Mechanism and Optimized Design of Vehicle Quiescent Current

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Abstract. This paper analysed the quiescent current generation mechanism of vehicles and the four stages of quiescent current presentation during the vehicle rest process. Then the quiescent current is optimized from the perspective of ECU and vehicle electrical design. Finally, standardized recommendations for test rectification were proposed.

1. Introduction
The vehicle quiescent current refers to the vehicle's Power-OFF current, when the key locked, that is the current consumed by the electrical system to maintain the quiescent function after the electrical system enters into the sleep state. With the improvement of the electrification and intellectualize of vehicle, the number of electronic equipment and controller used on vehicles increasing, which averagely from 30 in year 2006 to 40 in year 2018 [1], the quiescent current consumption situation of the vehicle becomes very serious. The excessive quiescent current consumption can cause the battery to lack of electricity which results in vehicle cannot be started normally after storage period. Frequent loss of power also affects the reliability and lifetime of the battery. A research on the mechanism and optimized design of vehicle quiescent current has become an issue that cannot be ignored.

2. Vehicle quiescent current generation
The quiescent current of vehicle is the sum of the quiescent current of each electrical controller. Now we take a BCM as an example to introduce the mechanism of quiescent current, Figure 1. When the controller enters the sleep state, the ROM of the microcontroller stores data such as error code and user preference setup, this still requires current. Another example is that, analog processing module, digital processing module, the high frequency receiving circuit module and the CAN bus interface module need to be maintained in the monitoring state to ensure that the BCM can react to some wakeup signal such as RKE/PE, anti-theft alarm signal or ignition signal. In addition, Electrolytes generally contain impurities that can cause load leakage current, which is also an important part of the quiescent current. From this, we can conclude that the controller generates quiescent current for four main reasons: clock circuit operation, memory module operation, monitoring function and component leakage current.
Table 1 gives the quiescent current reference value for some main ECUs of a vehicle. Among them, BCM, GW, IC, PEPS, EMS, MP5 have comparatively large quiescent current consumption due to more function and more internal modules. And as AC needs to record the user settings, ACU and the ESC need to monitor signals of some sensors, and T-BOX needs to memorize the vehicle state and GPS data for a period of time, they also have large quiescent current.

| No | ECUs | Main quiescent function | Qc reference (mA) |
|----|------|-------------------------|-------------------|
| 1  | BCM  | memory, monitoring      | ≤5                |
| 2  | GW   | memory, monitoring      | ≤3                |
| 3  | AC   | memory                  | ≤1                |
| 4  | ESC  | memory, monitoring      | ≤0.5              |
| 5  | ACU  | memory, monitoring      | ≤0.5              |
| 6  | DSCU | memory                  | ≤1                |
| 7  | IC   | clock, memory, monitoring | ≤3            |
| 8  | PEPS | memory, monitoring      | ≤5                |
| 9  | EMS  | memory, monitoring      | ≤3                |
| 10 | MP5  | clock, memory           | ≤2                |
| 11 | EBS  | memory, monitoring      | ≤0.3              |
| 12 | T-BOX| Memory, intermittent wake-up | ≤1.5 (wakeup state 100mA) |
| 13 | DVR  | memory                  | ≤0.1              |
3. Four stages of vehicle quiescent current

We collected some quiescent current data of vehicle, and it is found that the quiescent current has four relatively stable stages as the curve shown in Figure 2. After IGN OFF, the vehicle quiescent current is maintained at 1.5A, and after 5min, it enters the second stage, maintaining 0.5A. After 5min, it enters the third stage, maintaining 0.02A. After 5min, it enters the fourth stage and appears 0.1A periodic current.

![Figure 2. Four stages of Vehicle Quiescent Current](image)

Taking general design of the vehicle's electronic control, the quiescent current stage of the vehicle is analysed. In the first stage, IGN OFF, the most electrical function stops working, but B+ is still powered, that the controller does not enter the sleep state, and the bus is also awake. 5min after IGN OFF, some controllers enter the self-sleep state, but the bus is still awake. In the third stage, the bus enters the sleep state and controls all ECUs to enter the sleep state. At this time, no message is sent on the bus. The quiescent current test value at this stage should correspond to the design value. In the fourth stage, some individual controllers, such as PEPS, start to periodically wake up to send key-seeking signals, and T-BOX periodically uploads vehicle state data. At this time, the bus also enters the period wake-up stage, that is to say, the quiescent current has a periodic peak.

4. Optimized design method for vehicle quiescent current

4.1. Component Design

Method of optimizing the quiescent current of components generally includes 3 classes: (1) reduce clock consumption such as reduce switching clock speed; (2) reduce the quiescent current consumption of ECU’s waking-up process, for example, reduce the scanning frequency of the wake-up signal detection circuit, and use as many microprocessors as possible with sleep function. For the function modules that do need long-term work, we can also take intermittent working strategy as well as reduce the duty cycle of awake state to sleep state; (3) control ECU manufacturing process to improve the performance of the controller. The quiescent current of internal sub-circuit of the controller should meet certain reference values, as shown in Table 2 [2], the controller quiescent current value is 2.4606mA, and the design value requires 2mA. It is obvious that the quiescent current of sleep capacitor Ckt is too large (generally 10^-3mA) according to practical value, and the capacitor should be replaced. Production process of the...
management controller is also important for controlling the quiescent current of ECU. Highly-purified insulating materials are used, and there should be no pseudo soldering or short circuit.

### Table 2. Worst Case Circuit Analysis result of an ECU

| Sub-Circuit               | Quantity | Qc reference | Qc real value | Subtotal |
|---------------------------|----------|--------------|---------------|----------|
| Regulator                 | 1        | $10^{-1}$    | 0.18          | 0.18     |
| Microcomputer             | 1        | $10^{-2}$    | 0.03          | 0.03     |
| Sleep Data Circuit        | 1        | $10^{-1}$    | 0.006         | 0.006    |
| Serial EEPROM             | 1        | $10^{-3}$    | 0.003         | 0.003    |
| Sleep Capacitor Ckt       | 1        | $10^{-1}$    | 0.456         | 0.456    |
| Inputs-Type A             | 2        | $10^{-1}$    | 0.4           | 0.8      |
| Inputs-Type B             | 3        | $10^{-2}$    | 0.06          | 0.18     |
| Inputs-Type C             | 12       | $10^{-2}$    | 0.0628        | 0.7536   |
| Outputs-Type A            | 5        | $10^{-3}$    | 0.001         | 0.005    |
| Outputs-Type A            | 7        | $10^{-3}$    | 0.001         | 0.007    |
| Miscellaneous Leak        | 1        | $10^{-2}$    | 0.04          | 0.04     |
| **Total**                 |          |              | **2.4606**    |          |

#### 4.2. Vehicle electrical design

Vehicle electrical design optimization for quiescent current generally includes 5 aspects: (1) Optimize the network architecture design, minimize the number and quiescent power consumption of electrical appliances connected to B+ electricity, take Domain Controller Unit-based architecture, such as integrating ADAS-related functions into the self-driving domain, integrating IC, Recorder, and MP5 into smart cockpit domain (Figure 3); (2) Optimize the network wake-up strategy to avoid false wake-up and add the network wake-up confirmation step [3] (3) Optimize the electrical structure design, improve the electrical insulation level, and design the isolation circuit to avoid the quiescent current caused by short circuit; (4) take measures to avoid abnormal operation from users, such as the small lamp alarming if not turned off or sleeps autonomously after the lock is locked; (5) add power control master switch to cut off the quiescent current consumption of controller that does not play actual role in sleep mode.

![Figure 3. E/E Architecture of Singulato](image)

#### 5. Vehicle quiescent current test rectification

Conduct standard quiescent current test on vehicle. If the quiescent current is large, firstly remove the fuse one by one and locate the loop with large quiescent current. Then check ECU, load of the fault circuit, switch and harness, battery one by one. Generally, there are four types of possible situations in which the quiescent current of vehicle is too large: (1) ECU or load fails, causing the controller unable to sleep; (2) electrical line failure, such as abnormal adhesion of the relay, insulate wire become short
circuit, and switch contact fails which cannot be shutdown normally, so that the load cannot stop working and ECU cannot sleep; (3) communication is blocked, for example, the CAN bus is damaged, the signal sent abnormally or even unable to communicate, these can also cause ECU awake; (4) the battery is damaged and the self-discharge is large.

Conclusion
With the increasing number of electrical & electronics appliances for vehicles, the problem of quiescent current is becoming more and more prominent. However, there is no clear standard for the design and design of quiescent current in the whole country. The circuit simulation can be used as a start point to analyze the quiescent current of the controller and the vehicle's various electrical circuits, followed by standardized work. At the same time, collect the possible failure mode of the vehicle's quiescent current and improve the empirical database is also important. All this should be done so that all stages of the vehicle's quiescent current management have rules to follow.

References
[1] Information on http://www.greencarcongress.com/2015/07/20150729-berger.html
[2] Yang Gao, How to reduce the quiescent current of automotive electronic controllers, EDN China, 2019, 10
[3] Jianhui Ma, Yun Zhang, Dairong Hu, Changqing Sun, Low power design and realization of car CAN node, Outlook of Electronic Technology. 2018, 25 (3) 42 - 44.