Benchmarking RF Front Ends Powered by DC-DC Converters Across a Discharging Battery

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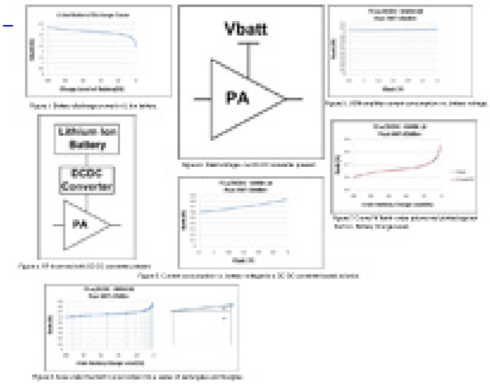
In the last decade mobile device users have seen unprecedented changes in technology. These changes have brought more functionality and lower cost to the overall handset market. Users are demanding more and more functionality in mobile devices, which comes at the cost of talk time. As more functionality is integrated into mobile devices, designers are faced with ever-increasing requirements for overall system efficiency and lower current consumption. In the face of these changes, there has been a push for designers to add DC-DC converters to power RF front ends. This is driving the need to evaluate RF components from a slightly different angle compared to the way it has been done in the past. In this paper, the authors would like to introduce a new approach to evaluating RF front end performance for current consumption when DC-DC converters are present.



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In the past, designers have followed a standard approach of comparing nominal RF front end performance at a given battery voltage. In non-linear modulations like GSM, it has been industry standard to specify RF front ends at 3.6 V. This comes from the nominal battery voltage of 3.7 V minus a 100 mV IR drop from the battery terminals to the power amplifier due to large battery current draw at peak power. The RF front end is specified across a battery voltage range for extreme conditions, but 3.6 V battery voltage is the point that most designers focus on to calculate nominal condition efficiencies and benchmark solutions. For linear modulations such as WCDMA, 3.4 V is normally where the comparisons are performed.

The approach of benchmarking at a fixed battery voltage comes into question when one considers the discharge of a real battery. Voltage changes as a battery discharges. Figure 1 illustrates the nominal battery discharge curve for a Lithium Ion battery, which is commonly found in many mobile devices today.

As Figure 1 depicts, the battery voltage can range from 4.2 V for a fully charged battery to less than 3.0 V for a completely depleted battery. Most current generation mobile devices power down their systems around the 3.0 to 3.2 V range, limiting the usage at these lower battery voltages.

Benchmarking RF front end current consumption to a fixed battery voltage can continue to be a valid approach when current does not vary by much across battery voltage. This case typically applies when there is no DC-DC converter present in the RF front end, as depicted in Figure 2. Measured results are shown in Figure 3. The current consumption for this GSM amplifier at 29 dBm varies slightly from 1.05 to 1.08 amps across a lithium-ion battery discharge. The current draw benchmark at 3.6 V provides a good estimate and is found to be 1.06 amps.

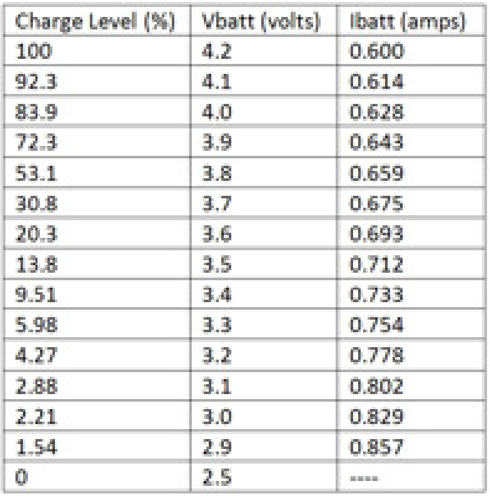
When a DC-DC converter is introduced to an RF front end, as illustrated in Figure 4, battery current varies much more as battery voltage changes. Measured performance of such a solution is shown in Figure 5. The current consumption for this GSM amplifier at 29 dBm varies from 600 mA to more than 800 mA as a lithium-ion battery discharges.

This large current change can be explained by taking a look at Equation 1. Battery current increases as battery voltage decreases when a DC-DC converter is present.

$$Ibatt = \frac{Vcc \bullet Icc}{Vbatt \bullet Efficiency_{(DCDC}}$$

Equation 1

As DC-DC converters become more of a standard for RF front end solutions, a new way of benchmarking these designs must be accounted for in order to accurately compare solutions as close to real-world usage a s possible. Comparing a DC-DC converter-based solution at a static voltage may lead designers to make false assumptions about current consumption for a particular solution. Improved accuracy can be had by taking the entire battery discharge curve into account. Averaging this curve provides a good single-point reference for benchmarking. Knowing the exact voltage at which the system will shut down is critical in this calculation as current consumption increases dramatically at extremely low battery voltages.



Charge Level (%)	Vbatt (volts)	Ibatt (amps)
100	4.2	0.600
92.3	4.1	0.614
83.9	4.0	0.628
72.3	3.9	0.643
53.1	3.8	0.659
30.8	3.7	0.675
20.3	3.6	0.693
13.8	3.5	0.712
9.51	3.4	0.733
5.98	3.3	0.754
4.27	3.2	0.778
2.88	3.1	0.802
2.21	3.0	0.829
1.54	2.9	0.857
0	2.5	----

Table 1. Captured Ibatt Data

The first step to calculating average current is to capture Ibatt data sweeping Vbatt across the battery discharge r ange. According to Figure 1, this range would be from 4.2 to 2.5 V for a lithium- ion battery. Front end modules are typically not specified below 2.9 V, so for this example, Vbatt is swept to 2.9 V in 0.1 V steps. Captured data for the solution in Figure 5 is shown in Table 1.

Average current can then be calculated according to Equation 2, where L is the battery charge level.

$$Ibatt_{ave} = \frac{1}{L1 - L0} \times \int_{L0}^{L1} Ibatt(L)\, dL$$

Equation 2

One approach to solving the integral in Equation 2 that is easily implemented in standard engineering software tools is to break up the area under the curve into geometric figures and calculating the area. Following the Riemann integral algorithm, the area under the curve is broken up into a series of rectangles, A1, as shown in Figure 6. Accuracy is improved further by accounting for the gap between the top of the rectangle, and the curve by adding a triangle, A2, and adding its area to the calculation.

Average current is then found by adding all the geometric area contributions and plugging the results into Equation 2.

$Ibatt_{ave}$=0.666A, Geometric Fit with Vbatt Stepped in 0.1 V Increments.

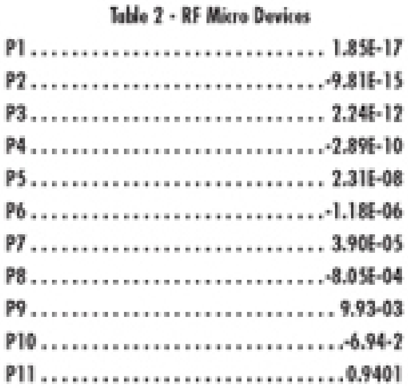


Table 2 - RF Micro Devices

P1	1.85E-17
P2	-9.81E-15
P3	2.24E-12
P4	-2.89E-10
P5	2.31E-08
P6	-1.18E-06
P7	3.90E-05
P8	-8.05E-04
P9	9.93-03
P10	-6.94-2
P11	0.9401

Table 2

Another more accurate approach to solving the integral is to fit the “Ibatt vs. Battery Discharge Level” curve to a polynomial equation and directly integrating. A tenth-order polynomial curve fit is chosen here as a check against the geometric approach, as shown in Equation 3 and compared against Ibatt in Figure 7. A good curve fit is achieved.

[2]

Equation 3 click to enlarge

Integrating Equation 3 is then straightforward, as shown in Equation 4.

Average Ibatt is then found by plugging Equation 4 into Equation 2. L0 is the battery level of 100 percent, and L1 is the battery level at the shutdown voltage of 2.9 V.

$\text{Ibatt}_{\text{ave}}$=0.665A, Curve Fit, Tenth Order Polynomial Equation

Results fall within 1 mA of the geometric approach.

[3]

click to enlarge Equation 4

In summary, the authors have presented a new approach to comparing RF front end solutions across a discharging battery. This approach gives the designers a much closer performance comparison to real-world environments as compared to benchmarking solutions at a static DC voltage. The authors conclude that to accurately benchmark RF front end solutions, the battery discharge curve needs to be taken into consideration and averages calculated in order to determine which RF solution can provide the best performance for current consumption.

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