Software

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Serial boot logs

When connecting to the UART serial header, the following is printed to the console during boot:

```
Basic POST completed...     Success.
Last reset cause: Hardware reset (Power-on reset)

PSPBoot1.4 rev: 1.4.0.6
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Press ESC for monitor... 1

(psbl)

Booting...
Attached TCP/IP interface to dummy unit 254
Attaching network interface lo0... done.

Adding 8764 symbols for standalone.
CPU: TI TNETV1057 Communication Processor.  Processor #0.
Memory Size: 0xffe000.  BSP version 7.2.7.20.


      ============================================================
      Board           : TI TNETV1057 Communication Processor
      SOC             : Titan, ChipId: 0x7, Version: 2
      Cache           : Write-Back, Write-Allocate
      PSP Version     : 7.2.7.20
      Type            : BasePSP 7.2.7.20 Patch
      PSPWIZ Version  : 0.5
      MIPS freq       : 87500000 Hz,
      System Freq     : 87500000->  Hz,
      VBUS freq       : 81250000 Hz
      BasePSP mode    : Routing
      ============================================================
Model no: 2
```

```
appCreate: autoBootLevel=2
MXP environment is created.
About to create Idle Task
About to create Measurement Task
Idle Measurement Tasks created
Panic button enabled
Heartbeat started
Creating Golden Gateway application...
Creating fs:/tmp 3145728
Decompress app module.... done
appmodule len=2770028
Creating fs:/DR 16384
/DR created
decompress constdat successfully:521344
flash_init . . .
  -- flash_raw_init . . .
  -- flash_fstr_init . . .
  -- flash_fsm_init . . .
  -- flash_license_init . . .
  -- flash_fpar_init . . .
  -- flash_custom_init . . .
  -- flash_fprv_init . . .
  -- flash_dhcp_prov_init . . .
flash_init done
0000008654 - DSPALLOC: AER instance 1, max_tail = 60 ms, usage = ( HS  HeS  GL_HS  GL_HeS )
0000008654 - DSPALLOC: AER instance 0, max_tail = 200 ms, usage = ( HS  HeS  HF  GL_HS  GL_HeS )
```

Boot Loader

The SPA504G uses the PSPBoot boot loader. This is an old bootloader with not much info out there but there is one piece of documentation floating arround and can be found here.

The bootloader can be found in the firmware update files: `psbl.elf`

Recovery Mode

There is also a recovery mode the device will boot into if it cannot load the bootloader. This is a minimal version of PSPBoot. This recovery mode can be manually entered into at device boot by pressing `esc` when prompted with `Press ESC for monitor...`.

```
PSPBoot1.4 rev: 1.4.0.6
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Press ESC for monitor... 1
(psbl) help
reboot          version         info            fa
printenv        setenv          setpermenv      unsetenv
defragenv       fmt             fmtkosmos       boot
dm              oclk            help            ls
df              cp              cat             rm
tftp            upgrade
(psbl)
```

Firmware validation

The logic to validate the firmware bundle begins at: `libupg_validate_firmware_mem`.

This is called from `libupg_upgrade_mem` that is subsequently called from the command `upgrade` in the `psbl` terminal.

This can be seen from the `upgrade` command handler:

```
int upgrade(int argc,char **argv)
{
  int iVar1;
  undefined4 *param2;

  if ((argc == 2 || argc == 4) && ((argc != 4 || (iVar1 = strcmp(argv[1],"-i"), iVar1 == 0)))) {
    *argv = "upgrade";
    argv[argc] = "/dev/ram";
    param2 = (undefined4 *)tftp(argc + 1,argv); // [1]
    if (0 < (int)param2) {
      iVar1 = libupg_upgrade_mem((astruct *)0xb4500000,param2); // [2]
      return iVar1;
    }
  }
  else {
    upgrade_usage();
  }
  return -1;
}
```

A couple of things to note from this snippet:

- [1] Shows the data is being obtained through `tftp` (wtf)
- We can see the address [2] `0xb4500000` being passed into `libupg_upgrade_mem`. This will be the location that the firmware is either downloaded to or where we will begin flashing.

libupg_validate_firmware_mem

The function starts by taking two arguments:

```
int libupg_validate_firmware_mem(byte *param1,uint param2)
[...]
```

- `param1` is the pointer into RAM discussed above (`0xb4500000`)
- `param2` is the result from `tftp` (Looks like it is being used as a data length)

The function begins by validating the firmware's header.

Header validation

The header validation can be found in function `validate_firmware_header`.

The function starts by taking a structure (we're going to call it `firmware_header_struct`).

The function contains two stages:

- Digest validation
- Randseq validation

Information regarding the "header format" has been split into a separate page. Please see Firmware format for more information. The rest of this section wiill use terminology sourced from it.

Digest validation

To calculate the digest you perform the following:

1. Zero out the Signature
2. Zero out the Digest
3. MD5 hash of the firmware header and module header table.

The size of the headers is calulcated with the formula below:

```
size = hdr->FirmwareHeaderSize + hdr->NumberOfModules * hdr->ModuleHeaderSize;
```

The process listed above can be seen in the following tidy Ghidra decompilation (Note: The `size` parameter is the one calulcated above)

```
int gen_fmhdr_digest(void *md5_struct_out, firmware_header_struct *fm_hdr, size_t size) {
  byte *pDigest;
  byte *pSignature;
  astruct_1 MD5Buffer [3];
  undefined lSignature [32];
  undefined lDigest [16];

  // Save signature and digest
  pSignature = fm_hdr->Signature;
  memcpy(lSignature,pSignature,0x20);

  pDigest = fm_hdr->Digest;
  memcpy(lDigest,pDigest,0x10);

  // Zero signature and digest
  memset(pSignature,0,0x20);
  memset(pDigest,0,0x10);

  // MD5 time
  MD5Init(MD5Buffer);
  MD5Update(MD5Buffer,fm_hdr,size);
  MD5Final(md5_struct_out,MD5Buffer);

  // Restore signature and digest
  memcpy(pSignature,lSignature,0x20);
  memcpy(pDigest,lDigest,0x10);
  return 0;
}
```

Randseq validation

To calculate the Randseq perform the following:

- Zero out the Signature, Digest and Ranseq elements of the header
- Perform the `nsdigest` on the same data as the MD5 digest above. `nsdigest` does the following:
  - For each 0x20 sized block in the firmware header and module header table:
    - For each byte:

        - Get the value from the byte array and add a special counter. Place this result of the addition into a temp buffer array
        - Increment counter by 0x19
    - Pass the 32 byte arrary into MD5Update
- Repeat until all bytes have been processed

This process can most clearly be seen with the following Python script:

```
import hashlib

SIGNATURE_OFFSET    = 16
DIGEST_OFFSET       = 48
RANDSEQ_OFFSET      = 64

def memset(data, start, size):
    temp_data_mutable = list(data)

    for i in range(size):
        temp_data_mutable[start+i] = 0

    return bytes(temp_data_mutable)

def nsdigest(data, size):
    data_index = 0
    addition_value = 0
    buf = [0] * 0x20

    md5 = hashlib.md5()

    while True:

        buffer_index = 0

        while True:
            buf[buffer_index] = (data[data_index] + addition_value) & 0xff

            addition_value += 19
            buffer_index += 1
            data_index += 1

            if buffer_index >= 0x20 or data_index >= size:
```

```
            break

        md5.update(bytes(buf))

        if data_index >= size:
            break

    return md5.digest().hex()

def main():

    with open("spa50x-30x-7-6-2g.bin", "rb") as f:
        data = f.read()

    # Calculates the size of the headers
    size = 0x80 + (0x4f * 0x40)

    data = memset(data, SIGNATURE_OFFSET, 32)
    data = memset(data, DIGEST_OFFSET, 16)
    data = memset(data, RANDSEQ_OFFSET, 16)

    x = nsdigest(data, size)
    print(x)

if __name__ == "__main__":
    main()
```

Firmware format

The firmware file is made up of the following components, each located in the firmware file after one another:

- Firmware header
- Module header table
- Module data

This can be extracted using the following Kaitai Struct definition:

Kaitai Struct definition

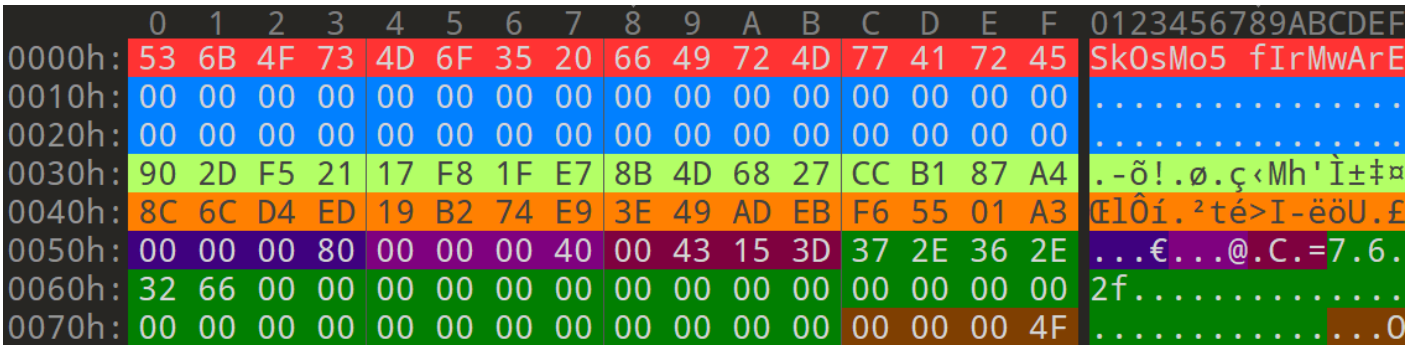
```
meta:
  id: spa504g
  endian: be
  license: Butlersaurus
  title: SPA504G firmware
  bit-endian: be
seq:
  - id: header
    type: header
  - id: modules
    type: module
    repeat: expr
    repeat-expr: header.module_count
types:
  header:
    seq:
      - id: magic
        contents: SkOsMo5 fIrMwArE
      - id: signature
        size: 32
      - id: digest
        size: 16
      - id: random_sequence
```

```
      size: 16
    - id: header_length
      type: u4
    - id: module_header_length
      type: u4
    - id: file_length
      type: u4
    - id: version
      type: str
      encoding: utf8
      size: 32
    - id: module_count
      type: u4
    - id: padding
      size: header_length - 128
module:
  seq:
    - id: module_sequence_number
      type: u2
    - id: module_compressed_flag
      type: u2
    - id: module_length
      type: u4
    - id: module_offset
      type: u4
    - id: module_digest
      size: 16
    - id: padding
      size: _parent.header.module_header_length - 28
  instances:
    body:
      pos: module_offset
      size: module_length
      process: zlib
```

Firmware header

The firmware header is located at the very beginning of the file. Its length is defined by the 32 bit unsigned integer (big endian) located at offset `0x0050`. For example: `0x00000080` (128 bytes).

The format for the **firmware header** is described below:



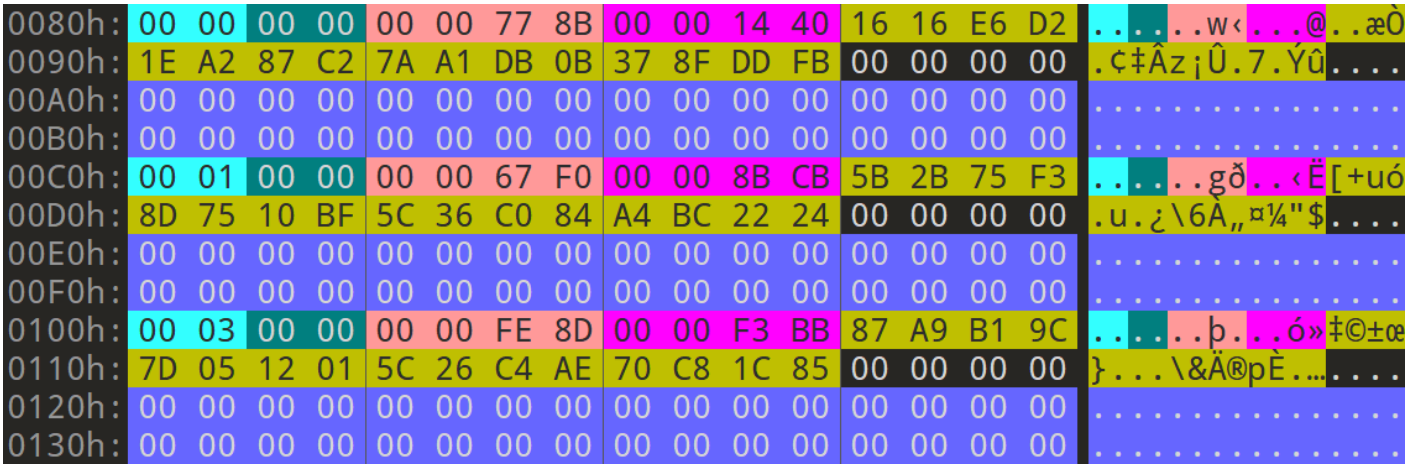
Size (byte)	Type	Description	Example
16	Byte array	Identifier	`SkOsMo5 fIrMwArE`
32	Byte array	Signature	Not used
16	Byte array	MD5 of **firmware header** + **module headers**	`90 2D F5 21 17 F8 1F E7 8B 4D 68 27 CC B1 87 A4`
16	Byte array	A random sequence	`8C 6C D4 ED 19 B2 74 E9 3E 49 AD EB F6 55 01 A3`
4	Unsigned BE Int	Length of the entire **firmware header**	`0x00000080` (128 bytes)
4	Unsigned BE Int	Length of each **module header**	`0x00000040` (64 bytes)
4	Unsigned BE Int	Length of entire file	`0x0043153D` (4396349 bytes)
32	Byte array	Firmware version number	`7.6.2f`
4	Unsigned BE Int	Number of modules present in the firmware	`0x0000004F` (79 modules)

Module header table

There are multiple modules in the firmware file. The number of modules is defined at offset `0x007C` in the **firmware header**. For example: `0x0000004F` (79 modules).

Each module has a **module header**, located in a **module header table**. These are of a length defined at offset `0x0054` in the **firmware header**. For example: `0x00000040` (64 bytes). Each **module header** is concatenated in order, directly after the **firmware header** (in this case, from offset `0x0080`).

The format for each **module header** is described below. The screenshot contains three of the 79 **module headers** present in this particular firmware (7.6.2f).



Size (byte)	Type	Description	Examples
2	Unsigned BE Short	Sector ID	0x00 (0) 0x01 (1) 0x03 (3) This was observed to increase from 0 to 127, skipping the following values: • 2 • 5 to 52 (inclusive)
2	Unsigned BE Short	Compressed flag?	0x00
4	Unsigned BE Int	Length of module data	0x0000778B (30,603 bytes) 0x000067F0 (26,608 bytes) 0x0000FE8D (65,165 bytes) ...
4	Unsigned BE Int	Offset to module data from start of file	0x00001440 (5,184 bytes) 0x00008BCB (35,787 bytes) 0x0000F3BB (62,395 bytes) ...
16	Byte array	MD5 digest of the uncompressed module	16 16 E6 D2 1E A2 87 C2 7A A1 DB 0B 37 8F DD FB 5B 2B 75 F3 8D 75 10 BF 5C 36 C0 84 A4 BC 22 24 87 A9 B1 9C 7D 05 12 01 5C 26 C4 AE 70 C8 1C 85 ...

Size (byte)	Type	Description	Examples
4	Byte array	Unknown	
32	Padding	Zero padding	

Module data

The offset and size for each module's data is defined in the corresponding **module header** in the **module header table**.

For example, the first module in this particular firmware (7.6.2f) is located at offset `0x00001440` (5,184 bytes) from the beginning of the file, and is `0x0000778B` (30,603 bytes) long.

It looks like all of this data is zlib compressed with a 'windowBits' parameter of `15`, as determined by reversing the 'uncompress' method in the psbl.elf binary.

Decompile: uncompress - (psbl.elf)

```
1
2  int uncompress(uchar *_destination,ulong _destinationLength,uchar *_source,ulong _sourceLength)
3
4  {
5    int ret;
6    uchar *source;
7    ulong sourceLength;
8    uchar *destination;
9    ulong destinationLength;
10   undefined4 local_3c;
11   code *libupg_zcalloc;
12   code *libupg_zfree;
13
14   memset(&source,0,0x38);
15   destinationLength = *(ulong *)_destinationLength;
16   libupg_zcalloc = ::libupg_zcalloc;
17   libupg_zfree = ::libupg_zfree;
18   source = _source;
19   sourceLength = _sourceLength;
20   destination = _destination;
21   ret = inflateInit2(&source,15);
22   if (ret == 0) {
23     ret = inflate(&source,4);
24     if (ret == 1) {
25       *(undefined4 *)_destinationLength = local_3c;
26       ret = inflateEnd(&source);
27     }
28     else {
29       inflateEnd(&source);
30       if (ret == 0) {
31         ret = -5;
32       }
33     }
34   }
35   return ret;
36 }
37
```

Using Python, these can be deflated trivially. A PoC deflation script is shown below:

Python deflate script

```
import zlib


compressed_data = open('spa50x-30x-...-module.bin', 'rb').read()
decompressed_data = zlib.decompress(compressed_data, 15) # windowBits of 15.


with open('spa50x-30x-...-module_deflated.bin', 'wb') as f:
```

```
    f.write(decompressed_data)
```

Firmware artefacts

Extracted using the SPA504G extraction utility available here.

spa50x-30x-7-6-2f_artefacts.zip