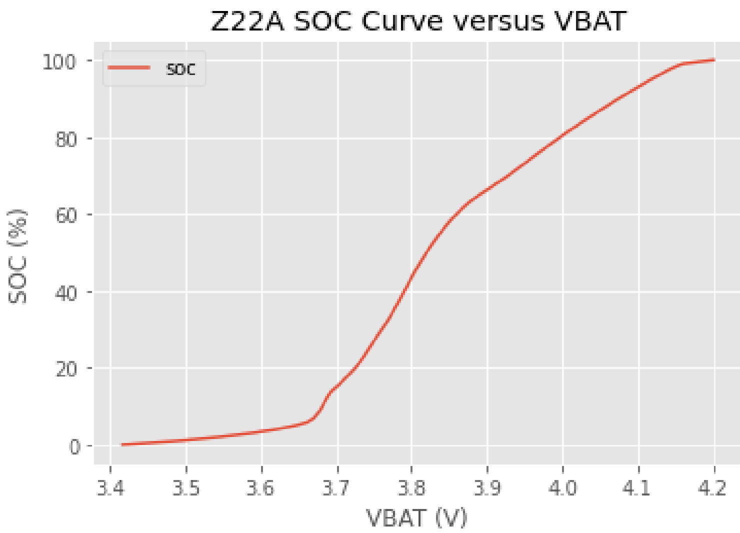
In [128…

```
dfSOC=pd.read_csv("Z22A.csv",sep="\t")
dfSOC['SOC'] = dfSOC['SOC'].str.rstrip('%').astype('float') / 100.0
SOCZ22A = scipy.interpolate.interp1d(dfSOC.VBAT, dfSOC.SOC)

x=np.linspace(3.417, 4.2, num=100)
z22A_soc_table = pd.DataFrame({'vbat':x,'soc':100*SOCZ22A(x)})
z22A_soc_table.plot.line('vbat','soc')
plt.title("Z22A SOC Curve versus VBAT")
plt.xlabel("VBAT (V)")
plt.ylabel("SOC (%)")
```

Out[128…

```
Text(0, 0.5, 'SOC (%)')
```



Read in the Empirical Ratio Data

Here is a sample of 6103 HPM10 ratios measured by production. Observe that while the bulk of HPM10 ratios are tightly bunched, there are a small number that are significantly different.

In [129…

```
df = pd.read_csv("RawRatio.csv")
display(df)
```

	Ratio
0	0.327312
1	0.328617
2	0.329617
3	0.331623
4	0.331720
...	...
6098	0.332991
6099	0.332991
6100	0.332991
6101	0.333009
6102	0.333018

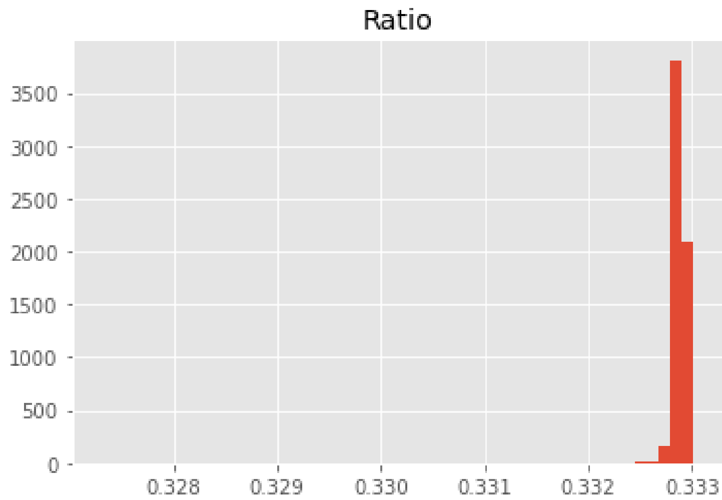
6103 rows × 1 columns

In [130…

```
print(f'Minimum ratio is {df.Ratio.min():.6f}.')
print(f'Maximum ratio is {df.Ratio.max():.6f}.')
print(f'Range is {df.Ratio.max()-df.Ratio.min():.6f}.')
plt.style.use("ggplot")
df.hist(bins=50)
```

```
Minimum ratio is 0.327312.
Maximum ratio is 0.333018.
Range is 0.005706.
```

Out[130…
```
array([[<AxesSubplot:title={'center':'Ratio'}>]], dtype=object)
```

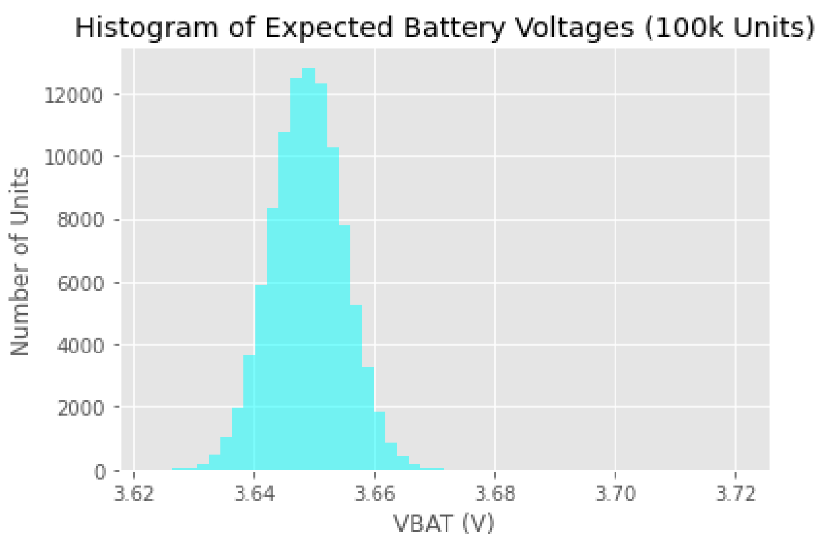


Compute the Battery Voltage Under Ratio and A/D Variation

In [131…
```
ratio=df.Ratio.sample(100_000, replace=True)
lsad=np.random.normal(loc=0,scale=0.002,size=100_000)
vbat = (VHA+lsad)/ratio
print(f'VBAT minimum is {vbat.min():.4f}V.')
print(f'VBAT maximum is {vbat.max():.4f}V.')
print(f'VBAT range is {vbat.max()-vbat.min():.4f}V.')
print(f'Notice how the range is quite a bit wider than where the bulk of the distribution
plt.hist(vbat.values, color='cyan', alpha=0.5, bins=50)
plt.title("Histogram of Expected Battery Voltages (100k Units)")
plt.xlabel("VBAT (V)")
plt.ylabel("Number of Units")
```

```
VBAT minimum is 3.6225V.
VBAT maximum is 3.7207V.
VBAT range is 0.0982V.
Notice how the range is quite a bit wider than where the bulk of the distribution resides.
```

Out[131…
```
Text(0, 0.5, 'Number of Units')
```

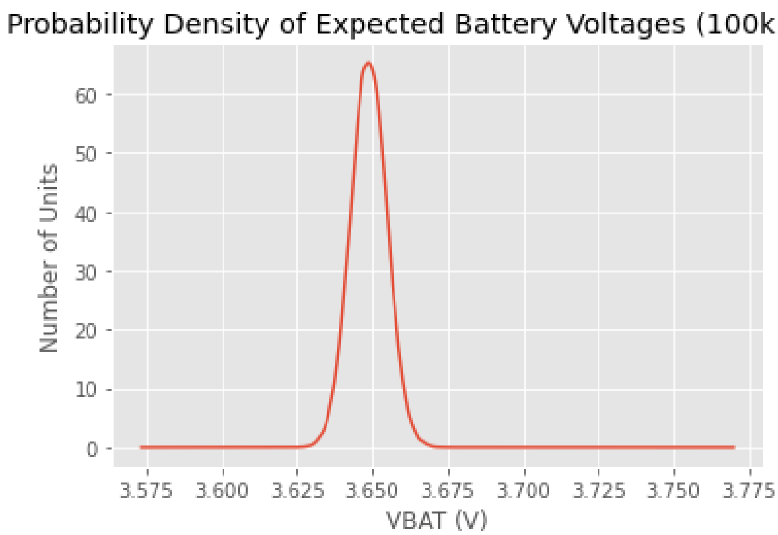


In [132…
```
vbat.plot.kde()
plt.title("Probability Density of Expected Battery Voltages (100k Units)")
```

```
plt.xlabel("VBAT (V)")
plt.ylabel("Number of Units")
```

Out[132…

```
Text(0, 0.5, 'Number of Units')
```



Compute SOC Variation Distribution

We now see how uncertainty in VBAT manifests in an uncertainty in battery SOC.

Assuming we will allow 1 out of 500 fail for SOC, we can compute the SOC range as follows.

In [133…

```
vTLow=np.quantile(vbat, q=0.001)
vTHigh=np.quantile(vbat,q=0.999)
print(f'Assume we set a VHA side threshold of {VHA:.4f}V.')
print(f'This VHA will map to a battery voltage range of {vTLow:.4f}V to {vTHigh:.4f}V.')
print(f'These battery voltage represent a SOC range of {SOCZ22A(vTLow):.1%} to {SOCZ22A(vT
```

```
Assume we set a VHA side threshold of 1.2146V.
This VHA will map to a battery voltage range of 3.6306V to 3.6694V.
These battery voltage represent a SOC range of 4.3% to 6.7%.
```

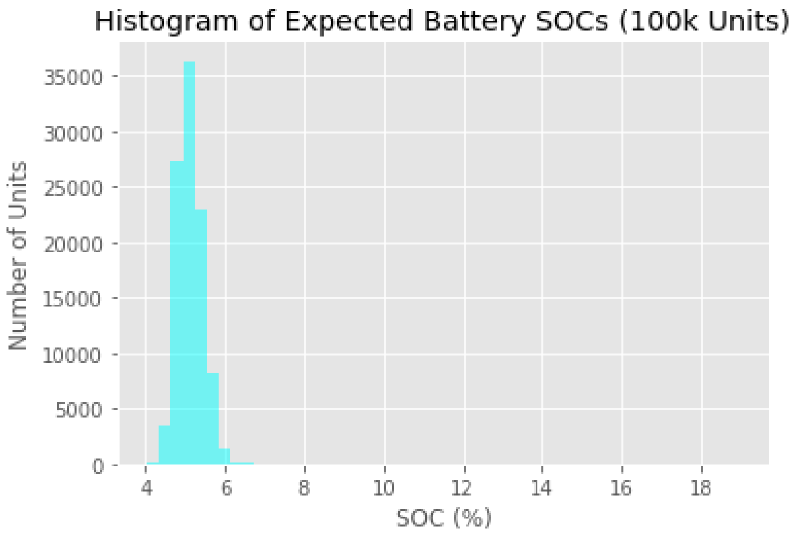
In [134…

```
# Given vbat values, I can generate the expected SOC values.
socz = SOCZ22A(vbat)
print(f'SOC minimum is {socz.min():.1%}.')
print(f'SOC maximum is {socz.max():.1%}.')
print(f'SOC range is {socz.max()-socz.min():.1%}.')
plt.hist(100*socz, color='cyan', alpha=0.5,bins=50)
plt.title("Histogram of Expected Battery SOCs (100k Units)")
plt.xlabel("SOC (%)")
plt.ylabel("Number of Units")
```

```
SOC minimum is 4.0%.
SOC maximum is 19.0%.
SOC range is 14.9%.
```

Out[134…

```
Text(0, 0.5, 'Number of Units')
```

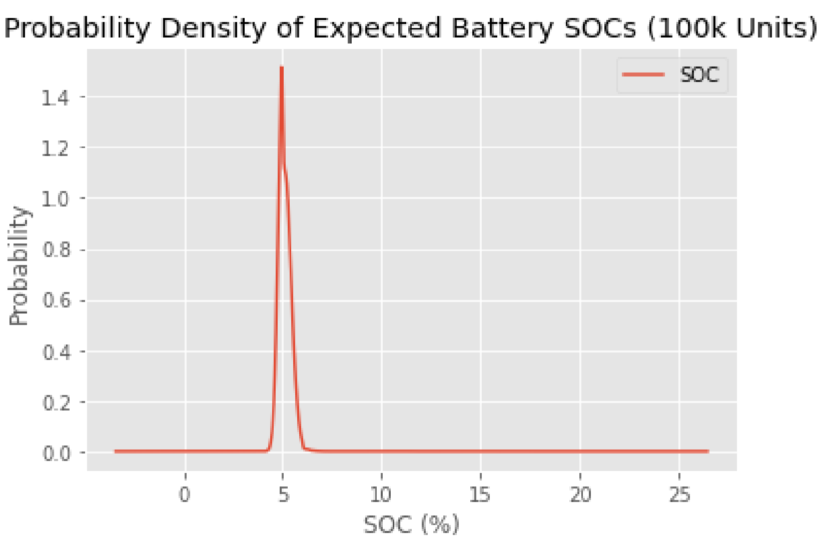


In [135…

```
sz = pd.DataFrame(socz,columns=['SOC'])
(100*sz).plot.kde()
plt.title("Probability Density of Expected Battery SOCs (100k Units)")
plt.xlabel("SOC (%)")
plt.ylabel("Probability")
```

Out[135…

```
Text(0, 0.5, 'Probability')
```



The issue with the Z22A is that the threshold is set on the portion of the SOC curve that is very flat.

Same Analysis for Accu60

Let's examine what happens when you use the same threshold with the Accu60/94 SOC.

Read in Accu60 SOC

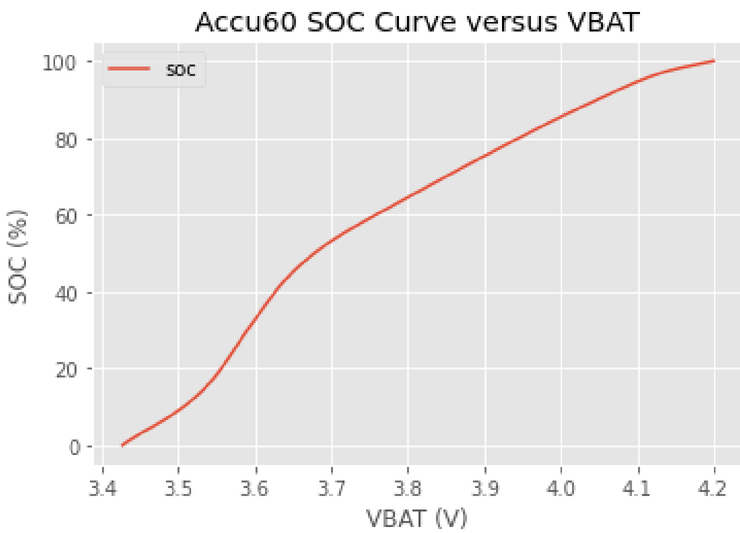
In [136…

```
dfSOC=pd.read_csv("Accu60.csv",sep="\t")
dfSOC['SOC'] = dfSOC['SOC'].str.rstrip('%').astype('float') / 100.0
SOC60 = scipy.interpolate.interp1d(dfSOC.VBAT, dfSOC.SOC)
x=np.linspace(3.427, 4.2, num=100)
Accu60_soc_table = pd.DataFrame({'vbat':x,'soc':100*SOC60(x)})
Accu60_soc_table.plot.line('vbat','soc')
plt.title("Accu60 SOC Curve versus VBAT")
```

```
plt.xlabel("VBAT (V)")
plt.ylabel("SOC (%)")
```

Out[136…

```
Text(0, 0.5, 'SOC (%)')
```



Compute the SOC Range

In [137…

```
print(f'Assume we set a VHA side threshold of {VHA:.4f}V.')
print(f'This VHA will map to a battery voltage range of {vTLow:.4f}V to {vTHigh:.4f}V.')
print(f'These battery voltage represent a SOC range of {SOC60(vTLow):.1%} to {SOC60(vTHigh
```

```
Assume we set a VHA side threshold of 1.2146V.
This VHA will map to a battery voltage range of 3.6306V to 3.6694V.
These battery voltage represent a SOC range of 40.9% to 48.6%.
```

Compute the SOC Distribution

The Varta batteries have a much higher SOC for a given threshold voltage.

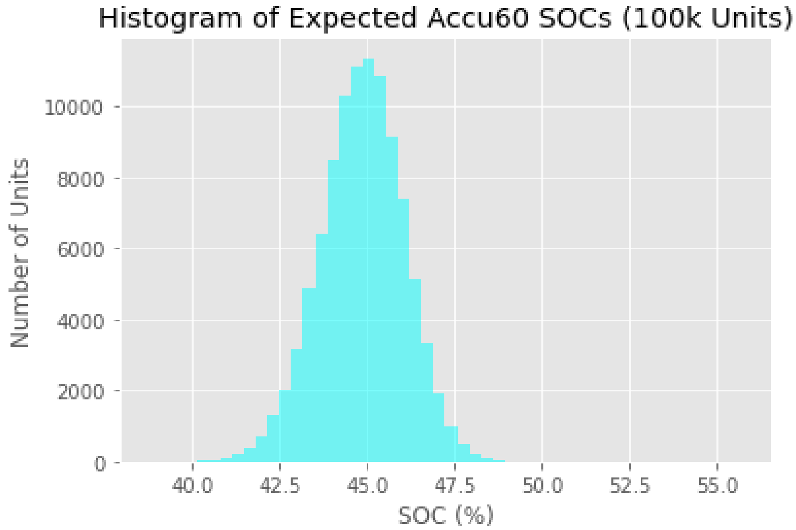
In [138…

```
soca = SOC60(vbat)
print(f'SOC minimum is {soca.min():.1%}.')
print(f'SOC maximum is {soca.max():.1%}.')
print(f'SOC range is {soca.max()-soca.min():.1%}.')
plt.hist(100*soca, color='cyan', alpha=0.5,bins=50)
plt.title("Histogram of Expected Accu60 SOCs (100k Units)")
plt.xlabel("SOC (%)")
plt.ylabel("Number of Units")
```

```
SOC minimum is 38.8%.
SOC maximum is 55.7%.
SOC range is 16.9%.
```

Out[138…

```
Text(0, 0.5, 'Number of Units')
```



In [139…
```
sa = pd.DataFrame(100*soca,columns=['SOC'])
sa.plot.kde()
plt.title("Probability Density of Expected Accu60 SOCs (100k Units)")
plt.xlabel("SOC (%)")
plt.ylabel("Probability")
```

Out[139…
```
Text(0, 0.5, 'Probability')
```