BlueCore ä 01

Transmit Power Control Application Note

AN051

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Introduction

Power control offers benefits in terms of power consumption, overall interference level and reception quality (by keeping the received power at the remote device within its optimum performance range).

To implement a link with power control, the transmitting module must support Transmit Power Control and the receiving module must have a Receive Signal Strength Indicator (RSSI) and a defined Golden Receiver range. The capability of each device is determined during link establishment.

The reduction in overall interference is the reason the Bluetooth Specification makes Transmit Power Control mandatory for Class 1 Bluetooth modules that transmit at over +4 dBm. It is optional for all other modules. Figure 1 illustrates the classes and the mandatory control range.

The implementation of an RSSI and Golden Receiver Range is optional for all modules, but is highly recommended. Without these features a module would be unable to control the transmit power of a nearby Class 1 module and runs the risk of degraded reception due to RF front-end overload. All BlueCore™ devices include an RSSI and programmable Golden Receiver Range.

Power control is managed by the Link Manager (LM) and Link Controller (LC) layers. The value of the RSSI and the current transmit power can be read by higher layers, but are for information only.

Transmit Power Table

In BlueCore™ devices power control step is represented as a row in a Transmit Power Table as shown in Table 1.

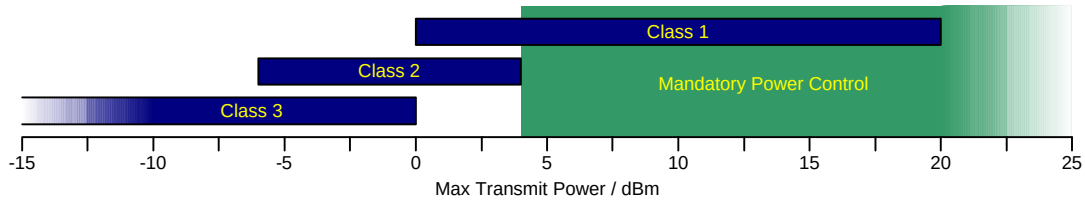

Figure 1: Operating Classes and Mandatory Power Control Range

Power Step	Power Amp Final Value				Module Transmit Power / dBm		Unused	
	Internal		External					
	Hex	Dec	Hex	Dec	Hex	Dec	Hex	Dec
1	0x32	50	0x00	0	0xE4	-28	0x00	0
2	0x32	50	0x10	16	0xE8	-24	0x00	0
3	0x32	50	0x20	32	0xEC	-20	0x00	0
4	0x32	50	0x40	64	0xF1	-15	0x00	0
5	0x32	50	0x60	96	0xF6	-10	0x00	0
6	0x32	50	0x80	128	0xFB	-5	0x00	0
7	0x32	50	0xFC	252	0x00	0	0x00	0

Table 1: Example Transmit Power Table

The first and second columns give the final values for the internal and external transmit power amplifiers respectively. They are referred to as final values because BlueCore™ ramps the transmit power up and down rather than switching it on and off in one step. Without ramping, significant out of band emissions would occur. Since the power amplifiers are turned on before each transmission and off immediately afterwards, these spurious emissions will cause the module to fail Bluetooth qualification.

The internal power amplifier has a 6-bit control, providing 64 settings (0x00 to 0x3f). 0 is minimum power.

The external power amplifier, if fitted, is controlled by a current source that provides 0 – 75 mA (nominal) with 64 settings (0x00 to 0xff; the two least significant bits are ignored). 0 is minimum power. Where maximum power occurs is dependent on the design of the external power amplifier.

If only an external power amplifier is used, it is ramped on and off while the internal amplifier is switched on in one step before ramping commences and off after it has concluded. If there is no external amplifier, the internal amplifier is ramped on and off.

Note: BlueCore™ cannot detect the presence of an external amplifier. It relies on the values in the Transmit Power Table. It is essential to set the power table's second column to 0 for modules without external amplifiers (i.e., most Class 2 modules). If this is not done, BlueCore™ will attempt to ramp the non-existent external amplifier up and down while switching the internal amplifier on and off in one step. The lack of ramping on the internal amplifier will create spurious emissions and the module will fail Bluetooth qualification.

The ramp rate is controlled by a separate unsigned 8-bit Persistent Store value. One

value is used for both internal and external amplifiers, but its effect is slightly different in each:

Internal Amplifier:

$$\texttt{Time\_To\_Complete\_Ramp} = \frac{\texttt{Final\_Value} \times 4}{\texttt{Ramp\_Rate}} \mu s$$

External Amplifier:

$$\texttt{Time\_To\_Complete\_Ramp} = \frac{\texttt{Final\_Value}}{\texttt{Ramp\_Rate}} \mu s$$

The required ramp rate will vary according to module design and there are no limits on the value other than the 8-bit range of 1 to 255 (0 is an illegal value, as it would cause a divide by zero).

The third column is a signed 8-bit integer, giving the effective transmit power of the module in dBm. This value is reported over Host Controller Interface (HCI) when the host issues the HCI command **Read_Transmit_Power_Level.**

There are various restrictions on the contents of the table:

- The table must be sorted according to module transmit power with the first entry being the smallest value.
- The steps between settings must be greater than 2 dBm and less than 8 dBm (this is a requirement of the Bluetooth specification). CSR recommends step sizes in the middle of this range (4–5 dBm). Step sizes towards the bottom of this range will cause the device to take too long to perform large changes in transmit power and to respond to changing circumstances too slowly. Step sizes towards the top of this range may risk the device to alternate between two settings.
- The minimum power level in the table must be below +4 dBm (Transmit Power Control is mandatory above this level).
- The Bluetooth specification, Section H1: 4.7.37, states that the transmit power reported over HCI must be from +20 dBm (the highest Class 1 power) to -30 dBm. However, section A:3 of the specification specifically suggests that minimum power is below -30 dBm.
- There must be an even number of 16-bit words in the power table (i.e., no partial lines).
- The power table must have at least one entry.
- The current version of Persistent Store Tools (within CSR Flashloader) allows only a maximum of eight entries in the table. This limit will be lifted in a future version.

The fourth column of the table is currently unused. All entries in this column should be 0x00.

Golden Receiver Range

The Golden Receiver Range is the range of received power that provides the best reception performance for a Bluetooth device. It is defined as an upper and lower limit of the RSSI. Implementation of RSSI and Golden Receiver Range is optional.

The Bluetooth specification defines the Golden Receiver Range lower limit as - 60±4 dB and the upper limit as 20±6 dBm above this giving a nominal Golden Receiver Range of -60 to -40 dBm. The tolerances are absolute, i.e., they are a combination over the full temperature range of transmit power accuracy (when calibrating or testing), measurement accuracy and measurement resolution. Knowledge of these figures allows calculations to be made to determine whether each module requires calibration individually or if one calibration setup can be used for all modules of a particular design. For example:

Transmit Power Accuracy	=	±0.35dBm
Receive Power Measurement Accuracy	=	±2dBm
Receive Power Resolution 0.5 dBm	=	±0.25dBm
Total	=	±2.6dBm

Since the lower limit of -60 dBm must have an absolute accuracy of ±4 dBm, the ±2.5 dBm listed above leaves ±1.4 dBm left over. 0.5 dBm resolution means that five settings meet specification (-1.0, -0.5, 0, +0.5, +1.0). If the process variation between modules is less than ±1.4 dBm, the same central setting can be used for all modules. If, however, the process variation is greater than ±1.4 dBm, each module requires individual calibration.
Setting the upper limit (nominally -40 dBm) is done in the same manner. However two lots of the Total tolerance must be considered, as the upper limit is defined as a range (20±6 dB) referenced to the lower limit. The tolerance on the accuracy of calibrating the lower limit must be considered when calibrating the upper limit.

Process variation is not just dependent on the BlueCore™ IC. It can change with PCB manufacturing variations. It is the module manufacturer's responsibility to ensure that the module's Golden Receiver Range upper and lower limits meet the Bluetooth specification, section A:4.7.

BlueCore™ compares the received power level with two levels: the Golden Receiver Range Upper and Lower limits. Each limit is configurable by altering a 1 byte Persistent Store value.

An HCI command is available to read the value of RSSI (**HCI_Read_RSSI**). The value returned indicates the number of dB above the Golden Receiver Range upper limit (if positive) or below the lower limit (if negative). 0 value indicates the RSSI is within the Golden Receiver Range. BlueCore™ makes a rough estimate of the RSSI from the behaviour of the reception hardware during packet reception. The Bluetooth specification makes no requirement on the accuracy of this measurement, only that the sign (positive, minus or zero) is correct. Even with an accurate RSSI, the returned value will not provide accurate information within the Golden Receiver Range. This is the reason that BlueCore™ does not implement a highly accurate RSSI measurement during normal operation. The HCI command is only for status information

Method Of Operation

During link establishment between two devices, information on the features supported by each can be exchanged via **LMP_features_req** and **LMP_features_res** PDUs (see Figure 2a). The latter message describes the features supported by the remote device, including RSSI and Power Control. A device can only send requests to increase or decrease transmit power to a module it knows supports power control.

Currently, a local device commences transmission to a remote device at maximum power. This behaviour will be changed in future. The most likely changes will be to make the initial power the closest level to 0 dBm or to make it configurable.

The remote device's Link Controller constantly monitors the RSSI. If the RSSI is above the Golden Receiver Range, it notifies its Link Manager, which sends a request to the local LM to decrease the local transmit power: **LMP_decr_power_req**

(Figure 2b). The local LM will act on the request (sending a message to the local LC and, on BlueCore™, moving to a higher step in the power table) unless there are no more steps available in that direction. In the latter case it responds that it is already at minimum power: **LMP_min_power** (Figure 2c). Once the remote device knows that the local device is at the minimum transmit power it cannot send another request to decrease power until it has sent at least one increase power request. (Note that the remote device does not need to keep a record of where the minimum limit occurred once it has moved away from it. The local device may need to send the **LMP_min_power** message again).

A similar sequence occurs if the RSSI falls below the Golden Receiver Range. BlueCore™ moves to a higher step in the power table on receipt of an **LMP_incr_power_req** (see Figure 2d) unless it is already at the maximum, in which case it responds with the **LMP_max_power** message (see Figure 2e).

If a Bluetooth device with power control is operating as a master it must keep separate records of each slave device's required transmit power and only alter that record when an increase or decrease request is received. Higher layers of the Bluetooth stack are not involved in power control.

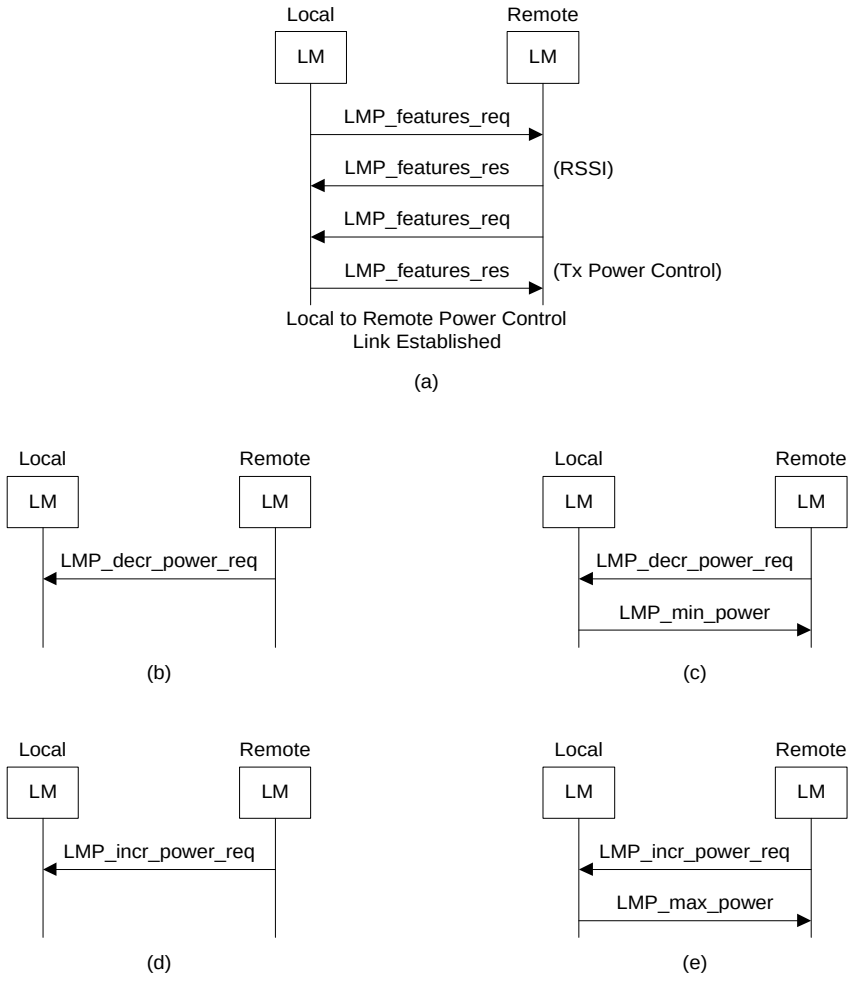

Figure 2: LMP Power Control Messages

Glossary / Acronyms

Term:	Definition:
BC	BlueCore™01
BT	Bluetooth
CSR	Cambridge Silicon Radio
HCI	Host Controller Interface
Host	Application's Microcontroller
Host Controller	Bluetooth IC
LM	Link Manager, a lower level protocol layer
LMP	Link Manager Protocol
RSSI	Received Signal Strength Indicator

Record of Changes

Date:	Revision:	Reason for Change:
11 OCT 00	a	Original publication of this document (ref: bc01-AN-051a).
20 NOV 00	a	Correction of settings information on page 3.
23 MAY 01	b	Corrected Bluetooth specified Golden Receiver Range lower limit to -60±4 dB (from dBm), page 4. (CSR ref: bc01-AN-051b).

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Referenced Documents

Document:	Reference:
Specification of the Bluetooth System	1.c.47/1.0bm dated 01 DEC 99