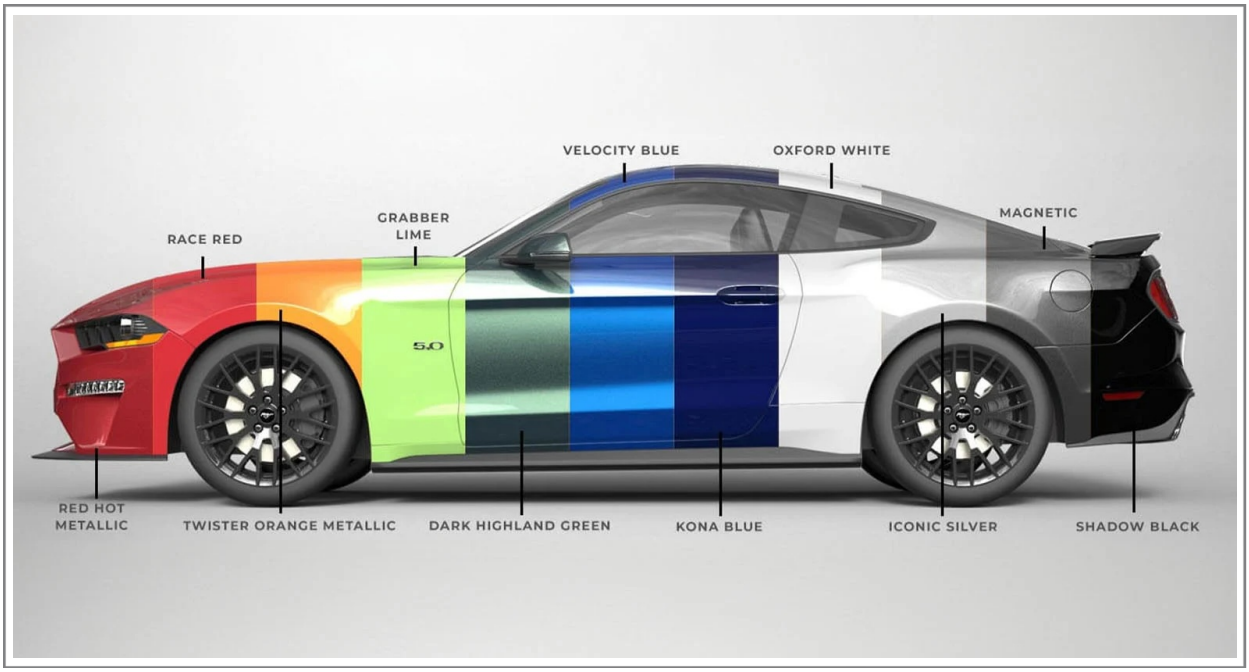


The S550 Active Anti-Theft, Intelligent Access, Passive Anti-Theft and Tire Pressure Monitoring Systems — A Primer

Table of Contents

Parts and PN#s listed in this primer are examples only. If interested in acquiring the correct part, review the Ford catalogs with a dealer or on-line.

Active Anti-Theft System

This primer will not go into great detail explaining the inner workings of the S550's Active Anti-Theft System. Depending on the Model Year and how optioned, an S550 Mustang will have the following features:

- Perimeter sensors: the Intelligent Access door and trunk sensors, explained in the next section
- Door, trunk and hood ajar sensors: If any of those are left open or forced open, an alarm will sound
- Interior motion detection: to determine if someone or something is moving in the interior. Can be disabled via the on-screen menus in the Instrument Panel Cluster (IPC)
- Incline sensor: if the vehicle is being lifted to steal a wheel or tow, the alarm will sound
- Motion sensor: if force is being used which moves the vehicle enough, an alarm will sound

From thread readings and parts pricing checks, the author is led to believe not only are the interior motion sensors are located in the interior overhead console ($700, new), but the vehicle inclination and motion sensors are there as well.

If equipped with Option 43M, Security Package, the following additions will be made:

- Locking center console
- Keyed wheel lugs

In addition to the factory-provided capabilities, the author recommends the following:

- Cover the windshield VIN with one piece of electrical tape, to notify you if someone has been looking at or studying the car, gathering information for a cloned key or FORScan changes
- Purchase Faraday Pouches for both fobs. Keep the fobs in the pouches when the car is not in use
- Lock the vehicle when not being driven, even if parked in the owner's garage

- Vary routines, routes and parking areas, especially if the car is a Daily Driver
- Keep a low social media presence and do not make it a point you own the car
- Disable vehicle bluetooth (802.15) and wireless access (802.11)
- Do not use the Ford Phone As A Key function; it's an additional attack vector

Additional deterrent methods are possible, including physical kill switches, tracking devices and tags, etc. The owner will need to evaluate their risk profile to determine which methods are worthwhile. Given the cost/benefit, most anti-theft measures are simple and cheap.

Intelligent Access (IA)

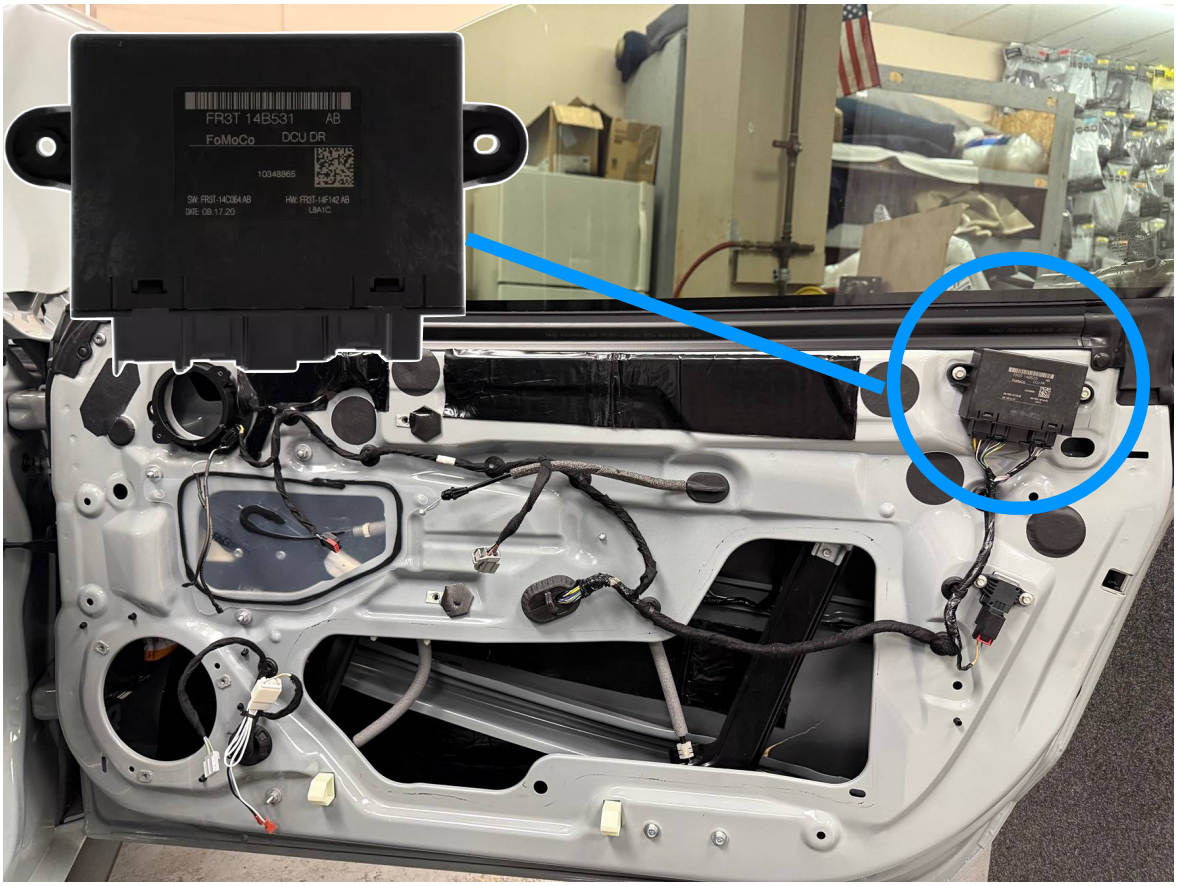
Ford's Intelligence Access (IA) feature is another term for keyless entry; it's a system that in some ways is more advanced and secure than traditional keys alone.

Inside the left and right door handles and deck lid area are proximity sensors. These sensors work on the principle of inductance.

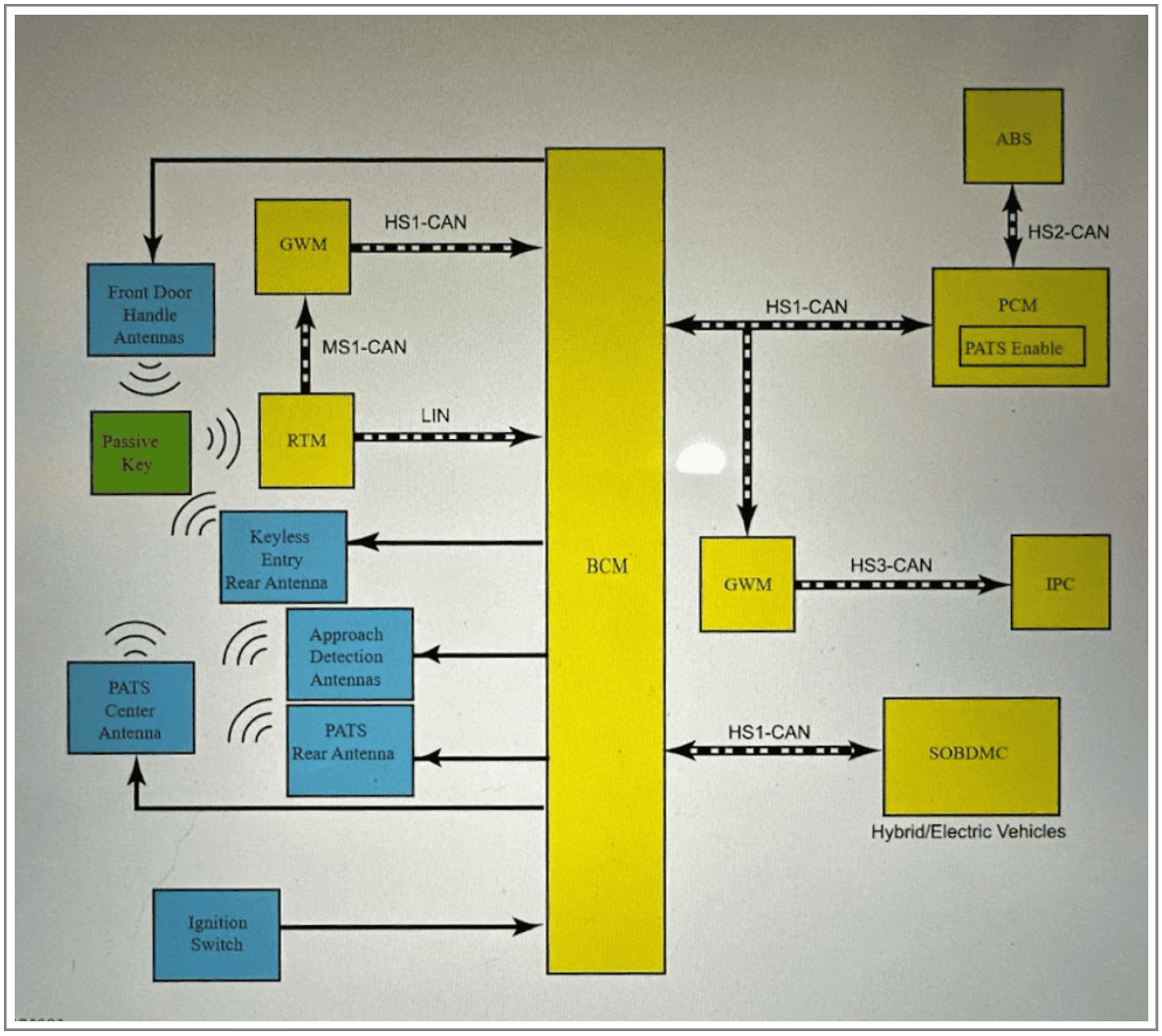
Each sensor generates an electromagnetic field attached to a coil. When an object (as in a hand or fob) comes in close contact with the field the impedance (resistance to current flow) of the coil changes.

Changes in those fields denote the presence of someone approaching or reaching for those areas.

The door sensors are directly connected to Door Control Modules (DCM) and ultimately managed by the Body Control Module (BCM) (1 of 2) in the interior cabin. The trunk sensor is directly managed by the Body Control Module (2 of 2) in the trunk. While the BCM is a main processor for the vehicle, the DCM is a main processor for the door and its inner workings.

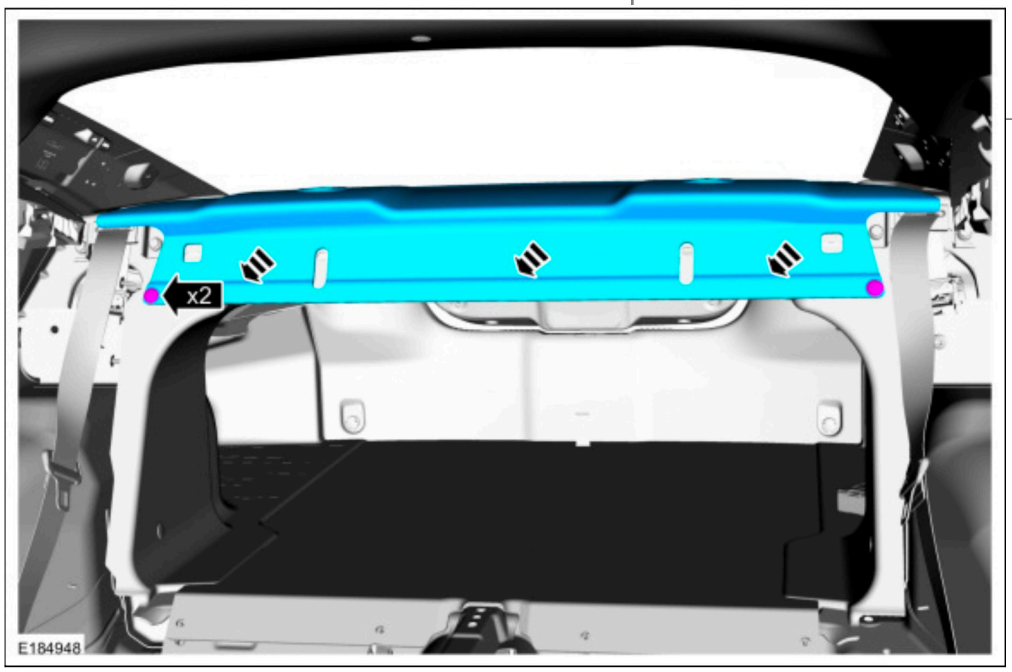


At this point, the proximity sensor determines someone is approaching the vehicle to gain access. The door or trunk sensor alerts the BCM, waking the BCM from sleep, if necessary.



With the proximity sensor tripped, the Mustang will then send a 125 kiloHertz (kHz) wake signal to the fob, alerting it to identify itself. The nature of the signal used requires the fob to be within 6 ft / 2 m of the handle.

The fob will use its Radio Frequency (RF) transmitter to talk to the vehicle's Remote Transceiver Module (RTM). The RTM will receive the information from the fob and send to the BCM. The BCM will then authenticate the fob.



The RTM is located on a "package shelf", underneath the parcel shelf and behind the rear seat. To access the RTM, the rear seat and interior trim pieces will need to be removed.

While the above events are occurring, the Driver is moving closer to the door handle (or trunk sensor). By touching the inner surface of the door handle, or pressing the button associated with the trunk latch, if the BCM has confirmed the identify of the fob, either will unlock.

The door handle uses capacitance sensing to determine when someone is touching these areas, the same principle used when someone swipes a trackpad or cell phone screen. A electrical field is generated inside the sensor. Coming in close contact or touching the outer surface of the device changes the field properties. The sensor then understands someone or something is making contact.

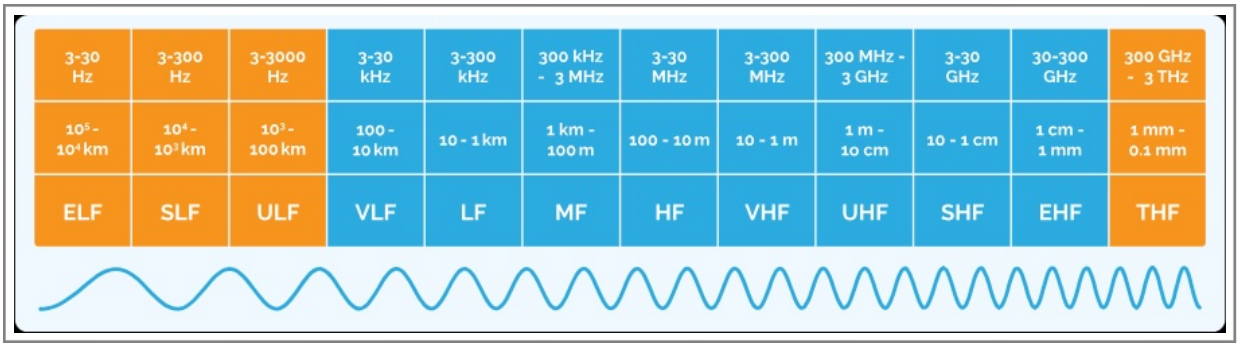
Programming of the key fobs and internal vehicle modules is required to access the car. The model and vehicle-specific information set in these units allow the modules to authenticate one another.

The following S550 Mustang modules require vehicle-specific information:

- Body Control Module (BCM)
- Powertrain Control Module (PCM)
- Telematics Control Unit (TCU)
- Accessory Protocol Interface Module (APIM)
- Restrain Control Module (RCM)
- Remote Transceiver Module (RTM)

For IA to operate, the fob, BCM and RTM must be configured. If Ford's Phone As A Key function is used, the APIM must also be programmed. Dealers can configure the modules. Private parties with FORScan or Ford Diagnostic and Repair System (FDRS) access might be able to set the modules with the required parameters.

Ford key fobs have a Low Frequency (LF) receiver and a Ultra-High Frequency (UHF) transmitter. When in motion, the fob is awake and ready to transmit. Upon receipt of the LF signal (125 kHz) from the Mustang's proximity sensor, the fob will attempt to communicate to the RTM via it's UHF transmitter. The fob's UHF transmit and vehicle Tire Pressure Monitoring System (TPMS) frequencies for the 6G Mustang are the same: 315 Mega Hertz (MHz).



The use of LF and UHF signals is for distance, security and power consumption. By operating the door and trunk area sensors with an LF signal, the distances are 6 ft / 2 m or less. This will enhance security and reduce confusion with other fobs, as signals are only sent as far as needed, while keeping power consumption at a minimum.

As opposed to LF, UHF will project farther, for connivence. For example, attempting to locate the car in a large parking lot, or opening the trunk from the front of the vehicle. While power consumption will be greater, these specific features are used less frequently.

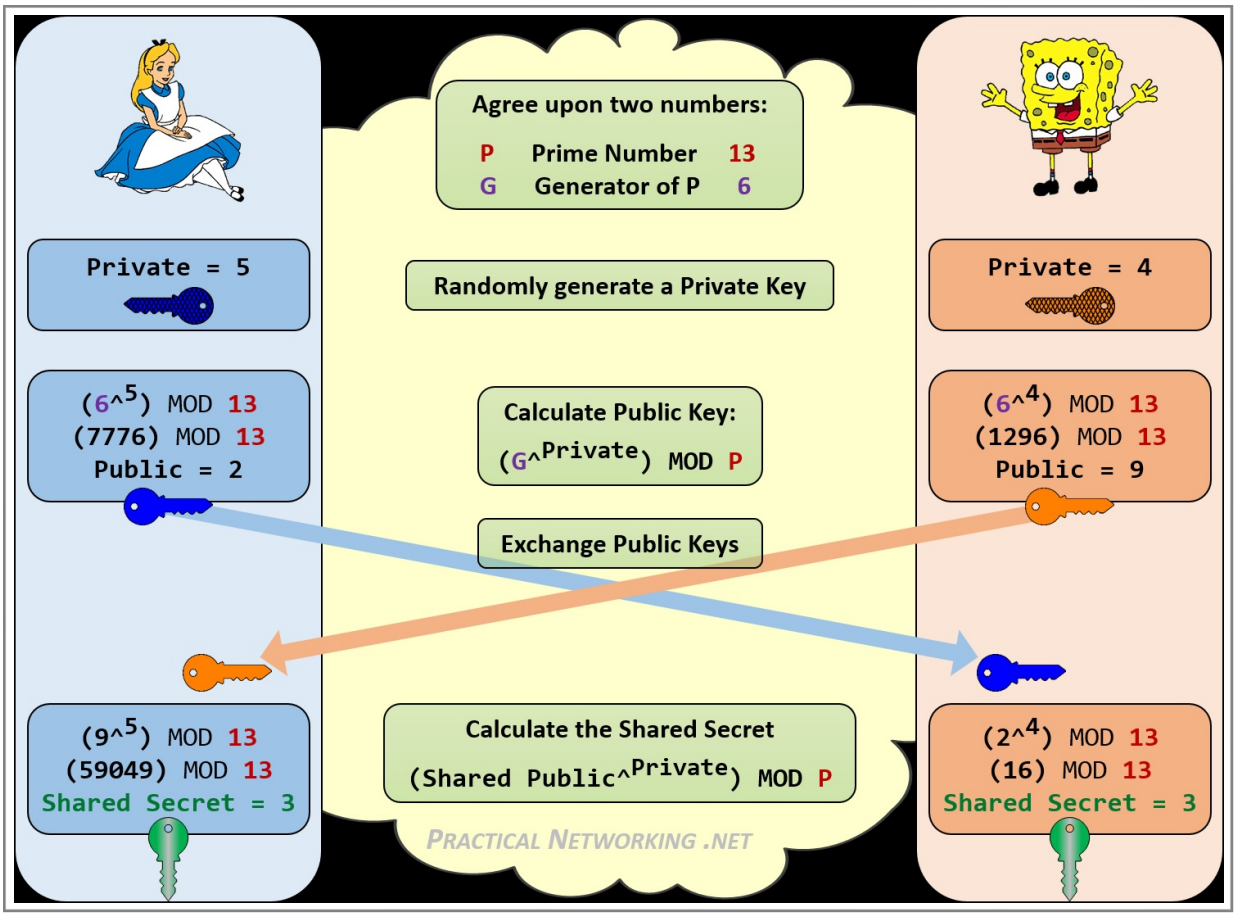
While accessing the vehicle without physical keys offers several benefits, it presents one significant challenge: doing so in a secure manner. The messages sent between fob and vehicle must be secured in some way, to prevent a eavesdropper from recording and repeating those conversations to later access and steal the vehicle.

In 1976, Whitfield Diffie and Martin Hellman published a method describing how two parties in a public setting could create a private shared secret or password. The following section will explain the Diffie-Hellman (DH) key exchange. The exact method of exchange and encryption is not know between the fob and the Mustang. The example provided helps explain how these communications can take place.

At the factory, the key fob and car are coded with specific information: a password, unique numeric sequence or other identifying information only those two objects should know. The DH key exchange allows for the establishment of a secure key between two parties, a key which can later be used to establish a secure channel. It's across the secure channel the PIN or password can be sent, to unlock the vehicle and later enable the drivetrain.

Using Modulus Math, the graphic below describes how two parties who've never met one another can create a shared secret between themselves. It involves the use of a private key, public key and some simple math. The end result is a secret that can now be used to encrypt or scramble communications between the two.

In the graphic below, you'll notice the word "MOD". MODulus math is when a number is divided by another, the remainder being item of interest. It's the use of these remainders, private and public keys and exponential math one-way functions can be used. While very simple to create these results in one direction, it's a practical impossibility to attempt to reverse engineer the answer to determine the private key.



In the example above, "2" and "9" are the remainders of the mathematical division; these numbers will become the public keys in the exchange.

The following links include a six-minute video which explains the graphic, protocol and math. Using your desktop or home calculator, you can perform the same functions.

https://www.youtube.com/watch?v=KXq065YrpiU&list=PLIFyRwBY_4bTwRX__Zn4-letrtpSj1mzY

https://www.practicalnetworking.net/series/cryptography/diffie-hellman/

Cyphers and secret codes have been in use for over a thousand years. Today, some of the most complicated cypher engines and encryption algorithms are available to anyone with a computer browser, cell phone, key fob or garage door opener.

While the engines used are common, the keys each party uses establishes their unique setup. In the example above, a shared secret of "3" was created between the two parties. Now, that "3" is used to setup the cypher engine used. The number will output a unique series of characters, numbers and symbols.

Using the key "3" , the encryption algorithm turns the sentence,

"The quick brown fox jumps over the lazy dog", into,

Adfjaweoriu[09u=0f9ajiq'4aewfiu[fe09u-93jsrkaq;pfvja'regjq';g'0rii-9 xv jx'kw'50ibg8ugbd0rqjn"sfdigaf[090 Ww'ij e'fpo]-9fa r';b[pb cb[vjxaihbygi1u2yeo[svadiou89u0i4h2lvz9

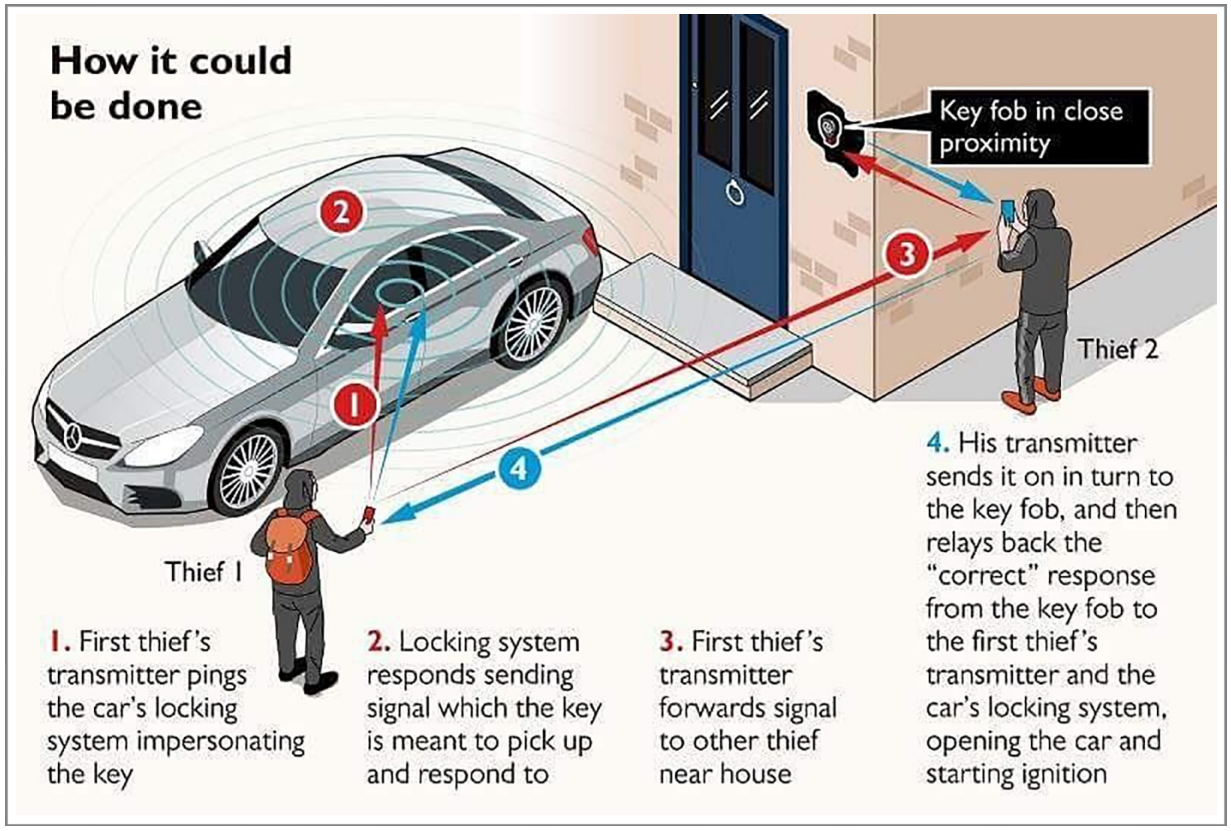
It's this output which is sent in the open. In our example, the numeric sequence or password, programmed at the factory or the dealer, is what is scrambled and sent, from the fob, through the RTM and to the BCM. Inside the BCM, the encrypted message is unscrambled, using the same cypher engine and the key. This same process it's also used to unlock the PCM, so the car can be started.

While anyone listening can record the scrambled information, because it is derived from a key known only to the two parties, it's impossible to unscramble the message.

Any of the systems described thus far will create one-time use keys as they are needed. "3" was the first key. During the next use, another exchange will result in yet another key and yet another unique output.

While the math remains the same, operational systems use very large numbers (in the thousands of digits) and complex encryption engines to create these secure channels.

While capturing a signal in an attempt to learn the encryption key is of little use, relaying that signal could be an easy method to gain access to a vehicle. In one setting, two people work toward compromising a car. One, near the fob, illuminates it with a 125 kHz signal. The information received from the now active fob is relayed to the other thief, near the door handle. The second thief emanates the received UHF signal while touching the handle. Access will be granted.



Someone sitting in a vehicle looking down at a computing device yields no attention these days. Once the vehicle has been physically compromised, it's takes only a few moments to access the On-Board Diagnostics (OBD) or use other devices to start the car.

Cloning fobs is yet another attack, the type which requires certain information and tools to complete. Once a fob is cloned, their is virtually nothing the Owner can do to thwart a theft.

Anti-theft measures span the simple to complex, budget-friendly to expensive. These tools are a form of insurance. Often, simple anti-theft measures can create enough hurdles where the attacker will go elsewhere. Special marks can bring special attention, those drivers taking additional action. Each individual will need to access their risk, profile, then use available tools to help mitigate those risks.

A key fob will become and stay active in two ways:

- When the fob is in motion
- When the fob is receiving a 125 kHz signal

"Active", as in on, not asleep. The fob will transmit its UHF signal if receiving 125 kHz. The fob will present key information as needed.

Ford has programmed fobs to sleep to help prevent relay attacks and conserve fob battery life.

Fobs will sleep in one of two ways:

- When the fob is no longer in motion, it will go dormant in 40 seconds

  and/or

- The illumination signal is no longer being received

"Sleep" as in low-power mode and not transmitting.

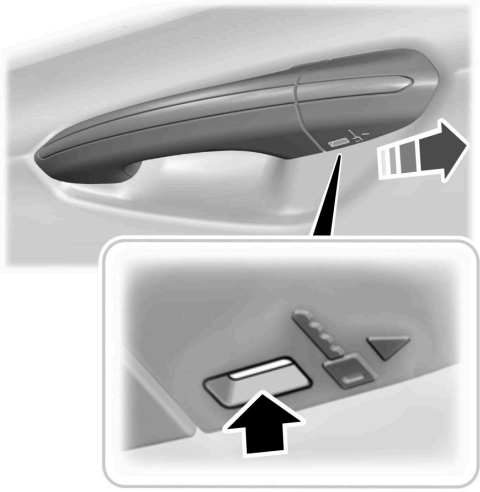
From various sources on-line, the fob talks to the vehicle only when necessary. When opening the vehicle, the fob is used once. As we'll later see with startup, the fob is used once to unlock the PCM. Otherwise, while the fob may remain illuminated and active, it is not sending key information unless required.

If either IA or TPMS operates as expected, this shows the RTM module, physical and logical connectivity to the BCM are good.

A faulty RTM, or one with poor connectivity, can cause both IA and the TPMS (explained later) to stop working.

If IA no longer works, the driver can use the physical key in the fob to unlock the door.

Push the release button and pull the key blade out.



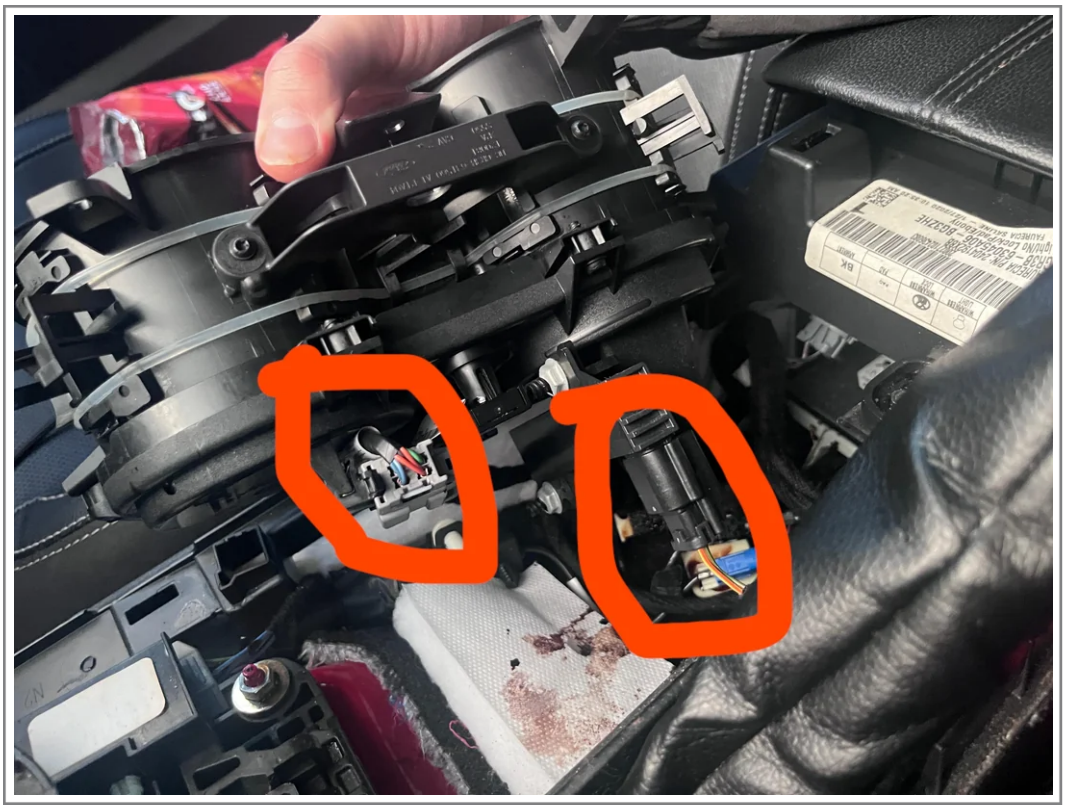
1. Insert the key blade into the slot on the bottom of the handle and apply upward pressure.
2. While maintaining upward pressure, move the cap rearward to release it. Gently remove the key while doing so.

Ford's Phone As A Key is a type of Intelligent Access: a physical key is not required to lock or unlock the vehicle. Using a cell phone, the Ford Pass App and Bluetooth connectivity, the client can lock and unlock their vehicle instead of relying on the fob. While convenient, the author believes the feature is an additional attack vector, another opening one can use to access and steal a vehicle.

Passive Anti-Theft System (PATS)

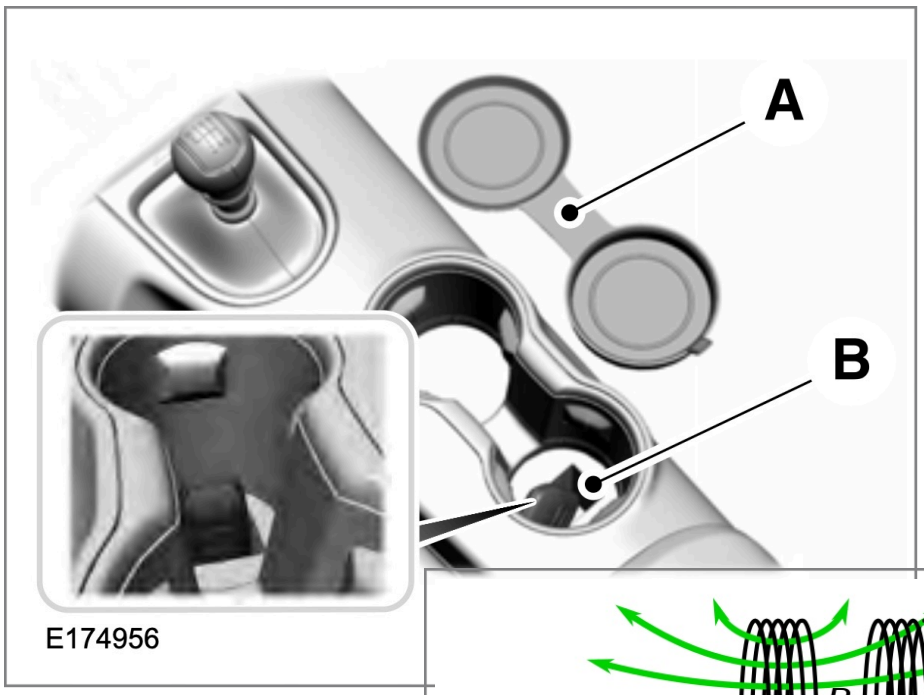
Once inside the vehicle, another system will unlock the drivetrain and allow the car to be started: the Passive Anti-Theft System (PATS).

Inside the center console, attached to the bottom of the rear-most cupholder, is an inductive coupler and antenna.

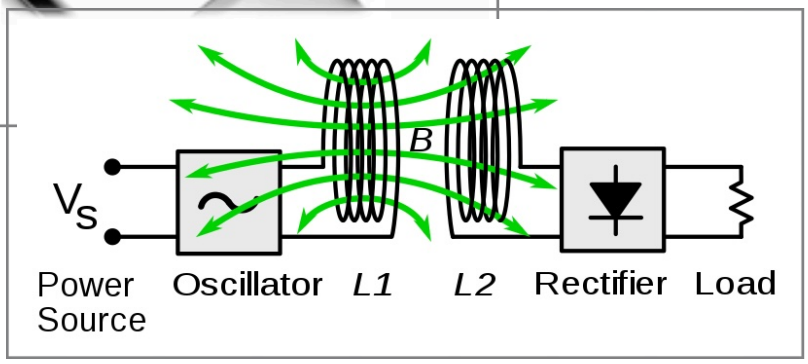


The inductive coupler performs two functions:

- Like the IA door sensors, can sense and illuminate the key fob
- In the event of a failed fob battery, the coupler can power the fob



Once the fob is transmitting its UHF signal, an antenna in the same area receives data from the fob for interrogation by the vehicle.



As mentioned previously, some modules require model and vehicle-specific information programming to work. Before the car can start, the fob, BCM and PCM must present the same information to one another.

Modules can be programmed by a Ford dealer. For those with access and insight, the author has read of some using FORScan to program modules. Locksmiths also have some capabilities, especially for fobs.

The driver need only unlock the drivetrain once. From excerpts in the Owners Manual and personal experience, the fob can be shielded or removed from the vehicle once the vehicle is running. Per the manual, the car can be turned off, then turned on again within 20 seconds, without a key present.

The ability to restart or drive without a fob is anti-security. But I believe Ford (and possibly other vendors) took this path for safety.

If the fob was required to speak to the PCM occasionally, it would have to remain in view of the console and always be operational (what if dead battery or malfunction?) while driving, potentially taking the driver's focus off the road, or giving the car 's operation preference over the driver.

Tire Pressure Monitoring System (TPMS)

The Tire Pressure Monitoring System (TPMS) was created for two purposes: fuel savings and safety.

A tire with an air pressure that is to high or two low will not operate at its expected rolling resistance and decrease the vehicles's mileage.

A vehicle with an over-inflated or under-inflated tire will operate with an increased risk of a blow out. With overinflation, the tire's pressure can exceed what it was designed for. Similarly, an under inflated can greatly increase rolling friction, leading to a breakdown of the tire's components and ultimately failing.

Finally, keeping tires as their designed pressures will allow them to wear evenly, allowing the operator to get the most from their purchase.

There are two types of TPMS: direct and indirect. Direct TPMS uses sensors in each wheel, while indirect TPMS relies on Anti-lock Braking Systems (ABS) and other monitors to measure for any changes to tire diameter. The S550 Mustang uses direct TPMS.

Direct TPMS sensors are installed in each wheel rim. Their main components include a motion sensor, pressure sensor, transmitter and battery.

In the Ford 1180-A (1180-A supports 2010-2014 Mustangs, while 1180-B supports 2015-2023 Mustangs) TPMS sensor installation and activation guide, the instructions state

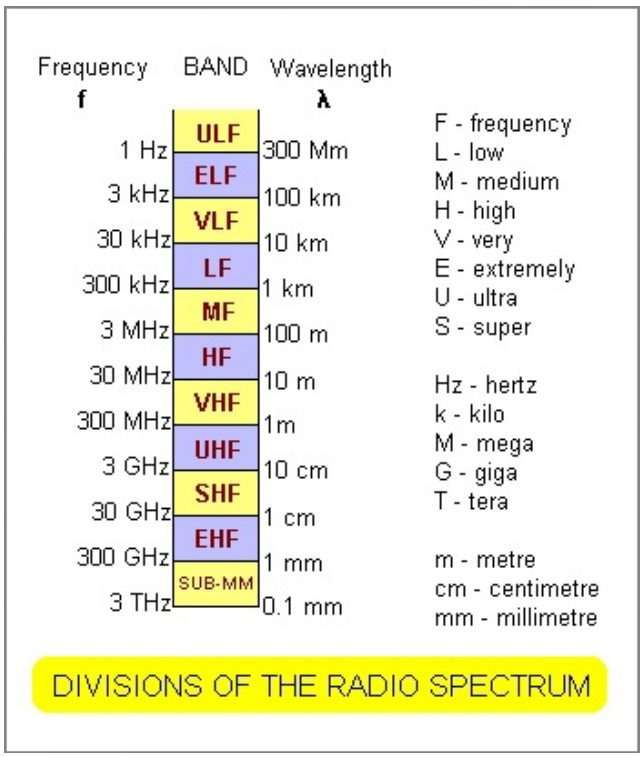
- Sensors will go to sleep if left stationary for 30 minutes
- The training procedure must be accomplished 3+ feet away from other sensors
- Be aware radio interference can be caused by generators, inverters and portable entertainment equipment
- If the BCM becomes aware of the 125 kHz training signal, it will wait for up to 2 minutes for a sensor to respond to the car. Afterwards, the BCM will time out, sound the car horn twice and alarm via the on-screen menus
- If using the sensor activation tool, it may take up to six seconds to enable a sensor. The training fob should be kept stationary for six seconds, the button pressed

Once rolling, the item's motion sensor activates the unit. Upon the device measuring the wheel’s air pressure, the transmitter sends that data to any available receiver. The sensor does not continuously transmit information. Most sensors send data once every 30 seconds to every few minutes.

Stationary, a TPMS sensor can be awakened to transmit data. With a manual training fob, upon pressing a button of that fob, LF 125 kHz wake signal will cause the sensor to illuminate, measure and transmit.

The batteries in each sensor are expected to last five+ years. When buying replacement units, this author recommends purchasing from the Ford Dealer, Ford Performance or nationally-recognized third party supplier. Sites such as eBay and discount web sites often sell dated stock with weak batteries, counterfeit units or devices listed as being compatible, but are not.

Activated by movement or manual wake signal, the pressure sensor will then transmit information via a UHF signal. The most common frequency used in the S550, 6G Mustang is 315 MHz; this frequency is used in the US and Japan.



In Europe, the most common S550 TPMS frequency is 433 MHz.

In the last few years, the frequencies used by these sensors have changed quite a bit. Some units are now using higher frequencies or dual frequencies. This author found 500 variants of vehicle applications at one Ford web site. While some continue to use 315 MHz, some use 433 MHz, or 315/433 MHz. Still others are using 433 MHz and even 868 MHz. When searching for sensors, it's best to confirm via two sources before making a selection.

Modern Ford sensors do not require manual training for the vehicle to recognize and accept them. For the last several years, Ford TPMS sensors will auto-sync. There is nothing to initiate the process, other than driving while free of other units in the immediate area. From as little as 50 yards / 45 meters to several minutes of driving, the vehicle should recognize the devices.

If manual learning is required, this can be accomplished using a TPMS fob.

In many vehicles, a TPMS "reset" feature is available via the on-screen menus. This is not the same as re-training sensors. Resetting the sensors keeps the same devices in the vehicle, but confirms which corner they are attached to. This feature is worthwhile after tires have been rotated.

Indirect TPMS has one advantage: TPMS sensors are no longer required in each wheel. Some Asian and European manufacturers continue to use Indirect TPMS.

Federal Motor Vehicle Safety Standard (FMVSS) No. 138, Tire Pressure Monitoring System, was established by the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000. FMVSS 138 defines how TPMS will work.

https://www.federalregister.gov/documents/2005/09/07/05-17661/federal-motor-vehicle-safety-standards-tire-pressure-monitoring-systems#h-8

- The minimum alarm requirement for a TPMS system is to alert the driver when one or more tires is operating with 25% less air than required. The driver must be alerted within 20 minutes

- Vehicle manufacturers must certify vehicle compliance under the standard with the tires installed on the vehicle at the time of initial vehicle sale

- The TPMS must include a low tire pressure warning telltale (yellow) that must remain illuminated as long as any of the vehicle's tires remain significantly under-inflated and the vehicle's ignition locking system is in the “On” (“Run”) position.The TPMS's low tire pressure warning telltale must perform a bulb-check at vehicle start-up

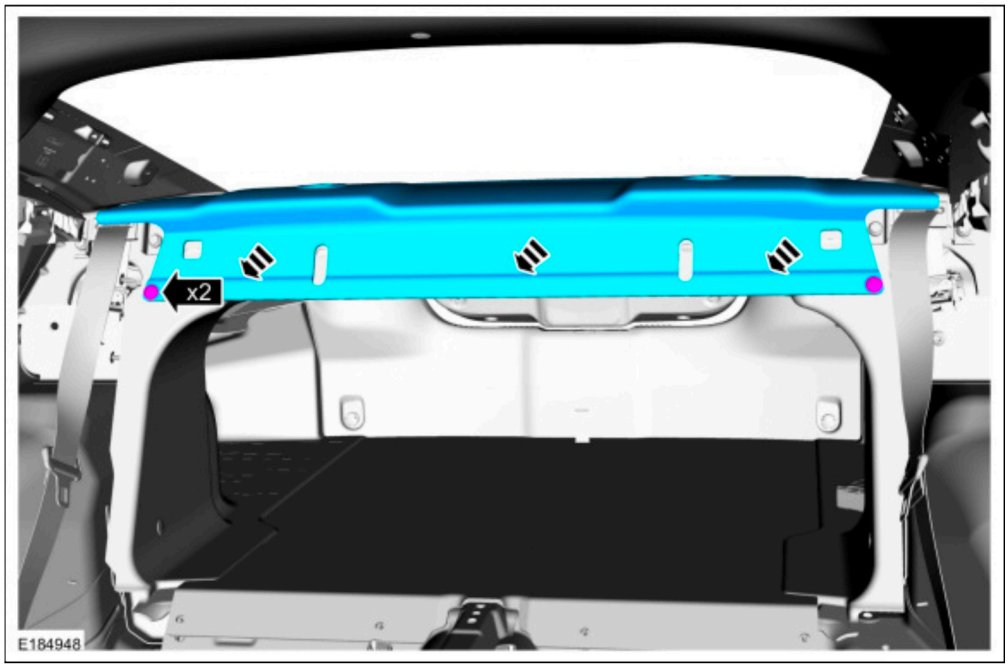
- The TPMS must also include a TPMS malfunction indicator to alert the driver when the system is non-operational, and thus unable to provide the required low tire pressure warning.The TPMS malfunction indicator must detect a malfunction within 20 minutes of occurrence of a system malfunction and provide a warning to the driver

Details described above are the minimum requirements. If the manufacturer would like to create and support devices which react and report quicker or provide greater details, they can do so.

With an understanding of the sensors and regulation, now, we can explain how the data makes it’s way to the Driver’s display.

A transmitting sensor is not directional; the radio waves follow the path of least resistance. In the back of the S550 Mustang is the RTM; this module captures the waves, converts them to a digital form, and reports them to the BCM. The BCM then displays that data in the IPC.

The rear seat of the S550 meets a parcel shelf, which itself sits in-between the rear seat and the rear window. Underneath the parcel shelf is a package tray. Inside the package tray is the RTM. To access the module, the rear seat and D-pillar trim needs to be removed. The author attempted to see the package shelf from the trunk area and could not. The RTM is well-covered and not easily accessible.



In addition to the internal vehicle reporting, the Mustang can also send this data to Ford and the owner by way of the Ford Pass App. Using the cell signal transmitters in the rear corners of the car, the TCU will send TPMS data to Ford.

As mentioned previously, the RTM supports IA and TPMS. If either IA or TPMS is working, the RTM and associated wiring is OK. If neither is working, the RTM or its connectivity could be at fault.

As the RTM is involved with IA and TPMS, the module does have to be programmed with vehicle-specific information before either feature will work. Ford dealers can program the RTM. Those with FORScan or FRDS could set the module up.

Acronyms

ABS - Anti-Lock Brake System
ACK - ACKnowledgment (See CAN message format, ISO 11898)
ACM - Audio Front Control Module (DACMC, Radio, CD, Speakers)
AM - Amplitude Modulated
ANC - Active Noise Cancelling
APIM - Accessory Protocol Interface Module (SYNC, steering controls, radio, NAV)
BCM - Body Control Module
BCMA - BCM (Interior, right side, near floor)
BCMB - BCM (Trunk, right side, near wheel well)
BECMB - Battery Energy Control Module B (RCM, SRS. Turns off fuel in crash.)
BLIS - Blind Spot Information System
BMS - Battery Management System
CAN - Controller Area Network (See also LIN)
CCA - Cold Cranking Amps
CCM - Cruise Control Module
CIP - Consumer Interface Protocol
CPA - Connector Position Assurance (SRS, airbag connector tabs)
CRC - Cyclic Redundancy Check (See CAN message format, ISO 11898)
DAB - Digital Audio Broadcasting
DACMC - Digital Audio Control Module-C (ACM, Radio, CD, Speakers)
DCM - Door Control Module (aka DDM, PDM, Intelligent Access)
DCSM - Dual Climate Seat Module (Seating Climate Control)
DCT - Dual-Clutch Transmission (Paired, electronically-controlled manuals)
DDM - Driver Door Module (Keyless Entry)
DIAG1 - A physical link, connecting LHD and RHD DLC/GWMs
DIAG2 - A physical link, connecting LHD and RHD DLC/GWMs
DLC - DataLink Connector (OBDII, GWM, both LHD and RHD)
DSM - Driver Seat Module (Seat Memory, Power)
DSP - Audio Digital Signal Processor (DSP) Module
DTC - Diagnostic Trouble Code. The fault code/s, seen by a OBDII scan tool
ECM - Engine Control Module (PCM)
ECU - Engine Control Unit (PCM)
EOF - End Of Frame (See CAN message format, ISO 11898)
EMF - ElectroMotive Force
EMI - Electro-Magnetic Interference
FCIM - Front Controls Interface Module (Center Console Push-Button Controls)
FCDIM - Front Controls Display Interface Module (FCIM Outputs)
FDIM - Ford DIsplay Module (Screen Outputs)
FDRS - Ford Diagnostic and Repair System (Ford diagnostic and programming tool)
FM - Frequency Modulated
FMVSS - Federal Motor Vehicle Safety Standard
FORScan - 3rd party diagnostic and programming tool
GENCOM - Generator Communications

Acronyms (cont.)

GENMON - Generator Monitoring
GSM - Gear Shift Module (GT500 Only)
GWM - GateWay Module (DLC, OBDII, LHD and RHD)
HS-CAN - High-Speed Controller Area Network (1,2,3 and 4)
HSWM - Heated Steering Wheel Module
HUD - Head-Up Display Module
HVAC - Heating, Ventilation, Air Conditioning
IA - Intelligent Access (keyless entry)
ICM - Information Center Module
ID - IDentifier (See CAN message format, ISO 11898)
IPC - Instrument Panel Cluster
IPMA - Image Processing Module A (Camera, Lane Departure)
ISO - International Organization for Standardization (See CAN message, ISO 11898)
kHz - kilo Hertz (frequencies in the thousands)
LF - Low Frequency (30 kHz - 300 kHz)
LHD - Left-Hand Drive (DLC, GWM, LHD and RHD OBDII linked via DIAG1 and 2)
LIN - Local Interconnect Network (low-cost, low-speed, low-reliability CAN supplement)
LVDS - Low Voltage Differential Signaling
MHz - Mega Hertz (frequencies in the millions)
MRCMA - Movable Roof Control Module, Primary (Convertible Roof)
MRCMB - Movable Roof Control Module, Secondary (Convertible Roof)
MS-CAN - Medium-Speed Controller Area Network
OBDII - On-Board Diagnostics, Gen 2 (DLC, GWM)
OCS - Occupant Classification System (Passenger Seat Only)
OCSM - Occupant Classification Systems Module (Passenger Sitting Detect)
OLM - Oil Life Monitor
PAM - Parking Assist Control Module (Backup Assist, Parking Assist)
PATS - Passive Anti-Theft System (Engine Immobilizer)
PCM - Powertrain Control Module
PDM - Passenger Door Module (Keyless Entry)
PMI - Programmable Module Installation
PSCM - Power Steering Control Module
PWM - Pulse Width Modulation
RCM - Restraint Control Module (Seatbelt, SRS, Crash Detect)
RF - Radio Frequency (all frequencies used in wireless communications)
RHD - Right-Hand Drive (DLC, GWM, LHD and RHD OBDII linked via DIAG1 and 2)
RKE - Remote Keyless Entry (IA, or Intelligent Access)
RPM - Revolutions Per Minute
RTM - Radio/Remote Transceiver Module (keyless entry, TPMS, remote start)
SCCM - Steering Column Control Module (High Beams, Turn Signals)
SCME - Seat Climate-controlled Module - E
SDL - Smart Device Link (Infotainment connectivity protocol, apps, systems)
SIM - Subscriber Identity Module

Acronyms (cont.)

SoC - State of Charge
SODL - Side Obstacle Detection Control Module LH (BLIS)
SODR - Side Obstacle Detection Control Module RH (BLIS)
SOF - Start Of Frame (See CAN message format, ISO 11898)
SRS - Supplemental Restraint System
SUMB - Vehicle Dynamics Control Module (VDM, Magneride)
TCM - Transmission Control Module (In GT500, a dedicated unit, attached to trans)
TCU - Telematics Control Unit
TCU - Transmission Control Unit (In GT500, a dedicated unit, attached to trans)
TPMS - Tire Pressure Monitoring System
TTS - Text To Speech
UHF - Ultra-High Frequency (300 MHz - 3 GHz)
VAC - Voltage Alternating Current
VDC - Voltage Direct Current
VDM - Vehicle Dynamics Control Module (Magneride)
VIN - Vehicle Identification Number
VIP - Vehicle Interface Protocol
VPWR - Vehicle PoWeR (PCM manages power needs)
VQM - Voltage Quality Module ("smoothes" voltage to components)

Links and Site References

Alternator

Alternator Animated Video Tutorial
https://www.youtube.com/watch?v=jdSKlg80DjU

Antenna

Antenna (Roof) And What They Do
https://www.mustang6g.com/forums/threads/job-1-vs-job-2-shark-fin-roof-antenna-and-what-they-do.146941/

Antenna (Shark Fin) PN#
https://www.mustang6g.com/forums/threads/shark-fin-antenna-part.146564/

APIM

APIM - YouTube Video Showing APIM and its location
https://www.youtube.com/watch?app=desktop&v=fI03A9lbYaA

Links and Site References

Battery

Battery, Case Size/Group Cross-Reference (EUR-to-USA)

https://antigravitybatteries.com/help-center/car-battery-fitment-sizing/?srsltid=AfmBOor3J6ZNjdJgqDEN721Kxy2dipGm5k9k057LbJqTLqDVy-7CUKz8

Battery, Case Size, Physical Measurements, in Imperial and Metric

https://batterycouncil.org/wp-content/uploads/2023/10/BCI-Group-Sizes.pdf

Battery, Lead-Acid, Animation Video Tutorial

https://www.youtube.com/watch?v=VnPRX5zQWLw

Battery, Lithium-Ion, Brief Explanation

https://letstalkscience.ca/educational-resources/stem-explained/how-does-a-lithium-ion-battery-work

Battery Tender

Battery Tender, Ford (CTEK) Charging Process

https://www.youtube.com/watch?v=GXsDrRRRqcU&t=4s

BCM

BCM Location, Diagrams, with Steps on How to Replace (BCMA and BCMB)

https://www.mustang6g.com/forums/threads/bcm-replacement-help.119035/

https://www.mustang6g.com/forums/threads/2018-gauge-cluster-retrofit.74133/page-27

BCM Partial Pinout, to include Fog Lights

https://www.mustang6g.com/forums/threads/anyone-have-the-pinout-wiring-diagram-for-2018-up-fog-running-light-assembly.132859/

BLIS

BLIS, A Step-By-Step Guide To Installing
https://www.mustang6g.com/forums/threads/step-by-step-guide-to-enabling-blind-spot-information-system-blis-and-cross-traffic-alert-cta.107623/

BMS

BMS, Characteristics of Lead Acid Batteries
https://www.pveducation.org/pvcdrom/lead-acid-batteries/characteristics-of-lead-acid-batteries

BMS, The Concept of Ford's Service
https://lockdownsecurity.forumbee.com/t/m2gvh9/ford-trucks-bms-battery-monitoring-systems

BMS: How to Reset in the S550 Mustang
https://www.mustang6g.com/forums/threads/bms-reset-no-tools-required.151602/

Links and Site References

CAN

CAN Tutorials, both Document and Video (See also LIN)

https://dewesoft.com/blog/what-is-can-bus

https://www.csselectronics.com/pages/can-bus-intros-tutorials

https://www.ti.com/lit/an/sloa101b/sloa101b.pdf

https://www.youtube.com/@CSSElectronics-CAN-Logger-X000/videos

CAN in Ford, Explained In Detail, with Logical Drawings

https://www.fofusion2.com/ford_fusion_communications_network_system_operation_and_component_description_description_and_operation-2613.html (Site explains which module uses which CAN)

https://www.fordgt500.com/threads/can-bus-2020-2022-gt500.205590/

https://www.mustang6g.com/forums/threads/the-how-to-disable-the-data-link-to-ford-thread.146863/page-5#post-3007057

Links and Site References

DCT

DCT Operation (Also see TCM below)

https://www.youtube.com/watch?v=t8aGgSbtoJE

Links and Site References

GWM

GWM Location with Dash Harness Connector Layout, HSWM
https://www.mustang6g.com/forums/threads/2018-gauge-cluster-retrofit.74133/page-27

Links and Site References

IA

A- Authenticating in an Unsecured Environment

https://www.youtube.com/watch?v=KXq065YrpiU&list=PLIFyRwBY_4bTwRX__Zn4-letrtpSj1mzY

https://www.practicalnetworking.net/series/cryptography/diffie-hellman/

https://www.youtube.com/watch?v=YEBfamv-_do

A- Wireless Power Transfer (Inductive Coupling)

https://www.nemko.com/blog/wireless-power-transfer

Links and Site References

LIN

- LIN Tutorial (See also CAN)

https://www.youtube.com/watch?v=TresvW4dxlc

LVDS

- LVDS Tutorials

https://www.allaboutcircuits.com/technical-articles/the-why-and-how-of-differential-signaling/

https://resources.system-analysis.cadence.com/blog/msa2021-the-advantages-of-differential-signaling

https://hardwarebee.com/understanding-lvds-low-voltage-differential-signaling/

Links and Site References

Modules

Modules, Electronic, their locations

https://www.youtube.com/watch?v=uzLq5AU1rIg

MRCMA

MRCMA Detailed Document with CAN explanations and Logical Diagrams

https://www.mustang6g.com/forums/attachments/sm_22-pdf.436431/

Links and Site References

PATS

PATS, Re-Initializing, Enabling, so as to Accept New Modules (BCM, etc.)

https://www.mustang6g.com/forums/threads/engine-immobilizer-lock-pats.166144/#post-3454664

PCM

PCM, 10R80 Harness Connectors and Connections

https://www.mustang6g.com/forums/threads/looking-for-trans-pcm-connector-pinout-10r80.147871/

PCM Control Pack Reference (5.0, 5.2, Harness and Connectors)

https://performanceparts.ford.com/download/instructionsheets/FordInstShtM-6017-504V.pdf

https://www.mustang6g.com/forums/threads/leaked-2019-gt500-5-2l-supercharged-engine-wiring-cad-diagram-from-ford.95772/

PCM, Fuel Pump Schematic

https://www.mustang6g.com/forums/threads/fore-wiring-2018-gt.114303/

PCM Ignition Coil Schematic (5.0)

https://www.mustang6g.com/forums/threads/dtc-code-p0354.145419/

PCM Location, Where to Find PCM, Codes Needed by Tuners

https://www.ortizperformance.com/post/locating-your-vehicle-s-pcm-code-1996-2021-mustangs

https://lmr.com/products/ford-mustang-ecu-computer-code-location

PCM Pinout, with Specific Pin Function

https://www.mustang6g.com/forums/threads/pcm-pinout-info-for-v6-mustang-and-v8-2016.136824/

PCM Wiring, Detailed Schematic (2.3L)

https://www.mustang6g.com/forums/threads/looking-for-a-wire-from-the-ecu.107905/

Links and Site References

SODL/R

SODL SODR modules (Detailed Guide, with Photos)
https://www.mustang6g.com/forums/attachments/step-by-step-guide-to-enabling-blis-and-cta-pdf.294019/

SRS

SRSTutorial (Ford)
https://www.repairerdrivennews.com/wp-content/uploads/2023/12/On-Target.pdf

https://fordcrashparts.com/wp-content/uploads/2020/12/On-Target-2020-Vol.-4-FINAL-12-7-20.pdf

SRS- YouTube Video Showing RCM and its location
https://www.youtube.com/watch?v=-VjR8bxT_HU

SRS YouTube Video Showing OCSM and its location
https://www.youtube.com/watch?v=KYgyc7oLLtI

SRS - YouTube Video Showing APIM and its location
https://www.youtube.com/watch?app=desktop&v=fI03A9lbYaA

SYNC Update Thread

SYNC
https://www.mustang6g.com/forums/threads/official-ford-sync3-3-4-release.145436/

Links and Site References

TCM

TCM (GT500) (Also see DCT Operation above)

https://www.motortrend.com/how-to/whats-inside-tremecs-new-seven-speed-dual-clutch-transmission-new-shelby-gt500-mustang/

https://www.mustang6g.com/forums/threads/what-is-this-part-number.157159/ (GSM-specific)

TCU

TCU Location (Telematics Control Unit) (location and logical)

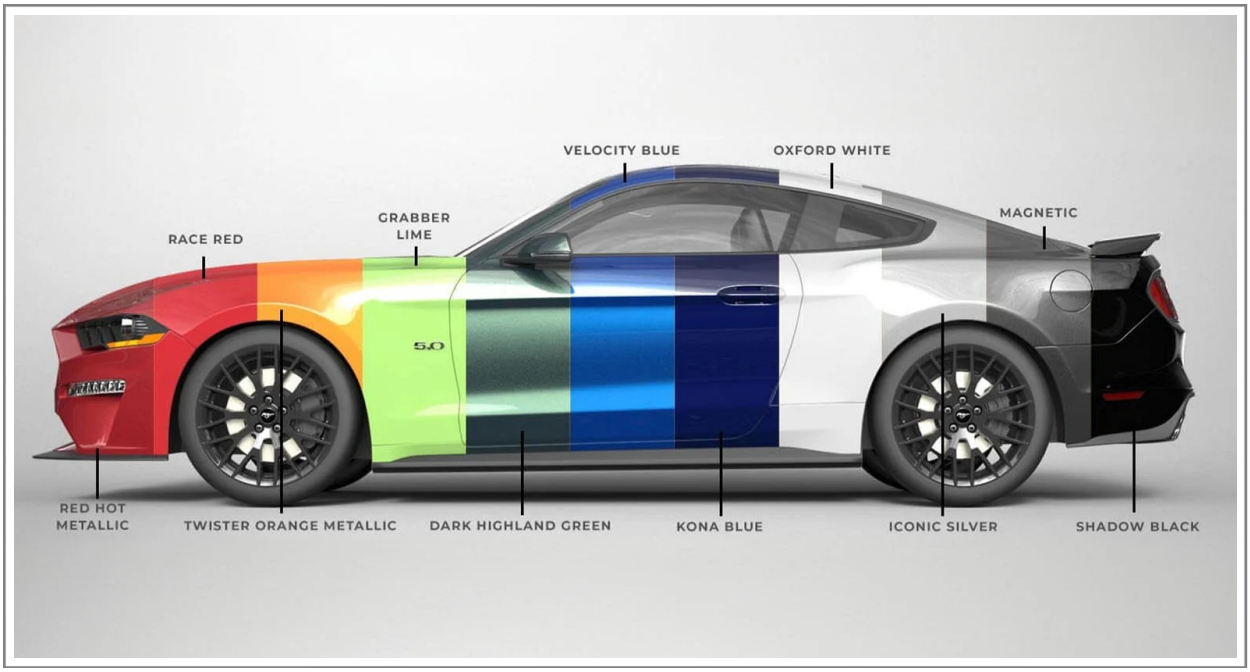
https://www.mustang6g.com/forums/threads/4g-modem-disabling-instructions.146860/

https://www.mustang6g.com/forums/threads/the-how-to-disable-the-data-link-to-ford-thread.146863/page-17#post-3028021

TPMS

TPMS - Federal Motor Vehicle Safety Standard

https://www.federalregister.gov/documents/2005/09/07/05-17661/federal-motor-vehicle-safety-standards-tire-pressure-monitoring-systems#h-8


VELOCITY BLUE
OXFORD WHITE
RACE RED
GRABBER LIME
MAGNETIC
5.0
RED HOT METALLIC
TWISTER ORANGE METALLIC
DARK HIGHLAND GREEN
KONA BLUE
ICONIC SILVER
SHADOW BLACK