Description of AND Gateway Protocol.

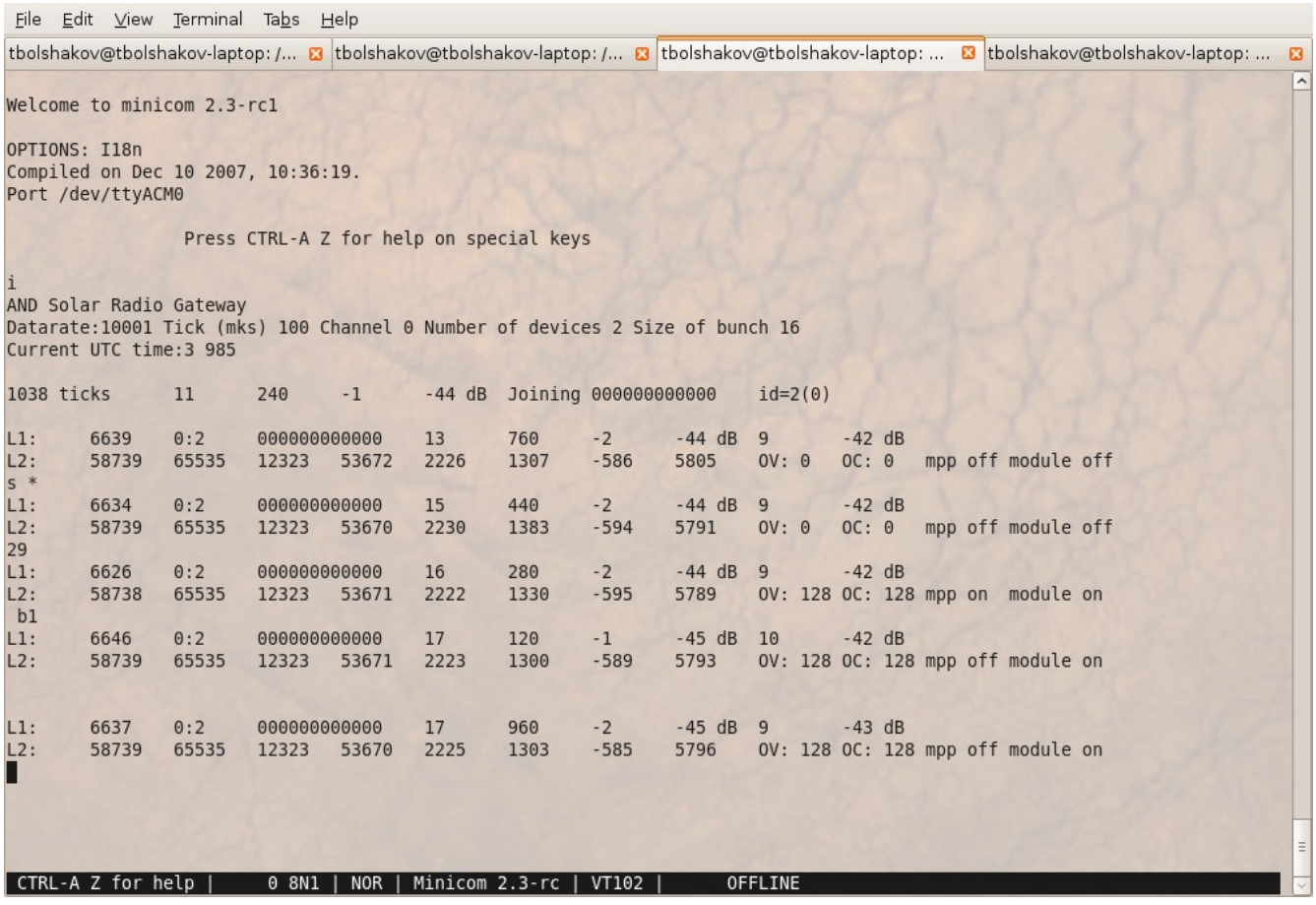
What it is and how it looks like.

Gateway is a USB device created to communicate with a network of end devices (SPT's). In this documents gateway will be referenced as GW and end device (SPT) as ED. GW forms a star network from several (many) ED's. This network is based on timeslot principle. Each device (GW or ED) has its own time to talk, so, ideally there are no conflicts.

GW distributes timeslots, assigns network ID's to ED's, synchronizes ED, sends them timestamps and commands, received from main computer over the USB, prints ED reports to main computer USB input.

ED measures SPT ADC values, calibrates them, executes commands, reports only in assigned timeslot, controls SPT.

GW looks for PC as USB serial device. There is a driver for Microsoft Windows XP, that allows Windows XP to recognize the GW as a serial device and to communicate with it using Hyperterminal. There are no device drivers for Windows Vista. Linux does not require any special device drivers. In Linux GW is recognized automatically and mounted as /dev/ttyACM0. GW was debugged mostly on Linux, because of that Linux behavior is better known and understood by developers. GW is intended to use with Linux too (at least in near term). Current version of GW present itself as device with 115200 bod, 8 bit, no parity, no software or hardware flow control. Program 'minicom' is used to communicate with GW under Linux. GW understand text commands send over USB from PC.



Radio Protocol.

GW sends messages by the radio. GW message includes: 6 bytes timestamp (UTC seconds and milliseconds), current bunch number, information 'is join available', commands (if any). There may be several bunches (no more then 255), starting from bunch #0. In each bunch there are up to 16 timeslots for ED's and 3 empty timeslots for new, not yet connected ED's. Each timeslot is 40 ms for 30kbod and 45 ms for 10 kbod. All messages are AES encrypted.

GW_0 ED_0 ED_1 ... ED_{15} __ __ __ GW1 ED_0 ED_1 ... ED_{15} __ __ __ ... GW_0
<--- Command Cycle -840 ms ------>
<---------- Report Cycle (840 ms – 2 min) ---------->

ED's Network ID consists of Bunch # (a byte) and Timeslot # (a nibble, half of the byte). After receiving the GW message with bunch #0 all ED's with Network ID make the measurements and prepare a packet. ED's sends this packet in its own assigned Bunch # and Timeslot. This way all the measurements are done synchronously in the whole network.

If ED has no Network ID it sends a special 'request to join' in one of the specially assigned 3 timeslots. ED selects one timeslot out of 3 randomly. GW assigns network id to this ED and sends information about it in next GW message in the form of command. Conflicts are possible during network join and because of this ED repeats the try to join after random (no less then 7, no more then 17 GW messages).

Normal ED report message includes 6 byte MAC address of the ED, 6 byte timestamp, 8 two-byte scaled values (Output Voltage (mV), Input Power (tens of mW - centiWatts), Output Current (mA), Input Voltage (mV), “External Temperature” (hundreds (centi) Degrees of Celsius), “Internal” Temperature, (hundreds (centi) Degrees of Celsius), Ground Measured (counts), V Reference Measured (counts)) , frequency offset from GW, signal strength from GW, current state of 2 DAC (overvoltage limit and overcurrent limit), 2 bits of state (MPP on/off, Module on/off).

GW formats normal ED message as 2 text lines, first starts with 'L1:', second – with 'L2:'. Values in both lines are separated by tabulator. They are:

 # ticks_till_cycle bunch:id mac seconds ms gw_off gw_rssi ed_off ed_rssi
L1: 6643 0:2 100000000000 1923 200 -1 -32 dB -39 -28 dB
 # Vout Power Iout Vin Text Tin Gnd Ref ov oc mpp module
L2: 235 234 235 234 2377 785 -615 64119 OV: 128 OC: 128 mpp off module off

When ED joins the network GW prints following line:

 # ticks_till_cycle seconds ms gw off gw rssi mac of new dev assigned id (bunch)
643 ticks 2265 920 -1 -31 dB Joining 000000000000 id=3(0)

ED may also send all the scaling coefficients – it will be described after the GW command 'Report Scaling Coefficients'.

ED normal messages are appearing continuously. Report cycle in test environment (for Sanmina) will always be 840 ms and the number of devices equal to 1.

Version D principal changes.

In order to handle “multi-path problem” and future GW power amplifier for FCC approval we add 2 features to previous stack – Frequency Hopping and Repeaters (with appropriate search algorithm). All those features may be switched on and off by commands / settings.

Frequency Hopping

The frequency hopping can be looked at from 2 different prospectives:

1. From the point of our current approved configuration. We are approved to use 256 channels in the range from 2410 MHz to 2471.5 MHz with -4 dB Gateway signal strength, with +1 dB signal strength on the SPT, with signal transmission length no more then 12.6 ms each 100 ms. We do exactly that with our frequency hopping, but we change channels every 840 ms (with join enabled) or every 720 ms (with join disabled). Period.
2. From the point of new certification. So, we are hopping over 25 distinct frequencies distanced from each other by 10 channels. We change frequencies by pseudo-random schedule. The schedule is always the same for the given “starter channel”. We have 10 not intersecting schedules and 246 intersecting ones. The set of channels is defined by this formula:

   ch(i) = (ch(0) + i * 25) % 256

Those channels are mixed by predictable pseudo - random algorithm. I want to test (be approved for) following configurations:

1. 12.6 ms packets exactly as before – 30 kbod
2. ~(12.6 * 2) ms packets – 30 kbod + FEC (Forward Error Correction)
3. ~(12.6 * 3) ms packets – 10 kbod
4. ~(12.6 * 3 * 2) ms packets – 10 kbod with FEC.

Starting from version E data rate was switched to 12 kbod, normal packet length is ~31.2 ms.

Repeaters

Repeaters just repeat Gateway signal to “slaves” and “slave” signal back to Gateway. Repeater talk to slave on 500 kbod (real spread-spectrum – MSK modulation of TI .) The length of the packets is 1.48 ms. Repeater talk to Gateway as it is a usual SPT – on tested 30 kbod with packets length 12.6 ms. When it is talking to GW it is “impersonating” the slave SPT for Gateway. The power on 500 kbod can be turned down significantly, despite it is already smaller then when I am transferring on 30 kbod. It is guaranteed by the middleware distribution of the timeslots that repeater would not talk longer then our approved 12.6 ms per sliding 100 ms window.

Sequence of channels search algorithm of “slaves” is expected to see is:

ch(0), (ch(0) + 25) % 250, (ch(0) + 2*25) % 250, ...

By FCC requirements we are taking out channels < 25 and > 231 – it should be still enough for any given system to work.

Starting from version F Repeater/Slave may also work on 250 kbod + FEC.

End Devices / Bridges ListCommands.

There are 3 types of commands – executed by GW, executed by ED(s), executed by both. Each command should be in the separate line, without leading spaces and, preferably, without trailing spaces. GW firmware now needs additional work to make it more 'error-proof'.

GW Commands

I, i print information about the GW

E 0/1 echo on/off

R reset GW. Device in Windows (and Linux) will disappear form the system.

T UTC ms set up GW timestamp. UTC is Universal Time Coordinates (seconds from midnight of January 1 1970 in Greenwich), ms may be zero. Convenient Linux one-liner:

> echo "T `date -u +%s` 0">/dev/ttyACM0

D decrease assigned network slot. GW keeps counter of assigned network slot. This command decreases this counter.

k nn sets the counter, mentioned above to value (decimal number) nn.

q resets commands counter. GW keeps 16 bit counter of commands sent. ED will react only on commands that are more then this counter. Ideally this command should be send to GW after sunset – so, when ED's will wake up in the morning they will see 'small' command counter. If 65535 is close – then reset for all ED should be sent before this command.

p push GW command counter by 1024. Purely debug command, allows not to restart ED when GW is restarted for some reason.

j (s|m|h|d)nn allow join for decimal value nn (seconds | minutes | hours | days).

W switch GW into CW mode

G write gateway parameters to flash

Gateway commands, introduced in versions D and E:

a 0/1 ADCs (temperature compensation) off/on

v 0/1 12 / 30 kbod

V 0/1 FEC (forward error correction) off / on

H 0/1 Frequency hopping off / on

L 0/1 Long output format off (hex format) / on (teletype)

l 0/1 packets limited to 2+16 bytes / packets are either 2+16 or 2+32

z n amount of repetition for a given command – default is 4, is not saved in flash

P (1|0|-1|-2|-4|-6|-8|-10|-15|-20|-25|-35|-65) Set gateway power to N dB

Y 0/1 Gateway in listening / transmitting mode

x Set USB watchdog

X clear network distributiion history

g NN write a shift for gateway base frequency

O print out GW scaling coefficients, there are 6 of them:
first 4 – gateway frequency calibration coefficients,
then 2 temperature linear coefficients

M HH..HH Set GW Mac address

K N VAL (N 0-5) Set register N with value VAL, registers from 0-3 are float and corresponds to dFk[N], registers 4-5 – float temperature linear coefficients, register 6 may be from 1 to 16 and sets bunch size

K 6 VAL VAL from 1 to 16 – set bunch size (flying gateway)

K 7 VAL VAL 0/1 – switch off/on 'spike beating mode'

K 8 VAL VAL from 0 to 16 – set 'boot over the air' bunch size (delay)

K 9 VAL VAL 0/1 – switch off/on supercycle line print

Commands, introduced in version E, cannot be used with ver D SPT's

'A 0/1 HHHH KKKKKKKKKKKKKKKKKKKKKKKKKKKKKKKK VVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv'

send AES vector

0 - send new AES key, 1 - send new AES IV

HHHH => network address in hex, first 2 letters - network id, second 2 letters - bunch

KKK...KKK => 16 bytes of 'real secret' AES key in hex

VVV...VVV => 16 bytes of 'real secret' AES initialization vector in hex

vvv...vvv => 16 bytes of new network key in hex

'A 2/3 vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv'

set AES vector to GW

0 - send new AES key, 1 - send new AES IV

vvv...vvv => 16 bytes of new network key in hex

'a 0/1' ADCs on /off

'B NNNN' set edAddr and gwAddr for this gateway, NNNN is in hex

'd 0/1' turn on/off 'bunch 255' mode - needed for boot over the air

'C'

'c addr bPage' clear the page, page from 1 to 30 inclusive

'D'

'b addr L Addr HexSeq' send n bytes for 'boot over the air' -

addr - address in network, as always,

L - length, in hex

Addr - address in flash, hex

HexSeq - data to send

'e' start sending requests in One second, used for synchronization of several gateways

ED S-Command

Most ED commands are represented on low level in a form of SET REGISTER (s-command). Some of those s-commands are abbreviated for convenience. There are 3 types of registers that are possible to set using these commands – BYTE registers, INT16 registers, and Floating Point registers. S-Commands are started from letter 's', have 3 parts (address, register and value) and following format:

#	address (All, NetId, String, MAC)	register	reg type	value
s	(*|#IXX|sXXXX|mXXXXXXXXXXXX)	N	(b | h | n | s | i | H | f)	NNNNNNN

Example:

s * 29 b1 # command for all devices to set byte register #29 to 1, please pay attention that there are no space between **b** and **1**.

Some of those registers are 'virtual' and that form is used just for convenience.

Prefixes:

b means 'byte', value is decimal 0-255,

h means 'hex' byte, values from 00 to FF, l means 'logical' byte, values 0 and 1. Any byte registers may be set by any of this values.

n means signed byte (from -128 to 127),

s means short, **i** means integer, both stands for unsigned 16 bit integer in decimal format.

H means unsigned 16 bit integer in hex format.

f means float respectively and stand for single precision floating point number.

Address * means for every End Device.

Address **#IXX** means for ED with network ID bunch=XX (hex) and slot # I (hex).

Address sXXXX means for ED from string # XXXX (hex)

Address mXXXXXXXXXXXX means for ED with MAC XX..XX (hex).

TI managed to create processor without predefined MAC address. Because of this the mac address are defined during programming / test. The default MAC address of 'fresh' device is all zero's – 000000000000. MAC address in ED corresponds to serial number, it should be written during first test. Serial number is in format WWYYFXXXXXX, where WW is week (01-52), YY is year (09, 10 etc), F is factory code (latin letter, K for Kenosha), XXXXXX is sequential number (000001 – 999999). It is directly translated into 6 byte MAC:

| 6 bits of W| 7 bits of Y | 5 bits of Factory | 10 bits of 0 | 20 bits of Number

Each command is repeated trice with the same command counter.

ED's Byte Registers

4 MPP on 1 or off 0

5 Module on 1 or off 0

Registers introduced in version G:

6 TEST1

7 TEST1

8 TEST1

9 TEST1

Test data is saved in the parameter block. It includes 1 byte for the test information / test result and 4 bytes for the utc timestamp. Future tests (production tests, calibration etc) should read parameter block, determine empty spot to save the test data and save it. Suggested meaning of the byte is: Upper bit = 0 – passed, 1 – failed. Other 7 bits represents test version / test type. The utc timestampt will be taken from GW packet timestamp. Example

s #0 6 h81 test1, test version/type 1 failed
s #0 7 h1 test2, test version/type 1 successful

10 CLEAR_THE_PAGE Clears the page in the flash. Register suppose to be contain page number to clear, page can be from 1 to 31 inclusive and belong to “complimentary” range to current startAddr

11 FLASH_REFRESH2 Flash refresh. When 1 is written into this register ED make one 'rejuvenation' of flash memory. This suppose to make flash memory to last longer (presumably 30 years). Command 's ADDR 11 b1' has abbreviation 'Z ADDR'.

12 Randomize For network build – make srand (or its analog in hardware)

13 Stay In Rx flag. If set to 1 SPT stays in Receive to keep power consumption constant.

14 Install date. Value is being ignore, timestamp from GW package is stored in the parameter block. Suggested usage – after network is being formed first time on the new installation we store that dat into the parameter block. When new device is being installed – we store the date when. It might be helpful for troubleshooting of devices from the field.

15 Spike Killer on / off

16 MAC byte 0

17 MAC byte 1

18 MAC byte 2

19 MAC byte 3

20 MAC byte 4

21 MAC byte 5

22 Over Voltage Limit register

23 Over Current Limit register

~~24,25 Not used anymore~~

26 Set Radio Channel, when used with '*' address GW switching to this channel as well. Command 's * 26 NN' has abbreviation 'H NN'.

~~27 Not used anymore~~

28 Write parameters to flash – writes all coefficients, network state – channel, network id, defaults OV, OC, MPP, and Module state to special area in flash memory.

29 writing 1 to this reg switches ED into CW mode – only hardware reset will return it to normal mode, useful for tests and FCC.

30 writing 1 to this reg restarts measurements on the ED – needed for correct test measurement. Command 's ADDR 30 1' has abbreviation 'm ADDR'. SPT measures 8 values per MPP cycle during 8 MPP cycles and then averages measured values. This command restarts the measurement sequence.

31 writing 1 to this reg disconnects ED from network (sets up default bunch FF and slot FF and writes them into flash). When it send on * GW nullify ED counter.

32 writing 1 to this reg forces ED to report scaling coefficients. Description of the format is below, right before double registers description.

33 Write parameters to flash – writes all coefficients, network state – channel, network id, NO defaults for OV, OC, MPP, and Module state.

~~34 not used anymore~~

35 This register is being copied to radio power. The settings are from the TI table, it is not just linear value, but a lookup table. The table is attached as appendix.

36 “Production” - writing 0 here will prohibit SPT from restarts on timer if the SPT does

not have GW communication. Default – 1, restart after 500 standard cycles => 500*0.84 = 7 min

~~37 Not used anymore~~

38 Use 12 kbod datarate, default = 1,

39 Use FEC – Forward Error Correction, default = 0

40 Enable Frequency Hopping, default = 1, TRUE

41 is Repeater, default = 0

42 is 500 Always, default = 0

43 Repeater Channel, default = 0

44 Repeater Power, default = CB, from the same table as 35

45 Search for communication – default 1, when 1 it wait 100 cycles on its default channel, then switch to 500 kbod and looks for communication on channels 0, 25,50,75,100,125,150,175,200,225 10 cycles on each channel, then it switch back to def channel for 100 cycles etc. Until restarted if 36.

46 SET_SHOW_STATE

0 – show text, tin, gnd, ref

1 – show text, tin, gnd, network debug

2 – show p1, p2, cur1, cur2 and text in place of ED offset

3 – show p1, p2, and cur1, cur2, and text in place of ED offset, show p3 instead of pin, cur3 instead of cur_out

4 – show p1, p2, p3, cur1 and text in place of ED offset

5 – show p1, cur1, cur2, cur3 (pyranometer mode) and text in place of ED offset

47 Critical signal level for 500 kbod mode search. Does not have sense in D8.

48 Critical signal level for 12 kbod mode search. Does not have sense in D8.

49 End Of Test – ch = 0, netId = 0xFFFF, groupId = 0xFFFF, write to flash

50 clear max bunch – command should be send after 'n' or 'k' command to ensure correct integration.

51 SYNCHRONIZE_MPP_CYCLES MPP cycle has 8 Hz frequency and its start is initiated by my program. Measurements are synchronized with MPP cycle. This command restarts mpp cycles on all SPT's. If some of SPTs are slaves then it suppose to be synchronized with ~4 ms precision.

52 BOOT_PAGE_IMAGE boot image from RAM address page.startAddr. This command proves inefficiency in all cases when command repeat counter is not equal 1 (z N, where N!=1 brakes this command) and was substituted by int16 command 13.

53 SET_START500_CHANNEL

Search algorithm improvements. The value written by this command is an initial channel value used by slave when it searches for repeater. It was suggested by Robert Porter, this value is not changed by set channel (26) command. May be it should.

54 TRY_OTHER_IMAGE set 1 here means it will try first try other image when booting – does not worth it

55 CHECK_FLASH compares flash lines with 0xFF, for clear / boot checks

56 SWITCH_SECURITY AES updates. Use new AES key. AES key suppose to be send initially to every device.

57 CALIBRATION_FROM_FLASH Read calibration from flash, not from memory

58 Calibration repeat Repeat calibration values N times, 4 by default.

59 Use 250 kbod in Slave – Repeater communication. So far is not enabled by FCC. Need new FCC testing.

60 speculative report Another try to improve robustness. Disabled by default. If SPT has bunch N and receives one or more of the N-5, N-4, N-3, N-2, N-1 GW bunch markers and did not

receive marker N it tries to send its data using previous markers anyway. This mode was not yet tested and it might be dangerous because not perfectly synchronized SPT (with jitter ~5 ms) can break other SPT messages. Especially if there are slaves around its timeslot.

61 rep_step A try to increase number of possible repeaters in search algorithm. This register describes number of channels between repeaters in the system – by default 25.

62 ov_startup see Startup Sequence paragraph
63 T superhot see Temperature Protection paragraph
64 T Hot see Temperature Protection paragraph
65 T Cold see Temperature Protection paragraph
66 T protection time see Temperature Protection paragraph

Used for network formation (see below):

67 NetCnst1 see Network Build paragraph
68 NetCnst2 see Network Build paragraph
69 T_OC_JUMP see Temperature Protection paragraph

~~70 POWER_DISSIPATION_LIMIT see power dissipation protection paragraph.~~
~~71 POWER_DISSIPATION_TIME see power dissipation protection paragraph.~~

72 WIGGLE_DCHAN This value can be 0 (disabled), 1 (wiggle by 1 channel) and 2 (wiggle for 2 channels). It is needed to bring 250 kbod transmission to the 15.247 radio standard by the width of trasmission.

73 OV_STEP see Startup Sequence paragraph
74 SHUNT This parameter is used when computing crosstalk between Voltage and Power measurements, default is 40, what corresponds to 4 mOhm, for pyranometer it should be 0.
75 MAX_OFF When ED receives GW messages it adjust its frequency to GW frequency, this parameter limits maximum adjustment, default value is 32, max value is 127.

76 VIN_LIMIT, value is in 2 deci Volts (1 == 0.2 V). There is an ability to turn SPT on applying voltage to output. Input voltage then will be close to 0. When that happens SPT will be converted into known state – channel 255, default key and IV values, 12 kbod, FEC off, syncword = 0xF0F0, edAddr = 2, gwAddr = 1, hopping off. It make possible to debug SPT from the field when all of the actual parameters are not known. When VIN_LIMIT = 0 the behaviour is disabled.
77 VIN_TURN_ON
78 VIN_TURN_OFF
Those 2 fields are substitute for former floating registers 7 and 8, unit as in 76
79 VIN_DISABLE_RADIO
substitute for former floating register 22, unit = 2 V

Network Build:

During the network build SPT sends request for join and sets a timeout when next request of join will be send. That timeout is defined by those constants by formula:

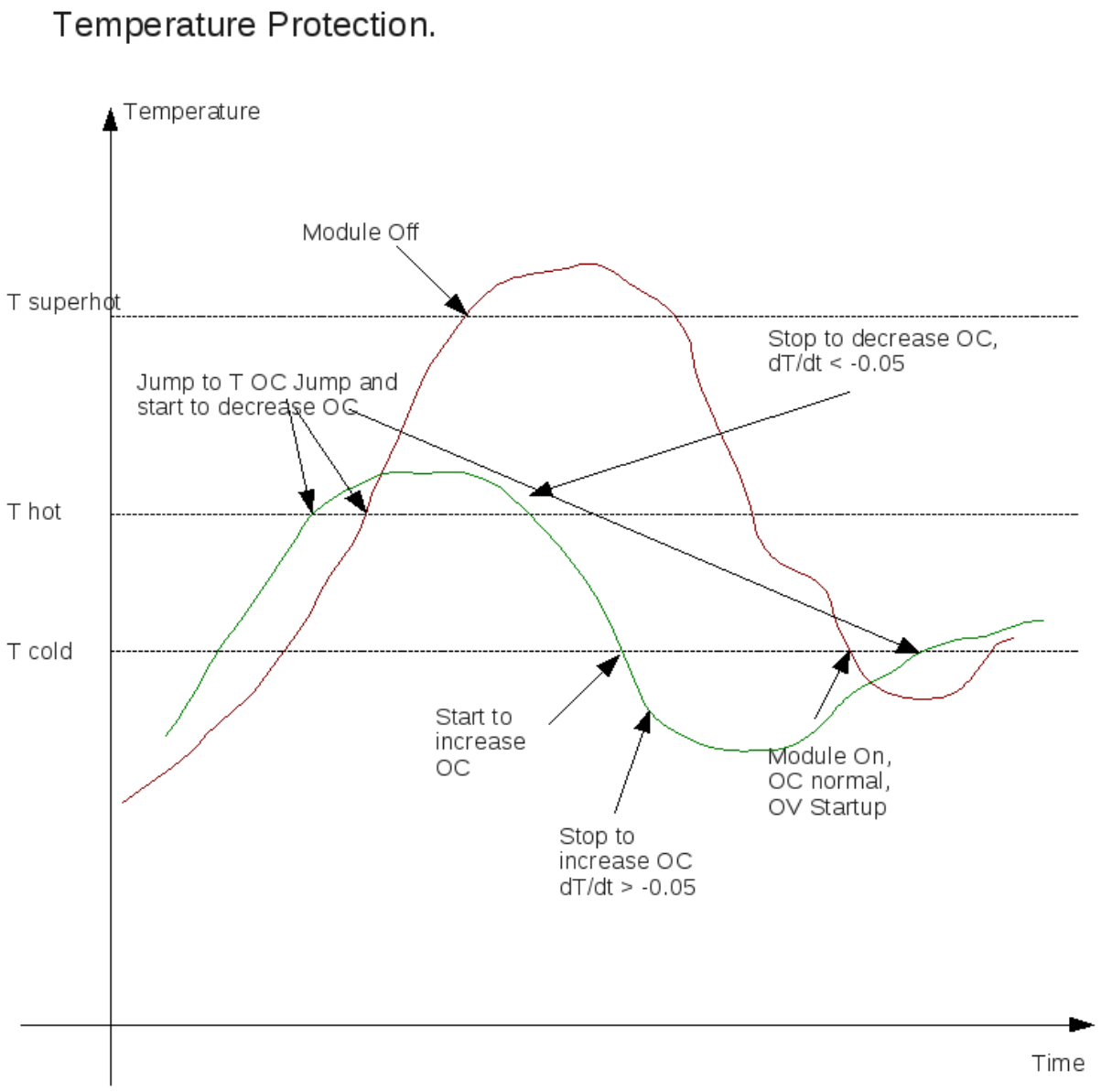
timeout = NetCnst1 + rand() % NetCnst2, in cycles

Related parameters:

12 Randomize , 67 NetCnst1, 68 NetCnst2

Startup Sequence:

Every time module is switching on OV = OV_startup (reg 62), then OV is increasing by OV Step (reg 73) every second.



Algorithm Parameters:
T superhot, Byte, Degrees C, 63
T hot, Byte, Degrees C, 64
T cold, Byte, Degrees C, 65
dt to check, Byte, Seconds, 66
T OC jump, Byte, OC value, 69

ED's INT 16 Registers.

1	set group id (string id)	
2	set network id (bunch * 16 + timeslot number)	
3	set ed and gw addresses	prohibited in D8, reenabled in E
4	cycles to 500, 120	rev D8
5	cycles to 12, 220	rev D8
6	cycles to step 500 channel, 20	rev D8
7	cycles to step 12, channel, 30	rev D8
8	cycles to light kick, 405	rev D8
9	cycles to soft kick, 7	rev D8
10	cycles to hard kick, 400	rev D8

In rev E, F and going forward:

8	cycles to soft kick, 7	
9	cycles to hard kick, 400	
10	SetImageAddr	Set address of next image in the page. In fact there are 2 addresses – 0x476 and 0x4076, but a int16 command was used for being general and flexible in the future.
11	SetVersionLow	Set version of the lower image
12	SetVersionHigh	Set version of the lower image
13	BootImage 'Try before buy'	immediately start image on the provided addr (0x476 or 0x4076) – if it would not work hardware watchdog will return SPT to initial state.

Registers introduced in version G:

14	SyncWord	characterize a wireless network. Default (all earlier version) = 0xF0F0. Was added to support bigger systems.

Registers from 4 to 7 are used in the search algorithm. Let describe it.

Search algorithm.

Let imaging that initially SPT is trying to connect on its hopping frequency (12 or 30 kbod). Then

1. It waits on “base channel”
2. If there was no GW packet for << cycles to step 12, channel (reg 7)>> cycles then it hops
3. If there was no GW packet for << cycles to 500 (reg 4) >> cycles, then it switch to 500/250 kbod on channel defined by byte 53 command (or base channel, or 0)
4. If there was no GW packet for << cycles to step 500 channel (reg 6) >> cycles then the 500 channel is changed to ch = (ch + 25 (or defined by byte 61)) % 250
5. If there was no GW packet for << cycles to 12 (reg 5) >> it switches to base hopping frequency (10 or 30 kbod), base channel
6. If there was no GW packet for << cycles to soft kick, reg 8 >> then all radio registers are reset according to current state
7. If there was no GW packet for << cycles to hard kick, reg 9 >> then SPT resets itself.

How and what is measured in ED.

Before describing floating point ED registers it worth to describe what and how is measured by ED. Each ED has several ADC channels. ED has following ADC channels – V out, P in, I out, V in,

external temperature sensor, ground, V reference, internal temperature sensor, VDD/3. To improve the accuracy internal integration is done by the processor. For this reason data is accumulated in circular buffer (cleared by byte register 30 write as described above). By the GW bunch 0 message data from this circular buffers is processed and scaled. First we produce temperature from both sensors using rough estimate for Vref and linear temperature coefficients:

T(mV) = (T(counts) – Ground(counts))*Vref0 / Referenced(counts)
T(degC) = (T(mV) – Offset(mV)) * K

Then temperature corrected V reference value is computed as quadratic polynomial:
Vref(mV) = Vref0 + (1 – Kvref * (T(degC) – T0) ^ 2)

Temperature adjusted frequency shift is computed from T(degC) as cubic polynomial:
dF = dF0 * T(degC) ^ 3 + dF1 * T(degC) ^ 2 + dF2 * T(degC) + dF3
it is compared to current shift and radio frequency get adjusted.

After that V_out, P_in, I_out, V_in are computed using calibrated Vref:
Value(raw mV) = (Value(counts) - Ground(counts)) * Vref / Reference (counts)

P_in and I_out are temperature adjusted (linear):
P (raw mV) = P (raw mV) * (1 + tk_power * (T(degC) – 25))
I (raw mV) = I (raw mV) * (1 + tk_current * (T(degC) – 25))

linear conversion:
Value(scaled) = K * Value(raw mV) + Off
After that crosstalk correction is executed for V_in and V_out (no settable coefficients).

V_in specifies quality of power supply and because of its variable nature we should continuously monitor V_in (rough version) and take actions: if ***V_in < V_Shut_Down_Radio*** we do not send data, when ***V_in < V_Voltage_Lockout_in_Bypass*** we switch SPT power conversion of in bypass mode, when ***V_in > V_Turn_On*** it is switched back on.

ED's Floating Point Registers

1	DFK0	cubic polynomial for frequency shift, coefficient fro T^3,	-0.000784329277
2	DFK1	cubic polynomial for frequency shift, coefficient fro T^2 ,	0.069999928482
3	DFK2	cubic polynomial for frequency shift, coefficient fro T,	-1.557036645365
4	DFK3	cubic polynomial for frequency shift, offset,	-261.914041475601

~~5 TK_CUR temperature coefficient for current 0.0~~
~~6 TK_POW temperature coefficient for power 0.0~~
~~7 VIN_TURN_ON, V_Turn_On, see above, mV, 20000.0~~
~~8 VIN_SHUT_OFF , V_Voltage_Lockout_in_Bypass , see above, mV, 24000.0~~
In Version G those registers were substituted by Byte registers 77 & 78

10	Linear coefficient for Vout	24.156

11	Offset for Vout	mV,	0.0
12	Linear coefficient for Pin		28.058
13	Offset for Pin,	cW,	0.0
14	Linear coefficient for Iout		5.264
15	Offset for Iout	mA,	-483.0
16	Linear coefficient for Vin		22.047
17	Offset for Vin	mA,	0.0
18	Linear coefficient for T external		0.435
19	Offset for T external,	mV,	623.0
20	Linear coefficient for T internal		0.39
21	Offset for T internal	mV,	745.12821
~~22~~	~~Vin_Disable_Radio, mV,~~		~~6000.0~~

In version G this register was substituted by byte register 79

24	Vref0	- quadratic polynomial for Vref, mV,	2435.0
25	Kvref	- quadratic polynomial for Vref,	0.0000004
26	T0,	- quadratic polynomial for Vref, degC	73.0

Planned changes for version G.

I. Special way to bring any SPT to communicating state will be done. For this SPT will be powered from output (using some features of Anatoli's AUX) and then input voltage will be close to 0. In order to accommodate different devices from SPT family (like pyranometer) there will be one more parameter – InputVoltageLowerLimit. If input volatage is lower then this Byte register then SPT will switch to following predefined state: Not-Hopping, 12 kbod, not FEC, channel 255, default key / IV pair, edAddr 2, gwAddr 1. The InputVoltageLimit will be byte register 76.

II. Several parameters may be / will be moved from floating point group to byte group. The planned parameters are:

7 VIN_TURN_ON, V_Turn_On, see above, mV, 10000.0

8 VIN_SHUT_OFF , V_Voltage_Lockout_in_Bypass , see above, mV, 12000.0

22 Vin_Disable_Radio, mV, 6000.0

They will be converted into deciVolts (for example 6000 => 60) or to volts (for example 6000 => 6). That is planned to do in order to save code space on comparison / conversion). Most likely they will become byte registers 77, 78, 79.

III. Superhot Temperature check correction.

IV. Floating coefficients might be retired to save code space:

5 TK_CUR temperature coefficient for current 0.0

6 TK_POW temperature coefficient for power 0.0

V. Byte reg 14 commands to use the current timestamp as a “install date”

VI. Byte reg 13 for “stay in rx” flag – try to keep constant power consumption to increase ADC accuracy, requested by Anatoli.

VII. Byte commands 6,7,8,9 to set “test number” passed by this device with the date.

S addr 6 b12

VIII. CW mode was reintroduced (the true CW)

IX. Spike Killer (like in GW) was implemented – controlled by BYTE parameter 15.

ED's Scaling Report Format

~~ED reports its scaling coefficients in 4 data packets following the byte command described above. GW formats them as following:~~

~~# N MAC mpp, module, ov, oc, channel, radioDebug, azimuth, positionInString, netId, myBunch, inst date (UTC sec), groupId, elevation, latitude, longitude, altitude – all hex~~
~~SC5: 000000000000 ...~~
~~# N MAC DF0 DF1 DF2 DF3 Vref0~~
~~SC4: 000000000000 -0.0007843292 0.069999928 -1.55703664 -197.91404728 2435~~
~~# Kvref~~
~~0.00000039999996~~
~~# N MAC T0 K Vout Off Vout K Power Off Power K Current out~~
~~SC3: 000000000000 73.0 24.15600014 0.0 28.084999088 0.0 5.26399994~~
~~# N MAC Off Cur K Vin Off Vin K Text off Text K Tin~~
~~SC2: 000000000000 -483.0 22.047000884 0.0 0.43500000 623.0 0.39000000~~
~~# N MAC Off Tin V Turn On V Bypass V radio tk I tk P~~
~~SC1: 000000000000 745.12823486 24000.0 20000.0 12000.0 0.0 0.0~~

The old calibration format has been retired in E2 in order to save code space. The new format is more straightforward – it is just a binary copy of memory area where parameter page is kept. It can be a binary copy of page in the RAM (command 32) or flash (command 57). That binary image is printed in bunches of 24 with SC started from SC5 to SCE. The current parameter (G) page record is as following:

```
typedef struct {
  UINT16 barrier;                                                    // 2
  BYTE   netId, myBunch;                                             // 2
  UINT16 groupId;                                                    // 2
  // MAC number is exactly a SERIAL NUMBER
  // format:
  // 3bit weekday | 6 bit week | 7 bit year | 1 byte test center | 2 byte seq number | 1 byte random
  BYTE   myMac[6];                                                   // 6
  // dF = -0.000561897 t^3 + 0.0539971 t^2 - 0.8658779608121610 t - 249.5883835010120000
  // t  = (adcs[5]-73000)) / 260
  float dFk[4];                                                      // 16

  float vrefPolynom[3];                                              //* 12
  // Vout Pin Iout Vin Text Tint
  float linearK [6][2];                                              //* 48
```

```
    // this is always 0 and not used anymore
    INT32  theDelta;                                                    // 4
    INT32  dF_Tolerance; // 16 in the offset register                   // 4

    char curKey[ AES_SIZE ];                                            // 16
    char curIV [ AES_SIZE ];                                            // 16
       // this is now settable and it needs to be used in middleware and in test program
    struct {
      BYTE   testNumber; // testNumber & 0x80 != 0 - successful, otherwise - not successful, 7 bites for
test Number
      UINT32 testDate;   // UTC timestamp
    }tests[4];                                                          // 20
    UINT32 installDate;  // UTC timestamp                               4

    // all the next fields are settable and readable, but not used now in middleware
    BYTE   azimuth, positionInString;                                   // 2
    UINT16 string, elevation, latitude, longitude, altitude;            // 10
    BYTE channel;                                                       // 1
    // first three are not used anymore, last 2 are not settable anymore
    float   VinTurnOn, VinShutOff, VinDisableRadio, tkCurrent, tkPower; // 20
    BOOL    mpp, module;
    BYTE    ov,  oc;
    BYTE    radioPower, edAddr, gwAddr, repeaterChannel, repeaterPower;
    BOOL
          production         :   1,
          ensureWDReset      :   1,
          use10kbod          :   1,
          useFEC             :   1,
          hoppingAllowed     :   1,
          isRelay            :   1,
          is500Always        :   1,
          searchCommunication :   1;

    BYTE    showState;
    signed char CriticalLevel500, CriticalLevel10;
    UINT16  version;

    UINT16  defCyclesTo500, defCyclesTo10, defCyclesToStep500Channel,
defCyclesToStep10Channel, defCycles2SoftKick, defCycles2HardKick;
    UINT16  imageAddr;    // magic number 0x7CD4
    UINT16  versionLow, versionHigh;
    BYTE    starting500Channel;
    BOOL    tryOtherImageFirst : 1,
              use250kbod       : 1,
          speculative_report : 1,
          stay_in_rx         : 1,
```

```
        theRest          : 4;
    UINT16  prepAddr;
    BYTE    repStep, ov_startup, t_mod_off, toff_fallback, ton_fallback, fallback_time, network_cnst_1,
network_cnst_2, oc_protection, power_dissipation_limit, power_dissipation_time, wiggle_dchan,
ov_step, shunt, max_off, vin_limit,  vin_turn_on, vin_switch_off, vin_disable_radio;
}
```

Right now it is 240 bytes even, so in the future underlined fields (20 bytes total) will be reused in order to avoid increasing the scaling size.

Useful commands list examples:

```
# refresh the flash for all ED
Z *
# save the flash for all ED
f *
# decrease the netId
d
# change the channel
h 10
# allow join for one second/minute/hour/day
j s1
j m1
j h1
j d1


# scaling coefficients
o *
s * 32 b1
# scaling coefficient repeat count = 2
s * 58 b2
# scaling coefficients from flash
s * 57 b1


# reset commands counter to 0
Q
# push commands counter to next 1024
```

p

#default MAC is 6 zero bytes - 00 00 00 00 00 00

setup mac

s *|mNNNNNNNNNNNN|#bbbi 16 bxx

s *|mnnNNNNNNNNNN|#bbbi 17 bxx

s *|mnnnnNNNNNNNN|#bbbi 18 bxx

s *|mnnnnnnNNNNNN|#bbbi 19 bxx

s *|mnnnnnnnnNNNN|#bbbi 20 bxx

s *|mnnnnnnnnnnNN|#bbbi 21 bxx

s m000000000000 16 b10

new set MAC command - MAC

s m000000000000 0 mXXXXXXXXXXXX

Vout mV

s * 10 f24.145

s * 11 f0

Pin/10

s * 12 f28.08

s * 13 f0

Iout mA

s * 14 f5.262

s * 15 f-483

Vin mV

s * 16 f22.03

s * 17 f0

s * 19 f621.27586

s * 18 f0.425

Vref polynomial coefficients (24,25,26) - Vref = Vref0_24 * T * T + Vref1_25 * T + Vref0_26
defaults: 0, 0, 2435.0
s * 24 f2435.0
s * 25 f0.0000004
s * 26 f73.0

Set overvoltage x is dec
s * 22 b128
s * 22 b40
s * 22 b80

SET overcurrent x is dec
s * 23 b150
s * 23 b20

Module On
s * 5 b0
s * 5 b1

MPP On
s * 4 b1
s * 4 b0

Set Bunch 2 and Network ID 3 for device BC4A800009DA, H means hex – for convenience
s mBC4A800009DA 2 H203
Set Bunch 11 and Network ID 10 for device BC4A800009DA, H means hex – for convenience
s mBC4A800009DA 2 HB0A

#Some Gateway commands:
set number of devices in gateway to 0
k 0
set frequency offset

K 3 -234

set gateway bunch size (1 to 16)

K 6 4

APPENDIX A

The power table

Current	Power Fund.	Power 2nd harm	Power 3rd harm	Power 4th harm	Power 5th harm	Power 6th harm	Register, hex	Register, dec
25.0	**0.6**	**-49.7**	**-51.8**	**-50.8**	**-47.4**	**-49.6**	**FF**	**255**
24.7	0.2	-50.2	-52.3	-50.9	-49.1	-49.6	FB	
23.4	0.1	-50.3	-52.7	-50.7	-45.7	-49.9	EF	
23.1	-0.3	-51.1	-53.0	-51.0	-46.8	-49.9	EB	
24.7	-0.4	-52.2	-53.1	-51.6	-49.7	-49.9	FE	254
24.7	-0.7	-52.6	-53.5	-51.7	-49.8	-49.9	FD	
23.1	-0.8	-51.3	-53.2	-51.9	-49.6	-49.8	EE	
24.4	-0.9	-54.1	-54.1	-51.7	-50.0	-49.9	FA	
23.1	-1.1	-51.9	-53.3	-51.8	-49.8	-49.8	ED	
24.3	-1.2	-54.0	-54.4	-51.8	-49.9	-49.7	F9	
22.7	-1.2	-53.5	-53.7	-51.7	-49.8	-49.6	EA	
22.7	-1.5	-53.5	-53.4	-51.8	-50.0	-49.9	E9	
21.6	-2.3	-49.6	-53.4	-51.7	-47.9	-49.9	BF	
21.2	-2.8	-51.1	-53.8	-52.1	-49.4	-49.9	BB	
20.5	-3.0	-49.1	-54.3	-52.1	-47.5	-49.4	AF	
20.1	-3.4	-50.5	-53.7	-52.0	-48.9	-49.8	AB	
21.3	-3.5	-51.7	-54.4	-51.9	-49.9	-49.8	BE	
21.2	-3.8	-51.7	-54.5	-52.1	-49.7	-49.9	BD	
20.9	-3.9	-53.7	-54.2	-52.1	-49.6	-49.9	BA	

20.2	-4.1	-50.6	-54.0	-52.2	-49.7	-49.8	AE	
20.9	-4.2	-53.6	-54.4	-52.0	-50.1	-49.8	B9	
20.1	-4.4	-51.1	-54.5	-52.1	-50.0	-49.9	AD	
19.8	-4.4	-52.3	-54.2	-52.2	-49.8	-49.9	AA	
19.7	-4.7	-52.9	-54.1	-52.2	-49.9	-49.7	A9	
18.7	-4.7	-46.8	-54.6	-50.9	-47.2	-49.7	DF	
18.3	-4.9	-47.6	-54.6	-51.6	-48.4	-49.7	DB	
18.3	-5.3	-47.1	-54.6	-51.4	-49.1	-49.8	DE	
18.3	-5.4	-47.3	-54.5	-51.2	-49.6	-49.8	DD	
18.0	-5.4	-48.0	-54.5	-51.8	-49.3	-49.9	DA	
17.9	-5.6	-48.5	-54.4	-51.9	-49.1	-49.6	D9	
23.5	-5.7	-49.1	-54.4	-52.1	-49.8	-49.7	F7	
21.8	-5.7	-48.9	-54.2	-52.1	-49.9	-49.8	E7	
23.2	-6.3	-50.7	-54.5	-51.8	-49.9	-49.8	F6	
21.5	-6.4	-50.9	-54.4	-51.7	-49.9	-49.8	E6	
23.2	-6.5	-51.3	-54.6	-52.0	-49.6	-49.8	F5	
21.4	-6.6	-51.0	-54.5	-52.0	-50.0	-49.9	E5	
18.5	-7.2	-50.5	-54.4	-52.1	-48.7	-49.7	7F	
18.2	-7.7	-52.2	-54.3	-52.2	-49.5	-50.0	7B	
17.0	-7.9	-52.0	-54.4	-52.0	-49.6	-49.8	D7	
18.0	-8.0	-50.1	-54.6	-52.0	-49.2	-49.7	6F	
17.4	-8.2	-47.6	-54.6	-51.9	-49.7	-49.7	9F	
17.0	-8.4	-48.3	-54.3	-52.0	-49.7	-49.6	9B	
17.6	-8.4	-51.5	-54.5	-52.0	-49.6	-49.9	6B	
18.2	-8.5	-52.6	-54.5	-52.2	-50.0	-49.8	7E	
16.6	-8.5	-53.5	-54.3	-51.9	-49.9	-49.7	D6	

20.0	-8.6	-51.4	-54.4	-52.1	-50.0	-49.6	B7	
16.6	-8.7	-53.7	-54.3	-52.2	-49.6	-49.9	D5	
17.0	-8.8	-48.6	-54.6	-52.1	-49.8	-49.8	9E	
18.2	-8.8	-53.2	-54.4	-52.1	-49.9	-49.9	7D	
18.9	-8.8	-51.5	-54.5	-52.2	-49.9	-49.9	A7	
17.8	-8.9	-53.8	-54.4	-52.1	-49.8	-49.6	7A	
17.0	-9.0	-48.5	-54.4	-52.0	-50.0	-49.9	9D	157
16.7	-9.0	-49.2	-54.3	-52.1	-50.0	-49.8	9A	
17.6	-9.1	-52.3	-54.3	-52.1	-49.5	-49.9	6E	
16.6	-9.1	-49.2	-54.5	-52.0	-49.9	-49.8	99	
17.8	-9.2	-53.8	-54.2	-52.0	-49.9	-49.6	79	
19.7	-9.3	-52.7	-54.5	-52.1	-49.8	-49.8	B6	
17.6	-9.4	-52.3	-54.3	-52.2	-49.9	-49.8	6D	
18.5	-9.5	-52.6	-54.6	-52.0	-49.8	-49.6	A6	
17.3	-9.5	-52.9	-54.6	-51.9	-49.8	-49.8	6A	
19.6	-9.5	-52.7	-54.5	-52.0	-50.0	-49.7	B5	
18.5	-9.7	-53.3	-54.5	-52.2	-49.8	-49.6	A5	
17.2	-9.8	-53.2	-54.6	-52.0	-49.9	-49.9	69	
16.6	-10.9	-48.1	-54.0	-52.1	-48.4	-49.7	CF	
16.2	**-10.9**	**-48.3**	**-53.9**	**-52.0**	**-49.4**	**-49.9**	**CB**	
16.3	-11.2	-48.4	-54.0	-52.2	-48.6	-49.8	CE	
15.9	-11.3	-48.7	-54.4	-52.0	-49.4	-49.6	CA	
16.2	-11.4	-48.5	-54.5	-51.9	-49.1	-49.7	CD	
15.7	-11.4	-53.7	-54.5	-52.2	-49.6	-49.7	97	
15.8	-11.4	-48.9	-54.4	-52.0	-49.3	-49.7	C9	
15.4	-11.9	-54.3	-54.4	-52.0	-49.6	-49.9	96	

15.3	-12.1	-54.1	-54.7	-52.0	-49.9	-49.7	95	
24.4	-12.4	-52.2	-54.6	-52.0	-49.9	-49.8	FC	
22.7	-12.4	-52.1	-54.5	-51.9	-50.1	-49.6	EC	
14.9	-12.6	-53.3	-54.4	-52.0	-49.5	-49.7	C7	
24.1	-12.7	-52.3	-54.7	-52.1	-49.9	-49.8	F8	
22.3	-12.7	-52.3	-54.5	-52.1	-49.7	-49.7	E8	
14.6	-13.1	-53.9	-54.4	-51.9	-49.8	-49.8	C6	
16.3	-13.1	-49.8	-54.5	-52.1	-49.9	-49.9	5F	
14.5	-13.2	-54.2	-54.4	-52.1	-49.8	-49.7	C5	
15.9	-13.4	-50.5	-54.5	-52.0	-49.9	-49.9	5B	
16.9	-13.5	-53.6	-54.5	-52.2	-49.9	-49.8	77	
16.3	-13.7	-53.5	-54.5	-52.0	-49.8	-49.7	67	
16.0	-13.9	-50.7	-54.3	-52.0	-49.9	-49.7	5E	
17.8	-14.1	-52.1	-54.3	-51.9	-49.7	-50.0	DC	
15.9	-14.1	-50.7	-54.4	-52.2	-49.8	-49.7	5D	
15.6	-14.1	-51.3	-54.5	-52.0	-49.9	-49.7	5A	
16.6	-14.2	-54.1	-54.5	-52.0	-49.6	-49.7	76	
15.5	-14.3	-51.7	-54.6	-52.0	-49.8	-49.8	59	
17.5	-14.4	-52.4	-54.6	-51.9	-49.7	-49.8	D8	
16.5	-14.4	-54.0	-54.3	-52.1	-49.8	-49.8	75	
16.0	-14.4	-54.1	-54.5	-52.1	-49.8	-49.8	66	
16.0	-14.5	-49.5	-54.3	-52.1	-49.7	-49.6	8F	
15.6	-14.6	-50.3	-54.2	-51.8	-50.0	-49.7	8B	
23.1	-14.6	-53.8	-54.6	-51.9	-50.0	-49.8	F3	
21.4	-14.6	-53.9	-54.6	-52.3	-49.8	-49.8	E3	
15.9	-14.7	-54.0	-54.3	-52.1	-49.8	-49.8	65	

15.7	-15.0	-50.0	-54.6	-52.1	-49.9	-49.9	8E	142
15.3	-15.1	-50.3	-54.6	-52.1	-49.4	-50.0	8A	
15.6	-15.1	-49.9	-54.3	-52.0	-49.7	-49.7	8D	
22.8	-15.1	-53.7	-54.5	-51.9	-49.8	-49.6	F2	
21.0	-15.2	-53.8	-54.4	-52.1	-50.0	-49.7	E2	
15.2	-15.2	-50.6	-54.2	-52.3	-49.9	-49.9	89	
22.7	-15.3	-53.9	-54.5	-52.2	-49.8	-49.8	F1	
21.0	-15.3	-53.7	-54.6	-52.1	-49.9	-49.9	E1	
20.9	-15.5	-52.7	-54.5	-52.0	-49.8	-49.8	BC	
19.8	-15.7	-52.3	-54.6	-52.1	-49.8	-49.9	AC	
20.5	-15.8	-52.8	-54.6	-52.1	-49.8	-49.9	B8	
19.4	-16.0	-52.7	-54.4	-52.2	-50.0	-49.6	A8	
16.5	-16.0	-53.7	-54.6	-52.0	-50.0	-49.4	D3	
22.8	-16.1	-53.0	-54.5	-52.1	-49.8	-49.4	F4	
21.1	-16.1	-52.4	-54.3	-52.1	-49.7	-49.8	E4	
14.3	-16.4	-54.2	-54.3	-52.1	-49.9	-49.9	87	
14.6	-16.5	-54.5	-54.3	-52.2	-49.9	-49.6	57	
16.1	-16.5	-53.5	-54.5	-52.1	-49.9	-49.7	D2	
16.1	-16.7	-53.8	-54.4	-52.0	-49.8	-49.8	D1	
14.0	-16.9	-54.1	-54.5	-52.1	-49.9	-49.6	86	
14.0	-17.0	-54.2	-54.4	-52.0	-50.0	-49.7	85	
14.3	-17.0	-54.4	-54.3	-52.1	-49.7	-49.7	56	
14.2	-17.2	-54.4	-54.5	-52.1	-49.9	-49.8	55	
16.6	-17.6	-53.1	-54.4	-52.1	-50.0	-49.5	9C	
16.2	-17.6	-53.0	-54.5	-52.0	-49.9	-50.0	D4	
19.5	-17.6	-54.1	-54.4	-52.1	-49.7	-49.8	B3	

18.4	-17.7	-53.8	-54.6	-52.2	-49.8	-49.6	A3	
15.8	-17.7	-53.3	-54.6	-52.1	-49.8	-49.8	CC	
16.2	-17.9	-52.9	-54.6	-52.4	-49.6	-49.5	98	
15.4	-18.0	-53.2	-54.6	-52.0	-49.7	-49.9	C8	
19.2	-18.1	-53.9	-54.6	-52.1	-50.0	-49.8	B2	
18.1	-18.2	-54.0	-54.5	-52.3	-49.9	-49.6	A2	
19.2	-18.2	-54.0	-54.5	-52.1	-49.8	-49.8	B1	
18.0	-18.3	-53.8	-54.6	-52.3	-50.0	-49.5	A1	
14.4	-18.9	-54.1	-54.5	-52.2	-49.7	-49.5	C3	
15.6	-19.1	-51.4	-54.0	-52.2	-49.8	-49.3	4F	
19.3	-19.1	-53.5	-54.6	-52.1	-49.3	-49.7	B4	
18.1	-19.2	-53.2	-54.6	-52.0	-50.0	-49.9	A4	
15.2	-19.2	-52.0	-54.3	-52.0	-49.9	-49.9	4B	
15.2	-19.3	-54.0	-54.4	-52.1	-49.8	-49.6	93	
14.1	-19.5	-53.8	-54.3	-52.1	-50.0	-49.8	C2	
14.0	-19.6	-54.1	-54.6	-51.6	-49.9	-49.9	C1	
15.2	-19.8	-51.5	-54.5	-52.1	-49.7	-49.8	4E	
14.9	-19.8	-53.9	-54.5	-52.2	-49.8	-50.0	92	
14.8	-19.9	-51.7	-54.5	-52.0	-50.0	-49.9	4A	
14.8	-20.0	-53.8	-54.6	-52.1	-50.0	-49.7	91	
15.2	-20.0	-51.5	-54.4	-51.8	-49.9	-49.8	4D	
14.8	-20.1	-52.2	-54.4	-51.8	-49.7	-49.8	49	
17.8	-20.5	-53.1	-54.4	-52.2	-50.0	-49.9	7C	
17.2	-20.7	-53.4	-54.5	-52.1	-50.1	-49.9	6C	
14.1	-20.7	-53.5	-54.5	-52.1	-50.0	-49.6	C4	
17.4	-20.8	-53.4	-54.3	-52.2	-50.0	-49.8	78	

14.9	-20.9	-53.2	-54.8	-52.0	-49.9	-49.8	94	
16.8	-21.0	-53.1	-54.5	-52.1	-50.0	-50.0	68	
13.9	-21.3	-54.2	-54.5	-52.0	-50.0	-49.6	47	
15.2	-21.4	-53.5	-54.5	-52.2	-49.7	-49.9	8C	
14.8	-21.6	-53.7	-54.5	-51.9	-49.9	-49.6	88	
13.6	-21.7	-54.3	-54.5	-51.9	-50.0	-49.9	46	
13.5	-21.9	-54.1	-54.2	-52.0	-49.8	-49.7	45	
16.4	-22.4	-54.1	-54.4	-52.1	-49.6	-49.9	73	
13.9	-22.4	-53.9	-54.5	-52.2	-49.8	-49.8	83	
15.9	-22.5	-54.2	-54.4	-52.1	-50.0	-49.4	63	
22.3	-22.6	-53.5	-54.5	-52.0	-50.0	-50.0	F0	
20.6	-22.6	-53.9	-54.5	-52.0	-49.9	-49.9	E0	
15.5	-22.6	-53.5	-54.6	-52.2	-49.7	-49.9	5C	
15.1	-22.9	-53.4	-54.3	-52.1	-49.6	-49.7	58	
16.1	-22.9	-53.8	-54.4	-51.8	-49.8	-49.8	72	
13.5	-23.0	-54.0	-54.3	-52.2	-49.9	-49.9	82	
15.5	-23.1	-54.1	-54.3	-51.7	-50.0	-49.8	62	
16.1	-23.1	-53.8	-54.4	-52.2	-49.7	-49.8	71	
13.5	-23.1	-54.3	-54.6	-52.1	-49.8	-49.8	81	
15.5	-23.2	-53.8	-54.3	-52.0	-49.8	-49.5	61	
15.7	-24.0	-53.5	-54.6	-52.1	-49.8	-49.7	D0	
16.2	-24.0	-53.2	-54.7	-51.8	-50.1	-49.9	74	
15.6	-24.2	-53.6	-54.4	-52.1	-49.9	-49.9	64	
14.2	-24.2	-54.1	-54.5	-52.1	-49.9	-49.4	53	
13.6	-24.3	-53.4	-54.3	-52.2	-49.9	-49.5	84	
13.8	-24.7	-53.9	-54.5	-52.2	-49.8	-49.6	52	

13.8	-24.9	-53.9	-54.4	-52.0	-50.0	-49.7	51	
18.8	-25.6	-53.3	-54.5	-52.2	-49.7	-49.7	B0	
17.6	-25.7	-53.5	-54.4	-52.2	-49.7	-49.6	A0	
13.9	-25.9	-53.6	-54.3	-52.1	-49.8	-49.8	54	
14.8	-26.3	-53.5	-54.6	-52.2	-50.0	-49.8	4C	
14.4	-26.6	-53.7	-54.5	-52.1	-49.9	-49.7	48	
13.7	-26.8	-53.9	-54.2	-52.0	-49.9	-49.8	C0	
14.5	-27.3	-53.8	-54.5	-52.1	-49.9	-49.7	90	
13.4	-27.3	-53.9	-54.3	-52.2	-50.0	-49.8	43	
13.1	-27.9	-53.7	-54.6	-52.2	-49.9	-49.8	42	
13.1	-28.0	-53.9	-54.4	-52.0	-49.8	-49.5	41	
13.1	-29.2	-53.5	-54.4	-51.8	-49.9	-49.8	44	
13.1	-30.3	-53.8	-54.3	-52.1	-49.8	-49.7	80	
15.7	-30.4	-53.8	-54.5	-51.9	-49.8	-49.8	70	
15.1	-30.5	-53.6	-54.3	-51.9	-49.9	-49.9	60	
13.4	-32.2	-53.9	-54.6	-51.9	-49.8	-49.7	50	
12.7	-35.1	-53.9	-54.4	-52.0	-49.9	-49.8	40	
11.9	-65.8	-53.9	-54.6	-51.9	-49.8	-49.8 0		