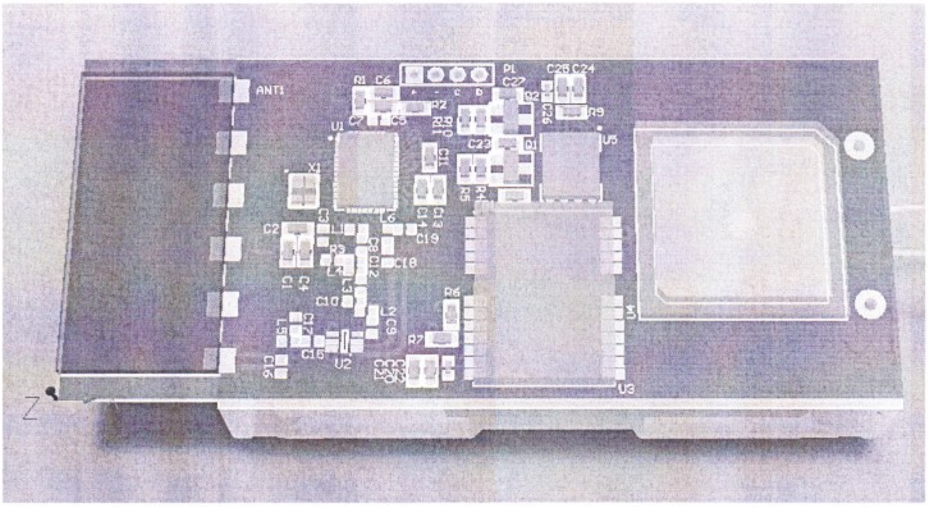
T-Patch GPS – Digital Matter Embedded

1 Introduction

The Digital Matter Embedded T-Patch GPS device is designed as a radio tag for asset tracking. It is quite simple in that it contains a GPS, some memory, a microcontroller, and a radio transmitter. This device periodically sends messages to a base station device which will in turn communicate with backend systems. It uses the 900 MHz ISM band. The unit is powered by two AA batteries and is housed in a rugged sealed plastic housing. It is intended to be disposable. The device can be used for asset tracking, and other associated tasks. The transmit period is configurable to meet customer requirements in terms of battery life etc.

This document provides some basic information about the device, its operation, and its various components for the purpose of FCC compliance testing. A description of what has been provided for testing has also been given. If additional information is required, the various datasheets and appendices should be consulted. The datasheets have been supplied with this document.



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2 Hardware Description

There are several main components to the design and are summarised below. If additional information is required, the datasheets for each of the relevant parts has also been submitted with this document.

2.1 RF transmitter and Microcontroller

The radio transmitter and microcontroller are combined in a single chip from Silicon Laboratories (SiLabs). The device is a Si1010 and is one of the SiLabs 8051 processor cores combined with their Si4432 radio front end.

As the device uses a Class E switching power amplifier, a number of filters are required on the output to attenuate the various harmonics as well as some circuitry to match the output to the antenna. A passive 3rd order Chebyshev Low pass filter is used together with some additional matching circuitry for this purpose.

2.2 Crystal

A 30MHz crystal is used by RF section of the Si1010. A Tai Saw crystal is used and it has the following specifications:

- 30.000000 MHz
- +/-10ppm frequency tolerance
- +/-10ppm frequency tolerance over the temperature range (-20°C to +70°C)

2.3 Antenna

The 'Splatch' antenna that has been fitted to the devices is a PCB antenna from Antenna Factor. The antenna arrangement is not ideal because the ground plane on this device is not ideal, and the batteries are mounted close to the antenna too. But, as the device is designed to be small this can't be avoided. The range requirement for the tag is not large, and therefore this will suffice.

The antenna specifications are given by the manufacturer as follows:

Electrical performance item	Specification
Centre Frequency	916 MHz
Bandwidth	30 MHz
Wavelength	¼ wave
VSWR	<= 1.9 typical at centre
Impedance	50 Ohms

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2.4 Capacitors

There are many different capacitors used on the board. The critical RF section and lower value capacitors all have a +/-5% C0G (30ppm/°C drift) rating from Murata's GRM15 series. And the higher values (1uF, 2.2uF etc.) have a X5R (-55°C to +85°C, +/- 15%) rating.

2.5 Inductors

The inductors used are all high-spec, wire wound inductors from Coil Craft. Each inductor has a +/-5% tolerance and is taken from Coil Craft's HP series of inductors.

2.6 Serial Flash Memory

Serial flash memory is used to store operational parameters, the device serial number, and any other information that may be required. This can also be used for logging the position of the device should the customer require. A 32-Megabit device has been used.

2.7 GPS

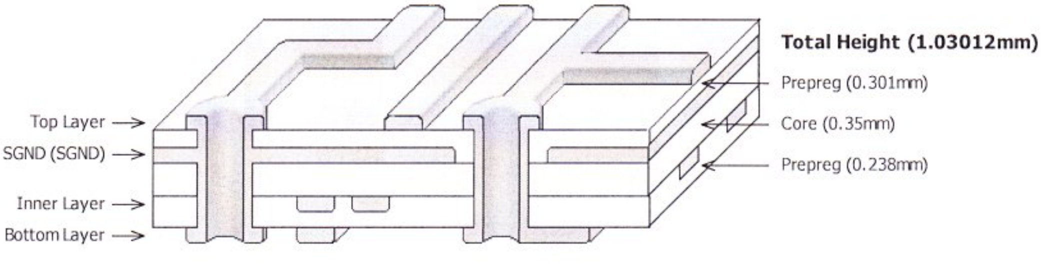
A uBlox Neo 6Q has been used as the GPS for the device. It is a small, low power, and accurate GPS module. Its fast acquisition and low power are of particular interest for this application.

2.8 GPS Antenna

A Taoglas 18 x 18 x 2mm patch antenna tuned at 1580MHz is used for the GPS. The ground plane for this antenna is smaller than ideal, however tests have proved that this is ample for this application.

2.9 Printed Circuit Board

The PCB is made up of 4 layers of FR4 board. The layer stack is as follows:



The inner copper layer thickness is 0.017mm, and the outer is 0.035mm. The 'SGND' layer is a dedicated ground plane with no traces on it, and most of the long traces are routed on the 'Inner' layer.

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2.10 Batteries

The power source for these devices is two 'AA' alkaline batteries in series, giving a nominal voltage of 3.0V. They are connected using a simple plastic batter holder that is soldered to the back of the PCB. The device does not require a lot of power, and these batteries will last for 3-4 years, depending on how the device is configured.

2.11 Housing

The devices will be housed in a custom, rugged injection moulded housing made of carbon free ABS plastic. The housing will be sealed at production, and it will not be possible to open the device once it has been sealed.

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3 Firmware Description

From a macro perspective, the firmware is written to periodically transmit a small packet of information containing the device serial number, a position, and some message overhead to a base station. The transmit interval is configurable at production time depending on the customer requirement but will be in the region of between 30 seconds, and 30 minutes. A Frequency Hopping Spread Spectrum (FHSS) protocol has been devised for the transmission.

3.1 Frequency Hopping Spread Spectrum (FHSS) Radio protocol

The FHSS system has been designed to meet the following specifications. Additional details on how certain values have been calculated are presented in *Appendix A* should more information be required.

- 171 channels between 902 and 928 MHz, centred on 915 MHz
- 150 kHz channel separation
- 120 kHz channel bandwidth
- 38.4kbps data rate
- Three hopping tables of 57 channels each
- Minimum dwell time of 352 ms and maximum dwell time of 398 ms
- Gaussian Frequency Shift Keying (GFSK) modulation is used

The channels are allocated 150 kHz apart, starting on 902.250 MHz and ending on 927.750 Mhz. The bottom and top start frequencies were chosen so that they are sufficiently clear of the 902 MHz and 928 MHz boundaries. As the bandwidth is less than 250 kHz, the FCC regulations require 50 or more channels to be used with a maximum dwell time of 400 ms per channel allowed within a 20 second period. In this case, 57 channels are used.

The FHSS implementation makes use of three hopping tables. These hop tables are outlined below.

Table A channels	Table B channels	Table C channels
0	1	2
3	4	5
6	7	8
9	10	11
…	…	…
168	169	170

In firmware, the channel selection is performed through using the built-in C library random number generation function *rand().* It is seeded on the device's serial number so that no two devices will generate the same random number pattern.

When the device starts to transmit, it first generates a list of all the possible channels in memory. This list contains the values of the hop table to which it is set. It then generates a random number between 0 and 32767 (the *rand()* function default), and takes the modulus of the number using the

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number of remaining unused channels in the list. This resultant value, N, is then used to select the 'Nth' unused channel from the list. The channel is then marked as 'used' in the list. The next channel selection is done in the same way until all 57 channels have been marked as 'used' in the list. Once all channels have been used, the process repeats again, starting with the generation the list of channels again. While the process itself repeats, the channel order will not repeat.

This method ensures that no channel is repeated within the 57 channel run. A minimum dwell time of 352 ms is used so that no repeat channels will occur in 20 seconds, and the maximum dwell time allowed is 398 ms, 2ms shorter than the 400 ms defined by the FCC regulations. While the device may only transmit a single message which is far shorter than the dwell time, it will internally remain on the same channel until the dwell time minimum and maximum requirements have been met, thus ensuring that it can't repeat a channel within 20 seconds.

For each transmission, the device sends 35.83 ms of 'preamble.' This 'preamble' is used by the receiving device (base station) to detect the transmission and synchronise to that channel. The data is sent after the 'preamble.' If the full data packet size is used, it will result in a total transmission time of 50.83 ms. The maximum data packet size of 64 bytes is defined by the size of the internal FIFO buffer of the radio transceiver.

It is important to note that the above is a description of how the protocol is implemented, and how it would operate if continuous transmission from the device were used. The T-Patch GPS device will only be sending a single packet every 30 seconds to 30 minutes, depending on the customers' requirements, and therefore many of the above specifications are irrelevant. In addition to this, the receiver will not attempt to synchronise to the T-Patch device because the T-Patch is a low power device and will try to conserve as much power as it can. It will enter 'sleep' mode as soon as it has transmitted its data, and will only wake up to transmit the next packet of data. In 'sleep' mode, no code will be executing on the device, and therefore it will not be able to internally follow a hopping table. It will remain 'sleeping' for periods of between 30 seconds and 30 minutes. The receiver will therefore not be able to remain synchronised to the device, and it is for this reason that the 'preamble' is sent for every transmission.

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4 Devices Provided for FCC Compliance Testing

In order to test each aspect of the device operation, several versions of firmware have been prepared. Each version of firmware has a specific function to aid the testing process of the device. None of these versions, with the exception of the final production version, will be used 'in the field.' As it is not easy to alter the operation of the devices without reprogramming them with a production programmer, several devices have been provided, each with a different version of firmware programmed on them. These firmware versions are outlined below. Each device has the identical hardware, and was manufactured on the same PCB panel at a production facility.

Each device has been labelled in as shown in the table below.

Device Label	Functional description
1: 902.25MHz	902.25 MHz fixed frequency with modulation enabled
2: 915.00MHz	915.00 MHz fixed frequency with modulation enabled
3: 927.75MHz	927.75 MHz fixed frequency with modulation enabled
4: FHSS cont.	Device with continuous data transfer FHSS code
5: Idle	Device in continuous idle state
6: Production	Final production code transmitting every 30 seconds

4.1 Fixed Frequency Firmware

In order to check the lowest, middle, highest channels, and the channel bandwidth, the following versions of firmware have been prepared. They simply continuously transmit packets of data on a single frequency.

- 902.250 MHz (channel 0) modulating
- 915 MHz (channel 85) modulating
- 927.750 MHz (channel 170) modulating

4.2 Hopping Frequency Firmware

This firmware utilises the FHSS system as implemented in the final product, but transmits continuously so that the implementation can be tested. The devices will not transmit continuously 'in the field.' This demonstrates the dwell time, randomisation, channel spacing, and channel bandwidth of the FHSS system.

Idle State Firmware

As the device is designed to transmit a packet of data and then return to its 'sleep' state, a version of firmware has been prepared to demonstrate this. This firmware simply keeps the device in its 'sleep' state so that emission measurements can be performed. The device will spend most of its life in this state.

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4.3 Final Production Firmware Implementation

The last version of transmitting firmware that is provided is the final implementation of the device. This is the firmware that will be used 'in the field.' It will transmit a small packet of every 30 seconds, as this is the shortest transmit interval.

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5 Appendix A – Detailed Specification of the RF Implementation

5.1 Data Rate

The over-the-air (OTA) data rate will be **38400** baud.

5.2 Frequency Deviation

The approximate minimum frequency deviation to be used is calculated as follows:

Dmin = (4 * Crystal_ppm) at the highest carrier frequency to be used.

Using a 10 ppm, 30 MHz crystal and the highest carrier frequency being 928 MHz:

Dmin = 40/1E6 * 928E6 = 37.12 kHz

*Therefore use frequency deviation of **40 kHz.***

5.3 Frequency Channels

For frequency hopping, the frequency deviation is the limiting factor for the minimum frequency channel step size, the absolute minimum being (2 * Dmin). However a guard band will be used between each frequency channel to minimise the possibility of adjacent channel interference. A *guard band of **110 kHz*** will be used, thus giving a *frequency channel step size of **150 kHz*** (frequency channel separation or spacing). Note that this also complies with the FCC regulation which requires the channel carrier frequencies to be separated by a minimum of 25 kHz.

Another factor to consider in choosing the channel spacing is the image channel generated by the radio. The Si4431 radio has an IF frequency of 937.5 kHz (low side injection), so the chip has a mixer image response located 1.875 MHz below the desired channel carrier frequency, typically about 30 dB rejection relative to the desired channel. So it is desirable to plan the channel step size such that the mixer image falls halfway between two channels. For example, a channel step size of 187.5 kHz would not be an optimal selection, as this would place the image response exactly 10 channels away. It may be more advisable to select a channel spacing of 178.5 kHz for example, where the image response would be 1875/178.5 = 10.5 channels away. For the 150 kHz channel spacing, the mixer image is 1875/150 = 12.5 channels away, which is ideal.

The available spectrum in the 900 MHz ISM band is (928 – 902) MHz = 26 MHz. The number of frequency channels that will fit into this band is: 26E6 / 150E3 = 173

*Use a total of **171** channels.* The spectrum for the 2 channels not used will be spread out below the lowest channel and above the highest channel to allow a larger guard band at the edges of the allowed frequency band.

The carrier frequency Fc for a frequency channel number N is given by: Fc = Fb + N * Fhs

Where Fb is the "base frequency channel" and Fhs is the frequency hop step size. From this, the

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frequency channel assignments are as follows:

Frequency Channel Number (N)	Fc (Carrier Frequency in MHz)
0	902.250
1	902.400
2	902.550
...	...
84	914.850
85	915.000
86	915.150
87	915.300
88	915.450
...	...
167	927.300
168	927.450
169	927.600
170	927.750

5.4 Hop Tables

For frequency hopping, the FCC regulations require a minimum of 50 frequency channels if the 20dB bandwidth of a frequency channel is less than 250 kHz or a minimum of 25 frequency channels if the 20dB bandwidth is 250 kHz or greater.

The 20 dB bandwidth can be roughly calculated as:

BW = 2 * (Deviation + Modulation Frequency)

= 2 * (Deviation + 0.5 * Data Rate)

= 2 *Deviation + Data Rate

The relationship of Modulation Frequency = 0.5 * Data Rate comes from the fact that it takes two bits of data, a 1 and a 0, to be equivalent to one complete cycle of an equivalent analogue modulating waveform.

For the parameters selected, the BW equates to:

BW = 2 * 40 + 38.4 kHz

= ***118.4 kHz***

Thus the system will be required to use 50 frequency channels or more in order to comply with FCC regulations.

*The system will use 3 hop tables, each containing **57** frequency channels.* During communication, the next channel to be used will be selected pseudo-randomly from the hop table, while satisfying the following:

- All channels in the hop table must be used before starting the hop cycle again
- No channel may be used more than once in a hop cycle

A hop cycle is defined as the process of sequencing pseudo-randomly through a hop table.

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5.5 Dwell Time

The FCC regulations state that the average dwell time on a particular channel shall not exceed 400ms within a 20 second period. To prevent channel repetition within a 20 second period, the minimum dwell time to be used during bulk transfer communication is:

Dwell(min) = 20/57 = 350.88 milliseconds

*The system will use a minimum dwell time of **352 ms.***

The maximum dwell time to be used can be anything from this minimum up to the maximum allowed (400 ms) minus a few milliseconds to ensure it meets the regulations.

*The system will use a maximum dwell time of **398 ms.***

5.6 Burst Transfers

This is a transfer where a single message is sent from a mobile unit (MU) to a base station (BS). For this type of transfer, the MU will transmit the message with a preamble long enough for the BS to be able to detect the message. The system will use a 6 nibble invalid preamble threshold (IPT) and a 4 nibble valid preamble threshold (2 valid preamble signals will be required). Thus the required MU transmit preamble length is (6 * 56) + (4 * 2) = 344 nibbles. For an OTA baud of 38400, this equates to ***35.83 ms*** transmission time. The maximum length packet is 72 bytes (64 data bytes + 8 bytes radio packet overhead), which equates to 15ms OTA time. Thus the maximum single message transmit time is ***50.83 ms***.

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