Tesla Roadster v2.x
TPMS (Baolong) Engineering
v1.0 2020-06-17

Introduction

This document describes the TPMS system in the Tesla Roadster v2.x vehicle, as manufactured by Baolong. It documents the hardware arrangements, as well as communications protocols used by this system. The information here is neither approved nor endorsed by Tesla and has been derived via black box methodologies.

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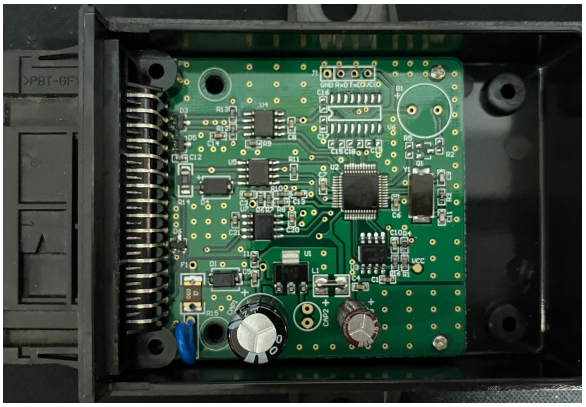
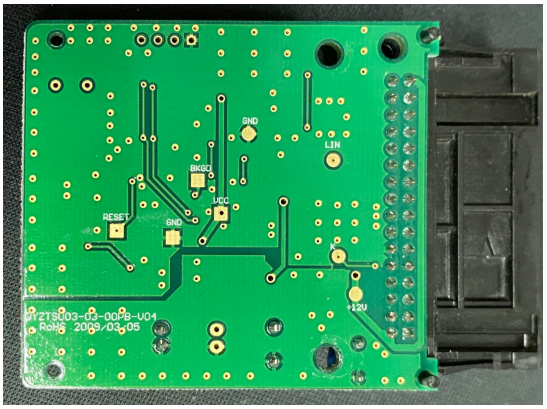
Components

The system is composed of:

1. One Baolong ECU (in dashboard area)
2. One Baolong Front Antenna (in front of car)
3. One Baolong Rear Antenna (in rear of car)
4. Tesla VMS (in passenger footwell)
5. Tesla/Baolong TPMS Engineering Tool
6. Baolong Wheel sensors

ECU





The circuit itself contains:

- U2 a Freescale HCS08 Microcontroller (MC9508DZ16)
- U3 a Intercil 4K SPI EEPROM (X5043)
- U4 a NXP CAN transceiver (TJA1050)
- U5 a NXP LIN transceiver (TJA1020)
- U7 a Freescale ISO K-line serial link interface (33290)

Front Antenna

Rear Antenna

Tesla VMS

TPMS Engineering Tool

Baolong Wheel Sensors

Network Connection Arrangement

The network connection arrangement is as follows:

1. Each of the four wheels has a Baolong TPMS sensor embedded into the inflator valve. When the vehicle is in motion, each sensor transmits its unique 32bit ID, along with the measured pressure and temperature of the tyre, over short range 315MHz radio waves. The communication for this is standardised, and well supported by TPMS tools. Note that each sensor includes a small battery with an expected lifetime of around 3-7 years (depending on distance driven).

2. The front and rear antennas are identical except for firmware (and colour of housing). They are programmed with 4 tyre IDs (stored in non-volatile memory), listen for radio transmissions from the four TPMS sensors in the wheels, and store that temperature and pressure data in volatile memory. The antennas have a LIN bus connection, shared between the two antennas and the Baolong ECU, with the antennas acting as slaves.

3. The ECU has several network connections.

    a. A LIN bus connected to both the front and rear antennas. The ECU acts as master, polling each antenna for their recorded pressure and temperature data for each wheel. In addition, LIN bus commands exist to program the four tyre IDs into the antennas, as well as to read back the pre-programmed tyre IDs.

    b. A K-Line bus connected to the OBDII connector in the driver's leg area, as well as the DIAG port in the passenger footwell. This operates on an async protocol, over K-line physical 1 wire, at 5volt levels, 9600N81. The ECU acts as a slave, and will respond to proprietary protocol commands on this bus (from the TPMS engineering tool). Commands exist to read and write tyre IDs.

    c. A CAN bus connected to the instrumentation CAN bus, running at 1MHz, and connected to both the VMS and DIAG connector. The ECU will periodically transmit status, pressure and temperature data, to the VMS on CAN IDs 0x343, 0x344, and 0x345.

4. The VMS connects to the ECU on instrumentation CAN bus. It passively receives the status, pressure, and temperature data from the TPMS ECU, and processes it for display on the VDS as well as raising alerts.

5. In order to read or program tyre IDs from/to the Baolong TPMS ECU, an engineering tool used to be sold by Tesla. This tool uses 315MHz radio communications to trigger

(wake up) the TPMS sensors in each wheel, and store in RAM. The tool can then be connected to the OBDII port in the vehicle (the K-Line bus pin) and a command issued (over K-line) to program the TPMS ECU with these new tyre IDs. The TPMS ECU will then in turn program both antennas using LIN bus messages. In addition, the tool can issue a query to the TPMS ECU to read back the recorded tyre IDs.

Connector Pinouts

Baolong TPMS ECU

Pin	Function	Notes
1	GND	Ground plane
2	+12V	Power in, from fuse 7, 10A
5	K-line bus	Diagnostics K-line bus
14	GND	Rear antenna Ground
15	CAN1-H	Instrumentation CAN high signal
16	+12V	Rear antenna Power
17	+12V	Front antenna Power
18	LIN bus	Connected with 30
22	GND	Front antenna Ground
30	LIN bus	Connected with 18
31	CAN1-L	Instrumentation CAN low signal

Baolong TPMS Antennas

Pin	Function	Notes
1	GND	Ground plane
2	+12V	Power in, from fuse 7, 10A
3	LIN bus	Diagnostics K-line bus

OBDII Connector

The K-line bus is exposed on pin #.... on the OBDII connector.

Pin	Function	Notes
7 12	K-Line Bus	Diagnostics K-line bus

DIAG Connector

The relevant DIAG port pins are:

Pin	Function	Notes
3	K-Line Bus	Diagnostics K-line bus
1	CAN-H	Instrumentation CAN bus (high signal)
6	CAN-L	Instrumentation CAN bus (low signal)

LIN Bus Communications

The LIN Bus is used to connect the Baolong ECU to the front and rear antennas. A single bus is used, with the ECU acting as master, polling each antenna for their recorded pressure and temperature data for each wheel. In addition, LIN bus commands exist to program the four tyre IDs into the antennas, as well as to read back the pre-programmed tyre IDs.

The LIN bus operates at 9600baud, LIN version 1.x, at 12v levels.

Each LIN bus frame is composed of:

- An ID (with parity bits)
- 8 bytes of data
- A single byte checksum

For simplicity, the table below shows normalised IDs, without parity added.

ID	Function
0x10	Set the tyre IDs for the front tyres in front antenna
0x11	Set the tyre IDs for the rear tyres in front antenna
0x12	Set the tyre IDs for the front tyres in rear antenna
0x13	Set the tyre IDs for the rear tyres in rear antenna
0x14	Read the tyre IDs for the front tyres in the front antenna
0x15	Read the tyre IDs for the rear tyres in the front antenna
0x16	Read the tyre IDs for the front tyres in the rear antenna
0x17	Read the tyre IDs for the rear tyres in the rear antenna
0x23	Read the tyre data (pressure and temperatures) from the front antenna
0x24	Not decoded, but related to front antenna (maybe status poll)
0x33	Read the tyre data (pressure and temperatures) from the rear antenna
0x34	Not decoded, but related to rear antenna (maybe status poll)

Note that the tyre temperature and pressure data is as per CAN bus message 0x344. The tyre IDs are presented as left then right tyres. Both front and rear antennas hold the IDs for all four tyres.

K-Line Bus Communications

The K-Line Bus is used to program the Baolong TPMS ECU. It is connected to both the OBDII connection in the driver's leg area, as well as the DIAG port in the passenger footwell. This operates on an async protocol, over K-line physical 1 wire, at 5volt levels, 9600N81. The ECU acts as a slave, and will respond to proprietary protocol commands on this bus (from the TPMS engineering tool). Commands exist to read and write tyre IDs.

The command and response frames are 19 bytes, arranged as follows:

- 1 byte 0x0F frame start
- 1 byte command/response code
- 16 bytes of data
- 1 byte 0xF0 frame end

The command to read the TPMS tyre IDs is 0x04. An example looks like this:

```
Tx 0F 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 F0
Rx 0F 05 01 01 0F D3 01 01 0F D8 01 01 0F 8A 01 01 1C 14 F0
```

Note that the response code for reading tyre IDs is 0x05. The tyre IDs are presented, 4 bytes for each ID, in the order front-left, front-right, rear-left, rear-right.

The command to write the TPMS tyre IDs is 0x03. An example looks like this:

```
Tx 0f 03 a1 a2 a3 a4 b1 b2 b3 b4 c1 c2 c3 c4 d1 d2 d3 d4 f0
Rx 0f 09 a1 a2 a3 a4 b1 b2 b3 b4 c1 c2 c3 c4 d1 d2 d3 d4 f0
```

Note that the response code for successfully writing tyre IDs is 0x09, The tyre IDs are presented, 4 bytes for each ID, in the same order front-left, front-right, rear-left, rear-right.

A bad write is indicated by a response code other than 0x09. With antennas disconnected, response code 0xcc has been observed:

```
Tx 0f 03 a1 a2 a3 a4 b1 b2 b3 b4 c1 c2 c3 c4 d1 d2 d3 d4 f0
Rx 0f cc 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 f0
```

K-Line / LIN Bus Interaction

Reading the tyre IDs shows no new traffic on the LIN bus, indicating that the tyre IDs are stored in the ECU. The tyre IDs can indeed be read from the ECU directly (over K-line) with no antennas connected.

By comparison, writing tyre IDs to the ECU involves:

1. Using K-line 0f 03 …. F0 command to write the IDs to the ECU
2. The ECU then uses LIN to write the IDs to each antenna in sequence
3. The ECU then uses LIN to read back the IDs from each antenna in sequence
4. Should everything match, the ECU then replies 0f 09 … f0 to confirm the write, otherwise it returns an error response such as 0xcc

CAN Bus Communications

The TPMS ECU and VMS communicate over the instrumentation CAN bus, at 1MHz. We have identified three actively transmitted messages from the TPMS ECU, each at an interval of approximately 1000ms:

- 0x343
- 0x344
- 0x345

We have decoded the 0x344 ID as follows:

0x344 TPMS Status Message

- B1 front-left tyre pressure (psi*2.755)
- B2 front-left tyre temperature (+40Celcius offset)
- B3 front-right tyre pressure (psi/2.755)
- B4 front-right tyre temperature (+40Celcius offset)
- B5 rear-left tyre pressure (psi*2.755)
- B6 rear-left tyre temperature (+40Celcius offset)
- B7 rear-right tyre pressure (psi*2.755)
- B8 rear-right tyre temperature (+40Celcius offset)

Each data byte is treated as a single 8 bit unsigned integer, then scale/offset factors applied as follows:

- Pressures in PSI are obtained by dividing the byte value by factor 2.755.
  (for example, 40psi is represented by value 110)

- Temperatures in CELCIUS are obtained by subtracting offset 40 from the byte
  (for example, 20celcius is represented by value 60)

Antenna Bug

Random TPMS failures have been reported by many Tesla Roadster owners. These failures are addressed by Tesla by a replacement of one antenna.

Investigation has shown that the tyre IDs stored in the antennas can become out of sync with those in the ECU. The data shown and LIN bus clearly shows the two antennas with different recorded tyre ID sets. The data appears corrupted in one, and looks like temperature and pressure data (message IDs 0x23 or 0x33).

Deliberately recreating this situation shows that while the ECU polls tyre IDs from the antennas, it will not attempt to correct incorrect IDs stored in the antennas.

With access to the K-line bus, a simple fix is to re-write the tyre ID set to the Baolong TPMS ECU. The ECU will then in turn re-write this to both antennas, as the system will resume normal operation.

It is theorised that the cause of this may be:

- A loose connection on the LIN bus connector of one or more antennas (or of the TPMS ECU).

- The vehicle passing over a road bump, or other cause to make the connection corrupt a data packet on the LIN bus.

- This to happen during a request for reading tyre data from the other antenna, and for the ID to be corrupted (including parity) to a command to write the antenna addresses.

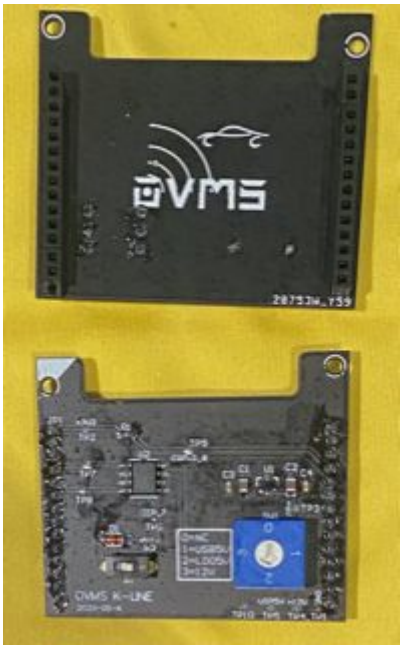
- While the above is fairly unlikely (requiring several bits to be flipped), given the polling frequency, loose connection, and vibration from vehicle travel, it is certainly possible and would lead to the corruption shown.

It should be noted that this arrangement is no longer used by Baolong in their system for the Tesla Model S (where the antenna and ECU are integrated into one single module, and the LIN bus connection no longer used).

OVMS K-Line Option

The result of this work has been the release of a K-Line option for OVMS v3.

This option provides for an interface between OVMS and the Baolong TPMS ECU, over K-Line bus. It requires the normal OVT1 vehicle cable and a v3.2 OVMS module.



Integrated to the OVMS firmware TPMS subsystem, in the Tesla Roadster vehicle, a command is provided to read TPMS tyre IDs from the Baolong ECU and store them in OVMS configuration. A separate command can re-write these tyre ID sets back to the ECU. In this way, the common arrangement of winter/summer tyres can be easily handled.

In addition, should the antenna bug appear, the ECU and antennas can be easily re-programmed with a simple command from OVMS.

This option is available in OVMS v3.2.013 firmware, or later, and is scheduled to be released in July 2020.

Credits and Conclusions

A large number of individuals have supported this work, both financially and with their time. Nobody has been paid for this. We would like to identify and thank a few specific individuals:

- Christian for the loan of a TPMS tool
- Scott for his comprehensive work on LIN bus decoding
- Peter for advise and pictures of the ECU unit
- Shawn for his work on the K-line bus decoding
- Charles for arranging loan of ECU and Antennas
- Brent for loan of ECU and Antennas
- Mark for integration to OVMS and adding the K-line option