THE ORIGIN AND IMPACT OF SECURITY VULNERABILITIES IN ST CHIPSETS

SE-2011-01

[Security weaknesses in a digital satellite TV platform]

Last update: 13 Mar 2019

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INTRODUCTION

This document presents information related to security vulnerabilities discovered by Security Explorations in STMicroelectronics' chipsets [1][2].

Its goal is to provide all interested parties (chipset / set-top-box / CAS vendors and security researchers in particular) with a summary information pertaining to the origin and impact of the weaknesses found in ST SoC processors.

These vulnerabilities are still a mystery to many and we keep receiving inquiries about them regardless of the fact that almost 6 years had passed since the disclosure. STMicroelectronics, although out of set-top-box and DVB chipset business [3], has not provided us with any details regarding the impact of the issues found [4].

We have reasons to believe that vulnerable IP (TKD Crypto core of STi7111 SoC) might be part of other ST chipsets and/or part of other vendors' solutions, not necessarily related to PayTV industry (e-passports, banking cards and SIM cards).

We have reasons to believe that ST actions were aimed to hide the impact of the issues found, that company's shareholders were not aware of these vulnerabilities, their impact and associated liabilities. We have reasons to believe that the issues have not been resolved up to this day.

This document is a work in progress. As such, it will be updated once new information is acquired regarding the impact of the issues found in ST chipsets.

GENERIC IMPACT FOR PAY TV INDUSTRY AND CAS VENDORS

Security Explorations discovered several security weaknesses in the implementation of the chipset pairing functionality used in set-top-box devices. We discovered that for STi7100 / STI7111 DVB chipsets, it is possible to extract plaintext values of Control Word cryptographic keys - the keys that protect security of content in a digital satellite TV system. For STi7111 DVB chipset, we also discovered a way to extract the plaintext value of the pairing key itself. By doing so, we broke security of the pairing function and the cryptographic relationship between a subscriber's smartcard and a set-top-box' DVB chipset.

Chipset pairing technology was invented to protect against hacking satellite TV. Chipset pairing uniquely ties a given subscriber's smartcard with a corresponding set-top-box equipment. The pairing has a form of a cryptographic function. It is usually implemented in a silicon (DVB chipset). The goal of the latter is to prevent set-top-box hijacking and unauthorized sharing / distribution of a satellite TV programming.

The implementation of many modern CAS systems that are in use by PayTV industry is based on the idea of a Key Ladder [5] for chipset pairing functionality. Although the date of a datasheet for STi7111 SoC (2007) precedes the date of the Key Ladder specification (2010), we still find the latter helpful for describing the likely cause of ST flaws (the base security principles described in the spec hold for STi7111 SoC).

Key Ladder is a functional block implemented by a secure chipset such as STi7111. It makes it possible to securely deliver descrambling keys (Control Words) to the target set-to-box device as illustrated on Fig. 1.

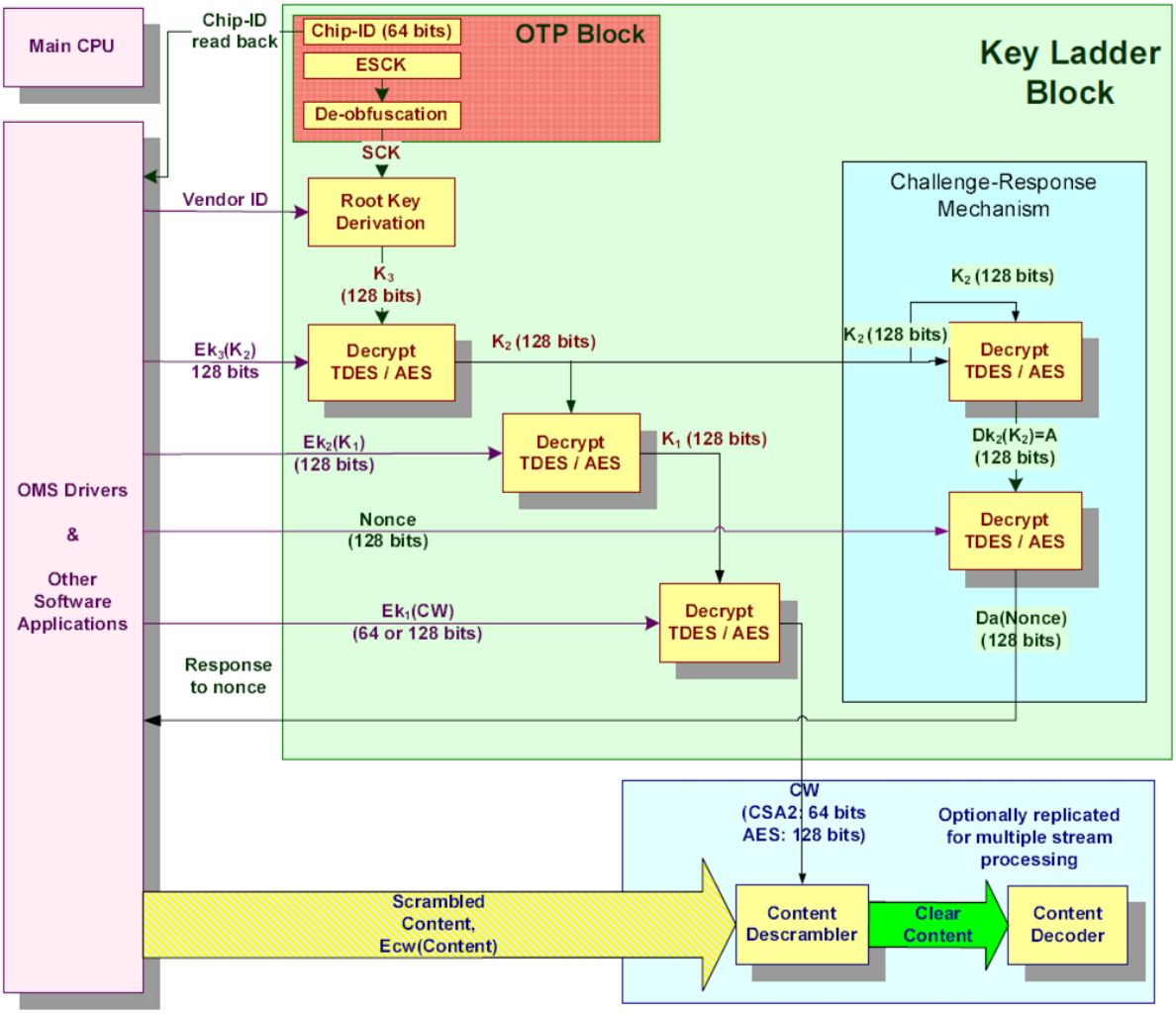

Image source: ETSI TS 103 162 V1.1.1 (2010-10)

Fig. 1 Key Ladder functional diagram (the case for 2 pairing keys).

Each chipset contains a unique secret SCK key. It is used directly (or indirectly by the means of a derived root key K3) to decrypt encrypted (and unique to each chipset) value of key K2. This key is further used to obtain a plaintext value of any other pairing key as they form a ladder like structure (key *Kn+1* is used to decrypt the value of key *Kn*). The final key (such as K1) is used to decrypt the encrypted Control Words. These are further used to obtain descrambled A/V content.

For Conax CAS [6], the following holds:

- K3 is likely the SCK key itself,
- K2 is the pairing key (CWPK),
- K1 equals K2 (there is only one pairing key for Conax CAS),
- TDES algorithm is used for decryption in the environment of NC+ operator in Poland.

For Nagra CAS [7], it seems there are more CWPK keys [8]. The number of keys used by the Key Ladder block does not seem to matter from a point of view of the exploitation of ST chipset vulnerabilities such as Issue 19. Once a plaintext value of a key higher in the Key Ladder hierarchy is obtained, all other keys below it can be decrypted. As a result, the given CAS can be successfully compromised in the environment of a vulnerable ST chipset. We have successfully proven this for Conax CAS [9].

The Key Ladder specification does seem to contain some security guidelines for the vendor willing to implement a chipset pairing functionality:

a) *The components in yellow in Fig. 1 shall all be in a single silicon chip* (fulfilled for STi7111, TKD Crypto core, OTP Block and SCK are all part of one SoC),

b) *The interface from applications that run on the CPU, even if the CPU is located on the same silicon as the key ladder, are permitted to input and output data only according to the interfaces that appear in the diagram* (not fulfilled for STi7111, the interfaces available for an application that run on SlimCORE CPU are permitted to input and output data in a manner other than according to the interfaces),

c) *The main CPU shall have absolutely no read/write access to the registers that store ESCK, SCK, Kn,…,K3, K2, K1 and A* (fulfilled for the main SH4 CPU of STi7111, but not SlimCORE CPU)

d) *There shall be write, but no read, access to CW* (not fulfilled for STi7111).

It is clear that 3 of the 4 abovementioned guidelines are violated in the environment of STi7111 SoC. While ST might have missed the weaknesses prior to the publication of the Key Ladder spec in 2010, the company should have implemented proper measures to mitigate the issues revealed by it in future SoC generations.

ORIGIN OF THE VULNERABILITIES

Issues 18 and 19 have their origin in TKD Crypto core, a hardware component of STi7111 DVB chipset SoC [10] (Fig. 2). Taking into account the nature of the flaws and the actual hardware component they affect, we conclude this is a hardware vulnerability.

As for the actual cause of the issues, the following hypotheses are considered by us among others:

1) the issues are simply implementation or configuration[1] flaws. The security of the chip did not take into account some potentially insecure combinations of source and targets for TKD commands (i.e. CWPK key being the source of / DMA key being the target of a given crypto operation). During our meeting with STMicroelectronics[2], the company indicated that its engineers did not take into account an attack conducted purely through software means as its engineers were solely focused on hardware based attacks (i.e. fault injection, glitches, side-channel, etc.),

[1] understood as configuration of security fuses.
[2] the meeting in Paris on Feb 13, 2012 attended by ST Platform Security Solution Director, Corporate System Security Roadmap and Lab Director, Product Security Group VP and Legal Affairs person.

2) the issues are the result of a possibility to use SCK key for operations different than CWPK key decryption (i.e. crypto DMA required for encrypting / decrypting FLASH memory with a chipset specific key),

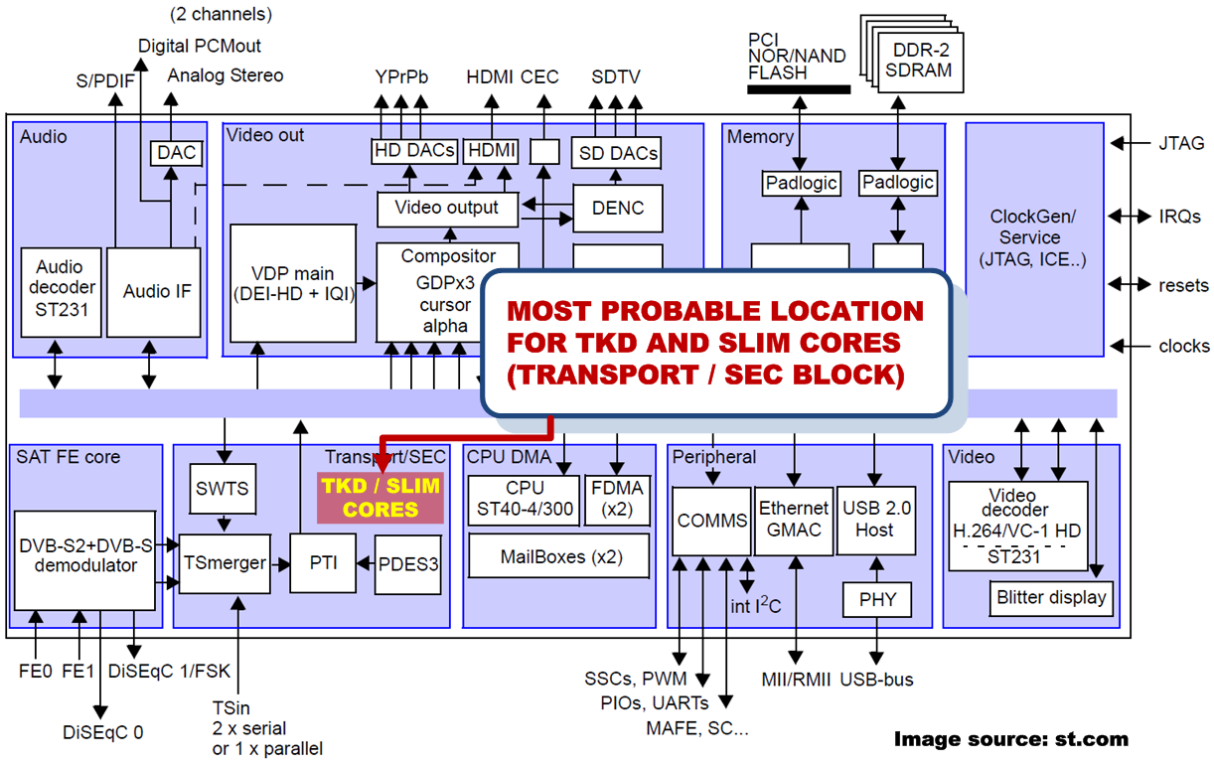

Fig. 2 STi7111 SoC architecture.

3) the issues are the result of implementing Key Ladder computation in a non-atomic fashion, Issue 19 allows to obtain CWPK key by executing 2 sequential operations (decrypt and encrypt) issued on a secret CWPK key value. The Key Ladder is shown in the specification as one block and it is solely composed of decrypt operations. Thus, it is reasonable to assume that the Key Ladder should produce an output (CWPK key) in a more atomic way (without the possibility to use any intermediate CWPK key in the middle of the computation and for any other operation than CW decryption),

4) the issues are the result of a compromise between the features of a crypto chip (generic crypto functionality vs. generic chipset pairing functionality such as a Key Ladder in particular) and/or the requirements of the Key Ladder specification itself (Nonce feature). As such ST choice might have been to provide means for implementing Key Ladder block and Nonce computation by the means of sequences of basic crypto operations (encrypt / decrypt and load key slot) issued to the crypto core from the outside.

From a perspective of a Key Ladder specification, we see a potential for similar attacks against other chipsets used in PayTV industry (Broadcom, HiSilicon, ALi). The more generic given chip's functionality and API implementing chipset pairing (Key Ladder) is, the more risk it may be vulnerable to attacks abusing sequences of specially crafted / key manipulation operations.

VULNERABLE CHIPSETS

The list of chipsets confirmed to be vulnerable to the issues found in STMicroelectronics SoCs is presented in Table 1.

VENDOR	VULNERABILITY	AFFECTED CHIPSET
STMicroelectronics http://www.st.com	Issue 17 (from 2012)	STi7100
	Issue 18 (from 2012)	STi7111
	Issue 19 (from 2012)	STi7111
	Issue 7 (from 2018)	STi7111

Table 1 Impact information.

Although the STi7111 chip alone is available in many variants [10] (STI7111-SUC, SGC7111BIUC, STI7111-LUC, STI7111BNUCT, STI7111-FUC, STI7111BFUC, STI7111-KUC, STI7111BOUC, STI7111BMUC, STI7111BHUCT, STI7111-SUCT, STI7111NUB, STI7111-NUC, STI7111-BUC, STI7111BNUC, STI7111BSUC, STI7111-KUCT, STI7111BIUC, STI7111BOUCT, STI7111BAUC, STI7111-DUC, STI7111-YUC, STI7111ZUC and STI7111BDUC), we don't know which of these models are vulnerable / which are not.

The vulnerabilities could potentially affect the whole Gen-1 (STi7100, STi7103, STi7109, STi5202) and Gen-2 (STi7104, STi7105, STi7111, STi7141, STi7200, STi5211, STi5206) of DVB chipsets from STMicroelectronics of which STi7100 and STi7111 are respective parts of [14]. The rationale for this is that these generations share the same SoC architecture.

Additionally, as it is common to include given IP in other products of a given hardware vendor[3], vulnerable IP (TKD Crypto core of STi7111 SoC) could be part of other ST chipsets (not-related to PayTV) or chipsets from other vendors (in case of IP licensing).

Additional impact due to a new vulnerability or a broken fix

In 2018, we discovered a completely new vulnerability affecting STi7111 chipset used by ITI-2851S device (Issue 7, non-atomic crypto key loading vulnerability). It is described in a detail in [23].

The new vulnerability is related to the design of STi7111 chipset. It probably cannot be fixed due to the origin of the vulnerability (chip design issue). It could be only mitigated.

What's interesting about the newly found issue is that it affected ST chipset, which was immune to attacks from 2012. As such, the issue could constitute a bypass of the fix / mitigation for ST vulnerabilities from 2012 or a completely new weakness (broken fix for a hardware vulnerability or yet another hardware vulnerability).

If the new vulnerability breaks the fix / mitigation implemented by STMicroelectronics for the issues from 2012, this means that all chipsets released by ST to the market since 2012/2013 are broken[4].

[3] SlimCORE processor is a good example o that. According to public sources, SlimCORE processor is the basis for various pieces of IP in STi chipsets [20]. For example, Flexible and Direct Memory Access (FDMA) controller is a slim core CPU with a dedicated firmware, which can be found in STi5197, STi5206, STi7100, STi7109, STi7105, STi7111, STi7141 and STi7200 SoCs [22]. Additionally, Orly family of set-top-box SoCs such as STiH407 and STiH416 make use of a SlimCORE processor [21].

VENDORS STATEMENTS

In order to obtain possibly accurate information about the impact of our ST DVB chipsets research to the PayTV ecosystem, we reached out to over 20 companies, which were potentially affected by it.

The inquiries

Below, more details are given with respect to the inquiries, which were sent by us between Feb 2 and Feb 5, 2019 to various members of a SAT TV / PayTV ecosystem.

Whenever possible, the inquiries were sent to official press / media communication contact addresses. In a few cases, web contact forms were used (Viaacess and Verimatrix companies). In 2 cases (Echostar and Coship companies), mails sent to the designated contact addresses could not be delivered (mail delivery system signaled en error).

TV operators, STB / equipment and CAS vendors

Being aware of STMicroelectronics persistent refusal to provide any information pertaining to the impact and fixing of security vulnerabilities found in its chipsets in 2012, in order to learn about the likely impact of a newly discovered ST weakness, we decided to inquire multiple vendors indicated by STMicroelectronics presentation from 2008 [24] as company's "long standing partners" (Fig. 3) about old ST flaws.

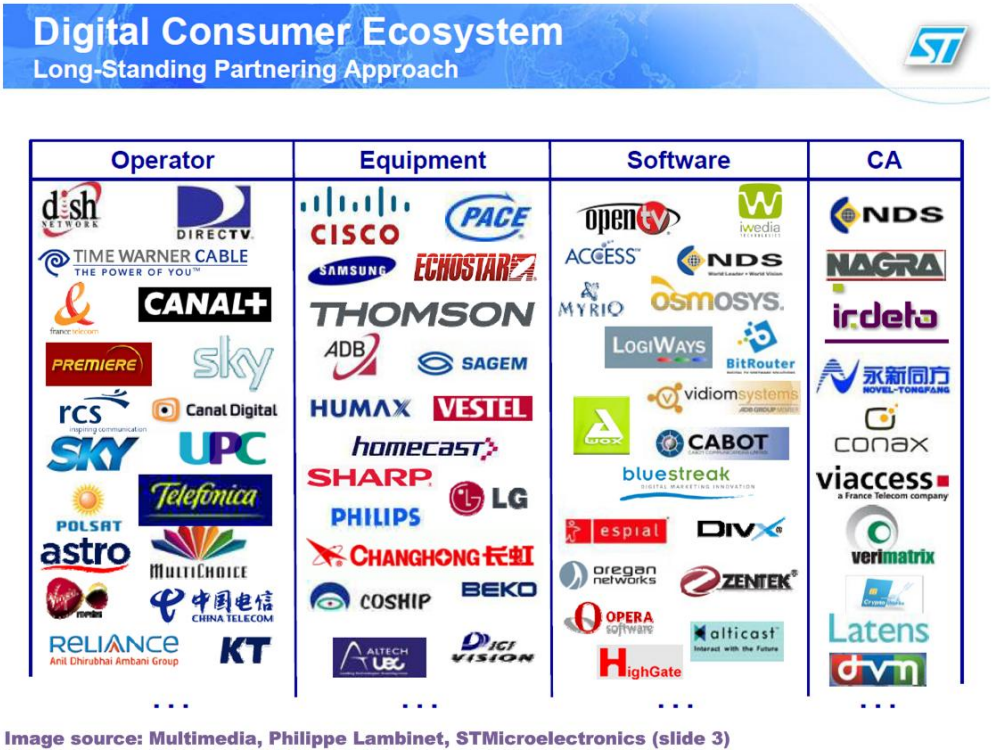

Fig. 3 STMicroelectronics' digital consumer ecosystem.

The following questions were issued to multiple TV operators, STB / equipment vendors and CAS vendors:

[4] information included on STi7111 product page indicated that this processor was in Active (*Product is in volume production*) as of Apr 2018 [25]. This status was changed in late 2018 to NRND (*Not Recommended for New Designs*) [10].

- has your company (its products such as cable and/or SAT TV set-top-boxes / Conditional Access System) been impacted by security vulnerabilities discovered in 2012 by Security Explorations in STMicroelectronics DVB chipsets (i.e. STi710x, STi7111) ?
- if yes, has STMicroelectronics provided your company with any information pertaining to these vulnerabilities, their impact and/or fixing process ? Have these vulnerabilities been addressed, fixed or mitigated in any way in your products ?

Responses (or their lack of)

We assumed 2 week wait time for a response to our inquiries. This should be completely sufficient taking into account that we asked about vulnerabilities that were 7 years old and which should have been already fixed / resolved / mitigated long time ago. Tables below provide a summary of the responses received.

COMPANY	RESPONSE
Dish Network	NO RESPONSE
DirecTV (ATT)	ATT informed that the company does not use these (ST) chipsets in any of its equipment.
KT	NO RESPONSE
Orange	NO RESPONSE
Polsat	NO RESPONSE
Sky	NO RESPONSE
Telefonica	NO RESPONSE
Telenor	NO RESPONSE
Time Warner Cable (Charter Communications)	NO RESPONSE
UPC / LibertyGlobal	NO RESPONSE

Table 2 Summary information for responses received (TV operators).

COMPANY	RESPONSE
Beko	NO RESPONSE
Changhong	NO RESPONSE
Humax	NO RESPONSE
LG	NO RESPONSE
Arris International (new owner of Pace)	An ARRIS spokesperson provided the following response: *We take security matters very seriously and undertake due diligence with all aspects of product engineering.*
Philips	NO RESPONSE
Sagem	NO RESPONSE
Samsung	NO RESPONSE
Technicolor (new owner of Cisco STBs)	NO RESPONSE
Vestel	NO RESPONSE

Table 3 Summary information for responses received (STB / equipment vendors).

COMPANY	RESPONSE
Irdeto	The following response / statement was provided by Irdeto: *Irdeto is bounded to NDA's and cannot share third party (ST in this case) to external parties or the public. It is not of Irdeto's interest to share to the "public" if Irdeto is*

	effected or not by the ST vulnerabilities. In the hypothetical situation that Irdeto could be effected, it is not of Irdeto's interest to share this the "public" which actions have been taken on this topic. This is clearly an ST issue, vulnerabilities in the ST chips/firmware and it is up to ST to comment and/or respond to your inquiries.
Arris International (new owner of Latens)	An ARRIS spokesperson provided the following response: *We take security matters very seriously and undertake due diligence with all aspects of product engineering.*
Nagra / Kudelski	NO RESPONSE
Technicolor (new owner of NDS CAS)	NO RESPONSE
Verimatrix	RESPONSE RECEIVED, NO INFORMATION PROVIDED
Viaacess	NO RESPONSE

Table 4 Summary information for responses received (CAS vendors).

Taking into account the lack of responses from the inquired companies along the knowledge that some were verified to be affected (i.e. Nagra / Kudelski and its Conax CAS) and some did rely on ST chipsets in its products (i.e. Samsung UDH87 STB from Orange), it is safe to assume that those not responding were likely affected by vulnerabilities in ST chipsets.

RATIONALES FOR FURTHER INVESTIGATION

Over the last 20+ years, we have been dealing with various vendors and ecosystems (desktop, cloud, mobile). The case of STMicroelectronics vulnerabilities is however truly unique as we have never met with such a persistent and long-term refusal to provide information pertaining to the impact and addressing of security vulnerabilities found.

The more resistance we experience from the vendor, PayTV ecosystem and arbitrary 3rd parties regarding requests for information, the more strange and suspicious the whole case starts to look.

The above along the following rationales are an indication for us to dig further into the case of ST chipsets' vulnerabilities :

- Since 2012, ST has been persistently refusing to provide information pertaining to the impact and addressing of the issues found in its chipsets [4]
  - this is regardless of the fact that STi7111 was still an active product 6 years following the disclosure (product was in volume production as of Apr 20, 2018) [25],
  - this is in high contrast to major CPU vendors' response such as AMD, ARM or Intel to Spectre and Meltdown CPU flaws [11][12][13],
  - ST stance has not changed a bit even though 6 years has passed since the disclosure.
- Public sources indicated that there could be hundreds of millions of flawed chips released to the market (STMicroelectronics own sources mentioned 541 millions as the number of these chipsets released to the market in 2008, with ST market share at 68% [14]).
- As of 2018, vulnerable set-top-boxes (based on vulnerable chipsets) are still deployed in the field (just to mention NC+ operator in Poland of which French Canal+ Group holds a majority of stake).
- ST is one of the major chipset vendors in the world

  - the company delivers solutions for Wireless, Automotive, Consumer, Computer, Telecom Infrastructure and Industrial markets,
  - among ST customers there are many big companies [15], just to mention Apple, Dell, HP, Cisco, Microsoft and DirecTV,
  - vulnerable IP (TKD Crypto core of STi7111 SoC) might have been licensed and become part of other vendors' solutions, not necessarily related to PayTV industry (e-passports, banking cards and SIM cards),
  - in our WWW server logs, we have observed an interest in ST vulnerabilities from various vendors, IP addresses indicating[5] R&D of Oberthur Technologies (a major smartcard / identity card / SIM card vendor) are of a particular interest here - public sources from 2010 indicate that ST and Oberthur teamed up for NFC SIM card development [16]),
- ST tried to achieve a non-disclosure / limited disclosure of the vulnerabilities (a vague proposal of a business relationship in exchange for a limited vulnerability disclosure, carefully worded statements indicating that publication or disclosure on the process we followed to extract control word from ST devices will damage ST and other vendors in the ecosystem [17]),
- ST noted a significant net income loss at the end of 2012 (a year of the disclosure) [18],
- ST announced its exit from the STB chipsets business in 2016 [3],
- In Mar 2018, we asked CERT-FR (French governmental CSIRT) and IT-CERT (CERT Nazionale Italia) for assistance aimed at obtaining information from STMicroelectronics regarding security issues found in their chipsets (ST is a French-Italian company and both French and Italian governments hold 13.8% of its stake each). For some unknown reason, both CERTs have stopped responding to our messages[6]. This could indicate a potential conflict of interest.

FINAL WORDS

The usual "crisis management" conducted by vendors for disclosures of high impact flaws involve carefully-worded statements indicating that the issues affect older products only or in case of low / limited impact flaws, a vendor usually publishes a list of vulnerable products to clearly emphasize the low nature of the issues found.

ST refusal to provide any information pertaining to the impact of vulnerabilities found in its chipsets can be perceived in terms of intentionally hiding the impact of a much larger magnitude than anticipated by the reporting party, customers or the public. It could be that these actions are aimed at avoiding the liabilities associated with manufacturing flawed products, the costs of their recalls and/or replacements.

ST has all the means to end any speculation pertaining to the nature of the issues found in its chipsets and their impact by simply delivering clear impact information to general public (vulnerable chipset models, whether vulnerable IP is used in other products, remediation steps, etc).

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[5] according to `http://ip-tracker.org`.

[6] in Apr 2018, we asked US-CERT (US Government CERT) for assistance aimed at obtaining information from STMicroelectronics regarding security issues found in their chipsets - this CERT also stopped responding to our messages. It also send us a message indicating the status of the case as resolved. Regardless of our inquiry, US-CERT did not provide us with any rationale behind closing / resolving the case of vulnerabilities in ST chipsets.

Security Explorations will continue engaging various entities in a goal to acquire accurate information pertaining to the impact and addressing of ST vulnerabilities. This document and our SE-2011-01 Vendor Status page [4] will reflect any new information acquired and our steps taken to obtain it.

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