

Особенности криминалистического анализа некоторых смартфонов на базе чипсетов Qualcomm

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АКТУАЛЬНОСТЬ

Версия ОС Android	Функция вычисления ключа из пароля (KDF)	Решение для перебора без участия телефона (offline)
4.3 (JellyBean) и ниже	PBKDF2	+
4.4 (KitKat)	scrypt	+
5 (Lollipop) и выше	scrypt + keymaster	?

Предположения об объекте исследования

- **Установлена последняя версия ПО – Android 5 и выше**
- **FRP: ON** – нет штатной возможности загрузить неподписанный образ boot.img/recovery.img
- **Шифрование: включено**
- **Secure Startup: ON** – ключ шифрования вычисляется на основе пароля пользователя

Moto G4



Год выпуска: **2016**
Чипсет: **Qualcomm
MSM8952**

Moto G4: подходы

1. chip-off/ISP ?

Moto G4: crypto footer

```
000000000: C4 B1 B5 D0 01 00 03 00 | 30 09 00 00 00 10 00 00 | 1>P@ ♥ 0o ▶
000000010: 10 00 00 00 01 00 00 00 | 00 6F 5A 01 00 00 00 00 | ▶ @ oZ@
000000020: 00 00 00 00 61 65 73 2D | 78 74 73 00 65 73 73 69 | aes-xts essi
000000030: 76 3A 73 68 61 32 35 36 | 00 00 00 00 00 00 00 00 | v:sha256
000000040: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000050: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000060: 00 00 00 00 00 00 00 00 | 5E 34 AB 50 48 EC A5 63 | ^4PH@c
000000070: A1 F4 1C D9 7D EC DB CA | 00 00 00 00 00 00 00 00 | >>L}
000000080: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000090: 00 00 00 00 00 00 00 00 | F7 93 6C 85 3F 27 FD 3D | ?1?'=-
0000000A0: 5F 7E 9D 9A EE 92 1C BD | 00 10 00 00 00 00 00 00 | ~L ▶
0000000B0: 00 20 00 00 00 00 00 00 | 00 10 00 00 05 0F 03 01 | ▶ +o♥
0000000C0: 00 6F 5A 01 00 00 00 00 | 00 00 00 00 00 00 00 00 | oZ@
0000000D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000000E0: 00 00 00 00 00 00 00 00 | 71 E8 63 60 64 7A 42 80 | qc`dzB
0000000F0: 98 31 CD 52 3B B7 40 5E | 31 71 CC 98 D1 BE CE 7B | >1R;@^1q_>{
000000100: C9 70 BB 08 CC 26 C7 D0 | 20 00 00 00 00 00 00 00 | >p&
000000110: 02 00 00 00 40 00 00 00 | 00 00 00 00 10 00 00 00 | @ ▶
000000120: 00 00 00 00 00 00 00 00 | 10 00 00 00 00 00 00 00 | ▶
000000130: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000140: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000150: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000160: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000170: 00 00 00 00 00 00 00 00 | D0 BB B8 1E A4 38 F0 1D | л>▲8+
000000180: D6 72 92 A7 B5 4E 3D 66 | 00 00 00 00 00 00 00 00 | >rN=f
000000190: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001A0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001B0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001C0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001E0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001F0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000200: 00 00 00 00 00 00 00 00 | 35 F4 E2 5D 9B 37 F3 A7 | 5]7
000000210: EE CB 2C 83 31 2B 3D 8C | 45 AE B1 C1 F2 07 33 4B | >>,1+=E•K
000000220: CB 2A 37 14 2C 94 27 99 | BA 41 42 EE DC F9 C3 24 | >*7, 'AB$
000000230: 3F 7E 63 19 84 79 3C AB | 40 4C 36 FE 86 82 57 99 | ?~c↓y<@L6W
```

AES-XTS ?

script+keymaster

зашифрованный
RSA-ключ

Moto G4: подходы

- ~~1. chip-off/ISP~~ – scrypt+keymaster
2. custom recovery (TWRP, ...) ?

Moto G4: подходы

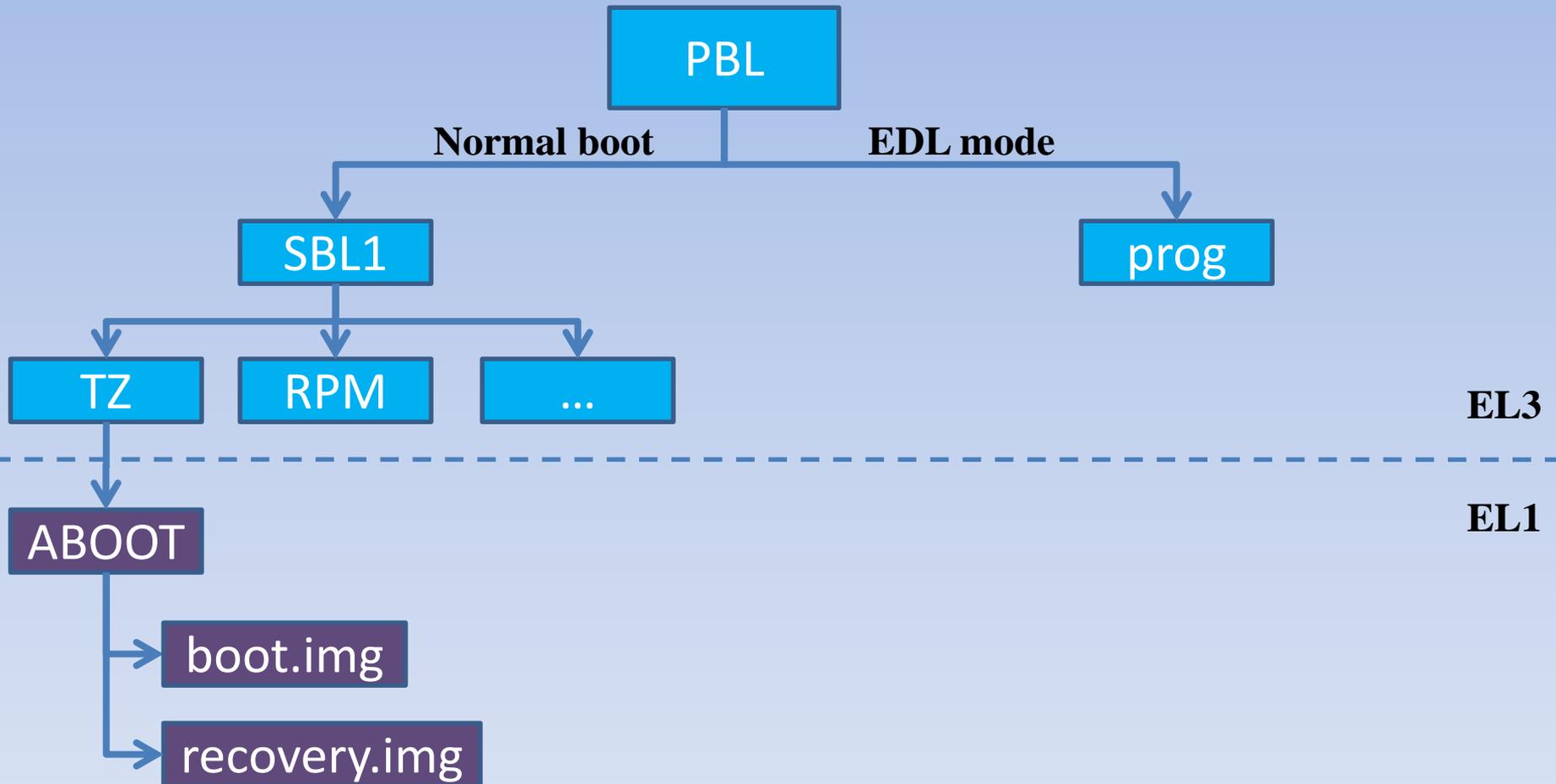
- ~~1. chip-off/ISP~~ – scrypt+keymaster
- ~~2. custom recovery (TWRP, ...)~~ – включен FRP
3. kernel cmdline injection (CVE-2016-10277) ?

Moto G4: подходы

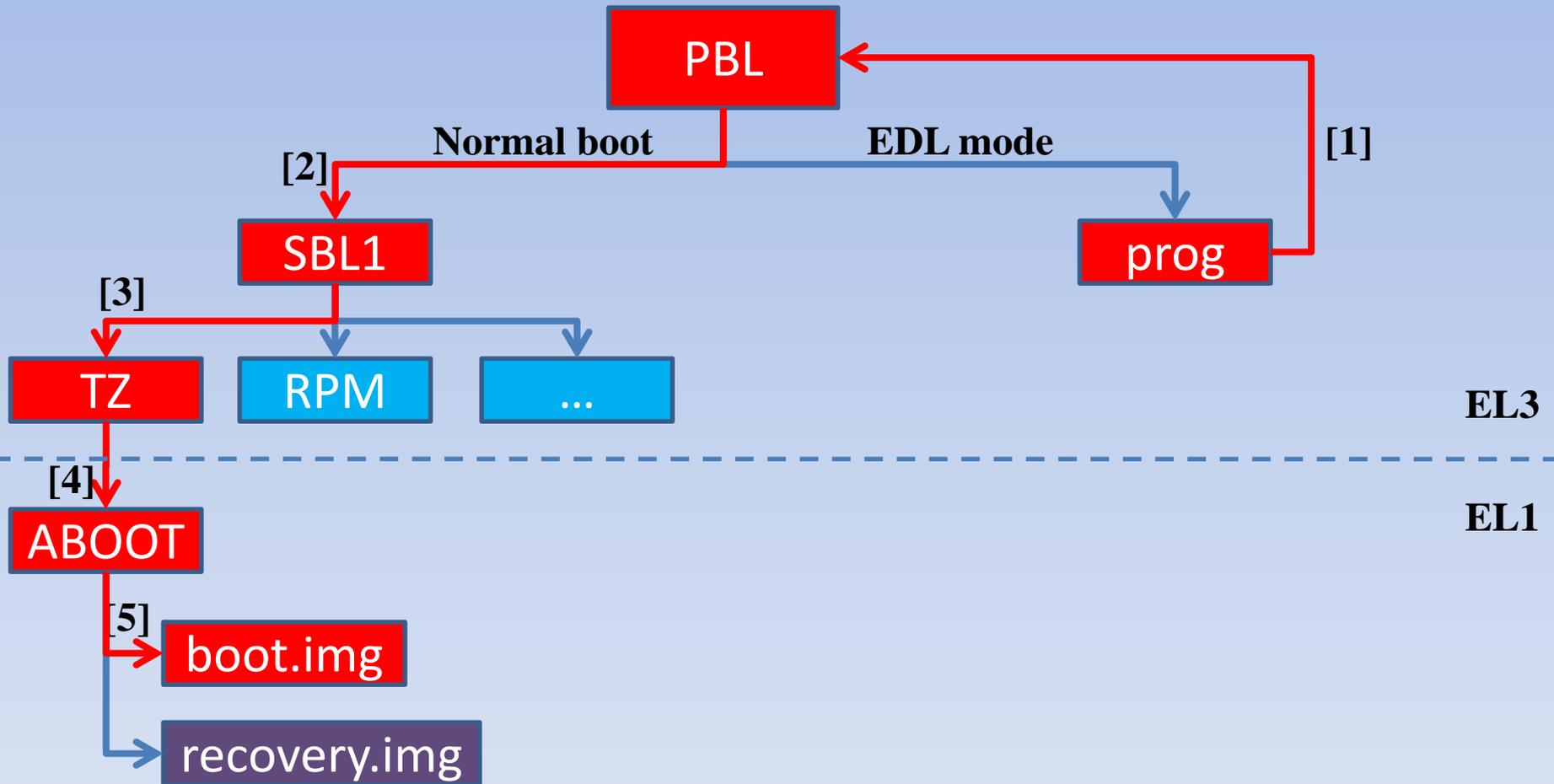
- ~~1. chip-off/ISP – scrypt+keymaster~~
- ~~2. custom recovery (TWRP, ...) – включен FRP~~
- ~~3. kernel cmdline injection (CVE-2016-10277) –
есть патч~~
4. EDL mode: peek/poke (QPSIIR-909)* ?

*<https://alephsecurity.com/vulns/aleph-2017028>

Описание QPSIIR-909 (1)



Описание QPSIR-909 (2)



Описание QPSIR-909 (3)

Необходимые условия:

1. Наличие **prog**-файла для данной модели
2. **prog**-файл выполняется с наивысшими привилегиями (**EL3** в терминах **aarch64**)
3. Учтены особенности аппаратной платформы
4. Реализованы и доступны функции **peek/poke**

Moto G4: подходы

- ~~1. chip-off/ISP – scrypt+keymaster~~
- ~~2. custom recovery (TWRP, ...) – включен FRP~~
- ~~3. kernel cmdline injection (CVE-2016-10277) –
есть патч~~
- ~~4. EDL mode: peek/poke (QPSIR-909)* – команды
peek/poke недоступны~~
5. Уязвимость в PBL MSM8952** ?

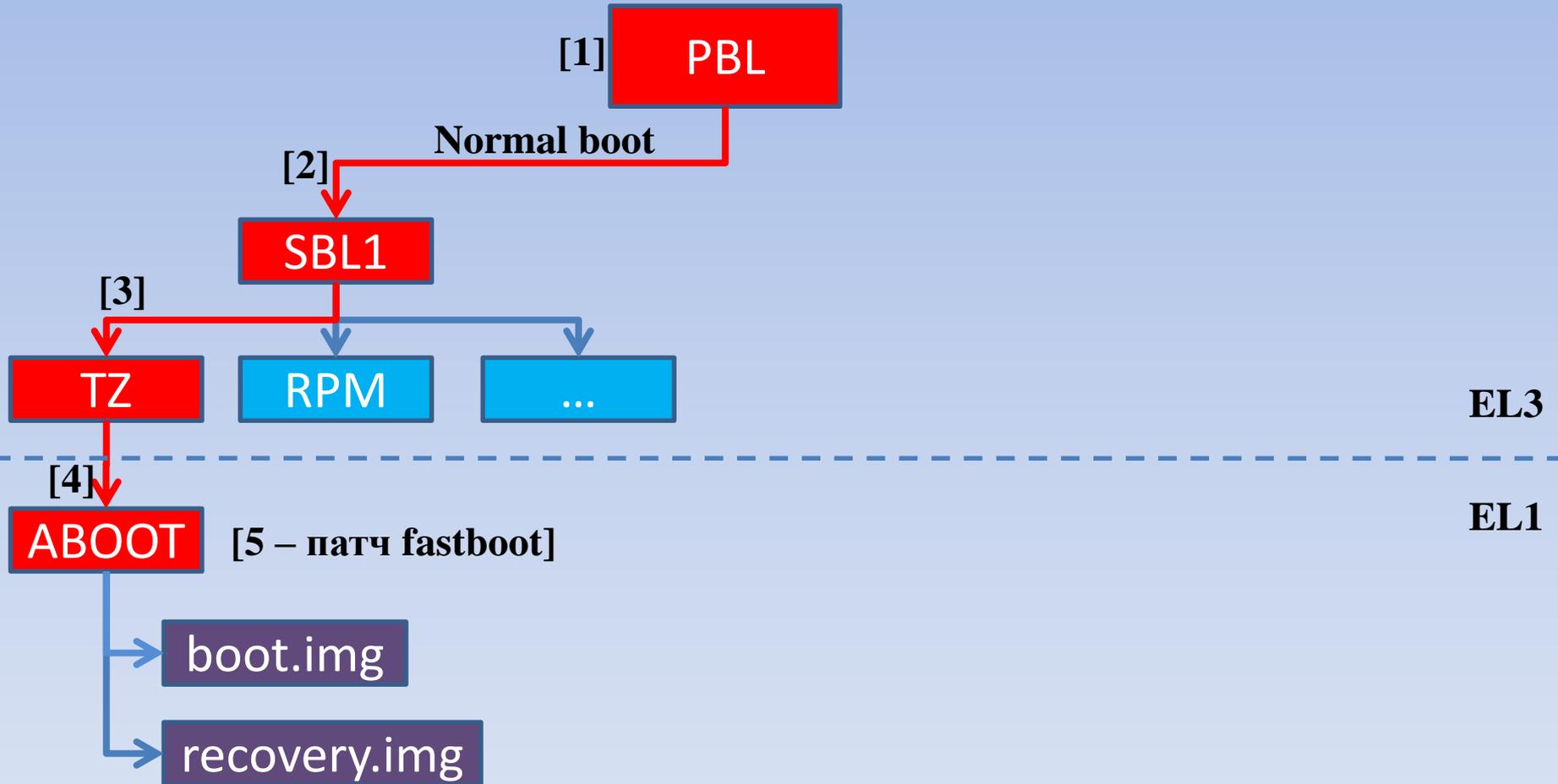
*<https://alephsecurity.com/vulns/aleph-2017028>

**<https://www.bluehatil.com/2018/files/Terrorist2%20Phone%20Unlocking%20101%20-%20BlueHat%20IL%202018.pdf>

Уязвимость в PBL MSM8952 (1)

- Устройство – **ZTE Zmax Pro (MSM8952)**
- Доклад:
 - Общее описание работы в режиме **EDL**
 - Никаких деталей об уязвимости/шифровании

Уязвимость в PBL MSM8952 (2)



Уязвимость в PBL MSM8952 (3)

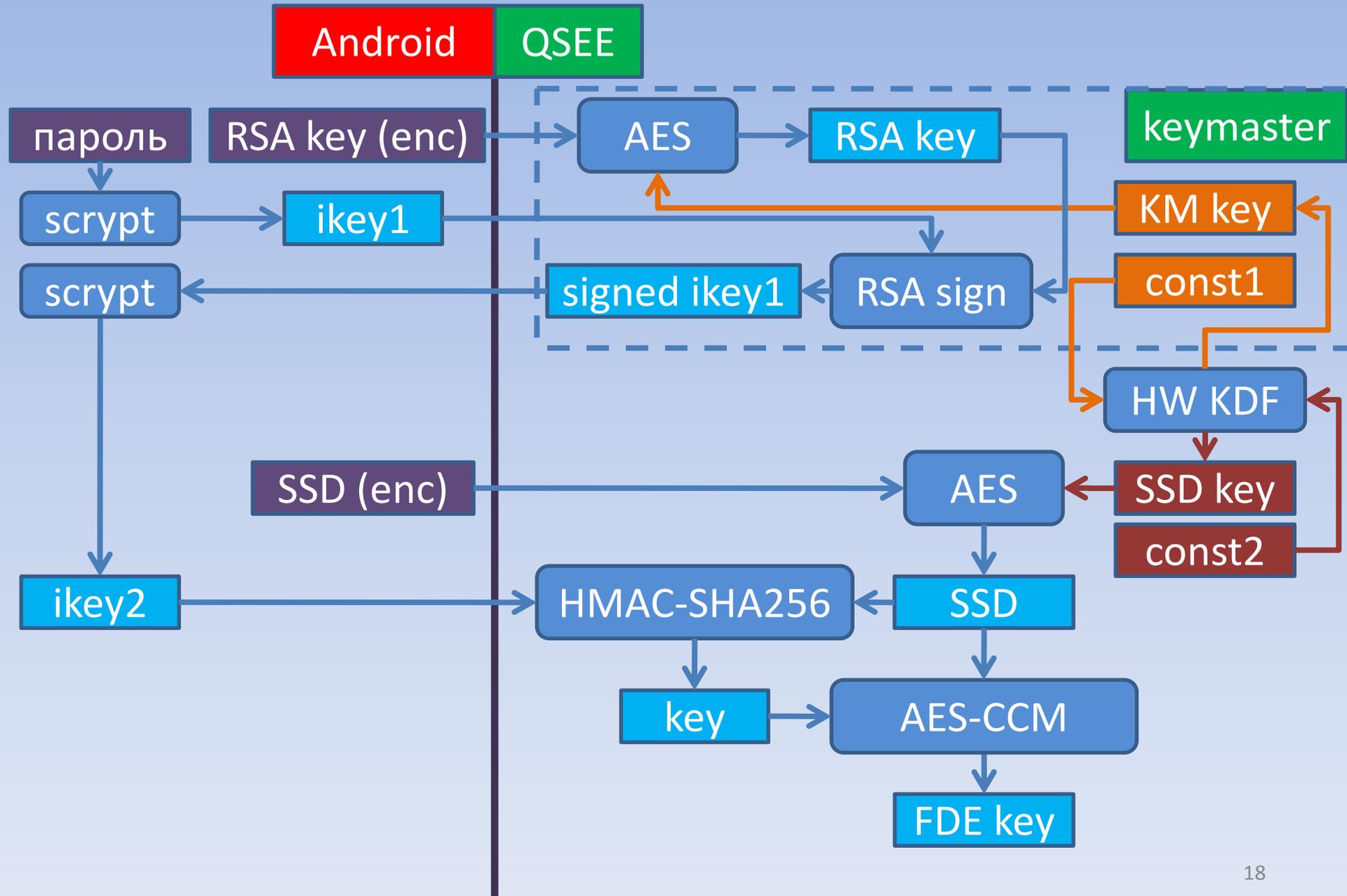
Необходимые условия:

1. Чипсет – **MSM8952**
2. Устройство должно быть переведено в режим **EDL** (программно/аппаратно)

Moto G4: перевод в режим EDL



Moto G4: схема FDE



Moto G4: итоги

1. Возможна компрометация **Secure Boot** через уязвимость в **PBL (MSM8952)**
2. Перебор **offline** возможен путём извлечения пары ключей (**KM key, SSD Key**)
3. Алгоритм перебора состоит из нескольких этапов:
 - **scrypt + RSA-sign + scrypt**
 - итеративный **HMAC-SHA256**
 - **AES-CCM**

Moto G3

Год выпуска: **2015**
Чипсет: **Qualcomm
MSM8916**



Moto G3: подходы

1. chip-off/ISP ?

Moto G3: crypto footer

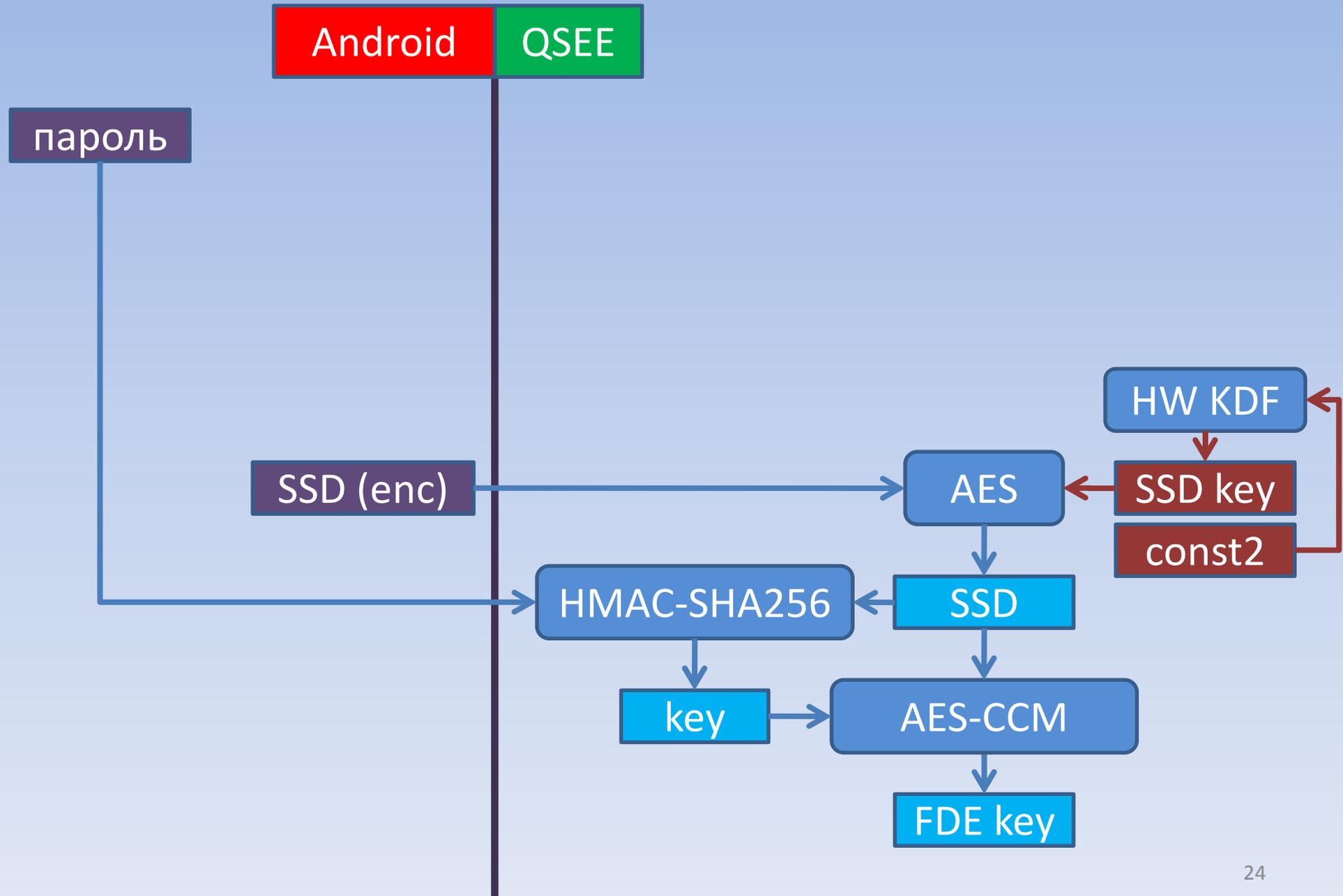
```
000000000: C4 B1 B5 D0 01 00 03 00 | 10 09 00 00 00 00 00 00 | i> 000 000 000
000000010: 10 00 00 00 03 00 00 00 | 00 7F 91 00 00 00 00 00 | 000 000 000
000000020: 00 00 00 00 61 65 73 2D | 78 74 73 00 00 00 00 00 | aes-xts
000000030: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000040: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000050: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000060: 00 00 00 00 00 00 00 00 | 3D CF D0 38 08 B4 E2 AD | =008 000
000000070: 23 37 98 E7 5F D4 48 B5 | 00 00 00 00 00 00 00 00 | #700_0H0
000000080: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000090: 00 00 00 00 00 00 00 00 | 7A FE 02 7F 3D 88 D7 B8 | z000=00>
0000000A0: 76 CD 36 34 E1 B9 56 49 | 00 10 00 00 00 00 00 00 | v0640EVI
0000000B0: 00 20 00 00 00 00 00 00 | 00 10 00 00 02 0F 03 01 | 0000000
0000000C0: 00 7F 91 00 00 00 00 00 | 00 00 00 00 00 00 00 00 | 000
0000000D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000000E0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000000F0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000100: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000110: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000120: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000130: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000140: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000150: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000160: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000170: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000180: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000190: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001A0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001B0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001C0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001E0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
0000001F0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000200: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000210: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000220: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000230: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000240: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000250: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000260: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
000000270: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 |
```

SCRIPT

Moto G3: подходы

- ~~1. chip-off/ISP~~ – scrypt, но aes-xts
- ~~2. custom recovery (TWRP, ...)~~ – включен FRP
- ~~3. kernel cmdline injection (CVE-2016-10277)~~ –
есть патч
- ~~4. EDL mode: peek/poke (QPSIR-909)~~ – нет prog-
файла
5. Уязвимость в PBL MSM8916 ?

Moto G3: схема FDE



Moto G3: scrypt VS hmac-sha256



Moto G3: итоги

1. Возможна компрометация **Secure Boot** через уязвимость в **PBL (MSM8952)**
2. Перебор **offline** возможен путём извлечения ключа **SSD Key**
3. Алгоритм перебора состоит из нескольких этапов (возможно ускорение на **GPU**):
 - итеративный **HMAC-SHA256**
 - **AES-CCM**

Samsung J5 (2016)



Год выпуска: **2016**
Чипсет: **Qualcomm
MSM8916**

Samsung J5 (2016): подходы

1. chip-off/ISP ?

Samsung J5 (2016): footer (1)

```
000000000: C5 B1 B5 D0 01 00 03 00 | 90 09 00 00 00 00 00 00 | ũ>␣␣ ♡ ␣o
000000010: 20 00 00 00 02 00 00 00 | B8 BF 69 01 00 00 00 00 | ␣ ␣␣i␣
000000020: 00 00 00 00 | 61 65 73 2D | 63 62 63 2D 65 73 73 69 | aes-cbc-essi AES-CBC
000000030: 76 3A 73 68 61 32 35 36 | 00 00 00 00 00 00 00 00 | v:sha256
000000040: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000050: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000060: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000070: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000080: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000090: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000A0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000B0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000C0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000E0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000000F0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000100: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000110: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000120: 00 00 00 00 00 00 00 00 | 00 80 7F D3 02 00 00 00 | ␣␣␣␣
000000130: 00 90 7F D3 02 00 00 00 | 00 0C 00 00 | 02 0F 03 01 | ␣␣␣␣ ♀ ␣␣␣␣ SCRYPT?
000000140: B8 BF 69 01 00 00 00 00 | 00 00 00 00 00 00 00 00 | >>i␣
000000150: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000160: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000170: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000180: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000190: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001A0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001B0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001C0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001D0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001E0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
0000001F0: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000200: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000210: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000220: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000230: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000240: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000250: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000260: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
000000270: 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00
```

Samsung J5 (2016): footer (2)

0000003200: 00 00 00 01 0C 00 00 00	11 10 00 00 00 00 30 00	0♀ ← 0
0000003210: 0E 00 44 06 4A 00 04 00	4A 08 10 00 4E 08 20 00	♫ D♯ J N
0000003220: 5E 08 10 00 9E 08 10 00	AE 08 04 00 BE 08 10 00	^ ▢ ▢ ▢ ▢ ▢
0000003230: C2 08 20 00 D2 08 10 00	12 09 10 00 22 09 00 00	▢ ▢ ▢ ▢ ▢ ▢ ▢ ▢
0000003240: 00 00 00 00 00 00 00 00	00 00 42 4B 4D 4B 00 00	▢ ▢ ▢ ▢ ▢ ▢ ▢ ▢
0000003250: 00 00 B8 03 39 3D 8E 40	9B 4B 58 74 86 E2 70 9E	ВКМК
0000003260: 84 BD E4 9F 7A F0 58 41	DD 13 CF ED 65 AA B1 77	♥9=@KXtPp
0000003270: 14 94 47 EF C8 90 B0 19	C8 E3 11 4A 3A 92 D9 B2	>>>>zXA@!!ePw
0000003280: DB 80 CE 12 21 F3 2F 76	C0 D9 2C B9 91 FD B4 F3	GGRR>↓-J: >
0000003290: 4A EC E0 11 7E 66 96 EE	2B EC 91 CE 5F 64 CB 73	>▢! ▢/v▢, ▢▢▢▢
00000032A0: 8E 4E B2 93 B3 CD 06 E8	7E 35 7E 14 57 2B 6B 56	J▢~f▢+▢▢_d▢s
00000032B0: D6 D7 FE A3 8E A6 96 AA	88 DC 43 5C 13 83 50 F1	>N▢▢▢▢~5~JW+kV
00000032C0: 54 9A E7 4C 68 22 44 86	26 04 D1 0E A1 22 97 D7	>>>>>>>>>C\!!P▢
00000032D0: 2A C2 D3 AD FA EC 22 A9	52 04 FC E2 35 3F 44 F0	T▢Lh"D▢&▢▢"▢▢
00000032E0: DA D4 8B B6 2A 98 D3 E8	2B 14 72 18 F2 B7 B5 06	*▢▢>▢▢"▢R▢▢5?D▢
00000032F0: 88 3D 6D E9 D1 49 2E 82	B1 EB 6D A6 37 8F D2 A0	>▢>▢*▢▢+▢r↑▢▢▢▢
0000003300: FE 19 C4 88 26 89 9D 84	ED A6 33 D7 93 58 DD 93	>=m▢▢I. ▢▢▢m▢7▢K>
0000003310: 0A 29 F0 0E BA 0A 64 3E	2D F4 7A 10 F7 AA 47 74	>↓Ĉ>&▢▢▢▢3▢>X▢>
0000003320: 77 A6 EE B7 3D 52 81 31	9D F2 82 F9 9F E3 FF 84	▢)▢▢▢▢ed>-▢z▢-▢▢Gt
0000003330: E0 9C 6D CD 55 5E DC C2	00 00 00 00 00 00 00 00	w▢▢▢=R▢1▢▢▢▢▢▢▢▢
0000003340: EC 69 D6 51 AF A1 99 0B	00 00 00 00 00 00 00 00	>>m▢U^▢▢>+'Z▢>>A
0000003350: A5 0D 00 00 00 00 00 00	00 00 00 00 00 00 00 00	>i▢Q▢▢▢▢▢B\k▢g▢>
0000003360: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	>▢
0000003370: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003380: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003390: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033A0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033B0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033C0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033D0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033E0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
00000033F0: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003400: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003410: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003420: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003430: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003440: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003450: 00 00 00 01 00 00 00 00	00 00 00 01 00 01 00 00	© © ©
0000003460: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	
0000003470: 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00	

зашифрованный RSA-ключ

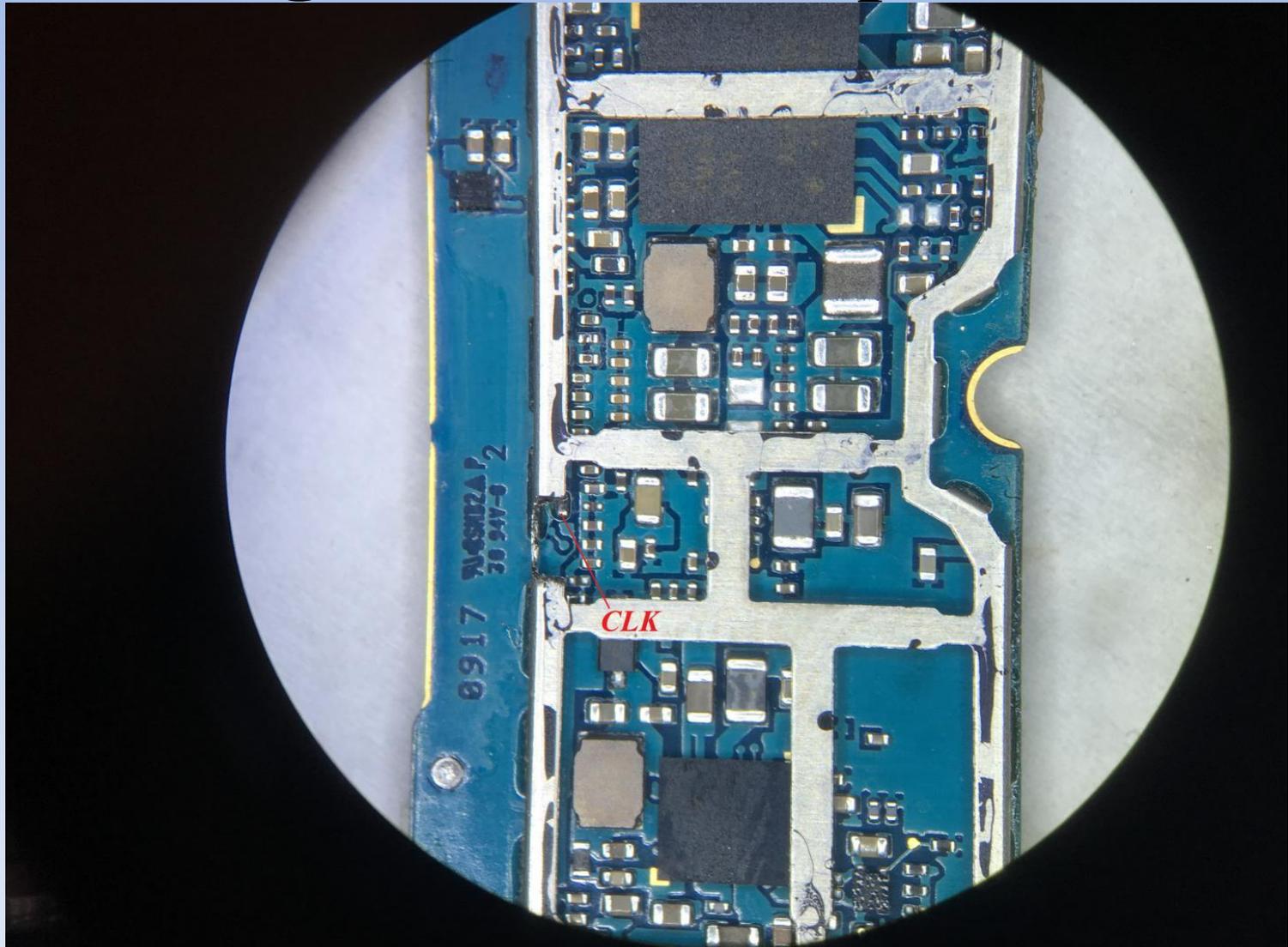
Samsung J5 (2016): подходы

- ~~1. chip-off/ISP – scrypt+keymaster~~
- ~~2. custom recovery (TWRP, ...) – включен FRP~~
3. engboot ?

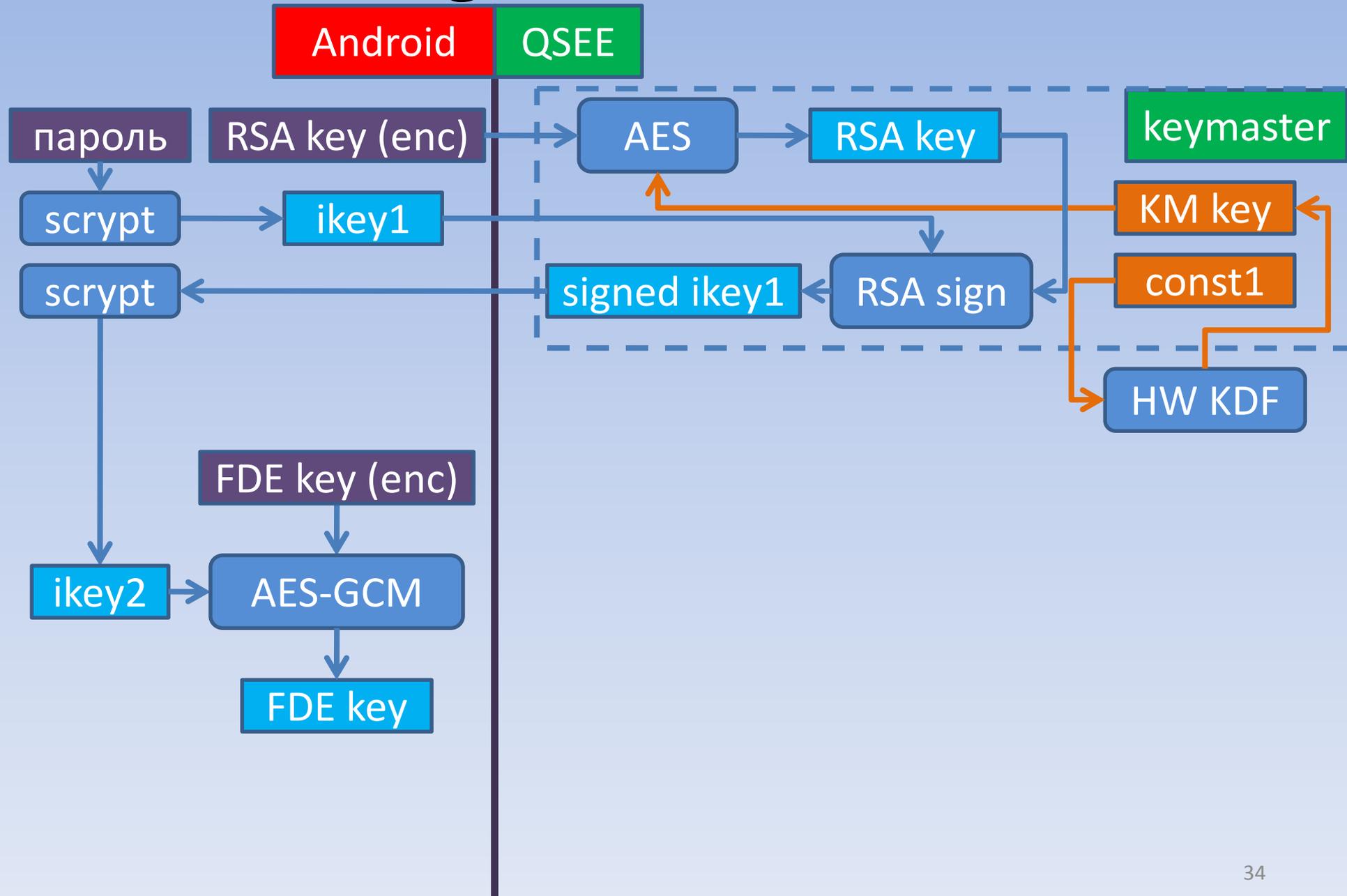
Samsung J5 (2016): подходы

- ~~1. chip-off/ISP – scrypt+keymaster~~
- ~~2. custom recovery (TWRP, ...) – включен FRP~~
- ~~3. engboot – есть только для Android 6 (актуальная версия – 7)~~
- ~~4. EDL mode: peek/poke (QPSIR-909) – нет прог-файла~~
5. Уязвимость в PBL MSM8916

Samsung J5 (2016): перевод в EDL



Samsung J5 (2016): cxema FDE



Samsung J510F: итоги

1. Возможна компрометация **Secure Boot** через уязвимость в **PBL (MSM8952)**
2. Перебор **offline** возможен путём извлечения ключа **КМ key**
3. Алгоритм перебора состоит из нескольких этапов:
 - **scrypt + RSA-sign + scrypt**
 - **AES-GCM**

Результаты работы

- Обнаружены слабости криптографических схем вычисления ключа шифрования для **FDE** в телефонах **Moto G4**, **Moto G3**, **Samsung J5 2016**, приводящие к возможности **offline**-перебора пароля и расшифрования раздела **userdata**.

Спасибо за внимание!