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METHOD FOR GAUGING REMAINDER OF BATTERY

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Abstract

As users need to know when a battery has to be charged, it is important to represent the current battery status for battery-based systems. But the present battery gauging system has a major flaw. It has the limit of compensation system according to rapid input variance. For example, in cellular phone, gauging remainder of a battery uses only-voltage based method. In other words, it has no consideration for the loading current. As loading current grows higher, it will cause the output to switch the value rapidly. So finally the gauging system has a distortion value. Thus in this paper, we propose the novel battery gauging system using current-based method to achieve the precise measurement.

1. Introduction

In cellular phone, battery remainder gauging circuit consists of components as shown in Figure 1. Using a simple resistance divider, it measures the scaled battery voltage, and then converts analog voltage into digital value in ADC circuit. And finally MSM (Qualcomm Main Baseband Chipset) translates it into the present battery remainder value [5]. Here is a problem with the measurement system; it has no consideration for the loading current. In case that heavy loading current flows into the system, a momentary voltage drop of the battery will occur.

Keywords and phrases : gauging remainder, battery, ADC, Schmitt Trigger Circuit.

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By the way, ADC or GPIO in MSM consists of the Schmitt Trigger Circuit [2]. As this utilizes the Hysteresis property [4], it has a stable feature for the variance noise. Schmitt Trigger is a simple electronic circuit in which the input above or below the threshold obtains the constant output. And Hysteresis is a property of systems that do not instantly follow the forces applied to them but react slowly. That is, systems whose states depend on their immediate history. This is usually used for noisy input systems, but there is a major flaw. In this paper, we will mention that problem and propose the solution for that.

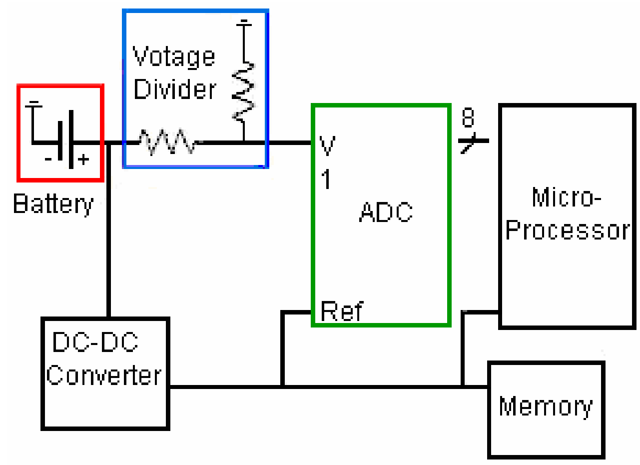

Figure 1. Battery remainder gauging system block diagram in the conventional cellular phone [5].

2. Schmitt Trigger Circuit

Schmitt Trigger Circuit [2] simply consists of transistor, resistor as shown in Figure 2. It can set the desired threshold voltage as adjusting a resistance value. In this Figure 2, if supply voltage is 10V, R_1 is 200 ohm and R_2 is 300 ohm, then the emitter voltage is 4V like equation (1) below:

$$V_E = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{200}{200 + 300} \times 10\text{V} = 4\text{V}. \quad (1)$$

And that time, input voltage equals to 4.7V like equation (2),

$$V_{in} = V_{in} + V_{BE} = 4\text{V} + 0.7\text{V} = 4.7\text{V}. \quad (2)$$

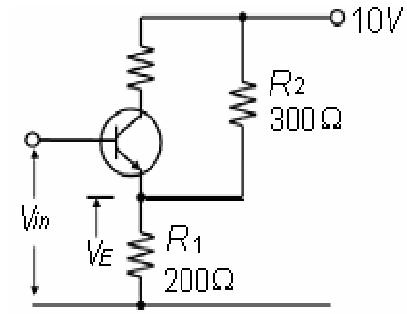

Figure 2. First circuit of Schmitt Trigger Circuit.

This means that transistor turns on above 4.7 threshold voltage. This is the basic circuit of Schmitt Trigger, and the second circuit adds one more transistor for the mediate amplification as shown in Figure 3. In Figure 3, if the input voltage is above 4.7V, then Q_1 is turned on, and similarly Q_2 is also turned on, finally the amplified current flow in the output.

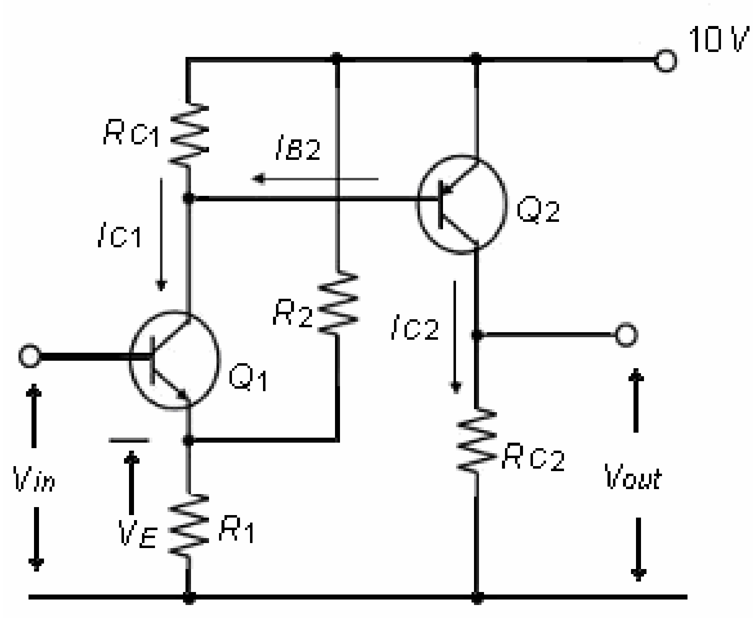

Figure 3. Second circuit of Schmitt Trigger Circuit [2].

But the problem of this circuit exists like following; if the input increases or decreases suddenly, output will reflect it and have a distorted value. So like Figure 4 as adding another transistor, this problem can be solved.

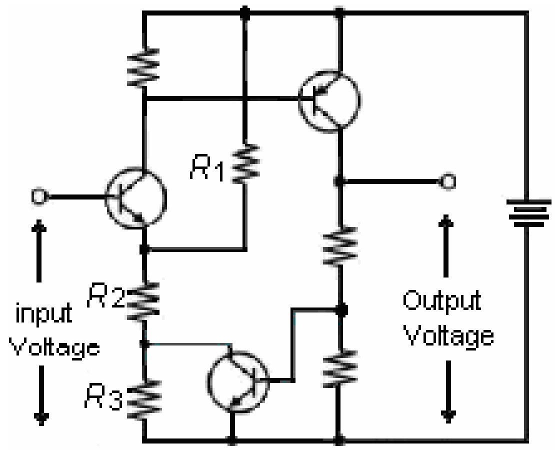

Figure 4. Final circuit of Schmitt Trigger Circuit [2].

As adding the third transistor, eventually the circuit gets two threshold voltages like Figure 5. One is the upper voltage threshold and another is the lower voltage threshold. The merit of this Schmitt Trigger Circuit is to have the stable property for switching input between the upper voltage threshold and the lower voltage threshold.

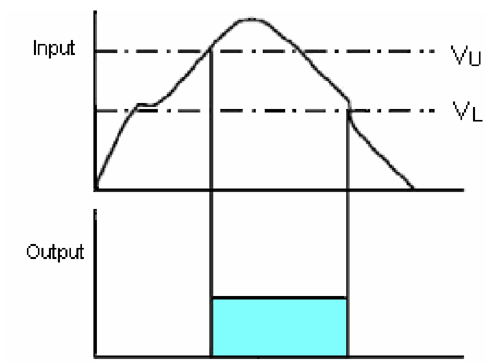

Figure 5. Final circuit of Schmitt Trigger Circuit [2].

3. Hysteresis Property

Hysteresis curve is as shown in Figure 6. When input increases, output changes at T, when input decreases, output changes at –T. In cellular phone, most GPIO consists of Schmitt Trigger Circuit which has this hysteresis property. Its representative symbol is as shown in Figure 7.

The advantage of hysteresis is noise immunity rather than single threshold. In case of single threshold, the noisy input signal will switch its output rapidly nearby threshold point.

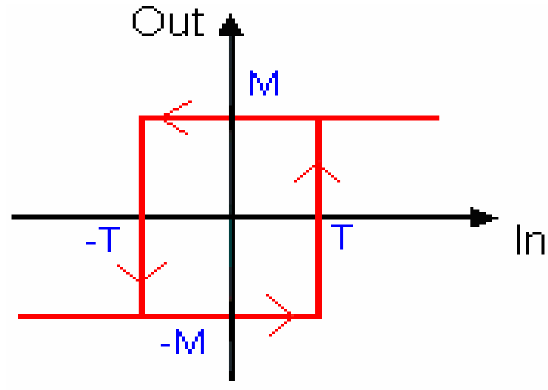

Figure 6. Hysteresis curve.

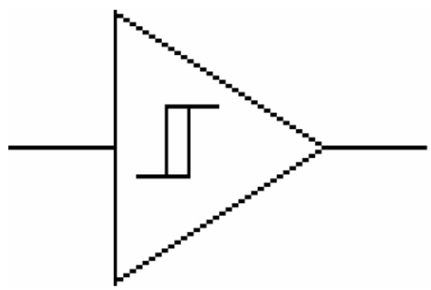

Figure 7. Schmitt Trigger Symbol.

4. Input Variance out of Hysteresis Margin

Hysteresis margin is the difference between upper threshold and lower threshold. For example, in cellular phone, if battery bar has total four steps and lower threshold voltage from four steps to three steps is 3.85V, upper threshold voltage from three steps to four steps is 3.90V, and then the hysteresis margin will be 0.05V. Recently Li-Ion or Li-Polymer battery [3] for cellular phone can be fully charged to 4.18V. And gradually it is discharged to 3.10V, eventually, device power will be off. The discharge curve is not linear; first it falls rapidly, soon it becomes a gentle slope. And at the end, it falls rapidly again. This total discharge time is divided by four (or three) steps, the battery remainder is displayed at LCD (or OLED). But this premise is like following: About 300mA constant current flows through the load. However in actual environment, the current consumption is not constant like this. In sleep mode, it consumes below 1mA, periodically it consumes about 5mA at idle mode as setting a slot cycle. And at traffic mode, it consumes about 300mA, at low signal area it consumes about 600mA max power. This light load and heavy load environment affects the battery voltage drop. At the light load below 10mA, it can neglect the battery voltage drop. But at the heavy load above 100mA, sudden battery voltage drop will occur. Experimentally, 0.09V drop per 100mA will occur, this value is out of hysteresis margin as mentioned above. Within hysteresis margin, input variance does not affect output. But without hysteresis margin, input variance cannot prevent output distortion. Actually, in cellular phone, software algorithm compensates for this distortion at each event. For example, when LCD turns on, it consumes 100mA, when motor turns on, it also consumes 100mA. And when power amplifier turns on, it consumes above 200mA ~ 600mA. So as mentioned above, 0.09V per 100mA drop compensation will be performed at each event. The detail is as shown in following Table 1. As you see, current consumption vs. voltage drop is nearly linear. So ADC computation [1] can be easily performed as fully charged voltage is 4.18V and its ADC max value is 255 in case of 8bit.

Here, there is critical problem. First, look-up table like Table 1 must be written one by one. Actually it is impossible task. Second, unpredictable event cannot be compensated for it.

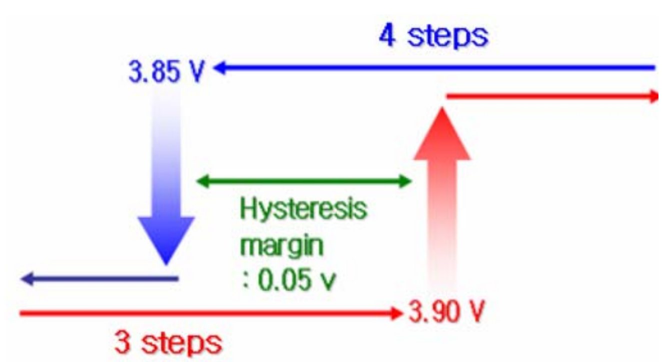

Figure 8. Hysteresis margin definition.

So, this paper first proposes the concept of "current compensation" to compensate sudden voltage drop.

Table 1. Current consumption and voltage drop and ADC compensation to each event

Event	ADC Compensation		
	Current consumption	**Voltage Drop**	**ADC Compensation**
LCD	100mA	0.09V	$255 * 0.09V/4.18V = ADC\ 5$
Keypad LED	50mA	0.05V	$255 * 0.05V/4.18V = ADC\ 3$
Motor	100mA	0.09V	$255 * 0.09V/4.18V = ADC\ 5$
Speaker amplifier	100mA	0.09V	$255 * 0.09\,V/4.18\,V = ADC\ 5$
Power amplifier	200 ~ 600mA	0.18 ~ 0.54V	$255 * 0.09V/4.18V = ADC\ 10$ $\sim 255 * 0.09V/4.17V = ADC\ 30$

5. Current Compensation for Battery Voltage Drop

In electronic circuit, the measure of current is so hard rather than voltage. In case of measuring the voltage, conventional oscilloscope or multi-meter can be used easily. If one of its probe contacts the ground and another contacts desired node, its voltage can be measured. But for measuring the current, a part of the circuit pattern must be cut. And at the cut both sides, it must be measured in serial. So actually it is not feasible method. The solution of this problem exists, "sense resistor concept" is right that as shown in Figure 9. In the pattern, small sense resistor, which does not affect impedance, can be connected with both end sides. And it can be simply computed as the differential voltage at both sides is divided by its resistance.

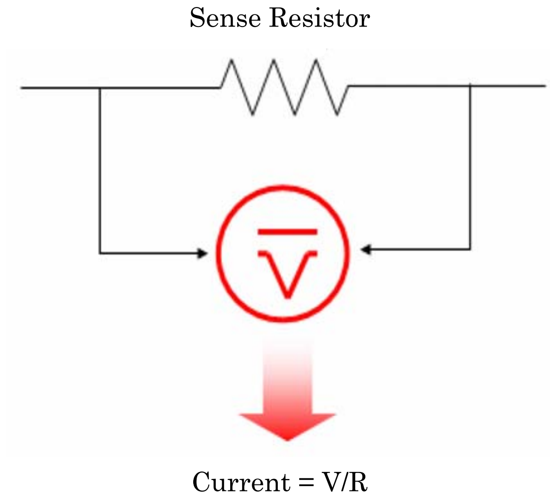

Figure 9. The measuring of current using “sense resistor”.

This circuit can simply be implemented. If the total current of cellular phone can be measured like this, conventional look-up table does not need to be written, and it can compensate for the sudden voltage drop by real time and precisely. The final block-diagram, which is proposed by this paper, is as shown in Figure 10. The sense resistor is located in front of DC-DC Converter, which supplies the desired constant voltage, and at both sides, current is computed by measuring differential voltage. And then through ADC, it converts it to digital signal, finally in micro-processor; it is compensated for battery voltage drop. In case of small input variance, conventional voltage-based method still will be used. And it will be able to use the property of Schmitt Trigger. But in case of large input variance out of hysteresis margin, it will be able to use this ‘current-based method’. So it will accomplish the precise and real-time battery remainder systems.

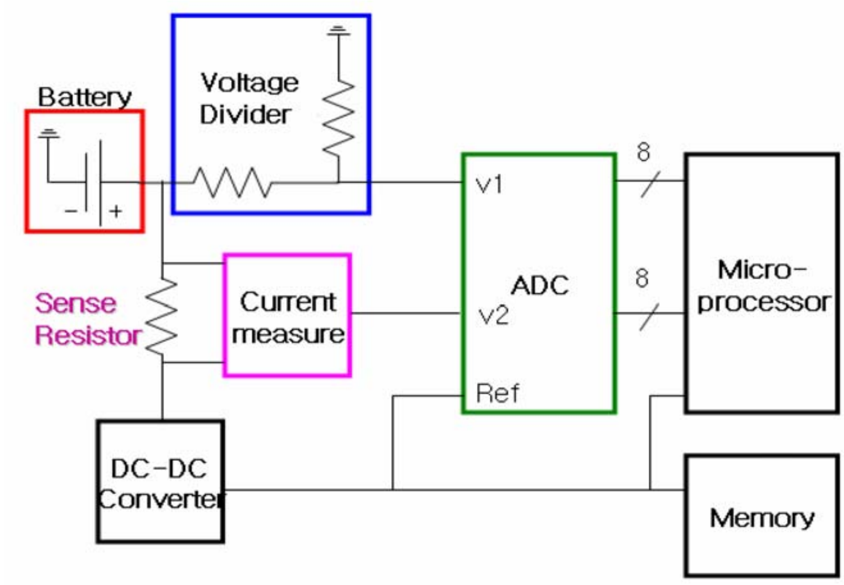

Figure 10. The final block-diagram using "current compensation structure".

6. The Verification of Experimental Result

In cellular phone, as variable event occurs, predictable result will be like the following Table 2.

Table 2. Voltage-based (conventional) vs. Current-based (proposed method) comparison

Actual Case	Voltage-based compensation	Current-based compensation
MP3 mode	LCD (5) + Key LED (3) + Speaker (5) = 13 Accuracy: 80%	LCD (5) + Key LED (3) + Speaker (5) + other consumption (2) = 15 Accuracy: 100%
Call mode	LCD (5) + Key LED (3) + PAM (10) = 18 Accuracy: 78%	LCD (5) + Key LED (3) + PAM (10) + LNA (5) = 23 Accuracy: 100%
Camera mode	LCD (5) + Key LED (3) + Camera (?) = 8 Accuracy: 78%	LCD (5) + Key LED (3) + Camera(5) = 13 Accuracy: 100%

In Table 2, in first case, let us assume that user plays MP3. In conventional method, the ADC sum of LCD, Key LED and Speaker is total 13. But this is not actually precise value. Actually the other consumption (ex, Multimedia chip) exists, so its precise value is 15. In second case, likewise, conventional method ignored LNA (Low Noise Amplifier) consumption. In last case, Camera ADC value does not exist in the LUT in conventional method. But in proposed method, as measuring the precise camera consumption, we can obtain accurately total compensation value without complex LUT.

7. Conclusions

In cellular phone, battery remainder system uses the voltage-based method. But this is not considerable for the load current. As load current is larger, sudden voltage drop will occur. And as load current is smaller, battery voltage will be returned. So, battery remainder display will switch rapidly. Conventional ADC or GPIO consists of Schmitt Trigger Circuit; it has strong property for input variance. But if the heavy load current through the system, input variance will be out of the hysteresis margin, eventually output will have a distortion value. For this compensation, previously look-up table is written and applied to each event. But this is the limit for a lot of case. Finally, this paper first proposed the concept of “current-based method” to compensate for sudden battery voltage drop. And it can provide users with the precise and real-time battery remainder information.

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