

Finding Vulnerabilities in Low-Level Protocols

Nordine Saadouni

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Computer Science
School of Informatics
University of Edinburgh

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Abstract

Basic example of an abstract (this will be changed)

Smart cards are used commercially and within industry for authentication, encryption, decryption, signing and verifying data. This paper aims to look into how the smart card interacts with an application at the lower level. PKCS#11 (public key cryptography system?) is the standard that is implemented at the higher level and then broken down into command/response pairs sent as APDU traffic to and from the smart card. It is the APDU low-level protocol that will be analysed to see if any vulnerabilities are present with regard to the smart cards tested.

Acknowledgements

Acknowledgements go here.

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Chapter 1

Introduction

Smart-cards are formally known as integrated circuit cards (ICC), and are universally thought to be secure, tamper-resistant devices. They store and process, cryptographic keys, authentication and user sensitive data. They are utilised to preform operations where confidentiality, data integrity and authentication are key to the security of a system.

Smart-cards offer what seems to be more secure methods for using cryptographic operations. (And should still provide the same level of security that would be offered to un-compromised systems, compared to those that are compromised by an attacker). This is partly due to the fact that the majority of modern smart-cards have their own on-board micro-controller, to allow all of these operations to take place on the card itself, with keys that are unknown to the outside world and stored securely on the device. Meaning the only actor that should be able to preform such operations would need to be in possession of the smart-card and the PIN/password. In many industries, for applications such as, banking/ payment systems, telecommunications, healthcare and public sector transport, smart-cards are used due to the security they are believed to provide.

The most common API (application programming interface) that is used to communicate with smart-cards is the RSA defined PKCS#11 (Public Key Cryptography Standard). Also known as 'Cryptoki' (cryptographic token interface, pronounced as 'crypto-key'). The standard defines a platform-independent API to smart-cards and hardware security modules (HSM). PKCS#11 originated from RSA security, but has since been placed into the hands of OASIS PKCS#11 Technical Committee to continue its work (since 2013). [reference wikipedia PKCS#11].

In the previous 10-15 years, literature has shown a great deal of research into the examination of the PKCS#11 API, and the security it provides.

Yet little attention has been paid to that of the lower-level communication (command-response pairs), in which the higher level API is broken down into. It is this area that we wish to research within this paper. The reasoning is simple. If we cannot trust the security of the low-level commands that implement the high level API functions, then in turn we cannot trust the security of the high level API. This is analogous to C code being compiled down to binary data to be operated on by the CPU. The addition of two integers cannot be considered correct in C, unless the corresponding binary instructions sent to the CPU are correct as well.

The research of the low-level communication will take two forms.

1. An analysis of the raw communication between PC and Smart-card for all API function calls
- 2.

Before we move into the above analysis, supporting material must be introduced. This the rest of this paper will be organized as follows.

Chapter 2

Background

In this chapter we give background knowledge on two essential standards that are required for the use of the contact smart-card we analyse in this paper. These two standards are PKCS#11 and ISO 7816.

2.1 PKCS#11

This is the API that each card manufacture implements themselves.

2.1.1 Key Object

2.1.2 Attributes

```
template = (\\
(CKA\\_CLASS, LowLevel.CK0\\_SECRET\\_KEY), [private, public, data, cert (X.509)],
(CKA\\_KEY_TYPE, LowLevel.CKK_DES), [AES,DES,RSA,ECC]
(CKA\\_LABEL, label), [name]
(CKA\\_ID, chr(id)), [id]
(CKA\\_PRIVATE, True), [requires authentication]
(CKA\\_SENSITIVE, True), [cannot be extracted unencrypted]
(CKA\\_ENCRYPT, True), [can be used for encrypting data]
(CKA\\_DECRYPT, True), [can be used for decrypting data]
(CKA\\_SIGN, True), [[can be used for signing data]
(CKA\\_VERIFY, True), [can be used for verifying data]
(CKA\\_TOKEN, True), [can be stored permanently on the device]
(CKA\\_WRAP, True), [can encrypt a key to be extracted]
(CKA\\_UNWRAP, True), [can decrypt an encrypted key]
(CKA\\_EXTRACTABLE, False)) [is allowed to be extracted from the device]
```

2.1.3 Most Common Functions

2.2 ISO 7816

This is the international standards organization that defines the low level communication protocol between smartcards and the API on the computer.

2.2.1 Command Structure

2.2.2 Response Structure

2.2.3 Inter-Industry/ Proprietary

2.2.4 Most Common Commands

CLA	INS	P1	P2	Lc	Data Field	Le	Description
00	-	-	-	-	-	-	Inter-industry (II)
80	-	-	-	-	-	-	Proprietary (P)
Xc	-	-	-	-	-	-	Secure Messaging (SM)
00	84	00	00	-	-	L	(II) Get Challenge [# bytes = L]
00	b0	X	X	-	-	L	(II) Read Binary [# bytes = L]
00	c0	00	00	-	-	L	(II) Get Remaining Bytes
00	d6	X	X	L	X	-	(II) Update Binary
00	e0	X	X	L	X	-	(II) Create Binary
00	47	00	00	L	params	-	(II) Generate RSA KeyPair
00	e4	00	00	00	-	-	(II) Delete File
00	2a	82	05	L	X	00	(II) Encrypt Data
00	2a	80	05	L	X	00	(II) Decrypt Data
00	2a	9E	12	L	X	00	(II) Sign Data
00	2a	80	0A	L	X	00	(II) Unwrap Key (RSA_PKCS)
80	a4	08	00	L	FL	-	(P) Select File [FL = file location; L = len(fl)]
80	a4	00	00	-	FL	-	(P) Select File [append previous path]
80	a4	08	0c	L	FL	-	(P) Read File Control Parameters
80	20	00	00	10	R	-	(P) Verify PIN [R = Response]
80	28	00	00	04	00 00 00 20	-	(P) Clear Security Status
80	30	01	00	00	-	-	(P) List Files
80	48	00	80	00	-	-	(P) Get Cards Public Key (genkey)
80	48	00	00	00	-	-	(P) Get Cards Public Key (genkeypair)
80	86	00	00	L	X	00	(P) Open Secure Messaging
80	86	ff	ff	-	-	-	(P) Close Secure Messaging
90	32	00	03	ff	X	-	Reallocate Binary 256 bytes
80	32	00	03	L	X	-	Reallocate Binary L bytes (changes file)

Table 2.1: Common APDU Commands

2.2.5 File Structure

Chapter 3

Cryptographic Operations

In this chapter we describe different cryptography standards, and give a brief overview of the terminology and maths used behind some of the types of cryptography. This will be used to aid our explanations in later chapters that regard the cards functionality and cryptographic operations used to attempt the secure transfer of sensitive information.

3.1 Hash Function

explain this in an overview term

3.2 Asymmetric Encryption

public and private keys for communicating over an insecure channel

3.2.1 RSA

Chinese Remainder Theorem RSA Keys

3.3 Symmetric Encryption

explain this in an overview term

3.3.1 DES

3.3.2 Triple DES

3.3.3 AES

3.3.4 ECB Mode

3.3.5 CBC Mode

3.4 Message Authentication Codes

explain what a message authentication code is, what its used for
(wikipedia have good diagrams and explanations of this!!)

3.4.1 Hash Based - Message Authentication Codes (HMAC)

3.4.2 Cryptographic Based - Message Authentication Codes (CMAC)

3.5 One Time Passwords

What is a one time password → what forms are there?

3.5.1 Hash Based - One Time Passwords (HOTP)

3.5.2 Time Based - One Time Passwords (TOTP)

Chapter 4

Tools

4.1 PCSC-lite

4.2 Virtual Smart-Card

frank something Explain how this creates a virtual smartcard reader This is then used to run API functions, and the commands are relayed to the actual card reader and therefore card.

4.3 Man in The Middle (MiTM)

Chapter 5

Related Work / Literature Review

This will be a brief chapter and will discuss all of the research I have conducted.

Mainly regarding PKCS#11 API attacks due to the small amount of literature that is available for APDU level attacks I shall also explain why some of the attacks are not able to be conducted on the particular card I am reviewing

5.1 Manually Overriding Attributes

This attack was found by previous literature. We simply tested to see if the same attack was feasible on the smart card we analyse.

To test this we created a DES3 key on the card that had the encrypt attribute set to False. We asked the card to encrypt the string '12345678'. The API returned an error stating that this function was not supported due to the attribute settings. We then override the API by manually sending the command ourselves. This results in the encryption taking place on the card, when in-fact it should not.

Chapter 6

PKCS #11 Functions - APDU analysis

In this chapter we analyse the APDU traces of 9 functions from the PKCS #11 API. C_sign and C_verify were not included in this analysis as from the traces of the previous work on this card it was clear that both of these functions operated in a similar manner to C_encrypt and C_decrypt. C_createObject was also omitted from this analysis, because of how similar it operates to generateKey and generateKeyPair. With the only difference is that the key values are provided by the user instead. The analysis will include a step by step guide of how the functions are broken down into command response pairs at the APDU level, and also suggest methods for attacking the card using this knowledge.

All of the traces are provided in appendix B, and have been shortened to only include the parts which we deem to be the most important to the evaluation of how each function is broken down into APDU command response pairs. However, the full traces for each function are given within the project directory. In the analysis to come we will refer to appendix B, with the corresponding command response pair in brackets to allow ease of locating the steps we analyse.

To prevent repetition within each functions analysis and within the appendix, we list the dependencies (other functions that must be run before hand) at the start of each functions analysis, if it is required. And then omit the dependencies from the appendix and explanation of the given function.

6.1 Initialization

The first process before anything can occur on the card is the initialization. This occurs as soon as a session is opened with the card. The process has the following steps:

1. Open the laser PKI file and select the applet (B.1 - command 1)
2. Open the file and send to the API the cards serial number (B.1 - command 4,5)
3. Open a second file and send to the API another serial number (B.1 - command 8,9)

None of these traces reveal sensitive information. But is required in order for the card to be able to operate and communicate with the API. The API is a generic library that works with many different hardware security modules created by the 'Athena smartcard solutions'. Hence this information is required by the library in order for it to operate correctly for the specific type of card.

6.2 C_login

Function dependencies → [Initialization]

The login function has 5 main components. The API locates the file control parameters to check if the retry counter is greater than 0. In the APDU trace this is highlighted in bold and has a value of AA. From there the PIN file is selected, a challenge is asked for by the card and a response is calculated from the knowledge of the PIN and the challenge. Once this is completed the security status of the card is cleared. This is done because every security operation requires a new login by the API. While the user only logs in once, at the APDU layer this occurs many times. These steps are listed below:

1. Open file control parameters for the PIN file (B.2 - command 10)
2. Open the PIN file (B.2 command 11)
3. Request challenge from card (B.2 - command 12)
4. Verify PIN (B.2 - command 13)
5. Clear security Status (B.2 - command 20)

From evaluating multiple traces of the login, it is clear that the response calculated seems to have an element of randomness. From studying the traces alone, the method of calculating the response cannot be intuitively determined.

While no immediate sensitive information is revealed in this trace as the challenge-response algorithm used for verifying a users PIN hides its value,

successfully reverse engineering the protocol will allow an attacker to calculate the users PIN given successful login trace.

Furthermore, if an attacker can find a method for changing the file control parameter, it might be possible to reset the retry counter at the APDU level to allow an unlimited number of attempts of logging in.

6.3 *C_findObject*

[For this trace to show meaningful information we pre-loaded a triple des key onto the card. The label of the key was 'des3' with id '01']

Function dependencies → [Initialization, Login]

The findObjects function is split into 3 main components. First a cmapfile is accessed. This file stores the location of key attribute files. Following this attribute files are accessed; They store all the information regarding a specific keys attributes (listed in section 2.1.2). And finally the last file is opened. This file is zeroized, which dictates that no more attribute files for keys are present on the card. These steps are listed below:

1. Select and open 'cmapfile' [List files command]. This stores all file locations for attributes of the keys (B.3 - command 32, 33, 34)
2. Based on those locations, find and open the attribute file for the des3 key (B.3 - command 36)
3. And also open the last attribute file to determine there are no more keys (B.3 - command 38, 39)

Due to key and attribute files being stored separately, this function call reveals no sensitive information. Only the attributes are opened and listed at the APDU layer. These attributes can be printed at the API layer as well.

A possibility for an attack is present here. The ISO 7816 proprietary 'RE-ALLOCATE BINARY' command can be used to modify a file. This will allow modification of attributes. As mentioned in the literature review, previous work on the same card was undertaken and modified the attributes of CKA_sensitive & CKA_extractable from false to true. The change in this direction is forbidden by the API. However the ability for changing these at the APDU level was achieved. It still yielded no significant results, as keys and attribute are stored in separate files. And the keys could still not be loaded. Thus, we investigate this no further.

6.4 C_generateKey

[For this trace we generate a triple DES key, key length of 24 bytes.]

Function dependencies → [Initialization, Login]

The generateKey function has 9 main components. 2 different secure messaging sessions are used to generate 24 bytes (same as the key length) on the card and send it to the API, and create the key file. The attribute file is created without the use of secure messaging as it does not contain sensitive information. The steps are listed below:

1. Open secure messaging (B.4 - commands 26, 27, 28)
2. Generate 24 random bytes and send them to the API via secure messaging (B.4 - command 29)
3. Close secure messaging (B.4 - command 30)
4. commands skipped include finding spare file for attributes and opening the file.
5. Update file with key attributes (B.4 - commands 40, 41)
6. Open secure messaging [again] (B.4 - commands 42, 43, 44)
7. Open key file directory via secure messaging (B.4 - command 45)
8. Create key file for triple DES key via secure messaging (B.4 - command 46)
9. Close secure messaging (B.4 - command 47)

From this analysis of the communication trace it seems that the card is requested to generate the key value from a 'get challenge' request (within secure messaging). We assume that these same bytes are used to be stored in the key file of the triple DES key we ask it to generate. We cannot verify this at this time, as two different secure messaging sessions are used, and therefore have different session keys. This causes the encryption of the generated bytes and the storing of them in a file, to be different. Despite the possibility they are in fact identical. As stated in the literature review, previous hardware security modules created by 'Athena smartcard solutions' have in the past done this without the use of secure messaging. Thus that vulnerability seems to be patched in this version of the API and smartcard, by using secure messaging when generating these bytes and storing them in the key file.

If this assumption turns out to be correct it poses as quite a significant vulnerability that could be exploited. If the protocol for secure messaging

can be reversed engineered, then we can inject our own bytes when the request challenge is sent to the card. Or simply we can use a man in the middle attack to generate two sets of session keys. One with the attacker and the API, and one with the attacker and the smartcard. The bytes can be sent to the card in the correct format, however the attacker will also be in knowledge of the key value. This should never be the case when the attribute CKA_Sensitive is set to true.

A second vulnerability is also present here. Which is the ability to alter attributes on the fly as they are being updated within the file (step 5). Changing attribute values would allow for the key to be extracted as soon as it is created (this has been checked) however the user will be aware of it, as it is printed at the API layer. In addition they will also be able to see the modified attributes which they had not set. Thus we determine this to be a vulnerability, but not as serious as the previous one mentioned, as if it were utilised the user would most likely notice and therefore generate a new key to be used.

6.5 C_generateKeyPair

[For this trace we generate an RSA-1024 public/private key pair]

Function dependencies → [Initialization, Login]

We find 15 main components in this generation of the RSA public and private key pair. 7 components transfer data that are wrapped within an ASN.1 BER encoding [?]. These are to transfer public key information and what we believe to be file location parameters. The steps listed below give the ordering of the most important commands, and below that we give the decoding of the ASN.1 BER encoding of those 7 commands that we have found.

1. Create public key attribute file (B.5 - command 54)
2. Add public key attributes to file [inc. public exponent] (B.5 - commands 56, 57)
3. Create private key attribute file (B.5 - command 59)
4. Add private key attributes to file (B.5 - commands 61, 62)
5. Create Private CTR RSA Key file (B.5 - command 64) [ref crypto section] [?]
6. Select temporary file (B.5 - command 65)
7. Generate RSA Key Pair (B.5 - command 66)
8. Select temporary file (B.5 - command 67)

9. Get RSA public key (B.5 - command 68)
10. Select parent folder of private key attribute file (B.5 - command 69)
11. Create new file, with public modulus and additional info (B.5 - command 70)
12. Select temporary file (B.5 - command 71)
13. Get RSA public key (B.5 - command 72)
14. Select public attribute file (B.5 - command 73)
15. Add public modulus to attribute file (B.5 - command 74)
16. The rest of the communication we believe to be resetting the temporary file, and adding file location information to file control parameters of parent directories. (These commands are not included in the traces within the appendix)

The following are the ASN.1 BER decodings of the commands that have these wrapping. An online tool was used in the aid of decoding these hexadecimal bytes [?]. We provide references to the above numbering of the commands, and the appendix references as well.

1. Create public key attribute file (B.5 - command 54)

Application 2(4 elem)

[10] (1 byte) 04
 [03] (2 byte) 01 40
 [00] (2 byte) 01 A7
 [06] (8 byte) 00 20 00 20 00 20 00 20

3. Create private key attribute file (B.5 - command 59)

Application 2(5 elem)

[10] (1 byte) 04
 [03] (2 byte) 02 00
 [00] (2 byte) 01 23
 [04] kx s0
 [06] (8 byte) 00 00 00 20 00 20 00 20

5. Create private CTR RSA key file (B.5 - command 64)

Application 2(6 elem)

[10] (1 byte) 04
 [03] (2 byte) 00 41
 [00] (2 byte) 00 80
 [05] (5 byte) 05 0C 20 00 A3
 [06] (14 byte) 00 00 00 FF 00 FF 00 20 00 20 00 00 00 20

Application 17(0 elem)

7. Generate RSA key pair (B.5 - command 66)

[12] (2 elem)
 [00] (1 byte) 06
 [01] (3 byte) 01 00 01

9,13. Get RSA public key (B.5 - commands 68, 72)

Application 73(2 elem)
 [01] (128 byte) D1 EF 7C A5 06 A1 87 FD 5F 13 5B 25 B7 16..
 [02] (3 byte) 01 00 01

11. Create new file with public modulus and additional info (B.5 - command 70)

Application 2(6 elem)
 [10] (1 byte) 04
 [03] (2 byte) 00 81
 [00] (2 byte) 00 80
 [05] (5 byte) 05 08 20 00 A3
 [06] (14 byte) 00 00 00 FF 00 FF 00 20 00 20 00 00 00 20
 Application 17(2 elem)
 [16] (3 byte) 01 00 01
 [17] (128 byte) D1 EF 7C A5 06 A1 87 FD 5F 13 5B 25 B7...

RSA key pair generation is supported on the card. A dedicated processor is used for this, hence the need to change to temporary files to access the generated key and then store the public information. We see no sensitive information within the traces that are outputted in plain text. We thought that the additional information provided that is wrapped within the ASN.1 BER encoding, especially for 5, might have exported the private key and the additional parameters required for CRT RSA keys [?]. To test this theory we deleted the generated key and generated another. The public modulus did change, however the remaining parameters did not. With a change in the public modulus, a change in the private exponent and therefore CRT parameters would also occur. Thus we concluded from that the private key is not exported out in plain text.

It seems these parameters that are listed above are used to save the location of the RSA private key, and the public key for that matter. We have not been able to intuitively decode the proprietary encoding of file directories to locate the private key. As we will see later in the 'unwrap' function when we utilise the private key, this occurs within secure messaging and therefore cannot find the location of it from that either.

Thus without the knowledge of the proprietary encoding of file directories

we do not see any vulnerabilities within the function as of yet. Studying multiple RSA key generation traces (without deleting the first keys) might show differences in these decodings which could lead to finding the location of the private key.

6.6 C_destroyObject

[For this trace we delete/destroy a triple DES key and its attribute file]

Function dependencies → [Initialization, Login, FindObjects]

Once the key and attribute files have been located and the user is authenticated with the card, there are 6 main components to the destruction of the object. These are listed below:

1. Select counter file for key attributes (B.6 - command 49)
2. Update counter (B.6 - command 50)
3. Select key file (B.6 - command 53)
4. Delete key file (B.6 - command 54)
5. Select key attribute file (B.6 - command 55)
6. Delete key attribute file (B.6 - command 56)

We believe a counter file keeps track of how many keys have been created and deleted in a certain path within the cards on board memory. We are unsure on its specific use as we have only seen it being updating upon deletion of an object, and the new counter value being appended to the new keys attributes (the one created after deleting an object). The original and updated counter value can be seen at B.6 - command 37 and 50 respectively.

Once this has been done the key attribute file and the key file are selected and deleted using the inter-industry command 'DELETE FILE'. This is the first time we have seen the location of a key file been accessed without secure messaging. Thus we thought this might present a vulnerability which would allow us to open and read key values at the APDU level.

Hence we attempted to use the 'SELECT FILE' command and then 'READ BINARY' command to try and read the files data. This resulted in an error message = '69 81', meaning the command is incompatible with the file structure. With this in mind we decided to try the other command which is 'OPEN FILE CONTROL PARAMETERS' which did successfully work. The output was wrapped in an ASN.1 BER encoding, thus we decoded it which gave the following result:

Application 2(6 elem)

[07] (1 byte) 08

[03] (2 byte) 00 C1

[00] (2 byte) 00 18

[10] (1 byte) 04

[06] (14 byte) 00 00 00 FF 00 FF 00 00 00 00 00 00 00 00

[05] (4 byte) 01 0C 10 00

This seemed quite similar to what we noticed with the RSA private key analysis in the previous section. There is not present a 16 byte key that could be used for triple DES. Rather it seems that these are more pointers to more files that could hold the keys value. All security policies [?] that we have read for 'Athena smart-card solutions' suggest that keys are held in a non-readable memory to outside actors, and only when required are encrypted internally (by the cards OS) and stored in the EEPROM for them to be used for the security operation required of them.

Thus we did not find any security vulnerabilities from this function.

6.7 C_encrypt

[For this function we use a triple DES key to encrypt a string 'TestString123456'] using ECB mode]

Function dependencies → [Initialization, Login, FindObjects]

The commands given for this trace are actually repeated and therefore occur twice for one encryption of a given string. This is due to PKCS #11 library being programmed in C by the card manufactures. The resulting length of the encryption is thought to be of an undetermined size. (For block ciphers and even RSA this can be pre-calculated given the input length) However the implementation runs the encryption twice, the first run is to calculate the resulting length of the encryption, and the second run will save the result in a buffer that has been pre-allocated the correct number of bytes in a char array.

This function only has two main components to it, these are listed below:

1. Select key file (B.7 - command 52)
2. Encrypt data (B.7 - command 53)

The key file is selected and then the encryption APDU command is called with the string in the data field. As stated in destroyObject function anal-

ysis, despite the key file location being revealed here. It is not a file that can be opened nor reveals the value of the key. Instead is a pointer to other locations in memory that hold the key value. We assume that only the operating system has access to these locations but are unable to verify this hypothesis.

Due to this we see no other vulnerabilities that could be exploited.

6.8 C_decrypt

[For this trace we use the same triple DES key to decrypt the message we previously encrypted]

Function dependencies → [Initialization, Login, FindObjects]

The decrypt function operates nearly an identical manner to the encrypt function, just simply changes one byte (P1 in the APDU command header) in command 65. The key is loaded and then the decrypt APDU command is sent, with the encrypted string placed in the data field. For the same reasons stated in the encrypt function, the APDU command is sent twice. We omit this repetition. The commands are listed below:

1. Select key file (B.8 - command 64)
2. Decrypt data (B.8 - command 65)

As the decrypt function operates so similarly to the encrypt function, we saw no vulnerabilities present here as well. However we did notice the implementation flaw that had been picked up within previous work. For some reason the first 8 bytes are removed from the encrypted data. This therefore only decrypts and returns the second 8 bytes. As this does not present a security vulnerability, and rather is an issue with the functionality of the decrypt function, we do not analyse it any further.

6.9 C_setAttribute

[For this trace we modify the label of the triple DES key from 'des3' to 'changed']

Function dependencies → [Initialization, Login, FindObjects]

There were only 2 main components for this function, similarly to encrypt and decrypt. The first one selected the attribute file, and the following 2

commands update the whole file to include the new name of the label to the key. Command chaining [?] was used as the number of bytes within the attribute file exceeded the limit of 256. Command chaining is indicated by the use of '90' instead of '80' as the CLA byte. The commands are listed below:

1. Select key attribute file (B.9 - command 51)
2. Modify attribute file with the changed in the label name (B.9 - commands 52,53)

Here we notice that at the APDU level attributes can be changed as long as a user is logged in. (We have not tested doing this without being logged in, but might be possible) This is a vulnerability that was discovered in previous work. With the main focus on changing the attribute values of CKA_sensitive and CKA_extractable from false to true. The change in this direction is forbidden by the PKCS #11 API, however this can be conducted at the APDU layer. As stated in the literature review, this had been carried out and due to the split between attribute files and key value files, there was no noticeable difference. Despite those attributes being set to True, the key value could still not be revealed.

Thus, despite the vulnerability being present it does not cause a major security issue, in the sense that the key value is still stored securely.

6.10 C_unwrap

[For this trace we used an RSA public key to encrypt a tripe DES key value = 12345678. With its encryption saved, we created a template and used the RSA private key to unwrap the key value and template, to save the key on the card]

Function dependencies → [Initialization, Login, FindObjects, Encrypt]

There are 10 main components involved in the unwrapping of a key. 2 different secure messaging sessions are used (just like in the generateKey function). These first secure messaging session is used to unwrap the encrypted key into a temporary file. The second secure messaging session is used to save that key into a key file. This comes after the attribute file has been created in between these two. The order of the commands are listed below:

1. Open secure messaging (B.10 - command 92, 93, 94)

2. Select a file [the file location is encrypted and therefore unknown] (B.10 - command 95)
3. Unwrap key and attributes (B.10 - command 96)
4. Close secure messaging (B.10 - command 97)
5. Select key attribute file (B.10 - command 119)
6. Add key attributes to file (B.10 - command 120, 121)
7. Open secure messaging (B.10 - command 122, 123, 124)
8. Select the key file directory (B.10 - command 125)
9. Create key file (B.10 - command 126)
10. Close secure messaging (B.10 - command 127)

In a scenario where we are not already in the knowledge of the key value, the secure messaging sessions are the main vulnerability we would wish to try and exploit here. While the key is not exported at the APDU layer in plain text. Successfully reverse engineering the secure messaging protocol, would allow an attacker to exploit it, inject his own session keys and decrypt the key value. This was mentioned in the generateKey function analysis.

Furthermore an attacker could also modify the attributes on the fly. But as discussed within the generateKey function analysis, this attack would make the user aware of the fact that the key has been exported and that attributes have been changed. And thus is deemed not to be as bad as a vulnerability compared to one that would expose the key in plain text at the APDU layer without the users knowledge.

6.11 C_wrap

The Tookan attack was mentioned within the literature review. It is an attack at the API level whereby one key can be given wrapping and decryption functionalities within its attributes. This allowed for any key (no matter the attributes) to be wrapped, exported out of the card, and then decrypted by the same key, and have its key value in plain text. This vulnerability bypassed all controls that the attributes of a key should provide. Due to this vulnerability discovery, we assume that 'Athena smartcard solutions' decided to remove the ability to wrap keys completely. This assumption came from that fact that requesting any key to wrap another key at the API level caused an error: *CKR_Function_Not_Supported*.

From analysing table 2.1 (section 2.24), we noticed a correlation between the P1 and P2 parameters for the APDU commands for encryption, decryption and unwrapping. These values are the following:

P1	P2	Command
82	05	encrypt
80	05	decrypt
80	0A	unwrap

The CLA and INS bytes are identical for all of the above commands.

Using the fact that for encrypt and decrypt P2 remains the same and only P1 alters from '80' to '82', then we inferred that the wrap command was still supported at the APDU layer then the command would have values for P1 = **82** and P2 = **0A**. Therefore an example full command would be:

00 2a 82 0a L Data 00. Where L is the length of the data, and the data is the key to be wrapped.

We ran a simple test to see if this command operates on the card:

1. Wrap key (string '12345678') (B.11 - command 1)

The result of the test was an APDU level error. '6A 80', meaning the parameters within the data field are incorrect. Suggesting that the command does exist and most likely corresponds to the wrap function.

The data field of unwrap is encrypted, as it is used within secure messaging. However if this was reversed engineered and we could understand the data field of the unwrap command, there is a high probability that we would be able to create the correct data field for the wrap command. This would allow us to bypass all attribute controls of keys at the API level, and implement the Toekan attack at the APDU level. Which in turn would allow all keys on the card to be exported out of the card in plain text, which would be a serious violation of the PKCS #11 standard.

Chapter 7

Attempts To Attack At the APDU Level

In this chapter we explain the motivations, implementation and results of the attacks we attempt at the APDU level. For clarity purposes we first give a brief overview of the API's function analysis at the APDU layer that we conducted within chapter 6. This analysis in combination with previous work completed on the same smart-card and for that matter other smart-cards as well, drove the motivations behind the attacks we selected to conduct.

7.1 Motivations

7.1.1 Vulnerabilities not investigated

The *initialization* function did not present any vulnerabilities that would be able to be exploited and was just needed in order for the API to correctly operate.

We did mention in the *Login* function analysis it might be possible to either use 'REALLOCATE BINARY' or 'DELETE FILE' and 'CREATE FILE' in order to modify the parent directories file control parameters for the PIN file that is stored on the card. The aim of this would be to change the retry counter before it reached 0, which would cause the card to be in a blocked state. If this is possible then an unlimited number of attempts at guessing the users PIN would be possible. We decided to not focus on this attack as it would not be particularly useful without the knowledge of the challenge-response algorithm that is used to verify the users PIN.

FindObject function did present the possibility to locate the object and at the APDU level modify any attribute. The two that have the most significance would be CKA_extractable and CKA_sensitive. This had been com-

pleted within previous work [?] and revealed no significant vulnerability. This was due to the fact that once the attributes had been set as part of the key generation process, the attribute file and key key file are separated and thus prevent the key from being exposed in plain text. Since this attack had already been investigated we did not see it fit to investigate it any further.

GenerateKey and *GenerateKeyPair* functions both provided a vulnerability whereby attributes could be modified on the fly as the key was being generated. This did leave the possibility of the key value being exposed as the key had not been generated yet. And effectively the card would be told to generate the key with the attributes the attacker sets. This vulnerability would always have to be exploited upon key generation and would be visible at the API level and therefore the user of the smart-card. Therefore while it is a viable attack to investigate, we decided to look into methods that would allow all keys to be exported in plain text regardless of whether or not the key was already generated and saved on the card.

Encrypt, *Decrypt*, *GenerateKeyPair* (private key) and *DestroyObject* functions all exported in plain text the directory of the key file. As we discussed in chapter 6 we thought that this might have provided the ability to open the file and read the key value in plain text. This hypothesis turned out to be incorrect, and instead seemed like the pointers to the cards memory were wrapped in an ASN.1 BER encoding. Decoding them did not give more insight, as a proprietary file directory organization was used. We also discussed that it is plausible that the keys are stored within memory that is only accessible by the smart-cards operating system. Thus, decided to not investigate this possible vulnerability due to the large possibility of not being able to open the files even if the correct directories were located.

Unwrap function did not provide any major vulnerabilities either. Instead we would like to know exactly how the data field is built, but this cannot be inferred from traces as the command is only ever used within secure messaging. Therefore the data field is encrypted. The reason for wanting to understand how the command works is explained in the next section.

7.1.2 Vulnerabilities to investigate

From studying the traces for the **login** function it was apparent that a challenge-response algorithm has been implemented in an attempt to provide a secure method for transporting the PIN for verification by the smart-card without ever revealing its value in plain text (which would be against the PKCS #11 standard). This is an improvement implementations from other card manufactures whereby they did just send the PIN in plain text over the APDU layer for the smart-card to verify it, leaving an attacker the ability to simply sniff the communication and extract the users PIN number. However the challenge-response algorithm that 'Athena smartcard solutions' have implemented on this card still leaves the potential for an

attacker to reverse engineer the protocol, and then brute force the PIN until the same response is calculated to be sent to the card. Doing this would give the attacker the knowledge of the users PIN and also remove the first dependency on the use of the API by an attacker. This is therefore the first attack that we investigate.

Furthermore the use of secure messaging to encrypt and also provide an integrity check (that the commands have not been altered in transit) in the form a a message authentication code being appended to the command was found within two functions. These are **GenerateKey** and **unwrap**. Successfully reverse engineering the secure messaging protocol would allow for two objectives to be complete. Firstly within the generateKey function an attacker would be able to implement a man in the middle attack to either alter the key being generated with a value known to the attacker, or simply decrypt the key to find out its value. This would be possible regardless of the attributes set for the key, and therefore would violate the standard to a large extent if the attributes for CKA_sensitive and CKA_extractable were set to true and false respectively. As an attacker would be able to be in the knowledge of the block cipher keys generated when the card should be the only system with said knowledge.

Secondly is the understanding behind how the **Unwrap** APDU command operates. As stated in section 6.11, despite the API removing the ability to use the **Wrap** functionality (most likely due the Tookan attack discovery [?]), with a high probability the APDU command still exists as we managed to send what we believe to be the correct command and received back an error stating the data field parameters were incorrect. Therefore reverse engineering the secure messaging protocol would allow us to fully understand the **Unwrap** command data field, and possibly then be able to generate the correct command for wrapping a key. If this is possible, then the Tookan attack could be implemented at the APDU level, bypassing all attribute controls and exporting any/ all keys that are stored within the card. This would be considered a serious vulnerability.

All the vulnerabilities stated within this section are also all to be implemented at the APDU layer and would not provide the user the knowledge the attack is in process. This is the main reasoning behind selecting these vulnerabilities to investigate, and the fact they are far more serious compared to the others mentioned, in terms of violations of the PKCS #11 API.

7.2 Reverse Engineering PIN Authentication Protocol

The first attack we investigate is the reverse engineering of the PIN authentication protocol. If this is successful an attacker will be able to brute

force and/ or use a dictionary attack to calculate the users PIN. It shall also remove one dependency on the use of the API. As of right now the API is required to login into the smartcard as we are unaware of how the challenge-response algorithm is implemented. Figure 7.1 shows the procedure for logging into the smartcard at the APDU level.

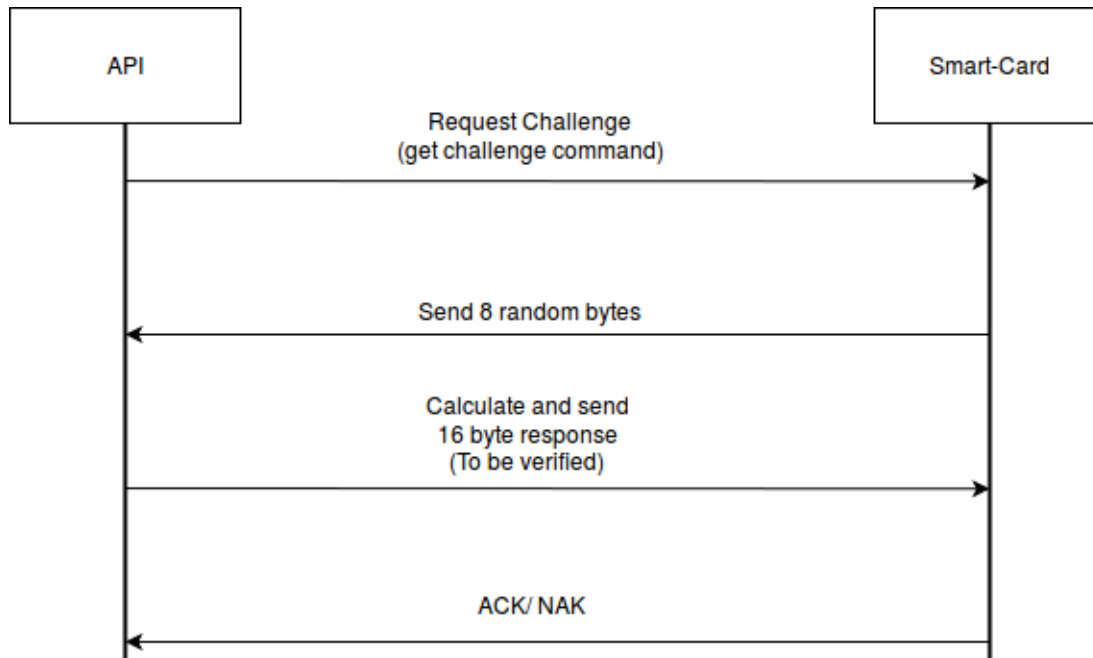


Figure 7.1: Challenge Response Procedures

The API requests (via a 'GET CHALLENGE' command) the smartcard to generate and send back 8 random bytes. The API then calculates a 16 byte response based upon the knowledge of the challenge (8 random bytes) and the users PIN. The 16 byte response is sent to the smartcard (via a 'VERIFY' command), which will return one of two possible outcomes:

1. '90 00' → Verification of users PIN succeeded
2. '63 CX' → Verification of users PIN failed. (X = number of attempts left before the card is blocked)

The following sections give explanations of the searches that we conducted to try and reverse-engineer the protocol showed above. To give a full understanding of how challenging this part of the project was, we will explain the combinations of possibilities we checked, and the reasoning behind each of them. These will be split up into different 'searches', and increment in terms of new findings and understanding of how the protocol may be implemented.

To aid these explanations, we introduce here 3 key sub-functionalities that most of the conducted searches use. Table 7.1 lists all the hash functions

(see section 3.1) that were used, and provides the output length in bits & bytes. Those hash functions were all supported by openssl and the smart-card. Table 7.2 provides the names of the bitwise logical operations that were used to 'join' two bytes together. And table 7.3 provides the description of truncation methods used to reduce the output size of a search down to 16 bytes to match the response provided by the API.

From here on, in the explanation of the searches I will just refer to **hash**, **join** & **truncate** which will suggest that all of the elements in the tables have been iterated over and performed on. For example **truncate(hash('example'))**, means the string, 'example', is to be hashed with all the functions in table 7.1, and then truncated to 16 bytes using all the methods listed in table 7.3.

Hash Name	Output Length (bits)	Output Length (Bytes)
MD5	128	16
SHA1	160	20
SHA256	256	32
SHA384	384	48
SHA512	512	64

Table 7.1: Hash Functions (*supported by the card*)

Logical Operations
AND
OR
XOR
NOT AND
NOT OR
NOT XOR

Table 7.2: Bitwise Logical Operations (Joins)

Truncation method	Description?
first_16	Truncates the output by taking the first 16 bytes
last_16	Truncates the output by taking the last 16 bytes
mod_16	Truncates the output by taking modulus 2^{128} [We use 128 because that's the number of bits in 16 bytes]

Table 7.3: Truncation Methods

Before any searches could be conducted, the first task was to extract the values of the 8 byte challenge (denoted X), and the 16 byte response (denoted Y), from a communication trace of C_login. Table 7.4 provides the

values for the PIN, X and Y in hexadecimal format.

Data	ASCII	HEX
PIN	'0000000000000000'	30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30
Y	N/A	53 17 55 20 F4 30 18 56 80 E6 75 55 E1 91 A7 EC
X	N/A	68 F1 E4 92 85 36 39 A3

Table 7.4

In the very first original experiments, we made assumptions that the PIN number was only numerical characters, only had 4-8 digits and if the PIN was less than 8 characters, it was padded using a special character to form 8 bytes. Some of these assumptions turned out to be false, and thus the elementary experiments were all flawed from the beginning. I have not included a description of those experiments in the following sections, as many of them were in fact very similar to those explained below, just with different assumptions of the PIN. They also used a PIN for the card that was '12345', and hence there was an exponential explosion in the number of experiments for a particular search, due to needing to test for different padding schemes and characters. Hence why in these following experiments the PIN had been set to '0000000000000000' (16 zeros, no need for padding). We found that 16 characters was the upper limit to what a user can set the PIN to be by changing the PIN and incrementing its length until the API returned an error.

7.2.1 Authentication Protocol Search 1.0 (Password Storage)

Assumptions:

- PIN consists of alpha - numeric characters
- PIN is a maximum of 16 bytes
- PIN is encoded in ASCII characters
- For a given challenge and PIN there is only one corresponding response that API will calculate

Search 1 - Hash functions

In this initial stages we thought that there is a large possibility that the 16 byte response was generated by hashing a combination of the PIN and the 8 byte challenge. This was partly due to common practices used in industry whereby users passwords are often hashed, and in most cases salted (see section 3.1), before storing them in databases. This practice is more secure

than storing plain text passwords, as if an attacker were to gain access to the back end databases storing said passwords, the password itself would not be available to see. For authenticating a user on a website the password is just hashed (and salted, if a salt is used), and then compared against to the stored value.

The fact that from multiple traces the 16 byte response seemed to be uniformly random, it supported this hypothesis. Thus the first search that we completed focused on the fact that a hash function was used to produce the 16 byte response. Below we have listed the methods tested in experiments to generate 16 bytes, given X and the PIN.

[We denote \parallel as the concatenation function. Thus for two strings 'string1' \parallel 'string2' = 'string1 string2']

Methods tested that produced a 16 byte output using X and the PIN

- `join(truncate(hash(X)), pin)`
- `truncate(hash(join(pin, X \parallel X)))`
- `truncate(hash(pin \parallel X))`
- `truncate(hash(X \parallel pin))`
- `truncate(hash(pin+X))`
- `truncate(hash(join(pin, square(X))))`

[The methods should be read from the most inner brackets, outward. Therefore this means that the first method dictates that X is first hashed using one of the hash functions listed in the table 7.1. The output of that is then truncated to 16 bytes using one of the functions from table 7.3. All iterations of the functions in the tables were tested.]

The following experiment did not result in finding a match to the response generated by the API. Thus we moved onto search 2.

Search 2 - PBKDF2

Following the failure of search 1, but still assuming there is a large possibility of a hash function being used, due to the common practices mentioned in search 1, and the characteristics known so far of the 16 bytes calculated by the API we decided to look at the password-based key derivation function.

PBKDF2 was created as part of PKCS #5 by RSA laboratories [?] and is starting to be used for more secure password storage as well as for key derivation. Essentially PBKDF2 takes as input, a password (the PIN), a salt (the 8 byte challenge X), a hash function, and the number of iterative rounds. If the number of iterative round is set to 10, then the salted password would be hashed once, and the output of that would be the input for the next round of hashing. This would be completed 10 times. Literature [?]

has shown that the standard for the number of iterative rounds used to be 10,000, back in 2008 (check this date). Now it is suggested to use as many rounds as is computationally feasible by the device. Due to the processing power of a smart-card I assumed that this would not exceed 100,000 rounds, in the case that PBKDF2 was used.

Hence this search generated experiments that ran through $1 \rightarrow 100,000$ rounds of PBKDF2. As the default of PBKDF2 is to truncate the output by taking the first i number of bytes, therefore the only truncation method used was 'first_16' (table 7.3).

Methods tested that produced a 16 byte output using X and the PIN

- PBKDF2(hash_function, PIN, X, number_of_rounds)

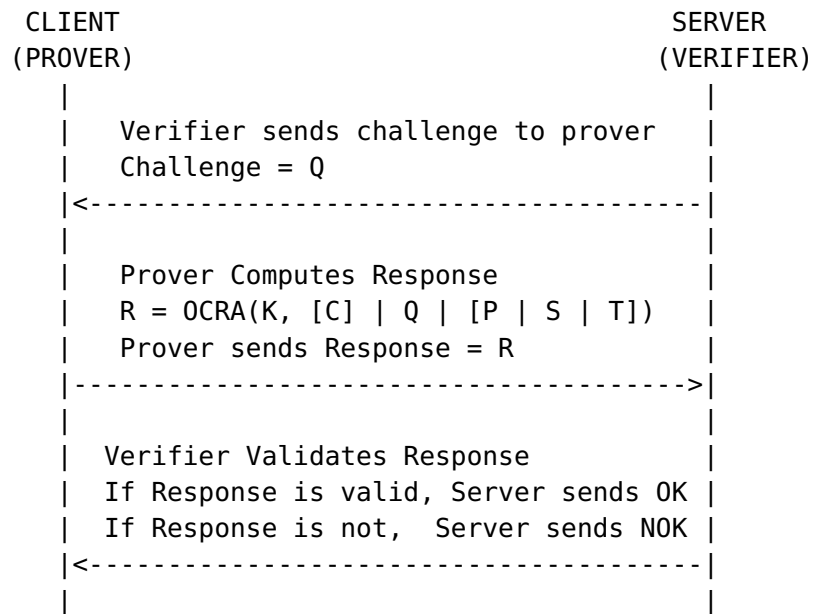
This generated 100,000 experiments per hash function. With 5 hash functions, this resulted in half a million tests being run. Due to the sheer computational power required for this search I decided to parallelize the search based on the hash function, and run them on separate cores of a server. Even by improving the efficiency of this search, it still took 2 weeks to conduct.

Again this unfortunately did not result in a match between the 16 byte responses calculated and Y (the API's response). Hence we move onto search 3.

7.2.2 Authentication Protocol Search 2.0 (One Time Pass-words)

Search 3 - OCRA: OATH Challenge-Response Algorithm

With no luck of deducing the challenge-response algorithm, we decided to look into more complex standards that exist and used in different parts of the computing industry for challenge response protocols, rather than password storage techniques. The international engineering task force (IETF) released a paper in 2011 [?]. Section 7.1 of the paper gives a one-way challenge response algorithm which fitted the characteristics of the authentication that takes between the API and the smart-card. We have extracted out the protocol and provided it below:



C - Counter, optional.

Q - Challenge question, mandatory, supplied by the verifier.

P - Hashed version of PIN/password, optional.

S - Session information, optional.

T - Timestamp, optional.

In the previous section of the paper they explain that OCRA in the instance of this protocol stands for a generic variable to state which form of HOTP is to be used. HOTP (see section 3.5.1 of this paper) can take on different formula's due to using different hash functions. The generic formula is:

$$HOTP(K,C) = Truncate(HMAC(K,C)) \quad \&\& \quad 0x7FFFFFFF$$

where K and C stands for the password (secret key) and is a counter (the challenge) respectively.

We ran experiments using the 5 hash functions listed in table 7.1, and even inter-changed K and C to have each others values instead. This did not result in finding a matching response to the one the API had calculated.

Search 4 - TOTP

With the above in mind, I also wanted to rule out the possible use of *time based one time passwords* (see section 3.5.2). TOTP algorithms are rarely

used within smartcards due to the complexity of syncing the clocks between the computer and the smart-cards processors, and then also accounting for any lag. Despite the low probability of it being used it was worth checking.

This was completed by halting communication between the smart-card and API using the man-in-the-middle tool (see section 4.2). I did this for upto 2 hours. We were looking for a failed verification, despite having the correct PIN. The failure should have been caused by the delay in the response if TOTP was used. This was not found and therefore ruled out that possibility.

7.2.3 Authentication Protocol Search 3.0 (Triple DES Encryption)

With none of the above searches concluding any useful results, and instead just ruling out them as possibilities we moved onto checking an assumption that we were not 100% sure was accurate. This would have been done earlier, however it had taken a while to get the code for the man in the middle attack to be operational, and was required for this. The assumption in question was, that *for a given challenge and PIN, the API will calculate only 1 corresponding response*.

To verify this assumption we used the man in the middle tool to inject our own challenge (that the card normally sends) and set it to '00 00 00 00 00 00 00 00'. Completing this multiple times, we noticed that this assumption was in-fact wrong. Over multiple attempts we saw different responses being calculated by the API, despite the PIN and the challenge being the same. However we also noticed that logins with quick successions of one an other had the same value for the response when the same PIN and challenge were present, and in some cases only the last 8 bytes changed with the first 8 bytes remaining the same.

Due to these observations we decided to run multiple experiments to find characteristics of the 16 bytes response (*which we now believe to be split into two 8 byte parts*). We did this by logging into the card twice each time, and altering the three parameters (*one at a time*) that we determined to cause the response to alter. The parameters we alter are **time**, **PIN** and the **challenge**. The results of the experiments are tabulated below:

*[To make the explanation of this clearer we have placed the actual traces of these experiments within **appendix A**. And use variable names for the two 8 byte sections of the 16 byte response. These are denoted below as A and B]*

16 byte response	1st 8 bytes	2nd 8 bytes
Y =	A	B

Time	PIN	Challenge	A	B	Appendix
Different	-	-	χ	χ	A.1.1
Same	Same	Same	✓	✓	A.1.2
Same	Same	Different	✓	χ	A.1.3
Same	Different	Same	χ	χ	A.1.4
Same	Different	Different	χ	χ	A.1.5

Table 7.5: Multiple logins with different parameters

Table 7.5 shows that changing the second the separate logins occur within, or changing the PIN causes the whole 16 bytes to alter. If both login attempts are within the same second, and the same PIN and challenge are given to the API then the exact same 16 byte response is calculated. However the most interesting characteristic discovered within these experiments is when the logins occur within the same second, with the same PIN but different challenge. This causes the first 8 bytes to remain the same, but the second 8 bytes to differ, within the 16 byte response.

This is the characteristic that provides the evidence to support our theory that the 16 byte response is in-fact split into to 8 byte sections. This also shows that that the second 8 bytes is a function that utilises the challenge. As a different challenge causes it to change. Based on these facts we assume the following:

1. The first 8 bytes is a random number N_A = Nonce API, which is seeded with time (in seconds)
2. The second 8 bytes is a another number that verifies the knowledge of both the challenge and N_A . We denote this as V_{AC}
3. A block cipher (see section 3.3) is used to encrypt both of these numbers, to send over to the card for PIN verification
4. A function of the PIN, is the password to the block cipher
5. The PIN is still of maximum length 16 bytes
6. The PIN is still in ASCII format

To sum up we assume at this stage the challenge-response algorithm uses a function of the PIN to be the password to a block cipher which encrypts a message in this format:

$$block_cipher_encrypt(N_A || V_{AC})$$

The block ciphers that are supported by the card are listed below:

Block Cipher	Key Size	Block Size
AES	16	16
DES	8	8
Triple DES (key option 2)	16	8
Triple DES (key option 3)	24	8

The use of the block cipher AES is ruled out as a possibility as if it was used the characteristic that we found would not be present. A change to the challenge, within the same second and given the same PIN would result in a different encryption of both 8 bytes because AES would operate over the entire 16 byte block. This leaves only DES and triple DES as a viable option.

We eliminated the possibility of standard DES being used due to its key size. It would not make logical sense to use a function of the password and then truncate it down to 8 bytes from 16 bytes. This would drop the security of the login from 256 bits to 128 bits for no reason, as other options are available.

This therefore only left us with triple DES key options 2 and 3. With the fact in mind that the PIN for the user is of maximum length 16 bytes we decided to focus on key option 2 which has 16 byte password. There is a possibility that the password is hashed for example and 24 bytes are used with key option 3, but we decided to first test key option 2 before moving onto 3 in the case that 2 fails.

Due to the assumption that the second 8 bytes is a verification (possible join, or hashing) of both the cards challenge and N_A , then we could not simply just decrypt the 16 byte response and analyse it. As both number could be completely unknown to us, therefore we would have no method of verifying we have the correct protocol. To mitigate this we decided to get 2 different responses, within the same second and with the same challenge, but using different PIN's. If the password to the block cipher is in-fact a function of the PIN, then the correct decryption of both responses with different passwords should evaluate to the same 16 bytes. This is how we will verify if we have found the correct protocol.

Search 5 - Triple DES (Key option 2)-ECB

Table 7.6 shows the data for two logins that occurred within the same second, with the same challenge (that we injected), but using two different PINs. We then generate 6 different possible passwords for the encryption using the PIN. The first is simply the PIN in ascii format at 16 bytes (all zeros). The following 5 are the PIN hashed with the hash functions in table 7.1, and truncated only using the first_16 truncation method within table 7.3. Using the generated passwords we decrypt the 16 byte responses using triple DES key option 2, and list the results in table 7.7.

Response ₁	93 57 F7 53 42 A3 27 3D E6 B8 7E A6 81 98 5B 1C
PIN ₁	0000000000000000
Response ₂	90 6A 74 D1 BD 2C 75 2E 52 bA 17 87 E3 70 51 EF
PIN ₂	1111111111111111
Challenge _{1,2}	00 00 00 00 00 00 00 01

Table 7.6: Experimental setup

Pin Method	Response	Decryption using Triple DES-ECB
PIN ₁	1	A4E8604FFFEABBC7 A85FDCA6E1D8187F
PIN ₂	2	23479D5F8CA2EAB7 AE0EB9D09C987484
MD5(PIN ₁)	1	C4B103E761F3688A 45681FD6B9F7137D
MD5(PIN ₂)	2	404F5882AFE4600D E8E8C4F918E0C55B
SHA1(PIN ₁)	1	FE5DBEA8ECAB2F86 9357F75342A3273C
SHA1(PIN ₂)	2	FE5DBEA8ECAB2F86 906A74D1BD2C752F
SHA256(PIN ₁)	1	5F6D92B899EF4557 A1B797A4F65D5B30
SHA256(PIN ₂)	2	74CED585EABBD62E B847856F6A3AEBC7
SHA384(PIN ₁)	1	DFF3A6A88508D7CF 802CF22A15E4051C
SHA384(PIN ₂)	2	A75AB9FEE2A2B445 54618384E33CA723
SHA512(PIN ₁)	1	473EF6CC4BA45EF7 EA740F801A595B4A
SHA512(PIN ₂)	2	1C202A831098546D 8EF674B4A0B0D7AD

Table 7.7: Decryption Results

The results are interesting. While we did not find an exact match of the entire responses when decrypting both of them, we did find a match for the first 8 bytes. This suggests we have found the correct formatting of the PIN, but the wrong decryption methodology. A change in the second 8 bytes suggest cipher block chaining is used. Hence we move onto search 6.

Search 6 - Triple DES (Key option 2)-CBC

Triple DES block cipher using cipher block chaining (CBC) requires an initialization vector (IV) to be used (see section 3.3). The IV is 8 bytes in length. Common practice is to send this in plain text along with the encryption of a message. However it is quite clear that this does not occur. The only other possibility is that the card and the API already have agreed upon a value to use, and always use this same value. The most common practice is too use an IV = 00 00 00 00 00 00 00 00. Despite it being a bad an insecure practice, this still does occur. Hence, in the following experiment we only test the pin method for SHA1(PIN_{1,2}) and decrypt the corresponding responses using triple DES-CBC with an IV of zeros.

Pin Method	Response	Decryption using Triple DES-ECB
SHA1(PIN)	1	FE5DBEA8ECAB2F86 0000000000000001
SHA1(PIN)	2	FE5DBEA8ECAB2F86 0000000000000001

Table 7.8: Decryption Results

Table 7.8 lists shows the results of both decryption's. The result is better than what we had originally assumed. The second 8 bytes, which we thought would have been a verification number (join or hash) (showing knowledge of both nonces), is in fact just the cards challenge. This almost completes our attack. As now we can produce a 16 byte response, given the cards challenge, the PIN and a nonce to place at the start of the message to encrypt.

The issue is we are not sure if we can just place any 8 byte nonce at the start of message to be encrypted. As the API might be expecting some sort of counter, and might refuse invalid values. Hence we conduct the final stage of this attack to test if we can place any value there, and hence will have fully reversed engineered the PIN authentication protocol.

To sum up so far this is the protocol we believe to be in place:

- Request and get an 8 byte challenge from the card, denoted N_c
- Password for encryption = $\text{Truncate_First_16}(\text{SHA1}(\text{PIN}))$
- Block cipher used = Triple-DES-CBC
- Initialization Vector = 00 00 00 00 00 00 00 00
- Calculate the response as the following:

$$\text{Encrypt}(N_a || N_c)$$

- where N_a is a nonce determined by the API.

We set N_a to equal 00 00 00 00 00 00 00 00, calculate what we believe to be a valid response and send it the the API. This experiment is shown within appendix A.2. The result of it is an APDU response of '90 00', successful login!

Thus concluding this attack.

7.3 Reverse Engineering Secure Messaging

The second attack we investigate is the reverse engineering of the secure messaging protocol used by the card. As stated within section 2.2, and within public 'Athena smart-card solutions' security policies [?] for several different cards the vendor produces, the secure messaging initialization is

used to derive 2 session keys. S_{Enc} , S_{Mac} are used to encrypt and compute a message authentication code (MAC) of the messages within a secure messaging session respectively. This provides confidentiality and data integrity of the messages. The decision for how to derive these keys is left entirely upto the card vendor. Which makes this particularly difficult as there are several methods that could be used.

The secure messaging sessions have seen to be used within the **GenerateKey** and **Unwrap** in the analysis conducted within chapter 6. And also seen to be used within **CreateObject** seen in the analysis conducted by an MSC student (place name here) last year [?]. In every case it is used to provide confidentiality of the CKA_value of block cipher keys. Successfully reverse engineering the secure messaging protocol would allow an attacker to use a man in the middle attack to derive two sets of session keys (one with the API and one with the card) which would allow the correct keys to be sent to the card, but also allow the attacker to decrypt them and find out the value is said keys. This would violate the PKCS #11 standard if the keys were set to be sensitive and un-extractable. In addition, it would also be an attack whereby the user would be completely unaware it had taken place. This is considerably worse than previously analysed attacks were there is a large possibility of the user finding out, and therefore changing the keys before an attacker is able to utilise them for malicious purposes.

We also hope to be able to learn how the **unwrap** command data field is built and then build the correct command for **wrap** at the APDU level. This should be able to be completed by decrypting the data field of the unwarp command when used via the API. With this knowledge it should be possible to implement the Toekan attack [?] at the APDU level, and will therefore allow the exporting of all keys including RSA private keys which are generated on the card and thought to be securely stored.

To begin with we use the API to call the function **GenerateKey**, as we know that secure messaging is utilised within this function. This gives us an overview of how the secure messaging protocol works. Below is a diagram that visually shows what exactly occurs at the APDU level. (The actual APDU commands are stored within appendix A.3.1)

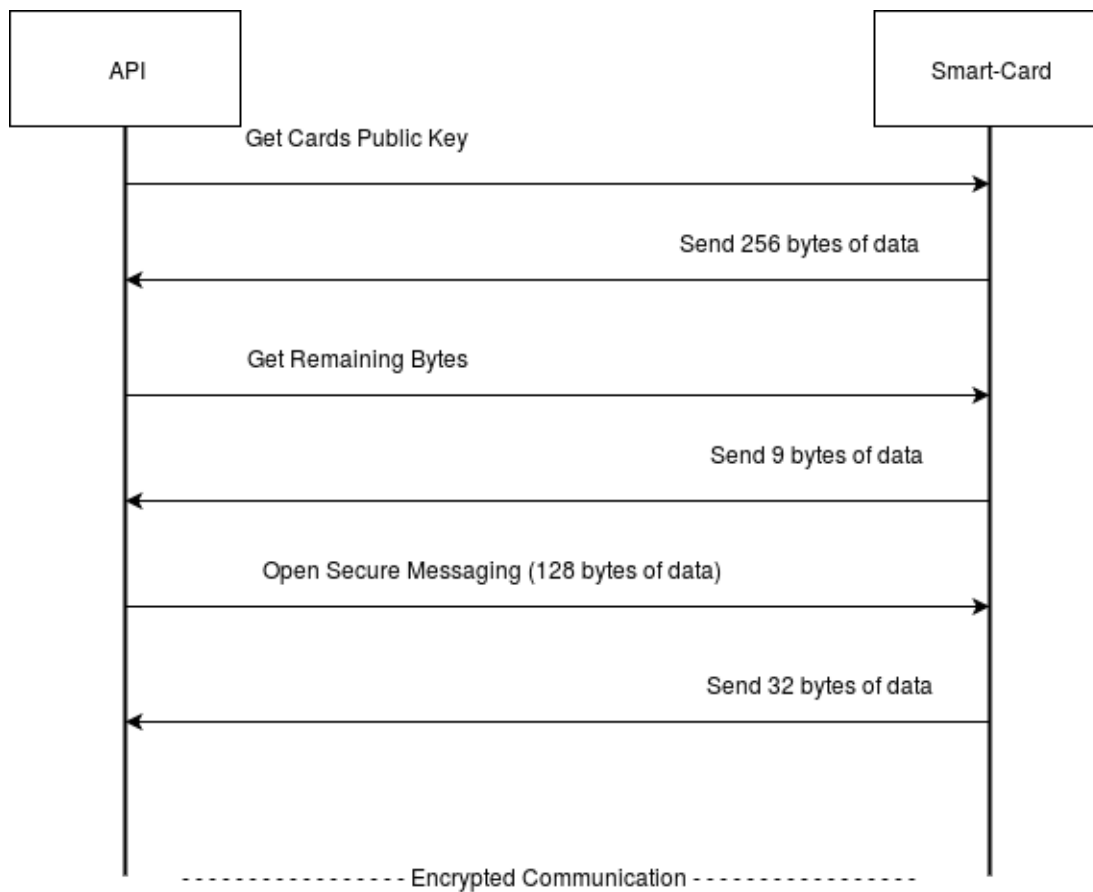


Figure 7.2: Secure Messaging Initialization

As shown in figure 7.2 the API first requests the public key of the card. In total (split between two messages due to the size exceeding 256 bytes) the card sends back 265 bytes worth of data, which is its public key. The API then proceeds to send back to the card 131 bytes worth of data (*from multiple traces we have found that these 131 bytes of data change every single time, a new secure messaging session is opened*). Finally the card sends 32 bytes of data, which concludes the initialization of secure messaging. Now the card and the API are both aware of two sets of block cipher keys S_{Enc} and S_{Mac} which are used to encrypt all of the following communication.

The first step we took was to analyse the raw bytes within the data field that are being sent over.

7.3.1 Raw byte analysis of the data fields

From multiple traces whereby we opened a secure messaging session we found 9 bytes within the data sent from the card → API that remained constant. This made us think the data might be wrapped in an ASN.1 BER

encoding. Using the online tool [?] we had utilised before (within chapter 6) we found 3 distinctive sets of data within the 265 bytes.

Send 265 bytes of data (cards public key) (A.3.1 - commands 24, 25)

[00] (1 byte) 05

[01] (128 byte) F7 B5 15 72 07 22 94 6F C4 08 ...

[02] (128 byte) 3C 52 D2 06 89 28 92 2C AB E6 ...

These command bytes in the BER encoding of the data have been highlighted in bold within the commands in the appendix to make it clear how the data is split.

We did not find any of the other data fields wrapped in an ASN.1 BER encoding. Thus now we know the following:

Data	Explanation
Cards public key (static key)	(1 byte) = 05 (128 bytes) = F7 B5 15 72 07 22 94 6F C4 08 ... (128 bytes) = 3C 52 D2 06 89 28 92 2C AB E6 ...
API data <i>public key or encrypted data</i> (Not static)	(128 bytes) = 08 9F EA A1 DC 8F C3 43 ...
Card random challenge (Not static)	(32 bytes) = 66 56 36 31 16 42 8D 8A ...

Table 7.9: Data organization within secure messaging initialization process

Using the information within table 7.9 we now begin finding protocols that would allow session keys to be derived, and also match the amount of data being sent across from the API to the card and vice versa.

7.3.2 Protocol search

There are three main protocols that would support session keys being derived that would remain a secret between the API and the card. These are: RSA, elliptic curve cofactor diffie hellman (ECCDH) and diffie hellman (DH). Within security policies for 'Athena smartcard solutions' it states that ECCDH is used for cards from 2012 onwards. The card we analyse supports the key generation of elliptic curve public and private keys, but only for the use of signing and verifying data.

Chapter 8

Conclusion / Results

This shall summarise the whole report and my findings in regard to low-level vulnerabilities on the card.

Chapter 9

Future work

1. Complete the reverse engineering secure messaging
2. Decrypt and understand the unwrap command
3. Test and get the wrap command to work (hopefully)
4. Implement the Tookan attack at the APDU level.
5. Try using 'reallocate binary' and/or 'delete file' then 'create file' (must be done with caution! could brick card) to alter the retry counter for logging in. (Then a successful login trace is not required!)

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Appendices

Appendix A

Attack Traces

A.1 Multiple C_login Traces

A.1.1 Different Second

```

----- APDU command/response pair 0 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08                      .....

00000000: 00 00 00 00 00 00 00 00 90 00          .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 61 50 65 E1 AF 05 7B C3 35 98 0D . . . .aPe...{.5..
00000010: DC 9D C5 42 96                      ...B.

00000000: 63 C9                                c.

----- APDU command/response pair 1 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08                      .....

00000000: 00 00 00 00 00 00 00 00 90 00          .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 BF 73 83 F9 30 B1 74 D2 E4 98 83 . . . .s..0.t....
00000010: 3A 9F 1F 37 BA                      ...7.

00000000: 63 C8                                c.

```

A.1.2 Same Pin, Same Challenge

```

----- APDU command/response pair 0 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 EE D2 F1 54 07 18 8A 8F AB A3 F7 . . . . .T. . . . .
00000010: 3E 64 17 2D 6E >d.-n

00000000: 63 C9 c.

----- APDU command/response pair 1 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 EE D2 F1 54 07 18 8A 8F AB A3 F7 . . . . .T. . . . .
00000010: 3E 64 17 2D 6E >d.-n

00000000: 63 C8 c.

```

A.1.3 Same Pin, Different Challenge

```

----- APDU command/response pair 0 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 6E 78 D4 D5 61 AD 3C 26 D3 89 E8 . . . . nx . . a . < & . . .
00000010: 96 B9 92 0D 40 . . . . @

00000000: 63 C9 c.

----- APDU command/response pair 1 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

```

```

00000000: 00 00 00 00 00 00 00 01 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 6E 78 D4 D5 61 AD 3C 26 BC C6 AA . . . .nx..a.<&...
00000010: 72 D3 95 2B 94 r..+.

00000000: 63 C8 c.

```

A.1.4 Different Pin, Same Challenge

```

----- APDU command/response pair 0 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 8F 58 1B 91 BC 78 D3 37 A9 D9 FB . . . .X...x.7...
00000010: 9C 20 58 F6 0A . X..

00000000: 63 C9 c.

----- APDU command/response pair 1 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 E0 30 33 BB 03 0F 6E 11 08 C0 8D . . . .03...n....
00000010: 1D 9D 85 C4 A6 .....

00000000: 63 C8 c.

```

A.1.5 Different Pin, Different Challenge

```

----- APDU command/response pair 0 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 00 90 00 .....

```

```

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 C2 29 5F 78 D1 68 29 13 78 BE 7B . ....)_x.h).x.{
00000010: 8E 61 9B 32 2E .a.2.

00000000: 63 C9 c.

----- APDU command/response pair 1 -----
(Inter-Industry) Get Challenge
00000000: 00 84 00 00 08 .....

00000000: 00 00 00 00 00 00 00 01 90 00 .....

----- APDU command/response pair 1 -----
(Proprietary) Verify
00000000: 80 20 00 00 10 C4 6D 44 03 92 F3 6B EF 13 18 07 . ....mD...k....
00000010: CE 5A A4 B9 27 .Z..'

00000000: 63 C8 c.

```

A.2 Successful Login Injection

```

----- APDU command/response pair 12 -----

(Inter-Industry) Get Challenge
COMMAND from API
00000000: 00 84 00 00 08 .....

Do you want to automate the injection your own login response? (Y/n)

RESPONSE
00000000: E7 69 60 B5 C8 FC D2 02 90 00 .i'.....

----- APDU command/response pair 13 -----

(Proprietary) Verify
COMMAND from API
00000000: 80 20 00 00 10 4A D1 3D AB 98 7F C5 18 A9 B3 1F . ....J.=.....
00000010: 2F 96 B4 3C AF /...<.

(Proprietary) Verify
COMMAND injected
00000000: 80 20 00 00 10 32 5A 9F 38 CA 4F BE 44 3A CD E1 . ...2Z.8.0.D:...
00000010: C5 03 84 35 DF ...5.

RESPONSE
00000000: 90 00 ..

```


A.3 Open Secure Messaging Traces

A.3.1 Generator = 5, [Not modified]

----- APDU command/response pair 24 -----

(Proprietary) Get Card Public Key

COMMAND from API

00000000: 80 48 00 80 00

.H...

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J.... '.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 25 -----

(Inter-Industry) Get Remaining Bytes

COMMAND from API

00000000: 00 C0 00 00 09

.....

Do you want to to alter command? (y/N)

RESPONSE

00000000: A8 5D D3 30 E3 5C A9 00 39 90 00

.].0....9..

Do you want to alter the response? (y/N)

----- APDU command/response pair 26 -----

(Proprietary) Open Secure Messaging

COMMAND from API

```
00000000: 80 86 00 00 80 08 9F EA A1 DC 8F C3 43 FD FD 4A .....C..J
00000010: E6 95 7E C0 D3 C6 FE 81 61 59 4B CE 45 21 96 63 ..~.....aYK.E!.c
00000020: 0F AB 19 D8 61 1A B2 6B 00 E2 44 0F 06 A3 5B 60 ....a..k..D...['
00000030: 87 76 C0 B7 E9 15 D5 50 DB 17 D6 C1 3C 26 54 47 .v.....P....<&TG
00000040: AA A3 4B DC 2C 14 81 08 84 0D F0 CA FB 49 8B C1 ..K.,.....I..
00000050: B1 0B A1 2B 86 20 02 F2 0F 69 F0 56 2C 83 0C 6E ....+. ....i.V,..n
00000060: A6 6A E9 86 56 47 71 24 0C B7 91 7F 37 85 0A D4 .j..VGq$. ....7...
00000070: 12 35 1F CE 17 6C D2 52 FB 04 24 CF DD E9 53 BE .5...l.R..$.S.
00000080: DA 26 EA 54 FB 00 .&.T..
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 66 56 36 31 16 42 8D 8A BC 06 BA AC 5D 35 26 F5 fV61.B.....]5&.
00000010: BF 58 15 7F 00 4F EF 2F 54 FB C4 F2 10 8F CB D6 .X...0./T.....
00000020: 90 00 ..
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 27 -----

(Proprietary) Get Challenge [SM]

COMMAND from API

```
00000000: 0C 84 00 00 0D 97 01 20 8E 08 05 E4 4A 19 32 DE .....J.2.
00000010: 51 CB 00 Q..
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 87 29 01 BD 69 F3 85 A7 98 2E 08 07 21 88 30 2F .)...)!.0/
00000010: 06 FF 93 E4 2F 31 C5 4A 40 FB 45 3A 45 C1 4A 84 ..../1.J@.E:E.J.
00000020: 7F BA 59 BC 44 8A 70 A0 BC DA FB 99 02 90 00 8E ..Y.D.p.....
00000030: 08 44 26 95 74 6A 51 A3 72 90 00 .D&.tjQ.r..
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 28 -----

(Proprietary) Close Secure Messaging

COMMAND from API

```
00000000: 80 86 FF FF ....
```

A.3.2 Generator = 1

----- APDU command/response pair 24 -----

(Proprietary) Get Card Public Key

COMMAND from API

00000000: 80 48 00 80 00

.H...

Do you want to to alter command? (y/N)

RESPONSE

```

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r..".o...
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}...U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh....l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L....F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.

```

Do you want to alter the response? (y/N)

y

```

00000000: 80 01 01 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r..".o...
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}...U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh....l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L....F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.

```

response changed!

----- APDU command/response pair 25 -----

(Inter-Industry) Get Remaining Bytes

COMMAND from API

00000000: 00 C0 00 00 09
 Do you want to to alter command? (y/N)

RESPONSE

00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..
 Do you want to alter the response? (y/N)

----- APDU command/response pair 26 -----

(Proprietary) Open Secure Messaging

COMMAND from API

00000000: 80 86 00 00 80 00 00 00 00 00 00 00 00 00
 00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 00000080: 00 00 00 00 01 00
 Do you want to to alter command? (y/N)

RESPONSE

00000000: 7D 2C 25 47 1C 16 34 51 E9 C3 49 38 C8 79 1E ED },%G..4Q..I8.y..
 00000010: A2 6B 20 D4 54 BD 67 0A D3 85 3E B9 E0 6E D5 5E .k .T.g...>..n.^
 00000020: 90 00 ..
 Do you want to alter the response? (y/N)

----- APDU command/response pair 27 -----

(Proprietary) Get Challenge [SM]

COMMAND from API

00000000: 0C 84 00 00 0D 97 01 20 8E 08 08 C6 59 9B 57 E6Y.W.
 00000010: B4 4E 00 .N.
 Do you want to to alter command? (y/N)

RESPONSE

00000000: 69 88 i.
 Do you want to alter the response? (y/N)

----- APDU command/response pair 28 -----

(Proprietary) Close Secure Messaging

COMMAND from API

00000000: 80 86 FF FF

....

A.3.3 Generator = 0

----- APDU command/response pair 24 -----

(Proprietary) Get Card Public Key

COMMAND from API

00000000: 80 48 00 80 00

.H...

Do you want to to alter command? (y/N)

RESPONSE

```

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."o...
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh....l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WPn{....z..
00000100: 61 09 a.

```

Do you want to alter the response? (y/N)

y

```

00000000: 80 01 00 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."o...
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh....l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...

```

```

000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.
response changed!

```

----- APDU command/response pair 25 -----

(Inter-Industry) Get Remaining Bytes

COMMAND from API

```
00000000: 00 C0 00 00 09 .....
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 26 -----

(Proprietary) Open Secure Messaging

COMMAND from API

```

00000000: 80 86 00 00 80 00 00 00 00 00 00 00 00 00 00 00 .....
00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000080: 00 00 00 00 00 00 00 .....

```

Do you want to to alter command? (y/N)

RESPONSE

```

00000000: 7E 4B 40 E6 E3 B1 5D 25 2B 02 48 50 B3 63 CC 9E ~K@...]%+.HP.c..
00000010: 79 41 34 FC 04 B3 57 1C 06 E3 D1 36 3C 24 45 8D yA4...W....6<$E.
00000020: 90 00 ..

```

Do you want to alter the response? (y/N)

----- APDU command/response pair 27 -----

(Proprietary) Get Challenge [SM]

COMMAND from API

```

00000000: 0C 84 00 00 0D 97 01 20 8E 08 99 BD 52 69 31 DD .....Ri1.
00000010: DB FD 00 ...

```

Do you want to to alter command? (y/N)

RESPONSE

00000000: 69 88

i.

Do you want to alter the response? (y/N)

----- APDU command/response pair 28 -----

(Proprietary) Close Secure Messaging

COMMAND from API

00000000: 80 86 FF FF

....

A.3.4 First 128 bytes set to zero and generator 0

----- APDU command/response pair 24 -----

(Proprietary) Get Card Public Key

COMMAND from API

00000000: 80 48 00 80 00

.H...

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."..o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6.....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l...mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)....6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J.... '.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$. :ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..VO,WpN{....z..
00000100: 61 09 a.
```

Do you want to alter the response? (y/N)

y

```
00000000: 80 01 00 81 81 80 00 00 00 00 00 00 00 00 00 .....
00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
```

```

00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000080: 00 00 00 00 00 00 82 81 80 3C 52 D2 06 89 28 92 .....<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..VO,WPN{....z..
00000100: 61 09 a.
response changed!

```

----- APDU command/response pair 25 -----

(Inter-Industry) Get Remaining Bytes

COMMAND from API

```
00000000: 00 C0 00 00 09 .....
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..
```

Do you want to alter the response? (y/N)

(Halts here)

A.3.5 Second 128 bytes set to zero and generator 0

----- APDU command/response pair 24 -----

(Proprietary) Get Card Public Key

COMMAND from API

```
00000000: 80 48 00 80 00 .H...
```

Do you want to to alter command? (y/N)

RESPONSE

```

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r".o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt

```



```

00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A..u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.

```

Do you want to alter the response? (y/N)

y

```

00000000: 80 01 00 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r".o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....."
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 00 00 00 00 00 00 00 D#.{ 'g.....
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000A0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000B0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000C0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000D0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000E0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000F0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000100: 61 09 a.

```

response changed!

----- APDU command/response pair 25 -----

(Inter-Industry) Get Remaining Bytes

COMMAND from API

```
00000000: 00 C0 00 00 09 .....
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..
```

Do you want to alter the response? (y/N)

y

```
00000000: 00 00 00 00 00 00 00 00 00 90 00 .....
response changed!
```

----- APDU command/response pair 26 -----

(Proprietary) Open Secure Messaging

COMMAND from API

```
00000000: 80 86 00 00 80 00 00 00 00 00 00 00 00 00 00 00 .....
00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000080: 00 00 00 00 00 00 .....

```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 7D 2C 25 47 1C 16 34 51 E9 C3 49 38 C8 79 1E ED },%G..4Q..I8.y..
00000010: A2 6B 20 D4 54 BD 67 0A D3 85 3E B9 E0 6E D5 5E .k .T.g...>..n.^
00000020: 90 00 ..
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 27 -----

(Proprietary) Get Challenge [SM]

COMMAND from API

```
00000000: 0C 84 00 00 0D 97 01 20 8E 08 08 C6 59 9B 57 E6 ..... ....Y.W.
00000010: B4 4E 00 .N.
```

Do you want to to alter command? (y/N)

RESPONSE

```
00000000: 69 88 i.
```

Do you want to alter the response? (y/N)

----- APDU command/response pair 28 -----

(Proprietary) Close Secure Messaging

COMMAND from API

```
00000000: 80 86 FF FF ....
```

A.4 Overriding Attribute Controls

A.4.1 Encrypt_False

Appendix B

API Function Traces

B.1 Initialization

```

----- APDU command/response pair 1 -----
00000000: 00 A4 04 00 0C A0 00 00 01 64 4C 41 53 45 52 00 .....dLASER.
00000010: 01 00 ..

00000000: 90 00 ..

----- APDU command/response pair 4 -----
00000000: 80 A4 08 00 06 3F 00 30 00 C0 00 .....?.0...

00000000: 90 00 ..

----- APDU command/response pair 5 -----
00000000: 00 B0 00 00 00 .....

00000000: 49 44 50 72 6F 74 65 63 74 20 20 20 20 20 20 20 IDProtect
00000010: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00000020: 41 74 68 65 6E 61 20 53 6D 61 72 74 63 61 72 64 Athena Smartcard
00000030: 20 53 6F 6C 75 74 69 6F 6E 73 20 20 20 20 20 20 Solutions
00000040: 49 44 50 72 6F 74 65 63 74 20 20 20 20 20 20 20 IDProtect
00000050: 30 44 35 30 30 30 30 39 32 31 32 32 38 37 39 36 0D50000921228796
00000060: 0D 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 10 00 00 00 04 00 00 00 FF FF FF FF .....
00000080: 00 00 00 00 FF FF FF FF 00 00 00 00 01 00 01 00 .....
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000A0: 00 90 00 ...

----- APDU command/response pair 8 -----
00000000: 80 A4 08 00 08 3F 00 30 00 30 03 40 00 .....?.0.0.@.

```

```

00000000: 90 00                                     ..

----- APDU command/response pair 9 -----
00000000: 00 B0 00 02 64                             ....d

00000000: 41 54 48 45 4E 41 53 4E C0 AD AA 78 FC 88 42 0D ATHENASN...x..B.
00000010: 90 00                                     ..

```

B.2 C_login

```

----- APDU command/response pair 10 -----
00000000: 80 A4 08 0C 04 3F 00 00 20 00             .....?.. .

00000000: 62 2F 87 01 08 83 02 00 20 80 02 00 10 8A 01 04 b/.....
00000010: 86 0E 00 FF C0 30 00 FF 00 10 00 FF 00 10 00 00 .....0.....
00000020: 85 0F 00 01 00 00 AA 00 04 10 00 00 00 00 00 FF .....
00000030: FF 90 00                                     ...

----- APDU command/response pair 11 -----
00000000: 80 A4 08 00 04 3F 00 00 20               .....?..

00000000: 90 00                                     ..

----- APDU command/response pair 12 -----
00000000: 00 84 00 00 08                             .....

00000000: 11 B7 B2 80 4B 17 0D A4 90 00             ....K.....

----- APDU command/response pair 13 -----
00000000: 80 20 00 00 10 1D ED 9E 47 A8 C9 EA CE 37 82 2C . ....G....7.,
00000010: 92 CF 07 20 2D                             ... -

00000000: 90 00                                     ..

----- APDU command/response pair 20 -----
00000000: 80 28 00 00 04 00 00 00 20               .(.....

00000000: 90 00                                     ..

```

B.3 C_findObject

```

----- APDU command/response pair 32 -----
00000000: 80 30 01 00 00                                     .0...

00000000: D1 02 00 03 D2 02 03 40   D2 02 03 46 D2 0A 86 7F .....@...F....
00000010: 63 6D 61 70 66 69 6C 65   90 00          cmapfile..


----- APDU command/response pair 33 -----
00000000: 80 A4 08 00 06 3F 00 30   00 30 02          .....?.0.0.

00000000: 90 00                                                  ..


----- APDU command/response pair 34 -----
00000000: 80 30 01 00 00                                     .0...

00000000: D1 02 00 00 90 00                                     .....


----- APDU command/response pair 35 -----
00000000: 80 A4 08 00 08 3F 00 30   00 30 01 03 40      .....?.0.0..@

00000000: 90 00                                                  ..


----- APDU command/response pair 36 -----
00000000: 00 B0 00 00 00                                     .....

00000000: 00 03 03 40 01 23 18 00   00 00 00 04 04 00 00 00 ...@.#.....
00000010: 00 01 00 00 01 01 00 02   00 00 01 00 00 03 10 00 .....
00000020: 04 64 65 73 33 FF FF FF   FF FF FF FF FF FF FF FF .des3.....
00000030: FF FF FF FF FF FF FF FF   FF FF FF FF FF FF FF FF .....
00000040: FF FF FF FF FF FF FF FF   FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF   FF FF FF FF FF FF FF FF .....
00000060: FF 00 11 01 00 18 FF FF   FF FF FF FF FF FF FF FF .....
00000070: FF FF FF FF FF FF FF FF   FF FF FF FF FF FF 01 00 .....
00000080: 00 00 04 15 00 00 00 01   02 10 00 01 01 FF FF FF .....
00000090: FF FF FF FF FF FF FF FF   FF FF FF FF FF FF FF FF .....
000000A0: FF FF FF FF FF FF FF FF   FF FF FF FF 01 03 30 00 .....0.
000000B0: 01 01 01 04 00 00 01 01   01 05 50 00 01 01 01 06 .....P.....
000000C0: 00 00 01 00 01 07 50 00   01 01 01 08 50 00 01 01 .....P.....P...
000000D0: 01 0A 00 00 01 01 01 0C   10 00 01 00 01 10 10 00 .....
000000E0: 00 FF FF FF FF FF FF FF   FF 01 11 10 00 00 FF FF .....
000000F0: FF FF FF FF FF FF 01 62   50 00 01 00 01 63 00 00 .....bP....c..
00000100: 61 27                                                  a'

```

----- APDU command/response pair 37 -----

```
00000000: 00 B0 01 00 00 .....
00000000: 01 01 01 64 00 00 01 01 01 65 00 00 01 01 01 66 ...d.....e....f
00000010: 00 00 04 31 01 00 00 01 70 00 00 01 01 80 10 00 ...1....p.....
00000020: 00 01 00 99 03 99 03 90 00 .....
```

----- APDU command/response pair 38 -----

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 46 .....?.0.0..F
```

```
00000000: 90 00
```

----- APDU command/response pair 39 -----

```
00000000: 00 B0 00 00 00 .....
00000000: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000A0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000B0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000C0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000D0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000E0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
000000F0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000100: 61 2F a/
```

----- APDU command/response pair 40 -----

```
00000000: 00 B0 01 00 00 .....
00000000: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000010: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000020: 00 00 00 00 00 00 00 00 00 00 00 00 00 90 .....
00000030: 00 .
```


B.4 C_generateKey

----- APDU command/response pair 26 -----

00000000: 80 48 00 80 00

.H...

```

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."..o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J.... '.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A..9.u$. :ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..VO,WpN{....z..
00000100: 61 09
a.

```

----- APDU command/response pair 27 -----

00000000: 00 C0 00 00 09

.....

00000000: A8 5D D3 30 E3 5C A9 00 39 90 00

.].0....9..

----- APDU command/response pair 28 -----

```

00000000: 80 86 00 00 80 84 7F A0 E7 6C 8F AA 50 9C C3 6E .....l..P..n
00000010: 82 5E 84 B6 E4 F6 77 1C 45 FA AB 06 1B 24 C4 A8 .^....w.E....$.
00000020: 92 03 A9 9C A8 2B BE 1B 28 C4 57 83 A5 5E BB 8D .....+...(.W..^..
00000030: D2 BF 3F D5 02 8A 7C 13 10 9C 75 06 91 1A 0F 05 ..?...|...u....
00000040: 55 B4 C9 12 8A 69 59 B6 07 1D 67 F2 8A C9 FA BC U....iY...g....
00000050: F3 BE 16 73 51 C0 76 0C 11 E5 0C D3 8C FE 09 E5 ...sQ.v.....
00000060: 1E 52 DE 38 D9 AC 2D EB C6 A1 C4 8E ED 03 7D 07 .R.8..-.....}.
00000070: 85 B7 FE 66 82 2F 03 65 94 DC 27 77 2B 3A 28 71 ...f./..e..'w+: (q
00000080: 97 08 5D 03 80 00
..]...

00000000: F9 D0 66 F7 48 CB BB E8 CE 93 60 05 99 1B 81 2E ..f.H..... '.....
00000010: 73 0B B7 B8 DC 10 A7 84 B3 99 D8 C8 60 D6 48 5A s..... '..HZ
00000020: 90 00
..

```

----- APDU command/response pair 29 -----

00000000: 0C 84 00 00 0D 97 01 18 8E 08 2B 88 7C 0C 8C 24
00000010: 00 1F 00

.....+.|..\$
...

```

00000000: 87 21 01 69 AB B7 01 F5 F5 8E EA B8 F3 09 D7 5E .!.i.....^
00000010: F5 26 3C 7F 1D 15 90 B8 40 D4 A1 85 9C 57 3F 27 .&<.....@....W?'
00000020: 87 84 C6 99 02 90 00 8E 08 42 84 88 19 99 3B C2 .....B....;.
00000030: 10 90 00                                     ...

```

----- APDU command/response pair 30 -----

```

00000000: 80 86 FF FF                                     ....

```

```

00000000: 90 00                                     ..

```

----- APDU command/response pair 39 -----

```

00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 40       .....?.0.0..@

```

```

00000000: 90 00                                     ..

```

----- APDU command/response pair 40 -----

```

00000000: 00 D6 00 00 FA 01 03 03 40 01 23 18 00 00 00 00 .....@.#.....
00000010: 04 04 00 00 00 00 01 00 00 01 01 00 02 00 00 01 .....
00000020: 00 00 03 10 00 04 64 65 73 33 FF FF FF FF FF FF .....des3.....
00000030: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000060: FF FF FF FF FF FF 00 11 01 00 18 FF FF FF FF FF .....
00000070: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000080: FF FF FF 01 00 00 00 04 15 00 00 00 01 02 10 00 .....
00000090: 01 01 FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000B0: FF 01 03 30 00 01 01 01 04 00 00 01 01 01 05 50 ...0.....P
000000C0: 00 01 01 01 06 00 00 01 00 01 07 50 00 01 01 01 .....P....
000000D0: 08 50 00 01 01 01 0A 00 00 01 01 01 0C 10 00 01 .P.....
000000E0: 00 01 10 10 00 00 FF FF FF FF FF FF FF 01 11 .....
000000F0: 10 00 00 FF FF FF FF FF FF FF FF 01 62 50 00 .....bP.

```

```

00000000: 90 00                                     ..

```

----- APDU command/response pair 41 -----

```

00000000: 00 D6 00 FA 2D 01 00 01 63 00 00 01 01 01 64 00 ....-...c.....d.
00000010: 00 01 01 01 65 00 00 01 01 01 66 00 00 04 31 01 ....e.....f...1.
00000020: 00 00 01 70 00 00 01 01 80 10 00 00 01 00 88 03 ...p.....
00000030: 88 03                                     ..

```

```

00000000: 90 00                                     ..

```

----- APDU command/response pair 42 -----

00000000: 80 48 00 80 00

.H...

```

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."..o...
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}...U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M....s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R...2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A...9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..VO,WpN{....z..
00000100: 61 09
a.

```

----- APDU command/response pair 43 -----

00000000: 00 C0 00 00 09

.....

00000000: A8 5D D3 30 E3 5C A9 00 39 90 00

.].0.:9..

----- APDU command/response pair 44 -----

```

00000000: 80 86 00 00 80 C3 88 FD AF 64 0D 35 77 85 D4 20 .....d.5w..
00000010: 57 10 02 F4 1E 38 51 37 40 31 7F 7F 11 E8 4B 8D W....8Q7@1....K.
00000020: A5 CE C0 50 EB 6B CE E6 E0 DE E8 34 7C FE 0B 6C ...P.k.....4|..l
00000030: F0 70 9F E3 5D F7 AA 50 BB 1C F6 8C 00 1B 18 EA .p..]..P.....
00000040: BF 73 E4 BE 75 B6 AE 29 B1 A2 A3 B8 1D 52 FD 19 .s..u..).....R..
00000050: C9 CA 20 FB 80 C2 20 A9 E3 A6 15 6C 11 B3 E9 18 .. ... ..l....
00000060: 13 3F 65 02 28 21 74 72 29 EA E2 27 8B DA 3E 45 .?e.(!tr)...'...>E
00000070: 82 A1 B0 D9 A7 1A 3D F3 5D 4D 27 F4 D2 73 ED 0F .....=.]M'..s..
00000080: A8 88 41 F2 4F 00
..A.0.

```

```

00000000: 14 8C 30 9E D5 10 25 B1 F7 AF 07 E7 25 8B 22 3C ..0...%.....%."<
00000010: 62 61 8F 24 FB 59 E1 63 D7 B1 08 6D 07 7A DD 93 ba$.Y.c...m.z..
00000020: 90 00
..

```

----- APDU command/response pair 45 -----

```

00000000: 8C A4 08 00 15 87 09 01 E5 61 A8 BF 89 AD D7 FF .....a.....
00000010: 8E 08 C2 B3 32 7B D7 83 C9 D1
....2{....

00000000: 99 02 90 00 8E 08 E6 37 E6 BE 12 F8 73 6F 90 00 .....7....so..

```

```

----- APDU command/response pair 46 -----
00000000: 0C E0 08 00 4D 87 41 01 41 03 69 5A A4 EE 5F 44 ....M.A.A.iZ...D
00000010: 2C 4C A9 FE 46 8D 1F 5B 79 D6 89 68 EB 94 CF FB ,L..F..[y..h....
00000020: 6B A2 55 F6 65 B7 19 66 B3 67 E0 DF 46 F2 27 22 k.U.e..f.g..F.'"
00000030: AC D8 C1 57 C5 54 5B DF B9 10 87 58 81 2E 9E 65 ...W.T[....X...e
00000040: 07 B1 6E 14 F8 DE 09 AF 8E 08 8C 79 AD C4 3B E2 ..n.....y...;
00000050: D2 84 ..

```

```

00000000: 99 02 90 00 8E 08 A5 D0 49 2A C0 91 47 68 90 00 .....I*..Gh..

```

```

----- APDU command/response pair 47 -----
00000000: 80 86 FF FF ....

00000000: 90 00 ..

```

B.5 C_generateKeyPair

```

----- APDU command/response pair 54 -----
00000000: 00 E0 01 00 18 62 81 15 8A 01 04 83 02 01 40 80 .....b.....@.
00000010: 02 01 A7 86 08 00 20 00 20 00 20 00 20 .....

00000000: 90 00 ..

```

```

----- APDU command/response pair 55 -----
00000000: 80 A4 08 00 08 3F 00 30 00 30 02 01 40 .....?.0.0..@

00000000: 90 00 ..

```

```

----- APDU command/response pair 56 -----
00000000: 00 D6 00 00 FA 01 01 01 40 01 A3 16 00 00 00 00 .....@.....
00000010: 04 02 00 00 00 00 01 00 00 01 01 00 02 00 00 01 .....
00000020: 01 00 03 10 00 03 70 75 62 FF FF FF FF FF FF FF .....pub.....
00000030: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000060: FF FF FF FF FF FF 00 86 32 00 01 00 01 00 00 00 .....2.....
00000070: 04 00 00 00 00 01 01 10 00 00 FF FF FF FF FF FF .....
00000080: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000090: FF FF FF FF FF FF FF FF FF FF 01 02 10 00 01 03 .....
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000B0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000C0: 04 00 00 01 01 01 06 00 00 01 01 01 0A 00 00 01 .....

```

```

000000D0: 01 01 0B 00 00 01 00 01 0C 10 00 01 00 01 10 10 .....
000000E0: 00 00 FF FF FF FF FF FF FF FF 01 11 10 00 00 FF .....
000000F0: FF FF FF FF FF FF FF 01 20 00 00 80 A8 FD 0C .....

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 57 -----

```

00000000: 00 D6 00 FA AD 53 6B 7F 00 00 A8 FD 0C 53 6B 7F .....Sk.....Sk.
00000010: 00 00 B0 AA 47 51 6B 7F 00 00 00 30 00 00 00 00 ....GQk....0....
00000020: 00 00 B0 AA 47 51 6B 7F 00 00 02 30 00 00 00 00 ....GQk....0....
00000030: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000040: 00 00 00 00 00 00 00 00 00 00 11 01 00 00 00 .....
00000050: 00 00 58 FD 0C 53 6B 7F 00 00 58 FD 0C 53 6B 7F ..X..Sk...X..Sk.
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000080: 00 00 01 21 00 00 04 00 04 00 00 01 22 00 00 03 ...!......"....
00000090: 01 00 01 01 63 00 00 01 01 01 66 00 00 04 00 00 ....c.....f.....
000000A0: 00 00 01 70 00 00 01 01 80 10 00 00 01 00 93 03 ...p.....
000000B0: 93 03 ..

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 58 -----

```

00000000: 80 A4 08 00 06 3F 00 30 00 30 02 .....?.0.0.

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 59 -----

```

00000000: 00 E0 01 00 1E 62 81 1B 8A 01 04 83 02 02 00 80 .....b.....
00000010: 02 01 23 84 04 6B 78 73 30 86 08 00 00 00 20 00 ..#..kxs0.....
00000020: 20 00 20 .

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 60 -----

```

00000000: 80 A4 08 00 08 3F 00 30 00 30 02 02 00 .....?.0.0...

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 61 -----

```

00000000: 00 D6 00 00 FA 01 02 02 00 01 1F 16 00 00 00 00 .....
00000010: 04 03 00 00 00 00 01 00 00 01 01 00 02 00 00 01 .....
00000020: 01 00 03 10 00 04 70 72 69 76 FF FF FF FF FF FF .....priv.....
00000030: FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....

```

```

00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000060: FF FF FF FF FF FF 01 00 00 00 04 00 00 00 00 01 .....
00000070: 01 10 00 00 FF FF FF FF FF FF FF FF FF FF FF .....
00000080: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000090: FF FF FF FF 01 02 10 00 01 03 FF FF FF FF FF FF .....
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000B0: FF FF FF FF FF FF FF FF FF 01 03 30 00 01 01 01 .....0....
000000C0: 05 50 00 01 01 01 07 50 00 01 01 01 08 50 00 01 .P....P....P..
000000D0: 01 01 09 50 00 01 00 01 0C 10 00 01 00 01 10 10 ...P.....
000000E0: 00 00 FF FF FF FF FF FF FF FF 01 11 10 00 00 FF .....
000000F0: FF FF FF FF FF FF FF 01 62 50 00 01 01 01 63 .....bP....c

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 62 -----

```

00000000: 00 D6 00 FA 29 00 00 01 01 01 64 00 00 01 00 01 ....).d....
00000010: 65 00 00 01 01 01 66 00 00 04 00 00 00 00 01 70 e....f.....p
00000020: 00 00 01 01 80 10 00 00 01 00 93 03 93 03 .....

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 63 -----

```

00000000: 80 A4 08 00 06 3F 00 30 00 30 02 .....?.0.0.

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 64 -----

```

00000000: 00 E0 08 00 27 62 81 24 8A 01 04 83 02 00 41 80 ....'b.$.....A.
00000010: 02 00 80 85 05 05 0C 20 00 A3 86 0E 00 00 00 FF .....
00000020: 00 FF 00 20 00 20 00 00 00 20 71 00 ... . . . q.

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 65 -----

```

00000000: 80 A4 00 00 02 00 41 .....A

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 66 -----

```

00000000: 00 47 00 00 0C AC 81 09 80 01 06 81 81 03 01 00 .G.....
00000010: 01 .

```

```

00000000: 90 00 ..

```

----- APDU command/response pair 67 -----

00000000: 80 A4 08 00 08 3F 00 30 00 30 02 00 41?.0.0..A

00000000: 90 00 ..

----- APDU command/response pair 68 -----

00000000: 80 48 00 00 00 .H...

00000000: **7F 49 81 88 81 81 80** D1 EF 7C A5 06 A1 87 FD 5F .I.....|.....
 00000010: 13 5B 25 B7 16 B9 BA A7 21 43 3D DB 51 9D C1 D1 .[%.....!C=.Q...
 00000020: 5A 3C 95 7C B6 F0 37 57 83 CF 2D 0B 53 66 C7 11 Z<.|..7W...-Sf..
 00000030: D5 6B FD 28 FA A0 EA 50 1E 2B FD B5 09 49 E2 E7 .k.(...P.+...I..
 00000040: 51 67 1B 00 B0 9D 52 CD 22 D8 69 8C 36 74 54 41 Qg....R."i.6tTA
 00000050: 6E 40 58 4F 79 52 E4 D9 00 43 9C 2C 79 FE A6 48 n@X0yR...C.,y..H
 00000060: B7 31 8A B2 05 04 C4 DD B3 86 E6 4F 38 A6 5D 2A .1.....08.]*
 00000070: CD A8 3F 95 E4 FF 7B 05 1E ED 4A B5 99 69 36 F0 ..?...{...J...i6..
 00000080: B9 5B 29 C6 EC B3 25 **82 03** 01 00 01 90 00 .[)...%.....

----- APDU command/response pair 69 -----

00000000: 80 A4 08 00 06 3F 00 30 00 30 02?.0.0.

00000000: 90 00 ..

----- APDU command/response pair 70 -----

00000000: 00 E0 08 00 B0 62 81 AD 8A 01 04 83 02 00 81 80b.....
 00000010: 02 00 80 85 05 05 08 20 00 A3 86 0E 00 00 00 FF
 00000020: 00 FF 00 20 00 20 00 00 00 20 71 81 88 90 03 01 q.....
 00000030: 00 01 91 81 80 D1 EF 7C A5 06 A1 87 FD 5F 13 5B|.....[
 00000040: 25 B7 16 B9 BA A7 21 43 3D DB 51 9D C1 D1 5A 3C %.....!C=.Q...Z<
 00000050: 95 7C B6 F0 37 57 83 CF 2D 0B 53 66 C7 11 D5 6B .|..7W...-Sf...k
 00000060: FD 28 FA A0 EA 50 1E 2B FD B5 09 49 E2 E7 51 67 .(...P.+...I..Qg
 00000070: 1B 00 B0 9D 52 CD 22 D8 69 8C 36 74 54 41 6E 40R."i.6tTAn@
 00000080: 58 4F 79 52 E4 D9 00 43 9C 2C 79 FE A6 48 B7 31 X0yR...C.,y..H.1
 00000090: 8A B2 05 04 C4 DD B3 86 E6 4F 38 A6 5D 2A CD A808.]*..
 000000A0: 3F 95 E4 FF 7B 05 1E ED 4A B5 99 69 36 F0 B9 5B ?...{...J...i6..[
 000000B0: 29 C6 EC B3 25)...%

00000000: 90 00 ..

----- APDU command/response pair 71 -----

00000000: 80 A4 08 00 08 3F 00 30 00 30 02 00 41?.0.0..A

00000000: 90 00 ..

----- APDU command/response pair 72 -----

```
00000000: 80 48 00 00 00 .H...

00000000: 7F 49 81 88 81 81 80 D1 EF 7C A5 06 A1 87 FD 5F .I.....|.....-
00000010: 13 5B 25 B7 16 B9 BA A7 21 43 3D DB 51 9D C1 D1 .[%.....!C=.Q...
00000020: 5A 3C 95 7C B6 F0 37 57 83 CF 2D 0B 53 66 C7 11 Z<.|..7W...-Sf..
00000030: D5 6B FD 28 FA A0 EA 50 1E 2B FD B5 09 49 E2 E7 .k.(...P.+...I..
00000040: 51 67 1B 00 B0 9D 52 CD 22 D8 69 8C 36 74 54 41 Qg....R."i.6tTA
00000050: 6E 40 58 4F 79 52 E4 D9 00 43 9C 2C 79 FE A6 48 n@X0yR...C.,y..H
00000060: B7 31 8A B2 05 04 C4 DD B3 86 E6 4F 38 A6 5D 2A .1.....08.]*
00000070: CD A8 3F 95 E4 FF 7B 05 1E ED 4A B5 99 69 36 F0 ..?...{...J..i6.
00000080: B9 5B 29 C6 EC B3 25 82 03 01 00 01 90 00 .[])...%.....
```

----- APDU command/response pair 73 -----

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 02 01 40 .....?.0.0..@

00000000: 90 00 ..
```

----- APDU command/response pair 74 -----

```
00000000: 00 D6 00 F5 82 00 80 D1 EF 7C A5 06 A1 87 FD 5F .....|.....-
00000010: 13 5B 25 B7 16 B9 BA A7 21 43 3D DB 51 9D C1 D1 .[%.....!C=.Q...
00000020: 5A 3C 95 7C B6 F0 37 57 83 CF 2D 0B 53 66 C7 11 Z<.|..7W...-Sf..
00000030: D5 6B FD 28 FA A0 EA 50 1E 2B FD B5 09 49 E2 E7 .k.(...P.+...I..
00000040: 51 67 1B 00 B0 9D 52 CD 22 D8 69 8C 36 74 54 41 Qg....R."i.6tTA
00000050: 6E 40 58 4F 79 52 E4 D9 00 43 9C 2C 79 FE A6 48 n@X0yR...C.,y..H
00000060: B7 31 8A B2 05 04 C4 DD B3 86 E6 4F 38 A6 5D 2A .1.....08.]*
00000070: CD A8 3F 95 E4 FF 7B 05 1E ED 4A B5 99 69 36 F0 ..?...{...J..i6.
00000080: B9 5B 29 C6 EC B3 25 .[])...%

00000000: 90 00 ..
```

B.6 C_destroyObject

----- APDU command/response pair 35 -----

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 40 .....?.0.0..@

00000000: 90 00 ..
```

----- APDU command/response pair 36 -----

```
00000000: 00 B0 00 00 00 .....

00000000: 00 03 03 40 01 23 18 00 00 00 00 04 04 00 00 00 ...@.#.....
```



```
00000010: 00 01 00 00 01 01 00 02 00 00 01 00 00 03 10 00 .....  
00000020: 04 64 65 73 33 FF FF FF FF FF FF FF FF FF FF .des3.....  
00000030: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....,  
00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....,  
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....,  
00000060: FF 00 11 01 00 18 FF FF FF FF FF FF FF FF FF FF .....,  
00000070: FF FF FF FF FF FF FF FF FF FF FF FF FF FF 01 00 .....,  
00000080: 00 00 04 15 00 00 00 01 02 10 00 01 01 FF FF FF FF .....,  
00000090: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....,  
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF 01 03 30 00 .....0.,  
000000B0: 01 01 01 04 00 00 01 01 01 05 50 00 01 01 01 06 .....P....,  
000000C0: 00 00 01 00 01 07 50 00 01 01 01 08 50 00 01 01 .....P....P...  
000000D0: 01 0A 00 00 01 01 01 0C 10 00 01 00 01 10 10 00 .....,  
000000E0: 00 FF FF FF FF FF FF FF FF FF 01 11 10 00 00 FF FF .....,  
000000F0: FF FF FF FF FF FF 01 62 50 00 01 00 01 63 00 00 .....bP....c..  
00000100: 61 27 a'
```

```
----- APDU command/response pair 37 -----
```

```
00000000: 00 B0 01 00 00          .....
00000000: 01 01 01 64 00 00 01 01 01 65 00 00 01 01 01 66 ...d.....e.....f
00000010: 00 00 04 31 01 00 00 01 70 00 00 01 01 80 10 00 ...1....p.....
00000020: 00 01 00 97 03 97 03 90 00          .....

```

```
----- APDU command/response pair 49 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30  00 30 03 40 01          .....?.0.0. @.
```

000000000: 90 00

```
----- APDU command/response pair 50 -----
```

```
000000000: 00 D6 00 04 04 98 03 98 03      . . . . .
```

000000000: 90 00

```
----- APDU command/response pair 53 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 00 C1      ....?.0.0...
```

000000000: 90 00

```
----- APDU command/response pair 54 -----
```

```
000000000: 00 E4 00 00
```

000000000: 90 00

```
----- APDU command/response pair 55 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 40          .....?.0.0..@
```

```
00000000: 90 00 ..
```

```
----- APDU command/response pair 56 -----
```

```
00000000: 00 E4 00 00 ....
```

```
00000000: 90 00 ..
```

B.7 C_encrypt

```
----- APDU command/response pair 52 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 00 C1 .....?.0.0...
```

```
00000000: 90 00 ..
```

```
----- APDU command/response pair 53 -----
```

```
00000000: 00 2A 82 05 13 80 81 10 54 65 73 74 53 74 72 69 .*.....TestStri
00000010: 6E 67 31 32 33 34 35 36 00 ng123456.
```

```
00000000: 82 10 B4 F0 97 B6 63 E4 68 7A 8B 00 4F DF 3A C1 .....c.hz..0...
00000010: 49 9F 90 00 I...
```

B.8 C_decrypt

```
----- APDU command/response pair 64 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 00 C1 .....?.0.0...
```

```
00000000: 90 00 ..
```

```
----- APDU command/response pair 65 -----
```

```
00000000: 00 2A 80 05 0B 82 81 08 8B 00 4F DF 3A C1 49 9F .*.....0...I.
00000010: 00 .
```

```
00000000: 80 08 6E 67 31 32 33 34 35 36 90 00 ..ng123456..
```

B.9 C_setAttribute

```
----- APDU command/response pair 51 -----
```

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 40 .....?.0.0..@
```

```
00000000: 90 00                                     ..

----- APDU command/response pair 52 -----
00000000: 90 32 00 03 FF 01 27 00 00 62 82 01 27 00 03 03 .2....'..b..'...
00000010: 40 01 23 18 00 00 00 00 04 04 00 00 00 00 01 00 @.#.....
00000020: 00 01 01 00 02 00 00 01 00 00 03 10 00 07 63 68 .....ch
00000030: 61 6E 67 65 64 FF FF FF FF FF FF FF FF FF FF FF anged.....
00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000060: FF FF FF FF FF FF FF FF FF FF FF FF FF FF 00 11 .....
00000070: 01 00 18 FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000080: FF FF FF FF FF FF FF FF FF FF FF FF FF 01 00 00 04 .....
00000090: 15 00 00 00 01 02 10 00 01 01 FF FF FF FF FF FF .....
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000B0: FF FF FF FF FF FF FF FF FF FF 01 03 30 00 01 01 01 .....0...
000000C0: 04 00 00 01 01 01 05 50 00 01 01 01 06 00 00 01 .....P.....
000000D0: 00 01 07 50 00 01 01 01 08 50 00 01 01 01 0A 00 ...P....P.....
000000E0: 00 01 01 01 0C 10 00 01 00 01 10 10 00 00 FF FF .....
000000F0: FF FF FF FF FF FF 01 11 10 00 00 FF FF FF FF FF .....
00000100: FF FF FF 01                                     ....

00000000: 90 00                                     ..

----- APDU command/response pair 53 -----
00000000: 80 32 00 03 30 62 50 00 01 00 01 63 00 00 01 01 .2..0bP....c....
00000010: 01 64 00 00 01 01 01 65 00 00 01 01 01 66 00 00 .d.....e.....f..
00000020: 04 31 01 00 00 01 70 00 00 01 01 80 10 00 00 01 .1....p.....
00000030: 00 99 03 99 03                                     .....

00000000: 90 00                                     ..
```

B.10 C_unwrap

```

----- APDU command/response pair 92 -----
00000000: 80 48 00 80 00                                     .H...

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d...U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.q...p..G.q

```

```

00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..V0,WpN{....z..
00000100: 61 09 a.

```

----- APDU command/response pair 93 -----

```

00000000: 00 C0 00 00 09 .....
00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..

```

----- APDU command/response pair 94 -----

```

00000000: 80 86 00 00 80 D0 7E EE 17 C7 31 DD 53 FB 1F D4 .....~...1.S...
00000010: 36 65 EB 7F 2C B0 A2 34 44 80 D7 F4 31 96 12 DF 6e...,...4D...1...
00000020: C8 AD 3C 41 EE 8F 13 C2 8A 3B 8D 6B 73 18 A6 1B ..<A.....;ks...
00000030: 46 3E 10 93 5C 2F 35 1C A3 FC 48 09 DB E4 BB EA F>..5...H.....
00000040: 3F 1A 11 7D 85 57 2F 85 75 1D 8B F4 E6 39 2B FA ?..}.W/.u....9+.
00000050: 19 3D 7A BB E3 75 B2 A2 A9 E4 EE 79 4F A6 3F EE .=z...u....y0.?.
00000060: FD BF 4A F8 43 8F DA A9 D1 8D 58 63 12 5D C8 E8 ..J.C.....Xc.]..
00000070: 2C 77 8F 5F 96 C0 51 CA 19 B1 80 D5 80 4E 50 8B ,w._...Q.....NP.
00000080: 88 6B 64 43 0D 00 .kdC..
00000000: FD 74 3B 38 48 7E 0E D9 4D B0 BF E7 66 3D E4 63 .t;8H~...M...f=.c
00000010: 15 24 EC 7B F3 93 C7 90 85 43 E8 DF D9 E0 60 88 .$.{'.....C....'.
00000020: 90 00 ..

```

----- APDU command/response pair 95 -----

```

00000000: 8C A4 08 00 1D 87 11 01 65 FD 9A B5 09 70 96 93 .....e....p..
00000010: FB 5D 39 FF B3 24 6B 8E 8E 08 04 D7 B0 58 E0 96 .]9...$k.....X..
00000020: E6 01 ..
00000000: 99 02 90 00 8E 08 67 C9 1F 50 18 5F 6D 6A 90 00 .....g..P._mj..

```

----- APDU command/response pair 96 -----

```

00000000: 0C 2A 80 0A 99 87 81 89 01 1D 7A 97 D8 25 8F 60 .*. ....z...%. '
00000010: 52 07 AE DC A9 AC 33 7C 6E 12 A9 79 71 B8 36 1B R....3|n..yq.6.
00000020: 29 C3 54 C1 A8 29 A4 4F 75 72 4E C6 C5 71 22 88 ).T...).OurN..q".
00000030: 50 0C 29 9F 75 C7 99 39 E9 B6 5B AF A1 65 51 DE P.)..u..9..[.eQ.
00000040: 56 84 6D 30 B6 2F F3 19 6B 83 82 C4 6B AB 59 E3 V.m0./..k...k.Y.
00000050: 2B FD B1 4B FC 3D BE CD 16 C8 C0 69 80 5C 0E 72 +..K.=.....i...r
00000060: C0 0F 24 0A 3E 8A 88 4A CA 68 02 5C FA B5 36 33 ..$.>...J.h.:63

```

```

00000070: CB 5A F7 BE 86 21 2F 68 DB 5F 46 1D 67 FA C2 8B .Z...!/h._F.g...
00000080: A9 58 37 5C F0 34 7E FE FC 1A 78 46 C7 51 0B 13 .X74~...xF.Q..
00000090: B2 97 01 00 8E 08 F9 2D 53 7C AD 46 EB 79 00 .....-S|.F.y.

00000000: 87 11 01 FC E7 96 A5 B1 96 E9 E3 1D 2D 3A 49 46 .....-:IF
00000010: 8C 97 A7 99 02 90 00 8E 08 41 16 94 D4 58 27 D0 .....A...X'.
00000020: 3F 90 00 ?..

```

----- APDU command/response pair 97 -----

```
00000000: 80 86 FF FF .....
```

```
00000000: 90 00 ..
```

----- APDU command/response pair 119 -----

```
00000000: 80 A4 08 00 08 3F 00 30 00 30 01 03 41 .....?.0.0..A
```

```
00000000: 90 00 ..
```

----- APDU command/response pair 120 -----

```

00000000: 00 D6 00 00 FA 01 03 03 41 01 23 18 00 00 00 00 .....A.#.....
00000010: 04 04 00 00 00 00 01 00 00 01 01 00 02 00 00 01 .....
00000020: 00 00 03 10 00 04 74 65 73 74 FF FF FF FF FF FF .....test.....
00000030: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000040: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000050: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000060: FF FF FF FF FF FF 00 11 01 00 08 FF FF FF FF FF .....
00000070: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
00000080: FF FF FF 01 00 00 00 04 13 00 00 00 01 02 10 00 .....
00000090: 01 10 FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000A0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .....
000000B0: FF 01 03 30 00 01 01 01 04 00 00 01 01 01 05 50 ...0.....P
000000C0: 00 01 01 01 06 00 00 01 00 01 07 50 00 01 01 01 .....P....
000000D0: 08 50 00 01 01 01 0A 00 00 01 01 01 0C 10 00 01 .P.....
000000E0: 00 01 10 10 00 00 FF FF FF FF FF FF FF FF 01 11 .....
000000F0: 10 00 00 FF FF FF FF FF FF FF FF FF 01 62 50 00 .....bP.

00000000: 90 00 ..

```

----- APDU command/response pair 121 -----

```

00000000: 00 D6 00 FA 2D 01 00 01 63 00 00 01 00 01 64 00 ....-...c.....d.
00000010: 00 01 00 01 65 00 00 01 00 01 66 00 00 04 FF FF ....e.....f.....
00000020: FF FF 01 70 00 00 01 01 80 10 00 00 01 00 B0 03 ...p.....
00000030: B0 03 ..

```

```
00000000: 90 00 ..
```

----- APDU command/response pair 122 -----

```
00000000: 80 48 00 80 00 .H...

00000000: 80 01 05 81 81 80 F7 B5 15 72 07 22 94 6F C4 08 .....r."o..
00000010: 64 CB BD AF EA 55 7D BD 8F 55 36 B0 01 C2 8B 2E d....U}..U6....
00000020: 32 B6 5D 45 F1 74 5D 38 12 0B AD 9D 2C 03 9C 22 2.]E.t]8....,"
00000030: 46 68 EB 2E A2 8C 20 95 A8 2E 6C A8 E0 6D 47 F2 Fh.... ..l..mG.
00000040: D3 1E D7 01 F8 15 5C AD DC 05 70 C0 93 B2 6D 74 .....p...mt
00000050: B0 9B 95 E6 4D 8C D2 FC 73 3E CD 0F 30 68 79 A5 ....M...s>..0hy.
00000060: B9 35 F2 41 3F 52 AD AD 32 A0 99 1A 18 3D CC 57 .5.A?R..2....=.W
00000070: 7E 39 DA 47 53 1E 67 15 AB 01 70 7F F2 47 96 71 ~9.GS.g...p..G.q
00000080: 44 23 CE 7B 60 67 82 81 80 3C 52 D2 06 89 28 92 D#.{ 'g...<R...(
00000090: 2C AB E6 3C 4E E6 DF 0E D2 29 F1 01 BE 36 C4 F8 ,...<N....)...6..
000000A0: 54 40 56 F3 4A FA 8D 2E 9B 60 F5 07 BC ED B4 44 T@V.J....'.....D
000000B0: 56 68 5D 82 4C C4 EA D7 96 20 F8 C5 46 A6 E0 16 Vh].L.... ..F...
000000C0: B8 AB A5 D8 43 29 58 53 77 17 09 97 AA 70 68 33 ....C)XSw....ph3
000000D0: 9E F1 41 0A 5F 39 D9 75 24 7F 3A 53 63 61 47 87 ..A._9.u$.:ScaG.
000000E0: 87 7F 88 96 BC BB 83 A1 CB D1 42 E0 EB 99 CF 34 .....B....4
000000F0: 0E CA 56 4F 2C 57 50 6E 7B 1A FC 1F 90 7A E0 C2 ..VO,WpN{....z..
00000100: 61 09 a.
```

----- APDU command/response pair 123 -----

```
00000000: 00 C0 00 00 09 .....

00000000: A8 5D D3 30 E3 5C A9 00 39 90 00 .].0....9..
```

----- APDU command/response pair 124 -----

```
00000000: 80 86 00 00 80 95 3B CF 46 B8 4E 67 E4 6B 97 4B .....;.F.Ng.k.K
00000010: 70 AD B3 44 22 6A 1B 42 18 4B A9 44 FF 28 FA C0 p..D"j.B.K.D.(..
00000020: 0A EF 44 CD DA C1 28 2B CF FD 5D 20 48 50 33 59 ..D...(+) ] HP3Y
00000030: 7D B7 CB 73 4A EF 28 0A C7 E4 02 2A 91 A9 F6 55 }...sJ.(....*...U
00000040: 97 D3 A8 DE 21 90 0E 23 0B 9C ED 4B 52 39 46 ED ....!...#...KR9F.
00000050: 13 1F 7F 9D CB EF 7A DD 7C D7 39 EC 1F BD 2A 3A .....z.|.9...*:
00000060: 45 48 8F 6C 7E 82 71 E5 14 8F C1 9D F8 E8 53 2B EH.l~.q.....S+
00000070: D3 AF 3D 7C 11 59 E3 81 F4 0B 08 17 A9 0F 37 69 ..=|.Y.....7i
00000080: 90 C1 11 E2 1B 00 .....

00000000: B3 0F 6C 66 E6 56 8F 44 55 B2 A6 02 0E 0B 80 01 ..lf.V.DU.....
00000010: FF 89 7A 65 FC 68 25 82 22 C9 97 74 D1 6B 00 AB ..ze.h%.."..t.k..
00000020: 90 00 ..
```

----- APDU command/response pair 125 -----

```
00000000: 8C A4 08 00 15 87 09 01 82 46 BD FD 60 2D E4 C6 .....F..'-'...
00000010: 8E 08 25 35 C0 28 0E E1 20 93 ..%5.(...)
```

```
00000000: 99 02 90 00 8E 08 8C D6 A9 A8 99 7F 14 12 90 00 .....
```

```
----- APDU command/response pair 126 -----
```

```
00000000: 0C E0 08 00 3D 87 31 01 4D 4F 3D AB 31 72 FC F7 ....=.1.M0=.1r..
00000010: B4 84 D1 41 19 1C 22 DF 3F 60 BE 6B 0A 1E 49 5F ...A.."?.'.k..I_
00000020: AD 3D 6D 61 5E DA E3 F7 A8 0A 82 EA 65 16 8A 01 .=ma^.....e...
00000030: C5 4F BF 3F 44 73 9C 61 8E 08 A8 A9 A5 4D 55 BB .0.?Ds.a.....MU.
00000040: E7 B3 ..
```

```
00000000: 99 02 90 00 8E 08 23 E5 DF 34 11 21 87 1C 90 00 .....#..4.!....
```

```
----- APDU command/response pair 127 -----
```

```
00000000: 80 86 FF FF .....
```

```
00000000: 90 00 ..
```

B.11 C_wrap

Enter command (spaced integers)

```
00 42 130 10 08 49 50 51 52 53 54 55 56 00 (integers)
```

```
00 2A 82 0A 08 31 32 33 34 35 36 37 38 00 (hexadecimals)
```

command changed!

RESPONSE

```
00000000: 6A 80 j.
```