

LZE GMBH • FRAUENWEIHERSTRASSE 15 • 91058 ERLANGEN

# SMART SCREW CONNECTION Q-BO<sup>®</sup> EVALUATION KIT

## DATASHEET



VERSIONSDATUM: 28.10.2022

EDITION 1

REVISION 3

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# 1

## At a glance

The Smart Screw Connection Q-Bo® is a fully integrated IoT device that provides wireless and self-powered monitoring of bolted joints. It consists of four different technologies: A DiaForce® layer system for determining the preload force and temperature, mioty® for transmitting the sensor data, energy harvesting for self-powered operation and a programming box for tamper- proof programming of the bolted joint. The technology was developed in a joint research project by the Fraunhofer Institute for Integrated Circuits IIS, the Fraunhofer Institute for Surface Engineering and Thin Film IST, the Fraunhofer Institute for Structural Durability and System Reliability LBF and the Fraunhofer Institute for Applied and Integrated Security AISEC, coordinated by the Fraunhofer Cluster of Excellence Cognitive Internet Technologies CCIT.

### **The EVALUATION KIT consists of:**

(a) the MIOTY SOFTWARE or parts thereof

(b) one (1) set of Hardware components, which each contains:

- one (1) MIOTY Base Station
- one (1) screw system comprised by the screw and a sensory washer with MIOTY End-point
- various cables and power supply.

## 2 Purpose of application

### Disclaimer

The Evaluation Kit can be operated within the specified operating voltages, the rated operating temperatures and other conditions as specified. The Evaluation Kits are prototypes which are fabricated for evaluation towards potential system application. They are not intended for use in products at this stage of development AND must always be supervised in a laboratory environment by trained personnel.

The Evaluation Kit is designed for application e.g. in

<b>Wind turbines</b>	Ensuring the connection of tower segments as well as the blades at the blade bearing.
<b>Bridges</b>	Monitoring of the foundation anchors and bracing of the bridge piers during construction and operation.
<b>Rail</b>	Ensuring bolted connections to trains and infrastructure elements.
<b>Overhead cranes</b>	Ensuring the functionality of the crane runways and gearboxes.
<b>Bucket wheel excavator</b>	Checking the bolting of chain segments.
<b>Flange connections</b>	Monitoring of a permanent tightness of flange connections.

Please note: In the specific use cases, individual approvals from the authorities are required. LZE GmbH explicitly points out that these approvals are currently NOT available.

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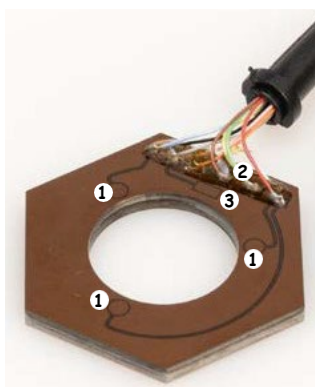
For questions and troubleshooting please contact the customer support:

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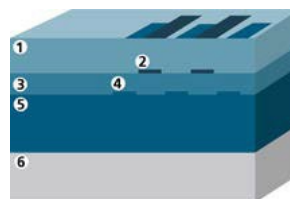
## 3 Insight

### 3.1 Thin-film sensor technology

The integration of the sensor technology into the Smart Screw Connection Q-Bo® is carried out at the Fraunhofer IST by applying a thin-film system on the surface of washers. For this purpose the piezoresistive DiaForce® layer developed at the Fraunhofer IST is deposited homogeneously on the washer in a PACVD process (plasma-enhanced chemical vapor deposition). Individual electrode structures are then manufactured from chromium, which form the sensor electrodes for load measurement as well as a structure for temperature compensation. Both conductive paths to the contacting points and a temperature-measuring meander structure made of chromium are structured on a subsequent electrically insulating SICON® intermediate layer. This hydrocarbon layer is modified with silicon and oxygen, which is also deposited by a PACVD process. These structures are protected against wear with a second final SICON® layer.



- 1 Force sensing structures
- 2 Temperature sensor
- 3 Temperature compensating structure



- 1 Insulating and wear-protection layer (3  $\mu\text{m}$ )
- 2 Temperature meander structure (0.2  $\mu\text{m}$ )
- 3 Insulating and wear protection layer (1  $\mu\text{m}$ )
- 4 Electrode structure Cr (0.2  $\mu\text{m}$ )
- 5 DiaForce® (6  $\mu\text{m}$ )
- 6 Metal base body

Pic.1 The sensory washer

Pic. 2 A schematic representation of the thin film system

## 3.2 Data transmission

The mioty® radio protocol from Fraunhofer IIS is used to transmit the sensor data of the Smart Screw Connection Q-Bo®. It is an ETSI- standardized Low Power Wide Area Network (LPWAN), which enables coverage of up to 15 km at 868 MHz thanks to efficient channel coding. Due to the Telegram splitting method, in which the data packets of a message are sent distributed over frequency and time, the transmission is very robust even in difficult environments and has a very low power consumption of



Pic.4 The Smart Screw Connection Q-Bo® is self-powered through energy harvesting.

<10  $\mu$ Ah. Due to a special error correction, the reception of 50% of the transmitted partial packets is enough to completely recover the message. The low intrinsic interference allows the system to receive up to 3.5 million messages with a single base station. Fraunhofer IIS supports both base station manufacturers and node manufacturers in implementing the radio technology through reference designs and software.



Pic.3 Due to its two-part design, the system can be retrofittable for DIN screws.

## 3.3 Energy supply

The Smart Screw Connection Q-Bo® uses energy harvesting technologies to cover its power consumption, whereby three options can be applied with the help of an energy management system from Fraunhofer IIS. In the first option, temperature differences between the bolt head and the environment are used to generate electrical energy with a thermoelectric generator. For example, a temperature difference of 25 K is required to provide sufficient energy for a measurement and data transmission every 20 seconds. In the second option, solar cells are located on the screw head. Here, e.g. only 500 Lux (indoor) are necessary to ensure a transmission of the sensor data every 30 minutes. Alternatively, it is also possible to supply the sensor via a 230 mAh battery. Depending on the update frequency, this has a service life of up to 15 years.

## 3.4 Data security

During commissioning, the Smart Screw Connection Q-Bo® is protected against any kind of threat, manipulation, unauthorized access or knowledge. Configuration and secure commissioning with calibration data via UHF RFID can be carried out in a radio-shielded box directly on site, a development by Fraunhofer AISEC. Individual cryptographic keys are also distributed to secure the radio communication, which then protect the LPWAN communication against manipulation and attacks.

## 3.5 Mechanics concept

The underlying mechanical concept for using the Smart Screw Connection Q-Bo® with commercially available DIN screws is based on FEM simulations by Fraunhofer LBF, in which the local stress distributions of the mechanical parts were analyzed and then design optimized based on the requirements of the sensors. The reliability in terms of tightening behavior as well as fatigue strength was experimentally validated to ensure the assembly and operational use of the Smart Screw Connection Q-Bo®. Resistance-force curves were determined to characterize the sensors and used in an experimental investigation to validate the Smart Screw Connection Q-Bo®, taking into account all system components.



## 4 Technical Data

The Smart Screw Connection is a fully integrated IoT device that enables wireless and energy-independent monitoring of screw connections. It consists of four different technologies: DiaForce®-layer to determine the preload force and temperature, mioty® transmission for transmitting the acquired sensor data, a programming box for a tamper-proof programming of the screw connection and energy harvesting modules for self-powered operation.

### 4.1 Sensor on washer

Pressure		
Number	3	120° offset on washer radius
Range	0 ... 150 kN	M18, 10.8
Accuracy	5-10 %	
Temperature		
Number	1	
Range	+20... +100 °C	
Accuracy	1-2 K	
Acceleration (Vibration monitoring, RMS values)		
Max. Data Rate	3.200 Hz	
Max. Recording Time	2.8 sec. (3 axis)	Optional: 800 Hz, 11 sec. (3-axis)
<b>Max. Acceleration</b>	<b>16 g</b>	

### 4.2 Communication

LPWAN		
Protocol	mioty®	
Coverage	5... 15 km	
Transmit power	Max. 12.5 dBm	
Transmit frequency	868 MHz	
UHF-RFID		
Frequency	868 MHz	Read/write access for configuration; without energy supply by means of energy harvesting possible
NFC (optional)		
<b>Frequency</b>	<b>13.56 MHz</b>	<b>Read/write access for configuration; without energy supply by means of energy harvesting possible</b>

### 4.3 Power supply

Solar module		
Illumination	500Lux (mean)	Transmission frequency 30 min
	Start-up time 30 min	At minimum illumination; cold start conditions
	18.000 Lux (Outdoor)	Update frequency 30 sec.
Thermoelectric generator		
Minimum Thermal gradient (thread to ambient)	10 K	Transmission frequency 15 min Start-up time 15 min
	25 K	Update frequency 20 sec
	33 K	Update frequency 15 sec.
Battery		

Capacity	230 mAh (CR2032)	Optional CR2450 for longer operation time
Operation time	2.6 years 3.2 years 15 years	Transmission frequency 60 min Transmission frequency 24 h Transmission frequency 30 days

## 4.4 Commissioning

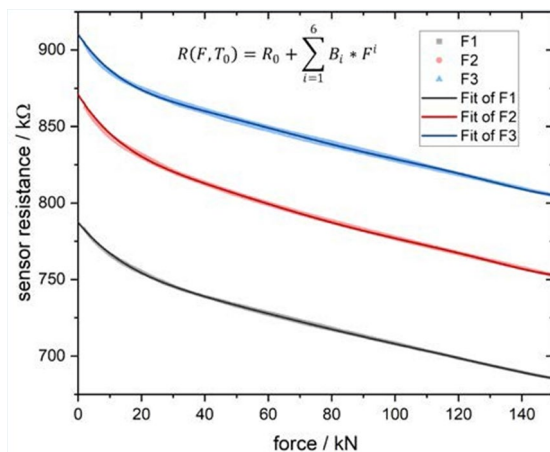
See RFID		
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## 4.5 Physical dimensions (add-on version)

Washer		
46 x 10 mm		AF* x height (hexagon)
Electronic module		
46 x 37 mm		AF* x height (hexagon)

## 4.6 Physical dimensions (full screw)

46 x 61.5 mm		AF x washer bottom side to heat sink top side
46 x 44.3 mm		AF x washer bottom side to antenna top side
M18		thread



Pic.5 Resistance [kΩ] of three pressure sensors (F1, F2, F3) on the washer as a function of the force [kN].

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List of Open Source Software for MIOTY telemetry platform Evaluation Agreement

Version: 1.1.4

Dated: 29.06.2022

Software Components

MIOTY Component	OSS Module Name	Module Version	License
Base station	libatomic_ops	7.3	MIT (1)
Base station	cmdline		BSD-3-clause (2)
Base station	cppformat	1.1.0	BSD (3)
Base station	HTTP-parser	2.7.1	MIT (1)
Base station	rapidXML	1.13	Boost/MIT (4)
Base station	JSON for modern C++	2.0.7	MIT (1)
Base station	tinyaes		The Unlicense (5)
Base station	libwshandshake	0.9	Zlib (8)
Base station	mbed TLS	2.7.11	Apache 2.0 (9)
Base station	Mersenne Twist		LGPL (10)
Base station	GCC Runtime Library		Multiple (11)
Base station	Ubuntu <i>main</i> amd64 <sup>1</sup>	20.04	Multiple (6)
Frontend	STM32Cube - HAL	V1.11.0	BSD (3)
Frontend	Rtudio	V5.1.0	(12)
Frontend	Libasound	Libasound2	LGPL (11)

<sup>1</sup> Source: <https://www.ubuntu.com/download/desktop/contribute?version=20.04.4&architecture=amd64>

<b>End-point – CC1310/CC13X2/S crew</b>	Little FS	2.4.1	ARM Ltd.: BSD-3-Clause (13)
<b>End-point – Screw</b>	SimpleLink CC13x2 26x2 SDK	4.20.00.35	TI: BSD-3-Clause (2)
<b>End-point - ALL</b>	Cortex-M CMSIS	v4.5	BSD-3-Clause (2)
<b>End-point - ALL</b>	newlib	v2.5.0	MIT (1)
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# 7

## Appendix

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We may make changes to this IPRights Policy from time to time. Please check this IPRights Policy from time to time to ensure that you are in compliance.

SimpleLink\_CC13x0\_SDK Manifest

11-14-2016

Manifest ID - SRAS00003412

Legend

(explanation of the fields in the Manifest Table below)

<b>Software Name</b>	The name of the application or file
<b>Version</b>	Version of the application or file
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5D992 (Authentication, secure hash algorithm (SHA) encryption that is NOT 5D002)

SimpleLink\_CC13x0\_SDK Windows Manifest Table

See the Legend above for a description of these columns.

Software Name	Version	License Type	Delivered As	Modified by TI	Location	
SIMPLELINK-CC13X0-SDK	1.0.0.x	TI Commercial	Binary and limited source	N/A		[as installed]
					<b>Obtained from</b>	Texas Instruments
SIMPLELINK-CC13X0-SDK-Sample Applications	1.0.0.x	BSD-3-Clause	Source	N/A		[as installed]
					<b>Obtained from</b>	Texas Instruments

CoreSDK for CC13xx and CC26xx Manifest Table

Software Name	Version	License Type	Delivered As	Modified by TI		
Core SDK	3.01.xx	BSD-3-Clause	Source and Binary	N/A	<b>Location</b>	[as installed]/packages
					<b>Obtained from</b>	Texas Instruments
FreeRTOSConfig.h	FreeRTOS V9.0.0	GPL-2.0 WITH FreeRTOS Exception	Source	N/A	<b>Location</b>	[as installed]/kernel/freertos/builds/MSP_EXP432P401R/release
					<b>Obtained from</b>	Texas Instruments
FATFS	R0.11a	FATFS	Source and Binary	No	<b>Location</b>	[as installed]/source/third_party/fatfs
					<b>Obtained from</b>	<a href="http://elm-chan.org/fsw/ff/00index_e.html">http://elm-chan.org/fsw/ff/00index_e.html</a>
Core SDK cdoc\icons	1.00.01.17	EPL-1.0	GIF	Yes	<b>Location</b>	[as installed]/docs/cdoc/int-blue.gif, int-red.gif, package.gif, packages.gif
					<b>Obtained from</b>	Eclipse
newlib	1.19.0	BSD-2-Clause and BSD-3-Clause and others	Binary	<a href="#">Yes</a>	<b>Location</b>	[as installed]/kernel/tirtos/packages/gnu/targets/arm/lib
					<b>Obtained from</b>	Texas Instruments

### CC13xxWare Manifest Table

Software Name	Version	License Type	Delivered As	Modified by TI		
driverlib	2.04.0x	BSD-3-Clause	Source and binary	N/A	<b>Location</b>	driverlib, driverlib/bin
					<b>Obtained from</b>	TI
CC13xx RF patches	2.04.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	rf_patches
					<b>Obtained from</b>	TI
CC13xx hardware header files	2.04.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	inc
					<b>Obtained from</b>	TI
CC13xx startup files	2.04.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	startup_files
					<b>Obtained from</b>	TI
CC13xx linker files	2.04.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	linker_files
					<b>Obtained from</b>	TI
CC13xx/CC26xxWare Crypto	1.01.00.x	BSD-3-Clause	Source	N/A	<b>Location</b>	utils/rom_crypto,driverlib
					<b>Obtained from</b>	TI
jquery.js	1.7.1	MIT	Source	No	<b>Location</b>	doc/driverlib
					<b>Obtained from</b>	jquery.org

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Software Name	Version	License Type	Delivered As	Modified by TI		
driverlib	2.24.0x	BSD-3-Clause	Source and binary	N/A	<b>Location</b>	driverlib, driverlib/bin
					<b>Obtained from</b>	TI
CC26xx RF patches	2.24.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	rf_patches
					<b>Obtained from</b>	TI
CC26xx hardware header files	2.24.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	inc
					<b>Obtained from</b>	TI
CC26xx startup files	2.24.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	startup_files
					<b>Obtained from</b>	TI
CC26xx linker files	2.24.0x	BSD-3-Clause	Source	N/A	<b>Location</b>	linker_files
					<b>Obtained from</b>	TI
CC13xx/CC26xxWare Crypto	1.01.00.x	BSD-3-Clause	Source	N/A	<b>Location</b>	utils/rom_crypto,driverlib
					<b>Obtained from</b>	TI
jquery.js	1.7.1	MIT	Source	No	<b>Location</b>	doc/driverlib
					<b>Obtained from</b>	jquery.org

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					<b>Obtained from</b>	Texas Instruments
TI-15.4-STACK Example Applications	2.0.1.x	BSD-3 Clause	Source	N/A	<b>Location</b>	[as installed]
					<b>Obtained from</b>	Texas Instruments
TI Wireshark Packet Convertor	1.12.16	TI Commercial	Binary	N/A	<b>Location</b>	[as installed]/tools/ti154stack/tiwspsc
					<b>Obtained from</b>	Texas Instruments
TI Wireshark Packet Convertor Graphics	N/A	Creative Commons Attribution 3.0	Binary (embedded within application)	No	<b>Location</b>	[as installed]/tools/ti154stack/tiwspsc
					<b>Obtained from</b>	<a href="http://www.fatcow.com/free-icons">http://www.fatcow.com/free-icons</a>
TI Wireshark 802.15.4e Dissector	1.0.7	GPLv2	Binary and source	N/A	<b>Location</b>	[as installed]/tools/ti154stack/tiwsds
					<b>Obtained from</b>	Texas Instruments
Microsoft .NET Framework 4 Redistributable	4	Microsoft Commercial	Binary	No	<b>Location</b>	[as installed]
					<b>Obtained from</b>	<a href="http://www.microsoft.com/en-us/download/details.aspx?id=17718">http://www.microsoft.com/en-us/download/details.aspx?id=17718</a>
Microsoft Visual C++ SP1 2010 Redistributable	2010	Microsoft Commercial	Binary	No	<b>Location</b>	[as installed]
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Credits

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SIMPLELINK-CC13X0-SDK

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SIMPLELINK-CC13X0-SDK-Sample Applications

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TI Wireshark Packet Converter Graphics

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VisualBasicPowerPacksSetup.exe

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vcredist\_x86.exe

vcredist\_x64.exe

vcredist\_IA64.exe

Subject to the license terms for the software, you may redistribute MSM files listed below unmodified as a part of your installation package:

Microsoft\_VC100\_ATL\_x86.msm

Microsoft\_VC100\_ATL\_ia64.msm

Microsoft\_VC100\_ATL\_x64.msm

Microsoft\_VC100\_CRT\_x86.msm  
Microsoft\_VC100\_CRT\_ia64.msm  
Microsoft\_VC100\_CRT\_x64.msm

Microsoft\_VC100\_MFC\_x86.msm  
Microsoft\_VC100\_MFC\_x64.msm

Microsoft\_VC100\_MFCLOC\_x86.msm  
Microsoft\_VC100\_MFCLOC\_x64.msm

Microsoft\_VC100\_OpenMP\_x86.msm  
Microsoft\_VC100\_OpenMP\_ia64.msm  
Microsoft\_VC100\_OpenMP\_x64.msm

For your convenience, we have provided the following folders for use when redistributing VC++ runtime files. Subject to the license terms for the software, you may redistribute the folder (unmodified) in the application local folder as a sub-folder with no change to the folder name. You may also redistribute all the files within a folder, listed below the folder for your convenience, as an entire set.

\\VC\redist\x86\Microsoft.VC100.ATL\  
atl100.dll

\\VC\redist\ia64\Microsoft.VC100.ATL\  
atl100.dll

\\VC\redist\amd64\Microsoft.VC100.ATL\  
atl100.dll

\\VC\redist\x86\Microsoft.VC100.CRT\  
msvcp100.dll  
msvcr100.dll

\\VC\redist\ia64\Microsoft.VC100.CRT\  
msvcp100.dll  
msvcr100.dll

\\VC\redist\amd64\Microsoft.VC100.CRT\  
msvcp100.dll  
msvcr100.dll

\\VC\redist\x86\Microsoft.VC100.MFC\  
mfc100.dll  
mfc100u.dll  
mfcm100.dll  
mfcm100u.dll

\\VC\redist\amd64\Microsoft.VC100.MFC\  
mfc100.dll  
mfc100u.dll  
mfcm100.dll  
mfcm100u.dll

\\VC\redist\x86\Microsoft.VC100.MFCLOC\  
mfc100chs.dll  
mfc100cht.dll  
mfc100enu.dll

mfc100esp.dll  
mfc100deu.dll  
mfc100fra.dll  
mfc100ita.dll  
mfc100jpn.dll  
mfc100kor.dll  
mfc100rus.dll

\\VC\redist\amd64\Microsoft.VC100.MFCLOC\  
mfc100chs.dll  
mfc100cht.dll  
mfc100enu.dll  
mfc100esp.dll  
mfc100deu.dll  
mfc100fra.dll  
mfc100ita.dll  
mfc100jpn.dll  
mfc100kor.dll  
mfc100rus.dll

\\VC\redist\x86\Microsoft.VC100.OpenMP\  
vcomp100.dll

\\VC\redist\amd64\Microsoft.VC100.OpenMP\  
vcomp100.dll

\\VC\redist\ia64\Microsoft.VC100.OpenMP\  
vcomp100.dll

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mfc100.dll

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atl100.i386.pdb  
atl100.AMD64.pdb  
atl100.IA64.pdb

msvc100.i386.pdb  
msvc100.AMD64.pdb  
msvc100.IA64.pdb

msvcr100.i386.pdb  
msvcr100.AMD64.pdb  
msvcr100.IA64.pdb

mfc100.i386.pdb  
mfc100.AMD64.pdb

mfc100u.i386.pdb  
mfc100u.AMD64.pdb

mfc100.i386.pdb



mfc100.AMD64.pdb

mfc100u.i386.pdb  
mfc100u.AMD64.pdb

vcomp100.i386.pdb  
vcomp100.AMD64.pdb  
vcomp100.IA64.pdb

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#### Visual F# Runtime Files

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FSharpRedist.exe  
FSharp.Core.dll

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#### .NET Framework 4

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dotNetFx40\_Client\_x86\_x64.exe  
dotNetFx40\_Full\_x86\_x64.exe

dotNetFx40\_Client\_x86.exe

dotNetFx40\_Full\_x86.exe  
dotNetFx40\_Full\_x86\_ia64.exe

dotNetFx40\_Client\_setup.exe  
dotNetFx40\_Full\_setup.exe

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dotNetFx40LP\_Full\_x86\_x64<Culture>.exe  
dotNetFx40LP\_Full\_x86\_ia64<Culture>.exe  
dotNetFx40LP\_Full\_x86<Culture>.exe

dotNetFx40LP\_Client\_x86\_x64<Culture>.exe  
dotNetFx40LP\_Client\_x86<Culture>.exe

Note: <Culture> represents the specific language identifier. Language Packs are available for the following (listed here with their associated identifier code):

Arabic (ar), Chinese-Taiwan (zh-cht), Czech (cs), Danish (da), German (de), Greek (el), Finnish (fi), French (fr), Hebrew (he), Hungarian (hu), Italian (it), Japanese (ja), Korean (ko), Dutch-Netherlands (nl), Norwegian (no), Polish (pl), Portuguese-Brazil (pt-BR), Russian (ru), Swedish (sv), Turkish (tr), Chinese (zh-chs), Portuguese-Portugal (pt-PT), Spanish (es)

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Visual Studio Tools for Office Files

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vstor40\_x86.msi

vstor40\_x64.exe  
vstor40\_x64.msi

vstor40\_lp\_x86\_ARA.msi  
vstor40\_lp\_x64\_ARA.msi

vstor40\_lp\_x86\_CHS.msi  
vstor40\_lp\_x64\_CHS.msi

vstor40\_lp\_x86\_CHT.msi  
vstor40\_lp\_x64\_CHT.msi

vstor40\_lp\_x86\_DAN.msi  
vstor40\_lp\_x64\_DAN.msi

vstor40\_lp\_x86\_DEU.msi  
vstor40\_lp\_x64\_DEU.msi

vstor40\_lp\_x86\_ESN.msi  
vstor40\_lp\_x64\_ESN.msi

vstor40\_lp\_x86\_FIN.msi  
vstor40\_lp\_x64\_FIN.msi

vstor40\_lp\_x86\_FRA.msi  
vstor40\_lp\_x64\_FRA.msi

vstor40\_lp\_x86\_HEB.msi  
vstor40\_lp\_x64\_HEB.msi

vstor40\_lp\_x86\_ITA.msi  
vstor40\_lp\_x64\_ITA.msi

vstor40\_lp\_x86\_JPN.msi  
vstor40\_lp\_x64\_JPN.msi

vstor40\_lp\_x86\_KOR.msi  
vstor40\_lp\_x64\_KOR.msi

vstor40\_lp\_x86\_NLD.msi  
vstor40\_lp\_x64\_NLD.msi

vstor40\_lp\_x86\_NOR.msi  
vstor40\_lp\_x64\_NOR.msi

vstor40\_lp\_x86\_PLK.msi

vstor40\_lp\_x64\_PLK.msi

vstor40\_lp\_x86\_PTB.msi  
vstor40\_lp\_x64\_PTB.msi

vstor40\_lp\_x86\_RUS.msi  
vstor40\_lp\_x64\_RUS.msi

vstor40\_lp\_x86\_SVE.msi  
vstor40\_lp\_x64\_SVE.msi

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o2007pia.msi

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MageUI.exe  
ResGen.exe

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Version 3.1, 31 March 2009

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