

Cryptographic Hardware Configuration and Features

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This presentation explains how cryptographic hardware uses private keys while preventing them from being viewed or copied.

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Outline

1. What problem are we trying to solve?
2. What is a PIV device?
3. Features of the Yubikey 4 Nano
4. Software configuration
5. PIV configuration
6. *Openssl* with PIV
7. Conclusion

1. What Problem Are We Trying To Solve? What Cryptography Can Accomplish

Authenticity Verify who is on the other end of the communication channel

Confidentiality Only the intended party can read the original messages

Integrity No other party can change or add messages

Non-repudiation Allow undeniable actions

The Problem With Passwords

- ▶ Passwords that are short enough to type and remember are easy enough to crack via brute force attacks
 - ▶ this is especially true if repeated password attempts are not blocked or if password attempts can be performed on a private copy of the data
- ▶ Uncrackable passwords are rarely rememberable or typeable

Updated password policies: [https://www.theverge.com/2017/8/7/16107966/
password-tips-bill-burr-regrets-advice-nits-cybersecurity](https://www.theverge.com/2017/8/7/16107966/password-tips-bill-burr-regrets-advice-nits-cybersecurity)

The Advantages of PKI

Before public key cryptography, the same secret key was required to encrypt and decrypt data. With public infrastructure (PKI), anyone can encrypt data and verify signatures using a public key. Only those with access to the private key can decrypt or sign documents.

Therefore, the security of the private key becomes critical. It is not typeable so it must be stored somewhere.

SSH PKI Keys

```
$ ls -la ~/.ssh
total 16
drwx-----  2 postgres postgres 4096 Aug 14 10:25 .
drwxr-xr-x  22 postgres postgres 4096 Aug 14 10:25 ..
-rw-----  1 postgres postgres 1679 Aug 14 10:25 id_rsa
-rw-r--r--  1 postgres postgres  401 Aug 14 10:25 id_rsa.pub
```

Gpg PKI Keys

```
$ ls -la ~/.gnupg/
total 36
drwx----- 2 postgres postgres 4096 Aug 11 12:48 .
drwxr-xr-x 22 postgres postgres 4096 Aug 11 10:08 ..
-rw----- 1 postgres postgres 9188 Jul 5 15:23 gpg.conf
-rw----- 1 postgres postgres 1646 Jul 5 15:27 pubring.gpg
-rw----- 1 postgres postgres 600 Jul 5 15:27 random_seed
-rw----- 1 postgres postgres 1731 Jul 5 15:27 secring.gpg
-rw----- 1 postgres postgres 1280 Jul 5 15:27 trustdb.gpg
```

Postgres PKI Keys

```
$ ls -la /u/pg/data/
total 128
drwx----- 19 postgres staff    4096 Aug 11 17:56 .
drwxr-sr-x  7 root      staff    4096 Aug 11 17:56 ..
...
-rw-r--r--  1 root root  4087 Aug 11 12:50 /u/pg/data/server.crt
-rw-----  1 root root  1704 Aug 11 12:50 /u/pg/data/server.key
...
```


PKI Key Pair Internals

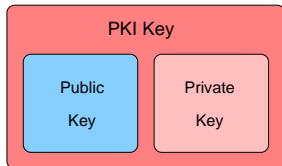
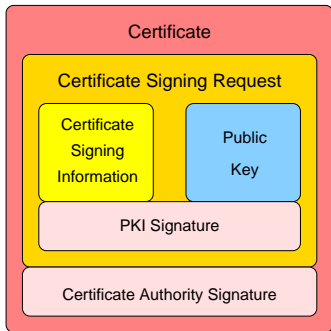
```
$ rsadump.sh -e id_rsa
key bits = 2047.2
# public
n (pq) ~ = 1e616
e = 65537

# private
d (1/e mod lcm(p-1,q-1)) ~ = 2e614
p ~ = 1e308
q ~ = 1e308

exp1 (dp, d mod (p-1)) ~ = 9e307
exp2 (dq, d mod (q-1)) ~ = 9e307
c (qinv, 1/q mod p) ~ = 7e307
```

The final three fields are used to speed computations involving the private key. The private key, also called “key pair” or simply “key,” also contains the public key. Script available at <http://momjian.us/main/writings/pgsql/rsadump.sh>, derived from http://www.vidarholen.net/contents/junk/files/decode_rsa.bash.

Certificate (with Public Key) and Public/Private Key Pair



Securing the Private Key

File system permissions protect the private key from ordinary users, but it does not protect it from unauthorized viewing, copying, and therefore use by:

- ▶ Operating system superusers
- ▶ Current and former employees
- ▶ Operating system exploits, trojans, and viruses

What Security Does PIV and OpenPGP with a Smart Card Provide?

- ▶ Use of a private key that cannot be viewed or copied by anyone, including the creator
- ▶ PIN access control with a limited number of failed attempts
- ▶ Removable private key storage

2. What Is a PIV Device?

PIV devices are US NIST-defined electronic containers with storage for owner:

- ▶ Identification
- ▶ Image
- ▶ Fingerprints
- ▶ Four PKI certificates and their keys

The standard defines how these items are accessed and manipulated:

- ▶ <http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-73-4.pdf>
- ▶ <http://csrc.nist.gov/groups/SNS/piv/standards.html>

PIV Interfaces

- ▶ USB (e.g. Yubikey)
- ▶ Card and card reader (e.g. CAC)
- ▶ Contactless

PIV Device: US Military Common Access Card (CAC)



https://en.wikipedia.org/wiki/Common_Access_Card

<http://www.cac.mil/common-access-card/>

<https://www.army.mil/article/54310/dod-to-drop-social-security-numbers-from-id-cards>

CAC (Card) Reader



<http://www.af.mil/News/Article-Display/Article/127233/new-policy-protects-air-force-networks/>

3. Features of the Yubikey 4 Nano

- ▶ The electronic properties of a PIV, including access control, but is not a card
- ▶ OpenPGP support
- ▶ USB interface, not a SIM chip
- ▶ No visually-identifying information
- ▶ Activity light and touch sensor
- ▶ The size of a fingernail

<https://www.yubico.com/product/yubikey-4-series/>

Yubikey 4 Security Features

- ▶ Creation of PKI keys on the device
- ▶ Import of externally-generated PKI keys
- ▶ Creation and import of certificates in PIV mode
- ▶ Stored keys can be used for decryption and signing, but never viewed or copied
- ▶ PIN controls use of the keys
- ▶ Three PIN failures blocks future use of the PIN until reset with a PUK (pin unblocking key)
- ▶ Three PUK failures requires a full device reset
- ▶ Certificates (with their public keys) can be viewed and exported anytime in PIV mode

https://developers.yubico.com/PIV/Introduction/Admin_access.html

Yubikey 4



<https://en.wikipedia.org/wiki/YubiKey>

Yubikey 4 Cryptographic Features

- ▶ Full PIV capabilities (already covered)
 - ▶ <https://www.yubico.com/why-yubico/for-businesses/computer-login/yubikey-neo-and-piv/>
 - ▶ https://developers.yubico.com/yubico-piv-tool/YubiKey_PIV_introduction.html
- ▶ OpenPGP support
- ▶ Brief-touch authentication slot
- ▶ Long-touch authentication slot

<http://lorgor.blogspot.com/2016/09/yubikeys-demystified.html>

Yubikey 4 Authentication-Only Options

- ▶ OATH
 - ▶ time-based one-time password algorithm (TOTP)
 - ▶ counter-based password algorithm (HOTP)
- ▶ Yubico one-time password (YOTP)
 - ▶ upload key to Yubico for later authentication
 - ▶ https://www.yubico.com/wp-content/uploads/2016/06/YubiKey_for_YubiCloud_ConfigGuide_en.pdf
- ▶ Unattended challenge-response
 - ▶ YOTP
 - ▶ HMAC-SHA1
 - ▶ other methods simulate keyboard input on touch
- ▶ Universal 2nd Factor (U2F), FIDO U2F
- ▶ Static password

<https://www.adfinis-sygroup.ch/blog/en/yubikey-and-twofactor-authentication/>

<https://www.adfinis-sygroup.ch/blog/en/yubikeys/>

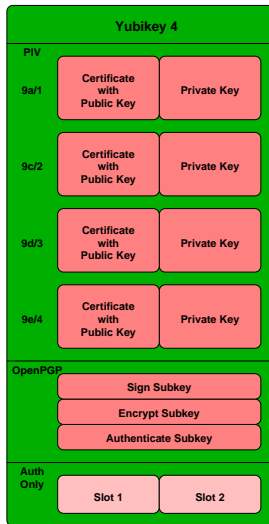
Yubikey 4 PIV Features

Description	<i>yubico-piv-tool</i>	<i>opencsc/openssl</i>	Private Key		
			PIN Required	Decrypt	Sign
PIV Authentication	9a	1	✓	✓	✓
Triple-DES key (not used)	9b				
Digital Signature	9c	2	✓	✓	✓
Key Management	9d	3	✓	✓	
Card Authentication	9e	4			✓
Retired Key Management	82-8f, 90-95	n/a			
Attestation (prepopulated)	f9	n/a			

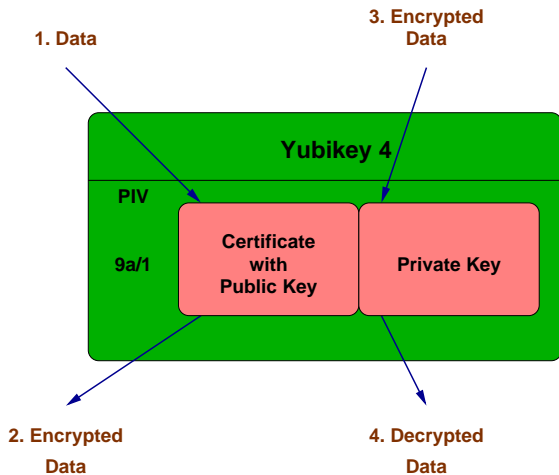
Openssl always requires a PIN; *pkcs15-crypt* honors the chart.

https://developers.yubico.com/PIV/Introduction/Certificate_slots.html

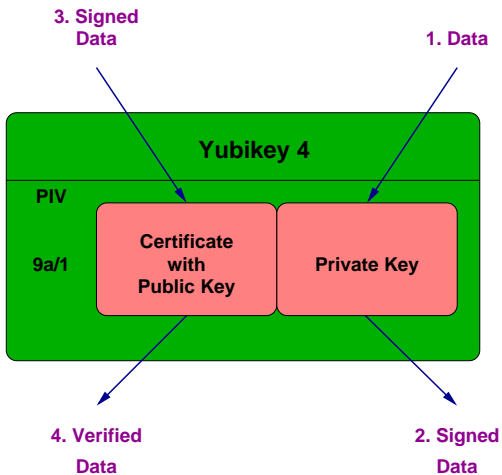
Yubikey 4 Illustrated



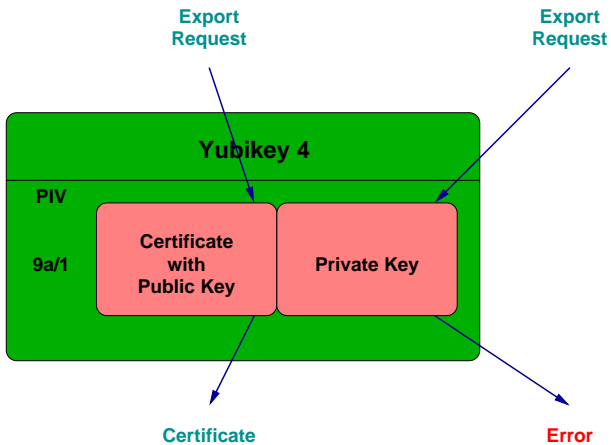
PIV Encryption



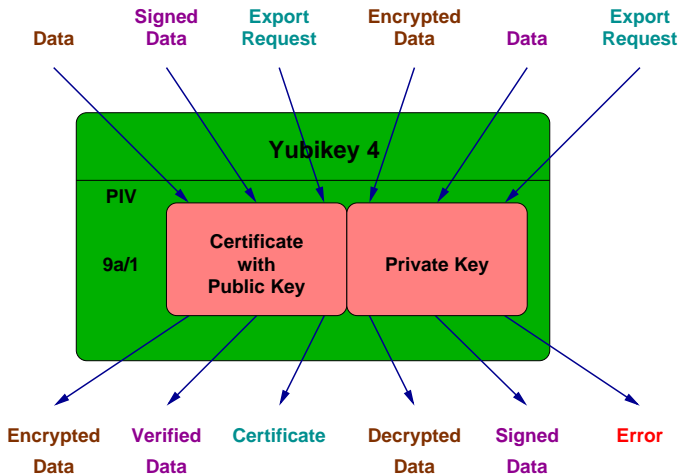
Piv Signing



PIV Exporting



All PIV Features



4. Software Configuration

1. Operating system software
2. USB configuration
3. *pcscd*
4. *openssl*
5. Yubikey configuration (not PIV configuration)

Configuration done using Debian 8 (Jessie) and Ubuntu 14.04 (Trusty Tahr).

Operating System Software

```
# only needed for Ubuntu 14.04
# https://ubuntuforums.org/showthread.php?t=1557180
$ sudo add-apt-repository ppa:yubico/stable
$ sudo apt-get update

# Debian 8 (Jessie) needs the addition of '-t jessie-backports'
$ sudo apt-get install yubikey-personalization yubikey-personalization-gui

# also installs libccid, libykpin1, and pcscd packages
# Debian 8 (Jessie) needs the addition of '-t jessie-backports'
$ sudo apt-get install yubico-piv-tool

# needed for PIV
# installs pkcs11-tool, pkcs15-tool, pkcs15-crypt
# also installs engine_pkcs11 package
$ sudo apt-get install opensc
$ sudo apt-get install libengine-pkcs11-opensc
```

Update USB and CCID Configuration Files

```
# Update CCID for device detection
# modifies /etc/libccid_Info.plist and /etc/udev/rules.d/70-u2f.rules
# download script from https://raw.githubusercontent.com/Yubico/yubikey-neo-manager/master/resources/linux-fix-ccid-udev
$ chmod +x ./linux-fix-ccid-udev
$ sudo ./linux-fix-ccid-udev
Updating /etc/libccid_Info.plist...
Adding: Yubico Yubikey 4 CCID
Adding: Yubico Yubikey 4 OTP+CCID
Adding: Yubico Yubikey 4 U2F+CCID
Adding: Yubico Yubikey 4 OTP+U2F+CCID
Restarting PCSCD...
Adding Udev rule for U2F...
Done!
```

Access Control

```
# modify /lib/udev/rules.d/69-yubikey.rules to set USB character device  
# permissions (in red)
```

```
$ sudo vi /lib/udev/rules.d/69-yubikey.rules
```

```
ATTRS{idVendor}=="1050", \  
ATTRS{idProduct}=="0010|0110|0111|0114|0116|0401|0403|0405|0407|0410", \  
ENV{ID_SECURITY_TOKEN}="1", OWNER="yubkuser", GROUP="yubigroup", MODE="0660"
```

<http://weininger.net/how-to-write-udev-rules-for-usb-devices.html>

http://www.reactivated.net/writing_udev_rules.html

Checking Character Device Permissions

```
$ lsusb
```

```
...
```

```
Bus 002 Device 002: ID 1050:0407 Yubico.com
```

```
$ sudo udevadm test $(udevadm info -q path -n /dev/bus/usb/002/002)
```

```
$ ls -l /dev/bus/usb/002/002
```

```
crw-rw---- 1 yubiuser yubigroup 189, 132 Aug 28 16:44 /dev/bus/usb/002/002
```


pcscd Configuration

By default, *pcscd* creates an unrestricted socket to interface to the card, so set the socket permissions:

```
# modify /lib/systemd/system/pcscd.socket to set socket permissions (in red)
$ sudo vi /lib/systemd/system/pcscd.socket
```

```
[Socket]
ListenStream=/var/run/pcscd/pcscd.comm
SocketUser=yubiuser
SocketGroup=yubigroup
SocketMode=0660
```

See *man systemd.socket*

Checking *pcscd* Socket Permissions

```
$ sudo systemctl daemon-reload
$ sudo systemctl restart pcscd.socket
$ ls -l /var/run/pcscd/pcscd.comm
srw-rw---- 1 yubiuser yubigroup 0 Aug 29 08:03 /var/run/pcscd/pcscd.comm
```

The Importance of Access Control

While it is true that private key information cannot be extracted from the Yubikey device, and requires a PIN for its use, unauthorized access can:

- ▶ Prevent use and force a device reset by exceeding the PIN invalid entry limit
- ▶ Reset the device and reprogram it with replacement keys that might not be immediately detected

<http://musclecard.996296.n3.nabble.com/>

[Restricting-reader-card-access-by-user-account-td431.html#a457](http://musclecard.996296.n3.nabble.com/Restricting-reader-card-access-by-user-account-td431.html#a457)

<https://access.redhat.com/blogs/766093/posts/1976313>

openssl Configuration

```
$ sudo vi /etc/ssl/openssl.cnf
```

```
# add before any sections are defined file
```

```
    openssl_conf = openssl_init
```

```
# and add these sections at the bottom
```

```
    [openssl_init]
```

```
    engines = engine_section
```

```
    [engine_section]
```

```
    pkcs11 = pkcs11_section
```

```
    [pkcs11_section]
```

```
    # https://github.com/openssl/openssl/blob/master/README.ENGINE
```

```
    engine_id = pkcs11
```

```
    # same as SO_PATH
```

```
    dynamic_path = /usr/lib/engines/engine_pkcs11.so
```

```
    MODULE_PATH = openssl-pkcs11.so
```

```
    init = 0
```

```
$ openssl engine pkcs11 -t
```

```
(pkcs11) pkcs11 engine
```

```
    [ available ]
```

<https://github.com/OpenSC/libp11>

<https://stackoverflow.com/questions/15052171/>

[pkcs11-engine-does-not-work-in-openssl-on-centos-6](#)

Yubikey Configuration

```
# Enable OTP/UTF/CCID mode
# Removing OTP mode also disables communication between ykpersonalize and
# the YubiKey.
```

```
$ ykpersonalize -y -m 6
```

```
# Erase the two authorization-only slots
```

```
$ ykpersonalize -y -1 -z
```

```
$ ykpersonalize -y -2 -z
```

```
$ ykinfo -a
```

```
serial: 6251544
```

```
serial_hex: 5f6418
```

```
serial_modhex: gvhfbj
```

```
version: 4.3.5
```

```
touch_level: 512
```

```
programming_sequence: 0
```

```
slot1_status: 0
```

```
slot2_status: 0
```

```
vendor_id: 1050
```

```
product_id: 407
```

<https://developers.yubico.com/yubikey-personalization/Manuals/ykpersonalize.1.html>

5. PIV Configuration: Check *opensc*

```
$ opensc-tool --list-drivers | grep '\<piv\>'  
piv                PIV-II for multiple cards
```

```
$ opensc-tool --info  
OpenSC 0.14.0 [gcc 4.9.2]  
Enabled features: zlib readline openssl pcsc(libpcsclite.so.1)
```

```
$ opensc-tool --name  
Using reader with a card: Yubico Yubikey 4 OTP+U2F+CCID 00 00  
PIV-II card
```

<https://github.com/OpenSC/OpenSC/wiki/Quick-Start-with-OpenSC>

<https://stackoverflow.com/questions/19456555/openssl-engine-pkcs11-libp11-opensc>

Reset the PIV Mode

```
#!/bin/bash
```

```
# Attempt to use an invalid PIN multiple times to block it #
```

```
yubico-piv-tool -a verify-pin -P 000000
```

```
yubico-piv-tool -a verify-pin -P 000000
```

```
yubico-piv-tool -a verify-pin -P 000000
```

```
yubico-piv-tool -a verify-pin -P 000000
```

```
# Attempt to change PUK using an invalid PUK multiple times to block it #
```

```
yubico-piv-tool -a change-puk -P 000000 -N 000001
```

```
yubico-piv-tool -a change-puk -P 000000 -N 000001
```

```
yubico-piv-tool -a change-puk -P 000000 -N 000001
```

```
yubico-piv-tool -a change-puk -P 000000 -N 000001
```

```
# Once PIN and PUK are both blocked, you can reset the YubiKey.
```

```
yubico-piv-tool -a reset
```

https://developers.yubico.com/yubico-piv-tool/YubiKey_PIV_introduction.html

<https://www.yubico.com/wp-content/uploads/2016/05/>

[Yubico_PIV_Tool_Command_Line_Guide_en.pdf](#)

Set configuration key, PUK, and PIN

```
#!/bin/bash
```

```
# don't write Bash shell history if run interactively
```

```
unset HISTFILE
```

```
cd "$HOME" || exit 1
```

```
umask 0077
```

```
mkdir .yubikey 2> /dev/null
```

```
rm -f .yubikey/pin.*
```


Set configuration key, PUK, and PIN

```
CONFIG_KEY='$(dd if=/dev/random bs=1 count=24 2>/dev/null |
    hexdump -v -e '/1 "%02X"')'
yubico-piv-tool -aset-mgm-key -n $CONFIG_KEY
echo "$CONFIG_KEY" | tee .yubikey/piv.config.key

yubico-piv-tool -k $CONFIG_KEY -a verify -P 123456 -a pin-retries \
    --pin-retries=3 --puk-retries=3

PUK='$(dd if=/dev/random bs=1 count=6 2>/dev/null |
    hexdump -v -e '/1 "%u"|cut -c1-8)''
yubico-piv-tool -achange-puk -P 12345678 -N $PUK
echo "$PUK" | tee .yubikey/piv.puk

PIN='$(dd if=/dev/random bs=1 count=6 2>/dev/null |
    hexdump -v -e '/1 "%u"|cut -c1-6)''
yubico-piv-tool -achange-pin -P 123456 -N $PIN
echo "$PIN" | tee .yubikey/piv.pin
```

Populate the Four PIV Slots

```
#!/bin/bash
```

```
unset HISTFILE
```

```
$ cd "$HOME" || exit 1
```

```
CONFIG_KEY="$(cat .yubikey/piv.config.key)"
```

```
PIN="$(cat .yubikey/piv.pin)"
```

```
echo "$CONFIG_KEY"
```

```
echo "$PIN"
```

```
cd .yubikey || exit 1
```

```
# https://developers.yubico.com/yubico-piv-tool/
```

```
# https://dennis.silvrback.com/openssl-ca-with-yubikey-neo
```

Populate the Four PIV Slots

```
for SLOT in 9a 9c 9d 9e
do    if [ "$SLOT" = "9a" ]
      # Generate the key in the Yubikey
      # 9a is the authentication slot, so we can regenerate it if
      # we lose it.
      then    yubico-piv-tool --key "$CONFIG_KEY" -a generate -s "$SLOT" -o pub
              # The public key is just dumped in the slot so we have
              # to create a real certificate.
              yubico-piv-tool --pin-policy=once --pin $PIN -i pub \
                  -a verify -a selfsign-certificate \
                  -s "$SLOT" -S "/CN=yubikey-$SLOT" -o cert
      # Generate the key on the server
      # We want to archive the values for these slots, so we generate the key
      # externally so we can save it before putting it on the card.
      else    openssl req -x509 -nodes -newkey rsa:2048 \
              -subj "/CN=yubikey-$SLOT" -days 365 -keyout key -out cert
              yubico-piv-tool --pin-policy=once --key "$CONFIG_KEY" \
                  -i key -a import-key -s "$SLOT"

      fi

      yubico-piv-tool --key "$CONFIG_KEY" --pin-policy=once -i cert \
          -a import-certificate -s "$SLOT"

      rm -f key pub cert
done
```

Key Generation Options

- ▶ Inside the Yubikey 4 (no private key backup possible)
- ▶ *openssl {req | genpkey}*
- ▶ *ssh-keygen (openssh)*
- ▶ *gpg2 -gen-key*

We used the first two in the previous slide.

Check the PIV Device

```
$ yubico-piv-tool -a status
```

```
CHUID: No data available
```

```
CCC: No data available
```

```
PIN tries left: 3
```

```
if dpkg -l opensc-pkcs11 > /dev/null 2>&1
```

```
> then PACKAGE="opensc-pkcs11" # newer packaging
```

```
> else PACKAGE="opensc"
```

```
> fi
```

```
$ export OPENSCL="$$(dpkg -L "$PACKAGE" | grep '/opensc-pkcs11.so$' | head -1)"
```

```
$ pkcs11-tool --module "$OPENSCL" --list-slots
```

```
Available slots:
```

```
Slot 0 (0xffffffffffffffff): Virtual hotplug slot
```

```
(empty)
```

```
Slot 1 (0x1): Yubico Yubikey 4 OTP+U2F+CCID 00 00
```

```
token label : PIV_II (PIV Card Holder pin)
```

```
token manufacturer : piv_II
```

```
token model : PKCS#15 emulated
```

```
token flags : rng, login required, PIN initialized, token initialized
```

```
hardware version : 0.0
```

```
firmware version : 0.0
```

```
serial num : 00000000
```

List PIV Features

```
$ pkcs11-tool --module "$OPENSC" --list-mechanisms
```

```
Using slot 1 with a present token (0x1)
```

```
Supported mechanisms:
```

```
SHA-1, digest
```

```
SHA256, digest
```

```
SHA384, digest
```

```
SHA512, digest
```

```
MD5, digest
```

```
RIPEMD160, digest
```

```
GOSTR3411, digest
```

```
ECDSA, keySize={256,384}, hw, sign, other flags=0x1800000
```

```
ECDSA-SHA1, keySize={256,384}, hw, sign, other flags=0x1800000
```

```
ECDH1-COFACTOR-DERIVE, keySize={256,384}, hw, derive, other flags=0x1800000
```

```
ECDH1-DERIVE, keySize={256,384}, hw, derive, other flags=0x1800000
```

```
RSA-X-509, keySize={1024,3072}, hw, decrypt, sign, verify
```

```
RSA-PKCS, keySize={1024,3072}, hw, decrypt, sign, verify
```

```
SHA1-RSA-PKCS, keySize={1024,3072}, sign, verify
```

```
SHA256-RSA-PKCS, keySize={1024,3072}, sign, verify
```

```
MD5-RSA-PKCS, keySize={1024,3072}, sign, verify
```

```
RIPEMD160-RSA-PKCS, keySize={1024,3072}, sign, verify
```

List PIV Objects

```
$ pkcs11-tool --module "$OPENSC" --list-objects|less
```

```
Data object 11293952
```

```
label:          'Card Capability Container'  
application:    'Card Capability Container'  
app_id:        2.16.840.1.101.3.7.1.219.0  
flags:         <empty>
```

```
Data object 11295440
```

```
label:          'Card Holder Unique Identifier'  
application:    'Card Holder Unique Identifier'  
app_id:        2.16.840.1.101.3.7.2.48.0  
flags:         <empty>
```

```
Data object 11296192
```

```
label:          'Unsigned Card Holder Unique Identifier'  
application:    'Unsigned Card Holder Unique Identifier'  
app_id:        2.16.840.1.101.3.7.2.48.2  
flags:         <empty>
```

List PIV Certificates

```
$ pkcs15-tool --list-certificates
X.509 Certificate [Certificate for PIV Authentication]
    Object Flags      : [0x0]
    Authority         : no
    Path              :
    ID                : 01
    Encoded serial    : 02 09 00CF66D8199E854D7A
X.509 Certificate [Certificate for Digital Signature]
    Object Flags      : [0x0]
    Authority         : no
    Path              :
    ID                : 02
    Encoded serial    : 02 09 00FCDD2A4D4B080F64
X.509 Certificate [Certificate for Key Management]
    Object Flags      : [0x0]
    Authority         : no
    Path              :
    ID                : 03
    Encoded serial    : 02 09 00AAB47AC5A07BD312
X.509 Certificate [Certificate for Card Authentication]
    Object Flags      : [0x0]
    Authority         : no
    Path              :
    ID                : 04
    Encoded serial    : 02 09 0083DEF6124008A6BC
```


List PIV Public Keys

```
$ pkcs15-tool --list-public-keys
```

```
Using reader with a card: Yubico Yubikey 4 OTP+U2F+CCID 00 00
```

```
Public RSA Key [PIV AUTH pubkey]
```

```
Object Flags      : [0x0]
Usage             : [0xD1], encrypt, wrap, verify, verifyRecover
Access Flags     : [0x2], extract
ModLength        : 2048
Key ref          : 154 (0x9A)
Native           : yes
Auth ID          : 01
ID               : 01
DirectValue      : <absent>
```

```
Public RSA Key [SIGN pubkey]
```

```
Object Flags      : [0x0]
Usage             : [0x2C1], encrypt, verify, verifyRecover, nonRepudiation
Access Flags     : [0x2], extract
ModLength        : 2048
Key ref          : 156 (0x9C)
Native           : yes
Auth ID          : 01
ID               : 02
DirectValue      : <absent>
```

List PIV Public Keys

Public RSA Key [KEY MAN pubkey]

Object Flags : [0x0]
Usage : [0x11], encrypt, wrap
Access Flags : [0x2], extract
ModLength : 2048
Key ref : 157 (0x9D)
Native : yes
Auth ID : 01
ID : 03
DirectValue : <absent>

Public RSA Key [CARD AUTH pubkey]

Object Flags : [0x0]
Usage : [0xC0], verify, verifyRecover
Access Flags : [0x2], extract
ModLength : 2048
Key ref : 158 (0x9E)
Native : yes
Auth ID : 00
ID : 04
DirectValue : <absent>

List PIV Private Keys

```
$ pkcs15-tool --list-keys
```

```
Using reader with a card: Yubico Yubikey 4 OTP+U2F+CCID 00 00
```

```
Private RSA Key [PIV AUTH key]
```

```
Object Flags      : [0x1], private
Usage             : [0x2E], decrypt, sign, signRecover, unwrap
Access Flags     : [0x1D], sensitive, alwaysSensitive, neverExtract, local
ModLength        : 2048
Key ref          : 154 (0x9A)
Native           : yes
Auth ID          : 01
ID               : 01
```

```
Private RSA Key [SIGN key]
```

```
Object Flags      : [0x1], private
Usage             : [0x20E], decrypt, sign, signRecover, nonRepudiation
Access Flags     : [0x1D], sensitive, alwaysSensitive, neverExtract, local
ModLength        : 2048
Key ref          : 156 (0x9C)
Native           : yes
Auth ID          : 01
ID               : 02
```

List PIV Private Keys

Private RSA Key [KEY MAN key]

Object Flags : [0x1], private
Usage : [0x22], decrypt, unwrap
Access Flags : [0x1D], sensitive, alwaysSensitive, neverExtract, local
ModLength : 2048
Key ref : 157 (0x9D)
Native : yes
Auth ID : 01
ID : 03

Private RSA Key [CARD AUTH key]

Object Flags : [0x0]
Usage : [0xC], sign, signRecover
Access Flags : [0x1D], sensitive, alwaysSensitive, neverExtract, local
ModLength : 2048
Key ref : 158 (0x9E)
Native : yes
ID : 04

Test PIV

```
$ pkcs11-tool --module "$OPENSC" --pin "$(cat "$HOME"/.yubikekey/piv.pin)" --login --
Using slot 1 with a present token (0x1)
C_SeedRandom() and C_GenerateRandom():
  seeding (C_SeedRandom) not supported
  seems to be OK
Digests:
  all 4 digest functions seem to work
  MD5: OK
  SHA-1: OK
  RIPEMD160: OK
Signatures (currently only RSA signatures)
  testing key 0 (PIV AUTH key)
  all 4 signature functions seem to work
  testing signature mechanisms:
    RSA-X-509: OK
    RSA-PKCS: OK
    SHA1-RSA-PKCS: OK
    MD5-RSA-PKCS: OK
    RIPEMD160-RSA-PKCS: OK
    SHA256-RSA-PKCS: OK
  testing key 1 (2048 bits, label=SIGN key) with 1 signature mechanism
    MD5-RSA-PKCS: OK
  testing key 2 (2048 bits, label=KEY MAN key) with 1 signature mechanism -- can't
  testing key 3 (2048 bits, label=CARD AUTH key) with 1 signature mechanism
```

Test PIV

```
# Debian 8 (Jessie) fails some of these tests
Verify (currently only for RSA):
  testing key 0 (PIV AUTH key)
    RSA-X-509: OK
    RSA-PKCS: OK
    SHA1-RSA-PKCS: OK
    MD5-RSA-PKCS: OK
    RIPEMD160-RSA-PKCS: OK
  testing key 1 (SIGN key) with 1 mechanism
    RSA-X-509: OK
  testing key 2 (KEY MAN key) with 1 mechanism
-- can't be used to sign/verify, skipping
  testing key 3 (CARD AUTH key) with 1 mechanism
    RSA-X-509: OK
Unwrap: not implemented
Decryption (RSA)
  testing key 0 (PIV AUTH key)
    RSA-X-509: OK
    RSA-PKCS: OK
  testing key 1 (SIGN key)
    RSA-X-509: OK
    RSA-PKCS: OK
  testing key 2 (KEY MAN key)
    RSA-X-509: OK
    RSA-PKCS: OK
```

6. Openssl with PIV

```
$ unset HISTFILE
```

```
$ PIN="$(cat "$HOME"/.yubikey/piv.pin)"
```

```
# 'pkeyutl' and 'dgst' generate "unimplemented" errors in  
# 'OpenSSL 1.0.1f 6 Jan 2014' and 'OpenSSL 1.0.1t 3 May 2016'  
# 'rsautl' can only process a limited length of data  
# also 'slot_1-id_3' or 'label_KEY MAN key' for -inkey  
# see 'man openssl' for --passin arguments
```

```
$ echo test |
```

```
> openssl rsautl -engine pkcs11 -keyform engine -encrypt -inkey 1:3 \
```

```
>                               -passin file:"$HOME"/.yubikey/piv.pin -out /tmp/crypt
```

```
$ openssl rsautl -engine pkcs11 -keyform engine -decrypt -inkey 1:3 \
```

```
>                               -passin file:"$HOME"/.yubikey/piv.pin -in /tmp/crypt
```

```
test
```

Test With *openssl* and *pkcs15-crypt*

```
$ echo test |  
> openssl rsautl -engine pkcs11 -keyform engine -encrypt -inkey 1:3 \  
>           -passin file:"$HOME"/.yubikey/piv.pin -out /tmp/crypt  
  
# use stdout so \n is properly output  
$ pkcs15-crypt --decipher -i /tmp/crypt -o /dev/stdout --pkcs1 -p $PIN --key 3  
test
```


Test by Extracting the Certificate

```
# Yubikeys store the certificate (with public key) and the private key,  
# not the public key alone.
```

```
$ pkcs15-tool --read-certificate 3 > /tmp/cert
```

```
$ echo test |
```

```
> openssl pkeyutl -encrypt -certin -inkey /tmp/cert -out /tmp/crypt
```

```
$ pkcs15-crypt --decipher -i /tmp/crypt -o /dev/stdout --pkcs1 -p $PIN --key 3  
test
```

Test Using a Hash

```
$ echo test |  
> openssl dgst -sha256 -binary > /tmp/hash  
$ xxd -p -c 999 /tmp/hash
```

f2ca1bb6c7e907d06dafe4687e579fce76b37e4e93b7605022da52e6ccc26fd2

```
$ openssl rsautl -engine pkcs11 -keyform engine -encrypt -inkey 1:3 \  
> -passin file:"$HOME"/.yubikey/piv.pin -in /tmp/hash \  
> -out /tmp/crypt  
$ openssl rsautl -engine pkcs11 -keyform engine -decrypt -inkey 1:3 \  
> -passin file:"$HOME"/.yubikey/piv.pin -in /tmp/crypt |  
> xxd -p -c 999
```

f2ca1bb6c7e907d06dafe4687e579fce76b37e4e93b7605022da52e6ccc26fd2

Certificates can be signed, https://developers.yubico.com/PIV/Guides/Certificate_authority.html

Test Signing

```
# switch to using the signing key (2, 'label_SIGN key')
$ echo test |
> openssl rsautl -engine pkcs11 -keyform engine -sign -inkey 1:2 \
>           -passin file:"$HOME"/.yubikey/piv.pin -out /tmp/sign

$ openssl rsautl -engine pkcs11 -keyform engine -verify -inkey 1:2 \
  -passin file:"$HOME"/.yubikey/piv.pin -in /tmp/sign
test
```

Software and Standards Summary

CCID a USB smart card interface standard

engine_pkcs11.so library to interface OpenSSL to PKCS#11 smart cards

OpenSC provides a standard interface to smart cards like PKCS#11

opensc-pkcs11.so library to interface OpenSC to PKCS#11 smart cards

OpenSSL TLS/SSL library

pcscd PC/SC smart card daemon

PIV smart card standard from us NIST

PKCS#11 software interface to cryptographic tokens

PKCS#15 token information format

Tool Summary

`opensc-tool` smart card operations

`openssl` TLS/SSL operations

`pkcs11-tool` read and manipulate the PIV container

`pkcs15-tool` read and manipulate PIV objects

`pkcs15-crypt` control PIV decryption and signing

`ykchalresp` perform YubiKey challenge-response operations

`ykinfo` report Yubikey settings

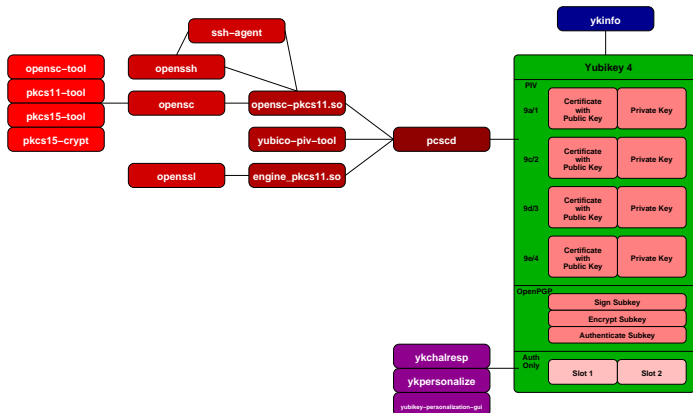
`ykpersonalize` Yubikey general (non-PIV) operations

`yubico-piv-tool` Yubikey PIV operations

`yubikey-personalization-gui` GUI for Yubikey operations

<https://blog-ftweedal.rhcloud.com/2016/08/smart-card-login-with-yubikey-neo/>

Software and Tools Illustrated



7. Conclusion

