

Axis Edge Vault

The hardware-based cybersecurity platform that safeguards Axis devices by providing:

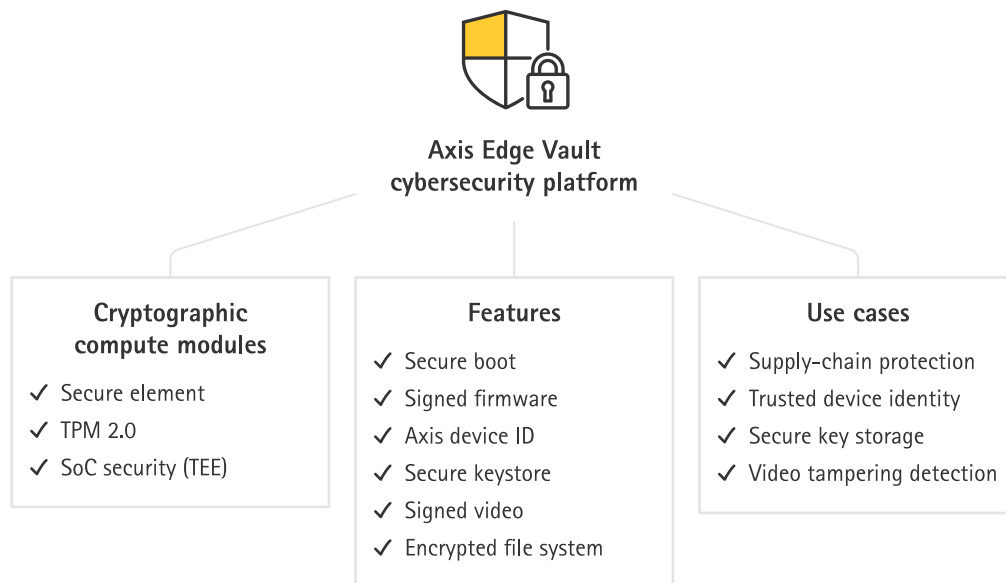
- trusted device identity
- secure key storage
- video tampering detection
- supply chain protection

April 2023

Summary

Axis Edge Vault provides a hardware-based cybersecurity platform that safeguards the Axis device. It relies on a strong foundation of cryptographic computing modules (secure element and TPM) and SoC security (TEE and secure boot), combined with expertise in edge device security. Axis Edge Vault has its anchor point in the strong root of trust, established by *secure boot* together with *signed firmware*. These features enable an unbroken chain of cryptographically validated software for the chain of trust that all secure operations depend on.

Axis devices with Axis Edge Vault minimize customer exposure to cybersecurity risks by preventing eavesdropping and malicious extraction of sensitive information. Axis Edge Vault also enables the Axis device to be a trusted and reliable unit within the customer's network.



- **Trusted device identity:** Being able to verify the origin of the device is key to establishing trust in the device identity. During production, devices with Axis Edge Vault are assigned a unique, factory-provisioned, and IEEE 802.1AR-compliant Axis device ID certificate. This works like a passport to prove the origin of the device. The device ID is securely and permanently stored in the secure keystore as a certificate signed by Axis root certificate. The device ID can be leveraged by the customer's IT infrastructure for automated secure device onboarding and secure device identification.
- **Secure key storage:** The secure keystore provides hardware-based, tamper-protected storage of cryptographic information. The secure keystore protects the Axis device ID as well as customer-loaded cryptographic information, and prevents unauthorized access and malicious extraction in the event of a security breach.
- **Video tampering detection:** Signed video ensures that video evidence can be verified as untampered without proving the chain of custody of the video file. Each camera uses its unique video signing key, which is securely stored in the secure keystore, to add a signature into the video stream. When the video is played, the file player shows whether the video is intact. Signed video makes it possible to trace the video back to the camera origin and verifies that the video has not been tampered with after it left the camera.
- **Supply chain protection:** Axis Edge Vault requires a secure foundation that acts as the root of trust. Without the help of secure boot and signed firmware, the root of trust chain cannot be established.

Secure boot, together with signed firmware, provides an unbroken chain of cryptographically validated software, starting in immutable memory (boot ROM). Secure boot ensures that a device can boot only with Axis signed firmware, which prevents physical supply chain tampering. With signed firmware, the device is also able to validate new firmware before accepting to install it. If the device detects that firmware integrity is compromised or the firmware is not signed by Axis, the firmware upgrade will be rejected. This protects devices from firmware tampering.

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1 Introduction

Axis follows industry best practices in implementing security in our products. This is done to minimize customer exposure to cybersecurity risks and to make the Axis device a trusted unit on the customer's network.

Axis Edge Vault provides a hardware-based cybersecurity platform that safeguards the Axis device. It builds on a strong foundation of cryptographic computing modules (secure element and TPM) and SoC security (TEE and secure boot), combined with expertise in edge device security.

This white paper will outline the multi-layered approach of Axis edge device security, and present common risks and how they can be prevented. Axis Edge Vault requires a secure foundation that acts as the root of trust. Therefore, we will also look at supply chain security aspects of Axis devices and learn how signed firmware and secure boot are fundamental measures that counter firmware tampering and physical supply chain tampering.

At <https://www.axis.com/support/cybersecurity/resources> you can find more information about product security, discovered vulnerabilities, and the measures you can take to reduce the risks of common threats.

The last chapter of this white paper contains a glossary.

2 Trusted device identity

In modern zero-trust security networks ("never trust, always verify"), the ability to verify the origin of the device, its authenticity, and its connections is a foundational need. A network device can verify its integrity and authenticity in a way similar to how you provide verification of your identity to the authorities by showing your passport at the airport.

2.1 Secure device identification with Axis device ID

The international standard *IEEE 802.1AR* defines a method for how to automate and secure the identification of a device over a network. If the communication is forwarded into an embedded cryptographic computing module, the device can return a trustworthy identification response according to the standard. This trustworthy response can be used by the network infrastructure to allow for automated and secure onboarding of the device into a provision network for initial device configuration and firmware updates.

To comply with IEEE 802.1AR, we manufacture most of our devices with device-unique and factory-provisioned Axis device ID certificate (IEEE 802.1AR Initial device identifier, IDevID). The Axis device ID is securely stored in the tamper-protected secure keystore, provided through a cryptographic

computing module on the device itself. This identity is unique for each Axis device and is designed to prove the origin of the device.

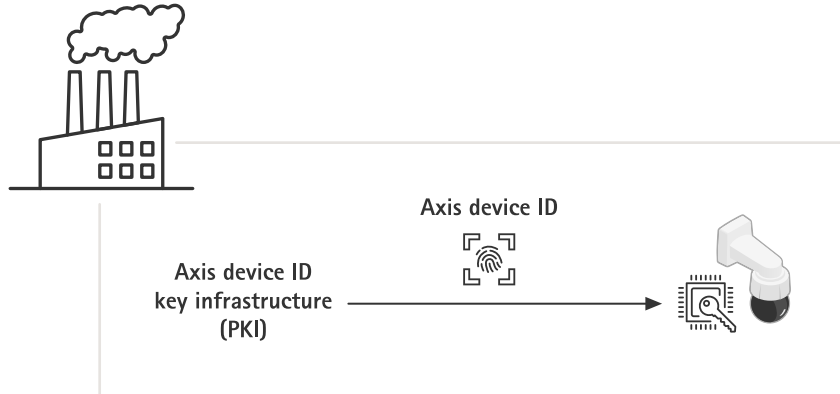


Figure 1. During the manufacturing process of a unit, the unique Axis device ID is stored in the unit's secure key store.

IEEE 802.1AR is based on the IEEE 802.1X standard for network access control, which is enabled by default in Axis devices with the Axis device ID pre-selected. This allows for secure identification and authentication of the Axis device through 802.1X-capable IT infrastructure, even in factory defaulted state.

The Axis device ID certificate comes in various cryptographic configurations (2048-bit RSA, 4096-bit RSA, ECC-P256). They are enabled by default to allow for secure device connections and identification through IEEE 802.1X network access control as well as HTTPS.

Axis manages its own dedicated IEEE 802.1AR public key infrastructure (PKI) for factory-provisioning the Axis device ID during the manufacturing process. The Axis device ID is signed by the intermediate certificate which in return is signed by the Axis root certificate. Both the root CA and intermediate CA are securely stored in cryptographic computing modules that are geographically separated. This prevents

malicious extraction in case of a security breach at Axis production facilities. More information about the Axis PKI infrastructure can be found at www.axis.com/support/public-key-infrastructure-repository

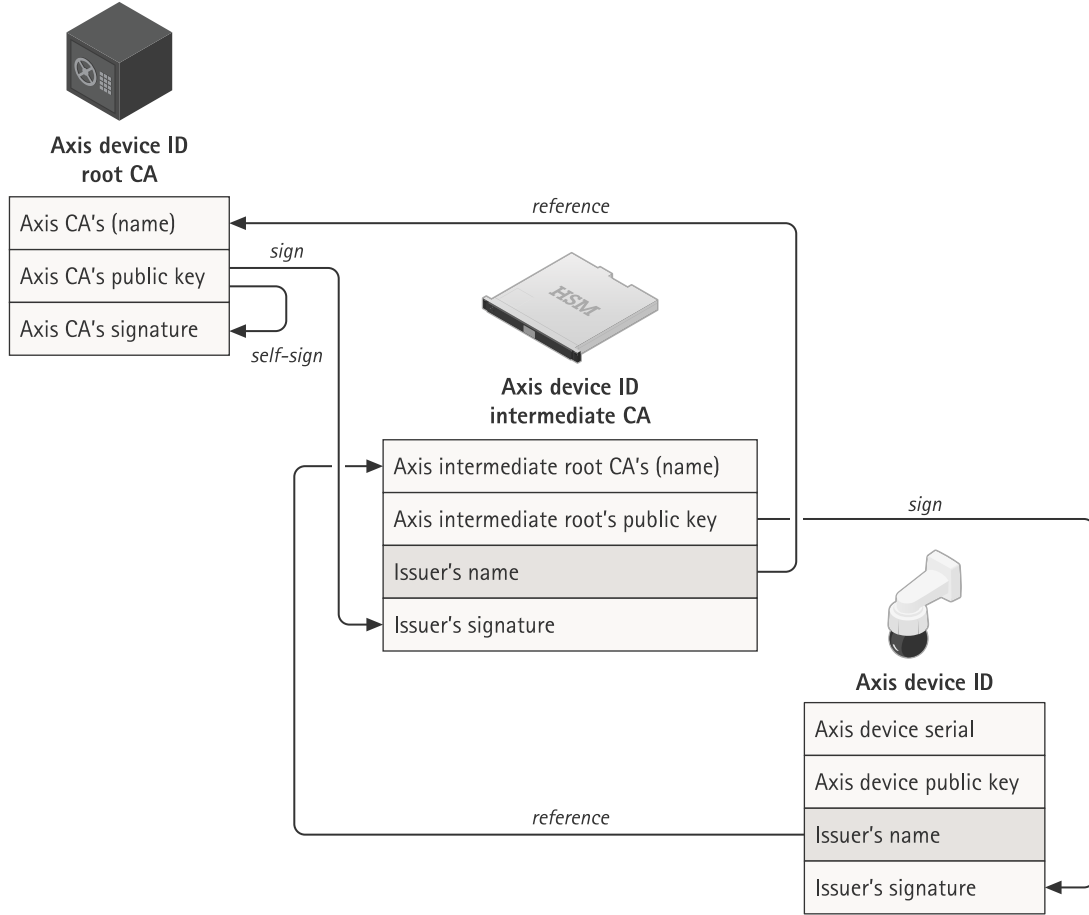


Figure 2. Axis IEEE 802.1AR public-key infrastructure (PKI) for factory-provisioning the Axis device ID during the manufacturing process. Axis device ID, which is a certificate incorporating the serial number of the product, is signed by an intermediate CA that was signed by the Axis device ID root CA. Since the Axis root CA is very valuable and needs to be stored in a safe, the intermediate CA is needed during provisioning in the factory.



Figure 3. Example of an Axis device ID.

2.2 Secure network onboarding

When you buy an Axis device you can perform a manual examination before you start using it. By visually inspecting the device and using prior knowledge about the look and feel of Axis products, you can be convinced that the device originates from Axis. However, you can do that type of inspection only if you have physical access to the device. So, when you communicate with a device over a network, how can you be sure that you are communicating with the correct device and be able to verify its identity? Neither networked equipment nor software on servers can perform a physical inspection. As a security measure, it has been common practice to first interact with a new device over a closed network, where it can be provisioned safely.

The Axis device ID provides your network with cryptographically verifiable proof that a specific device was produced by Axis and that the network connection to the device is indeed served by that very device. The Axis device ID can be used during the IEEE 802.1X network authentication process to gain access to a provisioning network where further firmware updates and configuration of the Axis device is performed before the Axis device is moved into the production network.

By using the Axis device ID, the overall security can be increased and time for deployment of devices can be reduced, since more automated and cost-efficient controls can be used for device installation and configuration.

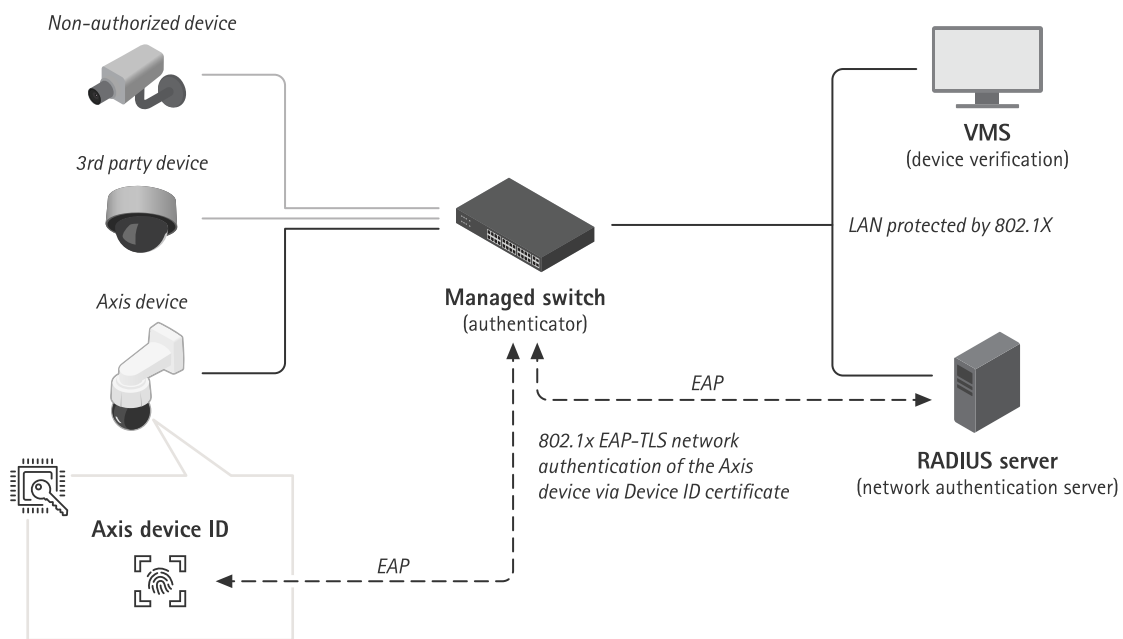


Figure 4. Secure network onboarding. You can instruct your authentication server to automatically accept Axis devices on to the network using device serial numbers and Axis device ID. Axis device ID is used as a fingerprint that ensures the devices to be securely and automatically onboarded. Non-authorized devices must be onboarded manually.

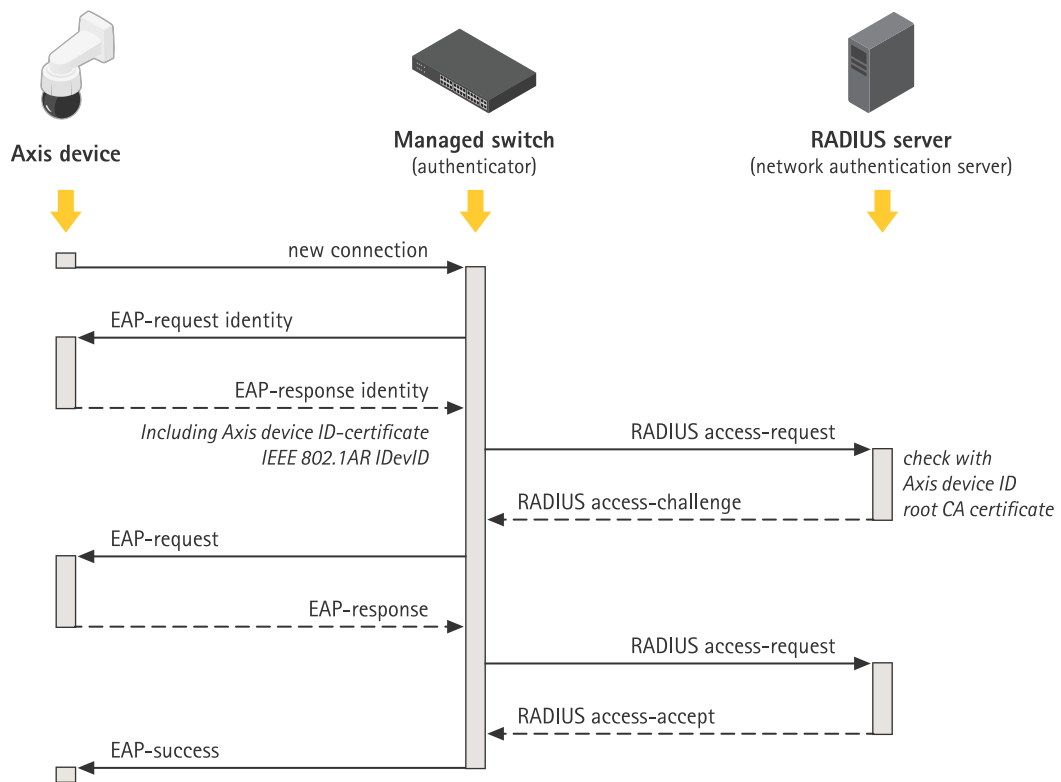


Figure 5. More detailed description of the onboarding process. IEEE 802.1AR for secure device identity defines a method for how to identify a device through IEEE 802.1X Extensible Authentication Protocol requests (EAP-TLS) using a Remote Authentication Dial-In User Service (RADIUS) server to grant device access to the network.

Apart from providing an additional, built-in source of trust, Axis device ID also provides a means to keep track of devices and allows for periodic verification and authentication according to zero-trust networking principles.

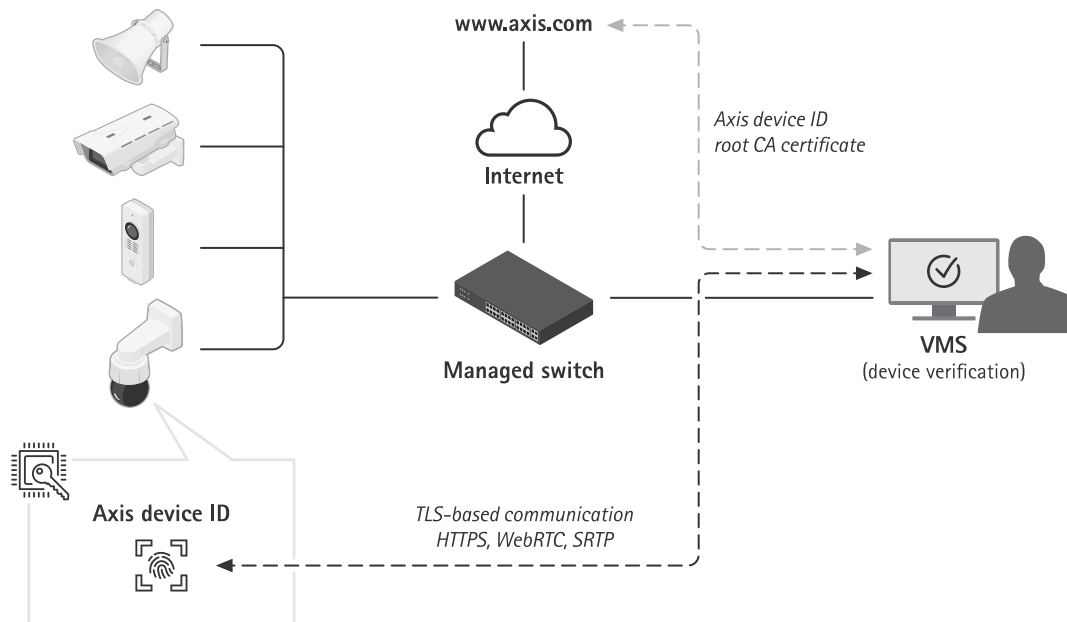


Figure 6. After a device has been securely onboarded, software applications in other parts of the system can use Axis device ID and cryptographic operations to verify the device in various TLS-based communication. The Axis device ID is verifiable by the publicly available Axis device ID Root CA certificate that can be downloaded from axis.com.

3 Secure key storage

Traditionally, sensitive X.509 cryptographic information (private keys) is stored in a device's file system. It is protected by the user account access policy only, which provides basic protection because the user account is not easily compromised. However, in the event of a security breach, this cryptographic information would be unprotected and accessible for an adversary.

From a security aspect, the secure keystore is critical for storing and protecting cryptographic information. Not only is the sensitive cryptographic information, included in the Axis device ID and signed video, stored in the secure keystore, but customer-loaded information can also be protected in the same manner.

3.1 Secure keystore

Sensitive cryptographic information (private keys) is stored in the device's hardware-based, tamper-protected secure keystore. This prevents malicious extraction even in the event of a security breach. Also, the private keys stay protected in the secure keystore even when they are being used. A potential adversary will not have access to the secure keystore, and cannot perform eavesdropping on network traffic, gain network access through IEEE 802.1X keys, or extract other private keys.

The secure keystore is provided through a hardware-based cryptographic computing module. Depending on security requirements, an Axis device can have either one or multiple such modules, like a TPM 2.0 (Trusted Platform Module) or a secure element, and/or a TEE (Trusted Execution Environment).

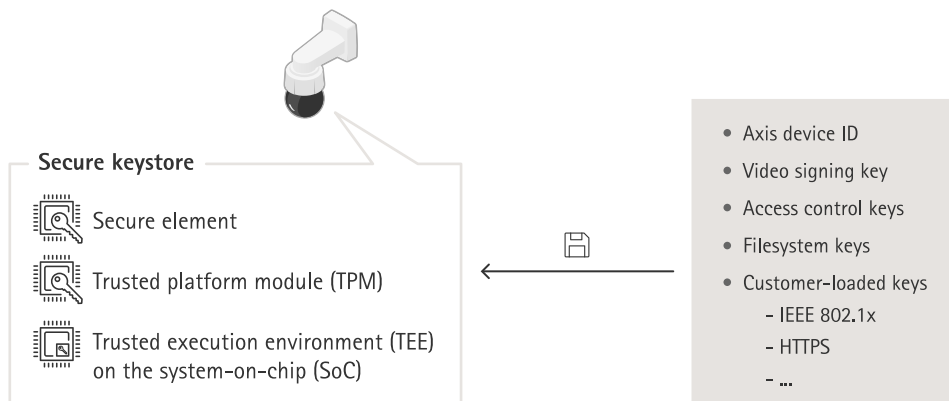


Figure 7. The secure keystore feature in Axis devices can employ a secure element, a TPM, or a TEE. They all provide protection of private keys and secure execution of cryptographic operations.

The TPM and secure element are hardware cryptographic computing modules that are PCB-mounted right next to the SoC's main processor. The TEE is a secure area of the SoC's main processor itself.

The TPM, secure element, and TEE all provide protection of private keys and secure execution of cryptographic operations. In the event of a security breach, unauthorized access and malicious extraction are prevented.

3.2 Common Criteria and FIPS 140

Cryptographic computing modules may be certified using the Common Criteria Evaluation Levels (CC EAL) as well as the FIPS 140 compliance levels (1-4). These certifications are used to determine the correctness and integrity of cryptographic operations and to verify various tamper-countermeasures, such as self-verification, tamper resistance, and other resistance measures. You can find information about the certification on the datasheet of an Axis device or in the Axis product selector. Axis requires its incorporated hardware cryptographic computing modules to be certified at least according to Common Criteria EAL4 and/or FIPS 140-2/3 level 2.

3.2.1 Common Criteria

Common Criteria (CC) (also known as Common Criteria for Information Technology Security Evaluation) is an international standard (ISO/IEC 15408) for IT product security certification. Common Criteria provides a framework for manufacturers and implementers to specify the security functional and assurance requirements as Security Targets, which can be grouped into Protection Profiles.

These claimed Security Targets are then evaluated by certified independent testing laboratories, before being listed as certified products in the Common Criteria database. The requirements on and thoroughness of evaluation by the testing lab are conveyed through an assigned EAL (Evaluation Assurance Level) ranging from EAL 1 – functionally tested, to EAL 7 – formally verified design and tested. This means that Common Criteria can span from operating systems and firewalls to TPMs and passports.

More details about the certification requirements of Common Criteria can be found at the Common Criteria website, www.commoncriteriaportal.org/

3.2.2 FIPS 140

FIPS (Federal Information Processing Standard) 140-2 and 140-3 are information security standards for cryptographic computing modules, issued in the US by NIST (National Institute of Standards and Technology). FIPS 140-3 superseded FIPS 140-2 in 2019 as its updated version. Validation by a NIST-certified test laboratory assures that the module system and the cryptography of the module are correctly implemented. In short, the certification requires description, specification, and verification of the cryptographic computing module, approved algorithms, approved modes of operation, and power-up tests.

More details about the certification requirements of FIPS 140-2 and FIPS 140-3 can be found at the NIST website www.nist.gov.

3.3 Protection of private keys

For an adversary, extracting the private key would allow them to eavesdrop on HTTPS-encrypted network traffic, or pretend to be the actual device and get access to an 802.1X-protected network.

Axis devices support various TLS-based (Transport Layer Security) protocols for secure communication. These rely on X.509 cryptographic information protection such as Axis device ID (IEEE 802.1AR), HTTPS (network encryption), 802.1X (Network Access Control), and others.

The X.509 digital certificates of TLS use a certificate and corresponding public and private key pair for two hosts in the network to communicate. The private key is stored in the secure keystore and never leaves it, even while it is used to decrypt data. The actual certificate and public key are known, can be shared by the Axis device, and are used to encrypt data.

3.4 Protection of access control keys

The protection of the cryptographic information used in Axis access control solutions, such as Open Supervised Device Protocol (OSDP) Secure Channel is another example of why hardware-protected key storage is important.

OSDP Secure Channel is a widely used AES-128 based encryption and authentication scheme to protect communication between door controllers and peripheral devices such as readers.

The AES symmetric key, Secure Channel Base Key (SCBK), shared by door controller and reader, is used to initiate the mutual authentication, and later generate a set of session keys to encrypt the communication data between door controllers and readers.

To achieve true end-to-end security, the Master Key (MK) and the SCBK need to be securely stored within the secure keystore of the Axis network door controller. The Master Key derives a unique SCBK key per connected Axis reader. Also, the individual SCBK, which is distributed securely during the installation phase to an Axis reader, needs to be securely stored in the secure keystore of the reader. The reader is more critical considering it is normally installed on the unsecure side of the door.

In this way, the OSDP Secure Channel keys are protected at both ends in a hardware-protected environment. This prevents malicious extraction even in the event of a security breach.

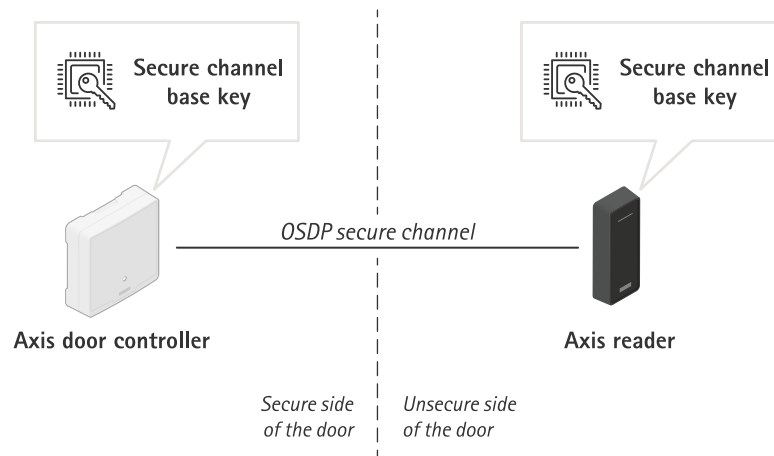


Figure 8. Achieving end-to-end security with secure keystore in access control. The master key and the individual secure channel base key (SCBK) are both stored in secure keystores, in devices on each side of the door.

3.5 Protection of the filesystem keys

An Axis device in operation carries customer-specific configuration and information. The same is true for when the Axis device is in transit to the customer from a distributor or system integrator that provided pre-configuration services. When physical access to the Axis device is achieved, a malicious adversary could try to extract information from the file system by demounting the flash memory and accessing it through a flash reader device. Therefore, protecting the read-writeable file system against extraction of sensitive information or configuration tampering is an important protection for when the Axis device has been stolen or intrusion is achieved.

The secure keystore prevents the malicious exfiltration of information and prevents configuration tampering by enforcing strong encryption upon the file system. When the Axis device is powered off, the information on the file system is encrypted. During the boot process, the read-write file system is decrypted with an AES-XTS-Plain64 256bit key so that the file system can be mounted and used by the Axis device. The file system encryption key is uniquely generated per device upon factory default and regenerated upon every following firmware update, meaning that the key is never the same throughout the device lifecycle.

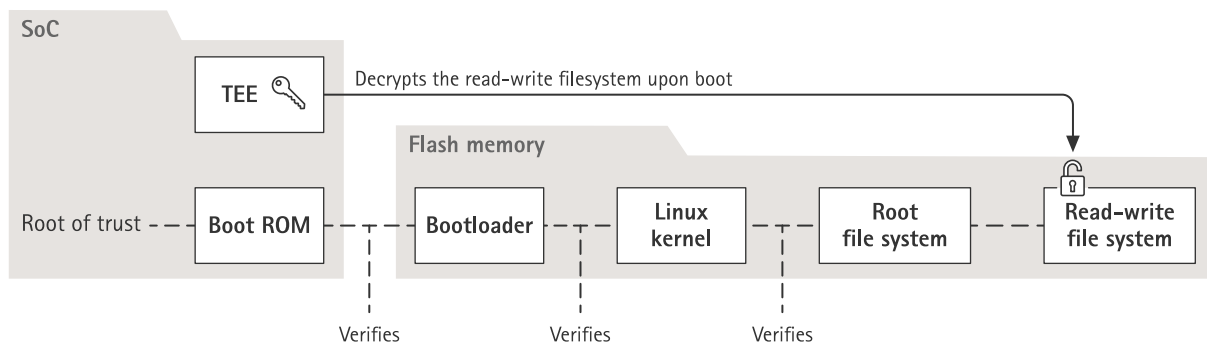


Figure 9. The TEE inside the SoC holds the key to decrypt the root file system.

4 Video tampering protection

A basic premise in the security industry is that video recorded by surveillance cameras is authentic and can be trusted. Signed video is a feature developed to maintain and further strengthen the confidence in video as evidence. By verifying video authenticity, the feature provides a means to ensure that video has not been edited or tampered with after it left the camera.

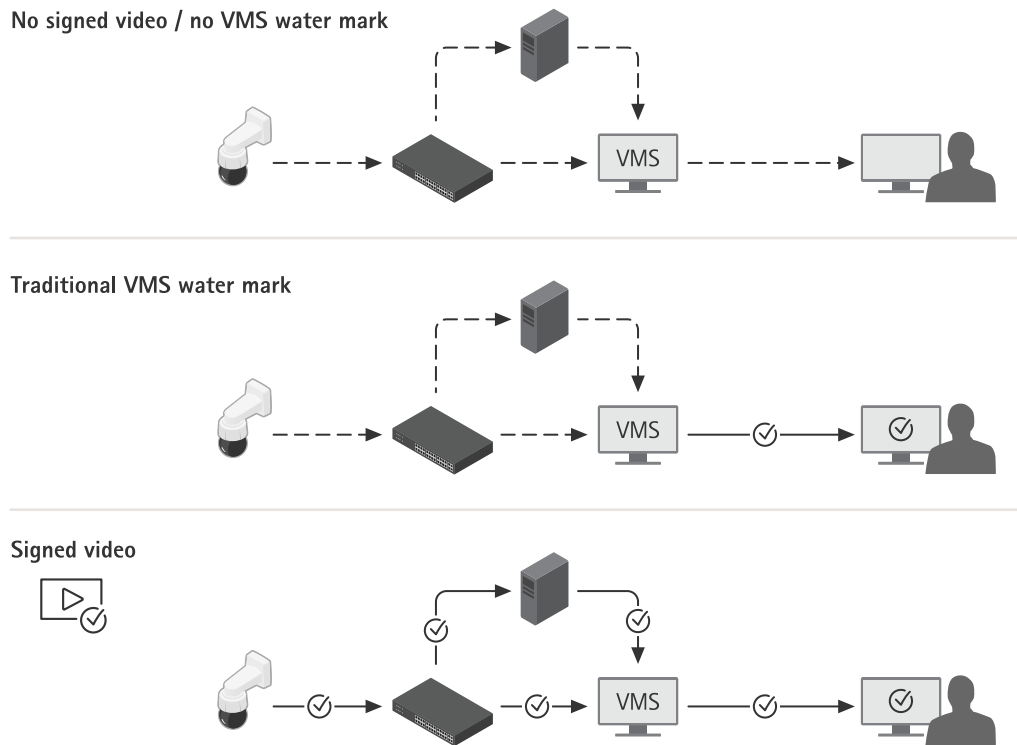


Figure 10. Verifying video authenticity.

Top: A video passes many steps on its way from the camera to a person viewing the recording. A skilled attacker can tamper with the video in any of these transitions.

Middle: With VMS watermarking added to the video during export, some steps are verified but there is no guarantee that the video had not been tampered with in an earlier stage.

Bottom: Signed video guarantees that the video has not been tampered with in any step on its way from the camera to a person viewing the exported recording. The video can be traced back to the device that recorded it.

4.1 Signed video

With the Axis-developed signed video feature, which was proactively open-sourced, a signature in the video stream can be used to safeguard that the video is intact and verify its origin by tracing it back to the camera that produced it. This makes it possible to prove the video authenticity without having to prove the chain of custody of the video file.

After an incident has been recorded by a security camera system, the police may receive the video as exported video files on a USB stick and save them in an EMS (evidence management system). While

exporting the video from the camera, the police officer can see that the video is correctly signed. If it is later used in a prosecution process, the court can control and verify at what time the video was recorded, by which camera, and whether any video frames have been altered or removed. With the file player from Axis, anyone with a copy of the video can see this information.

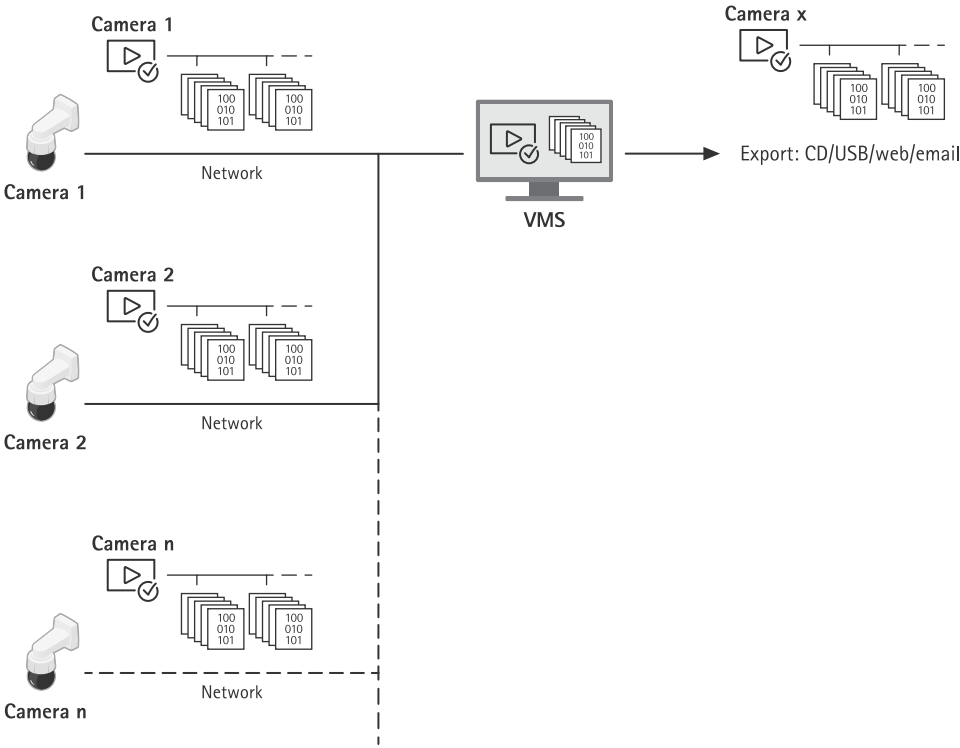


Figure 11. The signature is added already in the camera, enabling verification of the content at every step from the source to the final use of the video.

Each camera uses its unique video signing key, which is stored in the secure keystore, to add a signature into the video stream. This is done by computing a hash of each video frame, including metadata, and signing the combined hash. The signature is then stored in the stream in dedicated metadata fields (the SEI header).

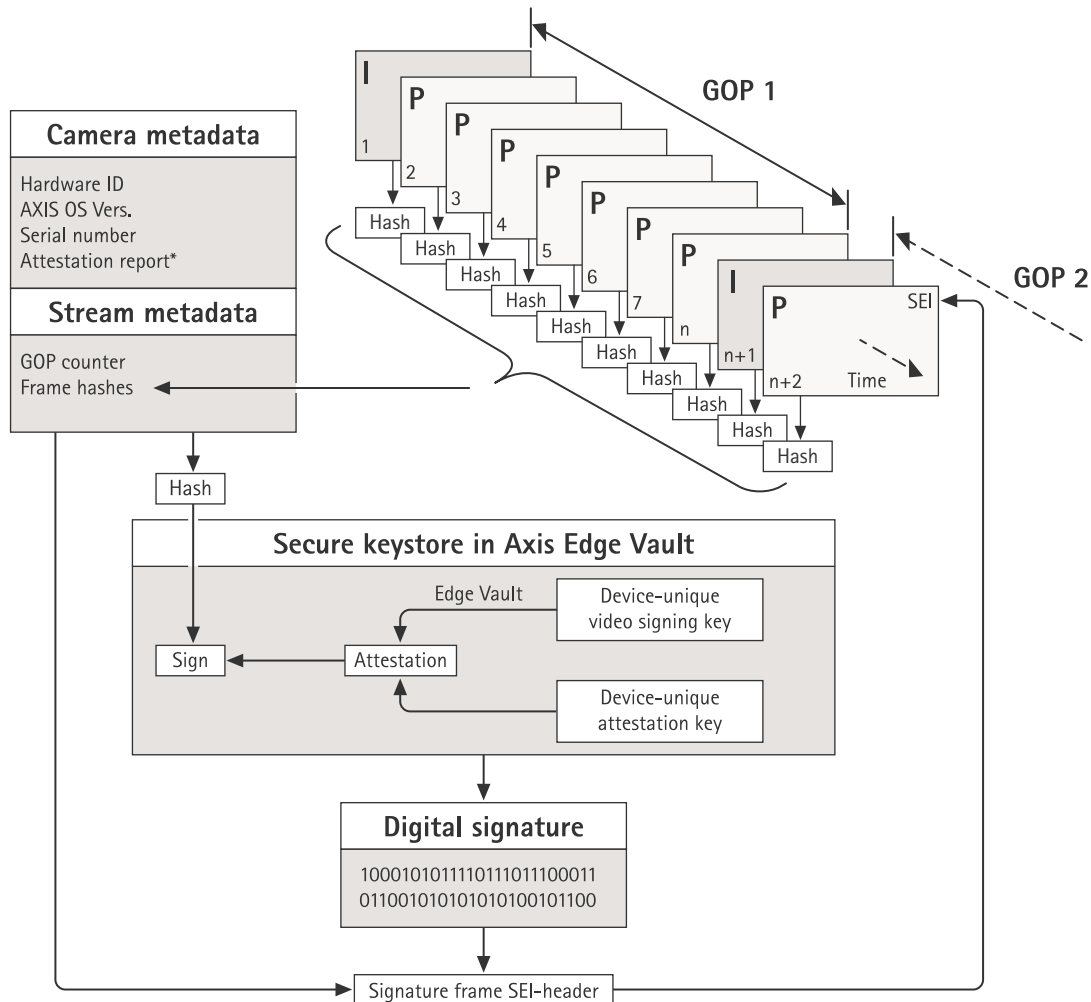


Figure 12. A graphical representation of how a signature is added to the video metadata. The content of each frame of a group of pictures (GOP) is hashed together with a hash of camera metadata and stream metadata. This forms the GOP hash, which is signed in Edge Vault. The signature and metadata are then added to a later SEI header that is transported along the stream.

* The attestation report can be used to verify the origin and provenance of the key pair used for signing. By verifying the key attestation one can ensure that the key is securely stored in hardware in a specific device. This secures the origin of the video.

The actual signing is done using a device-unique video signing key that is attested using a device-unique attestation key. The attestation report is attached to the stream at start and then at periodic intervals, typically once every hour. Since the metadata contains each individual frame hash it is possible to detect which individual frame is correct. To make the signing complete, the group of pictures (GOP) structure of the video must be protected. This is done by including the hash of the first I-frame of the next GOP, in the signature. This prevents undetectable cuts or reordering of the frames. The unlikely event of losing frames during streaming, or damaging content during storage, will be flagged in the same way.

5 Supply chain protection

Axis Edge Vault requires a secure foundation that acts as the root of trust. Establishing the root of trust starts at the device's boot process. In Axis devices, the hardware-based mechanism *secure boot* verifies the operating system (AXIS OS) that the device is booting from. AXIS OS, in turn, is cryptographically signed (*signed firmware*) during the build process.

Secure boot and signed firmware tie into each other. They ensure that the firmware has not been tampered with (by anyone with physical access to the device) before the device is deployed and that, after deployment, the device cannot install compromised firmware updates. Together, secure boot and signed firmware create an unbroken chain of cryptographically validated software for the chain of trust that all secure operations depend on.

5.1 Secure boot

The secure boot mechanism is a boot process that consists of an unbroken chain of cryptographically validated software, starting in immutable memory (boot ROM). Secure boot ensures that a device can boot only with authorized firmware.

The boot process is initiated by the boot ROM validating the bootloader. Secure boot then verifies, in real-time, the embedded signatures for each block of firmware that is loaded from the flash memory. The boot ROM serves as the root of trust, and the boot process continues only if each signature is verified. Every part of the chain authenticates the next part, ultimately resulting in a verified Linux kernel and a verified root file system.

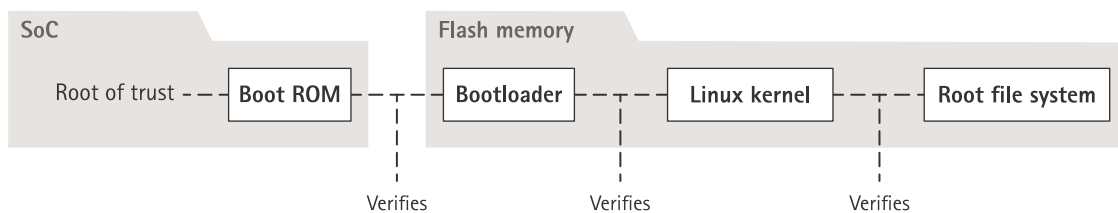


Figure 13. In the secure boot process, each part of the chain authenticates the next. This ultimately results in a verified root file system.

In many devices, it is important that the low-level functionality is impossible to alter. When other security mechanisms are built on top of the lower-level software, secure boot serves as a safe base layer that protects those mechanisms from being circumvented. For a device with secure boot, the installed firmware in the flash memory is protected from being modified. The factory default image is protected, while the configuration remains unprotected. Secure boot guarantees the correct state of the device, even after a factory default. But for secure boot to work, it must make sure that the boot verifies that the firmware is signed by Axis.

5.2 Signed firmware

Axis signed firmware involves Axis signing the firmware image with a private key that is kept secret. When firmware has this signature attached to it, a device will validate the firmware before accepting to install it. If the device detects that the firmware integrity is compromised, the firmware upgrade will be rejected.

The process of signing firmware is initiated through the computation of a cryptographic hash value. The value is then signed with the private key of a private/public key pair before the signature is attached to the firmware image.

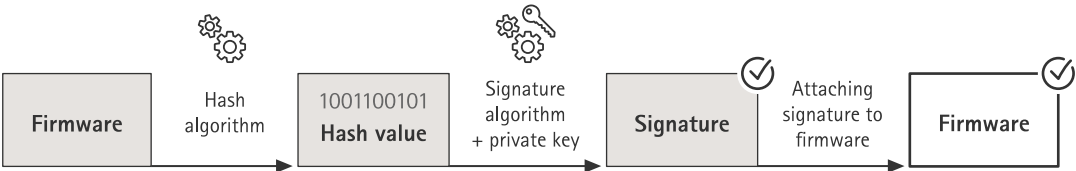


Figure 14. The process of signing firmware.

Before a firmware upgrade, the authenticity of the new firmware must be verified. To ensure this, the public key (which is included with the Axis product) is used to confirm that the hash value was indeed signed with the matching private key. By also computing the hash value of the firmware and comparing it to this validated hash value from the signature, the integrity of the firmware can be verified. The boot process of the Axis devices would be aborted in case the firmware signature is invalid or the firmware image has been tampered with.

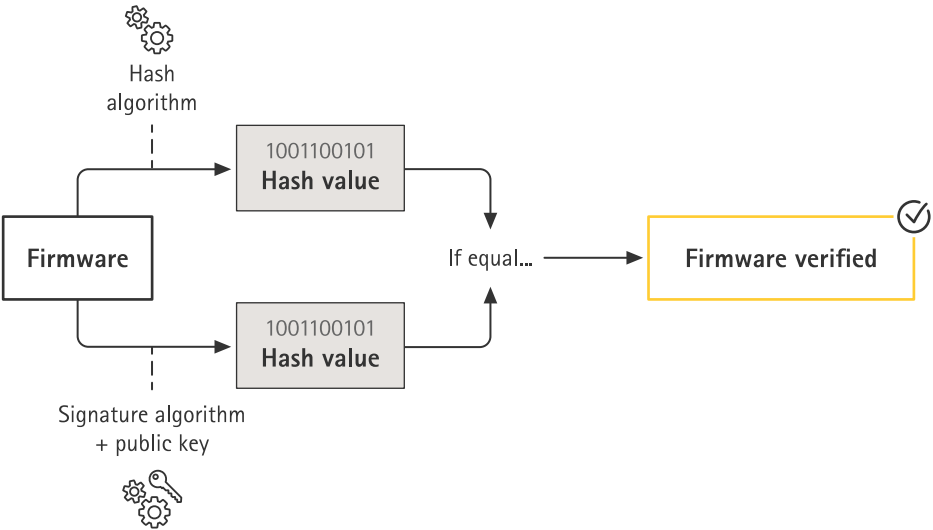


Figure 15. The process of verifying signed firmware.

Axis signed firmware is based on the industry-accepted RSA public-key encryption method. The private key is stored in a closely guarded location at Axis while the public key is embedded in Axis devices. The integrity of the entire firmware image is assured by a signature of the image content. A primary signature verifies several secondary signatures, being verified while the image is unpacked.

For test and custom firmware builds, Axis has implemented a mechanism that approves individual devices to accept non-production firmware. This firmware is signed in a different way, with approval by both the owner and Axis, and results in a custom firmware certificate. When installed in the approved devices, the certificate enables the use of a custom firmware that can run only on the approved device, based on its unique serial number and chip ID. Custom firmware certificates can be created only by Axis since Axis holds the key to sign them.

6 Glossary

Axis device ID: a device-unique certificate with corresponding keys that can prove the authenticity of an Axis device. The Axis device is factory-provisioned with an Axis device ID that is stored in the secure keystore. Axis device ID is based on the international standard IEEE 802.1AR (IDevID, Initial device identifier), which defines a method for automated, secure identification.

Axis Edge Vault: the hardware-based cybersecurity platform that safeguards the Axis device. It builds on a strong foundation of cryptographic computing modules (secure element and TPM) and SoC security (TEE and secure boot), combined with expertise in edge device security.

Certificate: a signed document that attests the origin and properties of a public/private key pair. The certificate is signed by a Certificate Authority (CA), and if the system trusts the CA, it will also trust the certificates issued by it.

Certificate Authority (CA): the root of trust for a certificate chain. It is used to prove the authenticity and veracity of underlying certificates.

Common Criteria (CC): an international standard for IT product security certification. Also referred to as Common Criteria for Information Technology Security Evaluation, ISO/IEC 15408.

FIPS 140: a series of U.S. computer security standards that are used to approve cryptographic computing modules. FIPS (Federal Information Processing Standard) 140 defines requirements on how a cryptographic module should be designed and implemented to mitigate risks of module tampering.

Immutable ROM (read-only memory): the read-only memory that safely stores the trusted public keys and the program that is used to compare signatures, so that they cannot be overwritten.

Provisioning: the process of preparing and equipping a device for the network. This involves delivering configuration data and policy settings to the device from a central point. The device is supplied with keys and certificates.

Public key cryptography: an asymmetric cryptography system where any person can encrypt a message using the receiver's *public key*, but only the receiver – using the *private key* – can decrypt the message. Can be used to both encrypt and sign messages.

Secure boot: a feature to prevent the loading of unauthorized software during startup of the device. Secure boot uses signed firmware that ensures that only authorized Axis software is used to boot the device.

Secure element: a cryptographic computing module that provides hardware-based, tamper-protected storage of private keys and secure execution of cryptographic operations. Unlike the TPM, the hardware- and software interfaces of a secure element are non-standardized but manufacturer-specific.

Secure keystore: a tamper-protected environment for the protection of private keys and secure execution of cryptographic operations. It prevents unauthorized access and malicious extraction in the event of a security breach. Depending on security requirements, an Axis device can have either one or multiple hardware-based cryptographic computing modules, which provide a hardware-protected secure keystore.

Signed firmware: firmware that has been digitally signed by a trusted party. The Axis device verifies the authenticity of the firmware image prior to performing a firmware update. Signed firmware is a requirement in the secure boot process.

Signed video: a feature that maintains and strengthens the confidence in video as evidence. Signed video provides video tampering detection and authenticity and is used to safeguard that the video is intact and traceable back to a particular Axis camera. The signing keys for signed video reside within the secure keystore of the Axis device.

Transport Layer Security (TLS): an internet standard for protecting network traffic. TLS provides the S (for secure) in HTTPS.

Trusted Execution Environment (TEE): provides hardware-based, tamper-protected storage of private keys and secure execution of cryptographic operations. Unlike secure element and TPM, the TEE is a secure, hardware isolated area of the system-on-chip's (SoC) main processor.

Trusted Platform Module (TPM): a cryptographic computing module that provides hardware-based, tamper-protected storage of private keys and secure execution of cryptographic operations. TPMs are internationally standardized (TPM 1.2, TPM 2.0) computer components defined by the *Trusted Computing Group (TCG)*.

Zero-trust security: a modern approach to IT security where connected devices and IT infrastructure (such as networks, computers, servers, cloud-services, and applications) need to recurrently identify, validate, and authenticate each other to achieve high security controls.

About Axis Communications

Axis enables a smarter and safer world by creating solutions for improving security and business performance. As a network technology company and industry leader, Axis offers solutions in video surveillance, access control, intercom, and audio systems. They are enhanced by intelligent analytics applications and supported by high-quality training.

Axis has around 4,000 dedicated employees in over 50 countries and collaborates with technology and system integration partners worldwide to deliver customer solutions. Axis was founded in 1984, and the headquarters are in Lund, Sweden