Automation! v0.0

Prolog

My name is Sandor Vamos. I was born in Hungary, have lived in Germany for approximately 20 years, and now hold German citizenship. I speak Hungarian, German, and English. I am over 50 years old and have about 25 years of experience in programming and designing industrial systems. I mainly design with the market leader in Europe, **Simatic systems**, but I have also worked on many other systems (*AB Rockwell, Bosch, Wago, Codesys, Mitsubishi, …*).

At first, I worked on production lines at Bosch; later, I founded my own company and worked in power plant technology. The Budapest (Rákospalota) Waste Incineration Plant (4 boilers, turbine, district heating) has been operating with my software for more than 20 years.

In 2006, my family and I moved to Germany, where I initially worked on programming trains; for example, I wrote the door control software module for the ICE4 (intercity train). For several years, I have been working on shore power supply for container vessels and cruise ships. In this area, my current references include the Hamburg CTB, the Toll Ports of Melbourne and Burnie, and the Thialf and Sleipnir ships in Rotterdam.

In addition to Simatic systems, I also work extensively with Arduino and ESP32 microcontrollers. I use these primarily for IoT projects, often as an economical complement to Simatic systems. Simatic is an expensive system, and in many cases it is not cost-effective to use; in those cases, its *"little brother"*, Arduino, comes in handy. In addition to control, I implement visualization (SCADA/HMI), typically with WinCC for Simatic systems. For data collection and exceptional communication, I develop IPC solutions in LabVIEW, which, of course, connect to Simatic and Arduino.

I use a wide range of industrial communication systems to service and communicate with the systems: ProfiNet, ProfiBus, (Industrial) Ethernet protocols, Modbus, IEC61850, … - check out my site.

The idea for the online book stems from the fact that I have many notes on *"real"* programming, i.e., the programming I use in practice. These are tricks and procedures that official books rarely present, or present with a significantly different emphasis. I felt that, amid the flood of technical books, a description focused on the practical application of PLCs might have its place.

The book **Automation!** is an ever-expanding online documentation project based primarily on my experiences. I highlight the knowledge I consider essential for programming. I also adjust the language so it reads as if I were explaining to a friend which things are unimportant and which are essential. The online documentation will also be available for download as a book, but I will provide it with a version number, precisely because of the continuous expansion. For now, the version starts with 0, since I have only just started writing this.

Sándor Vámos; lamaPLC.com

💡 To quickly review the content, use the "**Table of contents**" function in the upper-right corner ☝ (on PC).

You can save the entire page content as a **PDF** by clicking the PDF icon in the right menu (Export to PDF).

A few important notes regarding the document (Automation!):

- The document (Automation!) is freely available, but I hold the rights to publish it. Redistribution – even partially – requires my approval.
- The document's content reflects my personal judgment. Clearly, I cannot provide a comprehensive and detailed Simatic documentation, partly due to length constraints.
- The example programmes are written in SCL because it is the language I use for programming.
- Although I have taken great care, there might still be errors in this document. If you find any, please let me know at: info at lamaplc.com.

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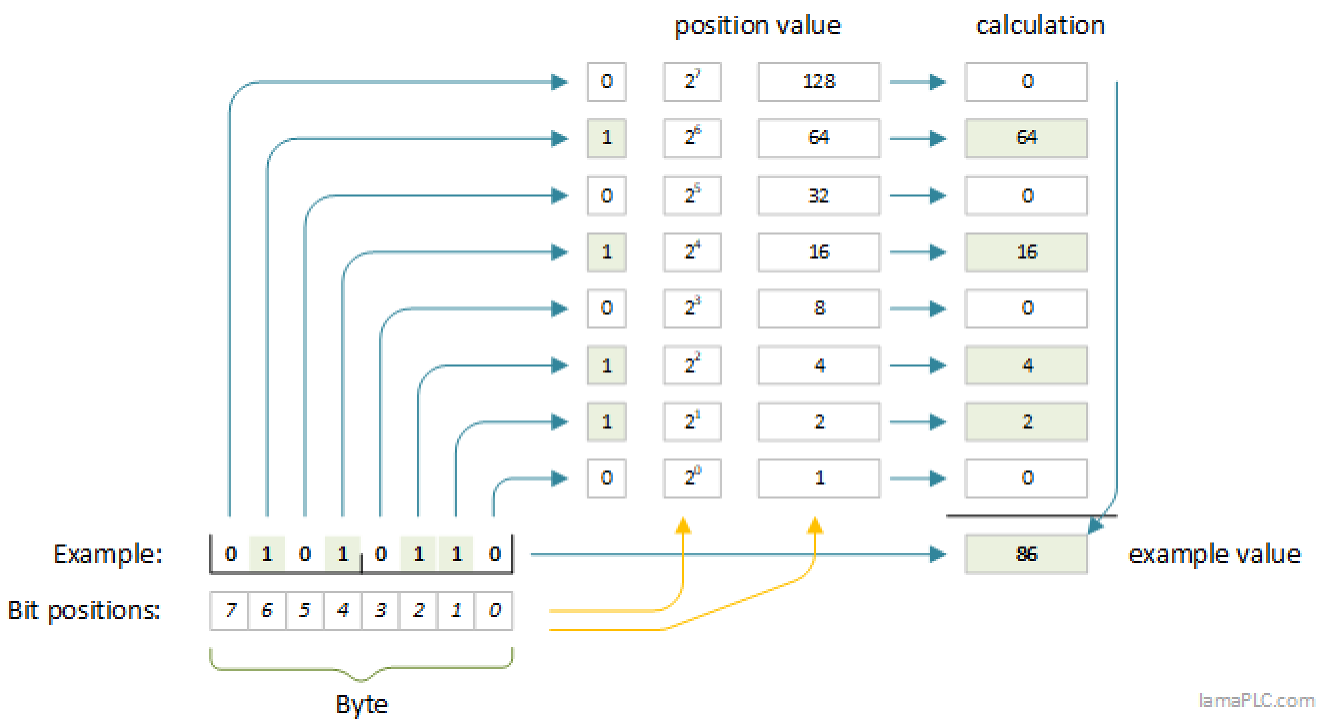
Simatic variable types

Bit & Byte

The **Bit** is the simplest form; it's a signal that can be true or false, with its official English equivalents being *“TRUE”* or *“FALSE,”* or even simply 0 or 1. There is no 2 anymore because two is represented by 10 according to the rules of the binary number system, which in this case is not ten but one zero. To clearly distinguish this, we write numbers in the decimal number system *“just like that,”* for example, 10. If this is a number in the binary number system, then we denote it as **2#**10.

The decimal number system stems from the fact that we have ten fingers and, historically, used them to perform all our calculations. If we had, say, three fingers on each hand, meaning six in total, then we would be using the six-number system now. Computing is based on the above yes-or-no logic, i.e., the binary number system, which is why we often use the hexadecimal number system. I'll talk about that later. Let's first look at the binary number system through a byte to see how it works.

A byte is a variable type consisting of 8 bits. The value stored in it must be somewhere between 0 and 255, depending on the bit positions. The example below may help you understand this a little:



Let's take the bit sequence *“01010110”* as an example, which fills the above byte. The bits of a byte are always numbered from right to left; position 0 is always on the right. Each position corresponds to a given power of the binary number system; position 4 corresponds to 24 = 16. If there is a 0 in this position in the example, then it does not *“count”*; if there is a one, then its value “counts”, and as can be seen in the rows marked in green, the sum of the *“counting”* rows gives the current decimal value of the byte, 86. That is, **2#**01010110 = 86.

Therefore, the byte reaches its maximum value when all bits are set to 1. It can be calculated that **2#**11111111 = 255. The byte data type holds values between 0 and 255.

In computing, we use the base-10 number system, as well as the binary and base-16 number systems. The values described in it are called hexadecimal numbers and are denoted by the prefix “**16#**” or sometimes “**hex#**”. Sometimes the hexadecimal number system is simply the hash, like this: “#ABCD”. The hexadecimal number system changes order of magnitude at 16, meaning that a position can contain a value between 0 and 15. This can be very confusing in the base 10 number system, so the two-digit positions are denoted by letters:

10 = 16#A
11 = 16#B
12 = 16#C
13 = 16#D
14 = 16#E
15 = 16#F

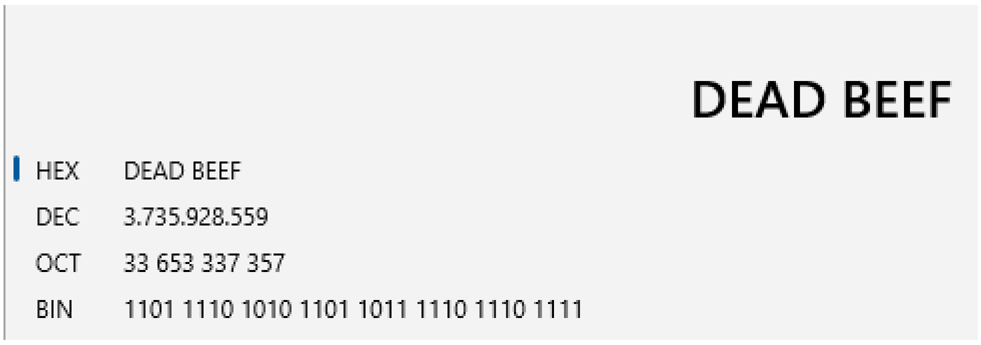
If a byte reaches its maximum value, meaning every bit is set to “1”, then: **2#**11111111 = 255 = **16#**FF

If we calculate: F, i.e., “15” * 16 + “15” = 255

In some ways, this can make our lives easier, because if we see a value of “**16#**FF” somewhere, or a longer series of these, for example “**16#**FFFF_FFFF”, then we can suspect that we have reached the maximum value of one of the variable types. I would also like to mention the 8-bit, i.e., octal number system, it sometimes still occurs here and there, for example, in the case of numerical symbols, but only rarely, we don’t really use it.

DEAD_BEEF

Just as *“FF”* is likely to represent the maximum of a given variable type, dead beef is a test value designation, a play on letters. The letters of the hexadecimal number system are a, b, c, d, e, f. #dead_beef contains all of them except c, so it is helpful for testing. The Windows calculator, switched to programmer mode, is very helpful for hex-dec-bin conversions. From this, it turns out that the value of **16#dead_beef** is:



DEAD BEEF

HEX	DEAD BEEF
DEC	3.735.928.559
OCT	33 653 337 357
BIN	1101 1110 1010 1101 1011 1110 1110 1111

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More information: TIA Datatypes: S7 data types summary table

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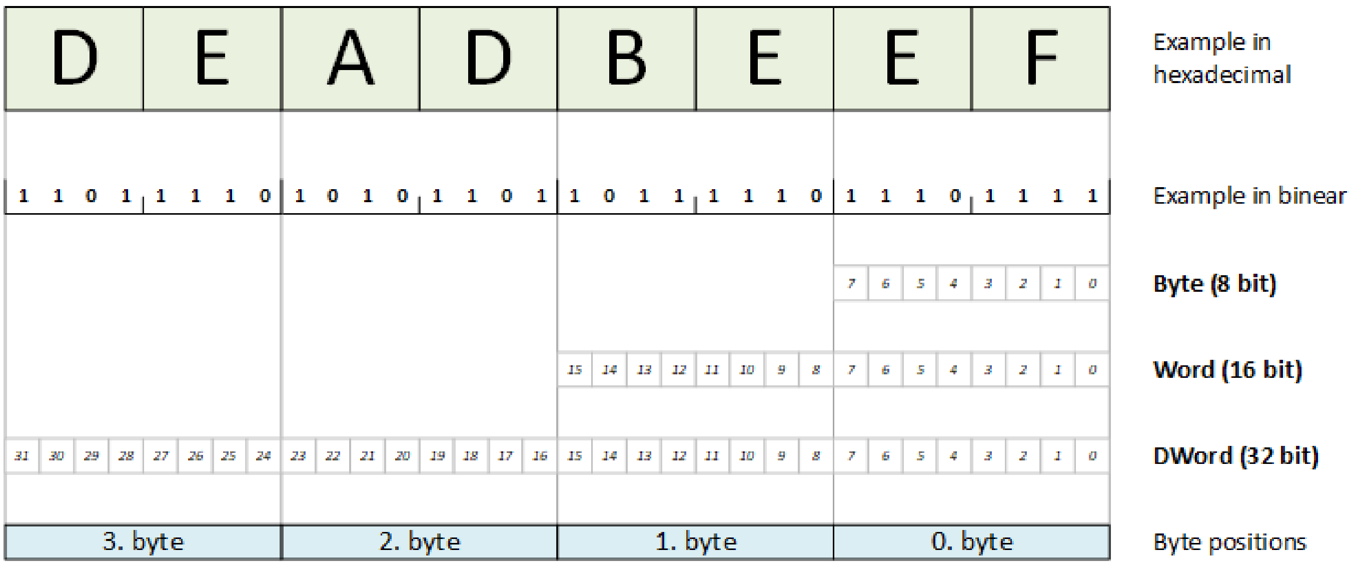
BYTE – WORD type variables

There are plenty of variables in the world of automation. They differ in scope (size) and internal structure depending on their use.

The simplest variable types have no internal structure, i.e., they can describe ones and zeros in different scopes:



The longest 64-bit LWord didn't fit in the example above, but I think it's relatively easy to imagine. The byte positions are on the bottom row. If everything works well, this is the byte order for the longer variable types, but sometimes confusion arises in the matrix, and this order gets *"tangled"*.

This most often happens when we try to transfer long variables via communication to other systems, such as HMI. In such cases, it is definitely worth testing the transfer, for example, with the above trick, because when the specified #deadbeef is on one side. If the destination side shows **#beefdead** or **#efbeadde**, we can rightly suspect a conversion discrepancy, which is easiest to correct on the starting side by swapping the structures.

The following types are unsigned (UNSIGNED), meaning their minimum value is always zero.

Let's review the basic variable types and their features:

Type	Bit	Min.	Max.	Value range HEX	Value range DEC
BYTE	8	0	2^{8}-1	0 .. FF	0 .. 255
WORD	16	0	2^{16}-1	0 .. FFFF	0 .. 65.535
DWORD	32	0	2^{32}-1	0 .. FFFF_FFFF	0 .. 4.294.967.295
LWORD	64	0	2^{64}-1	0 .. FFFF_FFFF_ FFFF_FFFF	0 .. 18.446.744.073.709.551.615

Any rules do not bind the contents of the above variables; they actually only contain some bit combinations. They can't have negative values by default; INT type variables are used for that.

More information: TIA Datatypes: S7 data types summary table

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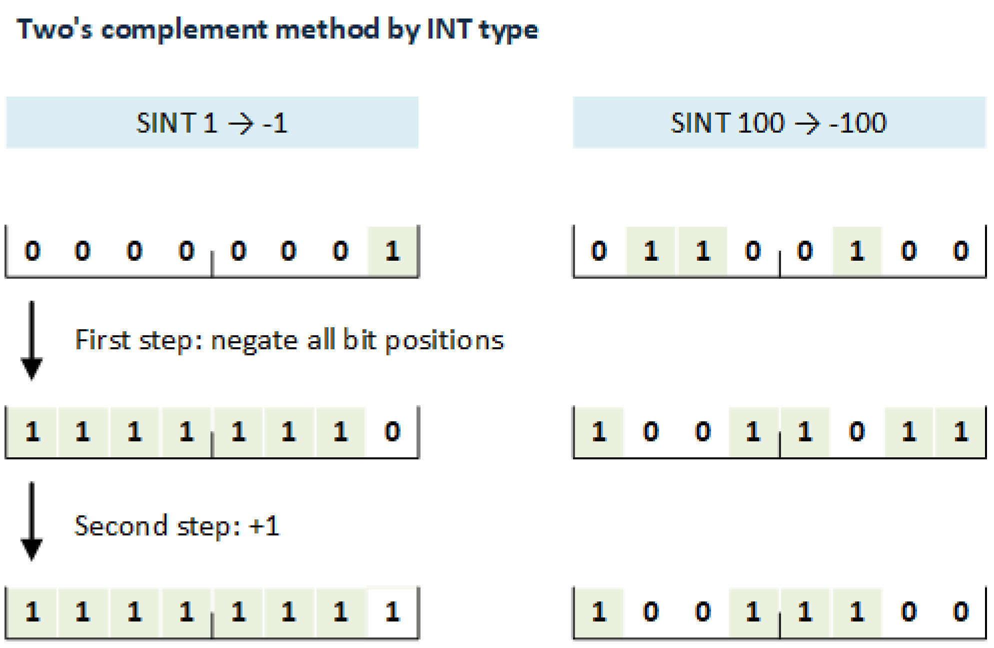
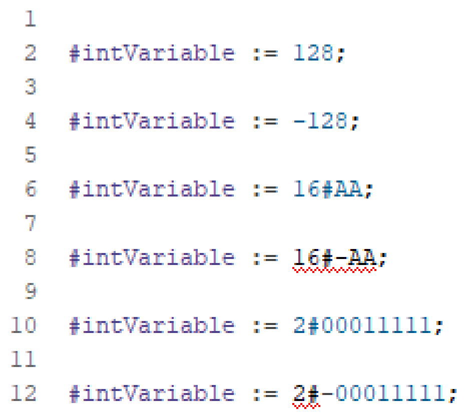
INT type variables

In the case of the INT, which is the integer type, the definition becomes slightly more complex in terms of formal constraints because of the introduction of the sign bit. This means that the highest value of the variable's position, the first bit on the left, will represent the sign: if it is “1”, the variable indicates a negative number, whereas if it is “0”, it indicates a positive one.

Really, just for completeness, in the case of negative numbers, the program uses the so-called *“two's complement”* representation. That is, it first negates all the bits of the numerical value, i.e., it converts 0 to 1 and vice versa, and then adds 1 to the resulting value. This conversion means that the negative value cannot be read directly from the bit combination unless the conversion is performed again in the opposite direction:



As a result, Simatic only uses binary and hexadecimal notations for positive numbers, meaning that negative hexadecimal or binary values will not show the actual numerical value but instead the value based on the bit pattern. For example, A, which equals ten, will still be 16#A, but -A, which equals -10, will be displayed in WORD format as FFF6. This misunderstanding is resolved by the rule that hexadecimal and binary signals cannot have negative values in Simatic:



```

#intVariable := 128;

#intVariable := -128;

#intVariable := 16#AA;

#intVariable := 16#-AA;

#intVariable := 2#00011111;

#intVariable := 2#-00011111;
```

In the above example, I tried to assign a value to an INT variable. It is clear that the compiler accepted the negative value when specified in decimal, but not when specified in hexadecimal or binary. Let's look at the contents of the INT variable in several forms:

DEC	SINT HEX (8-bit)	SINT BIN (8-bit)	INT HEX (16-bit)	INT BIN (16-bit)
12	16#7F	2#0111_1111	16#007F	2#0000_0000_0111_1111
1	16#01	2#0000_0001	16#0001	2#0000_0000_0000_0001
-1	16#FF	2#1111_1111	16#FFFF	2#1111_1111_1111_1111
-85	16#AB	2#1010_1011	16#FFAB	2#1111_1111_1010_1011
-128	16#80	2#1000_0000	16#FF80	2#1111_1111_1000_0000

The INT type is optimized for decimal handling; it can also be used in hexadecimal and binary forms, but in these cases, you need to pay close attention to the type's special characteristics.

Compared to byte and word type variables, this means that the maximum value of these variables is almost halved when dealing with decimal numbers. However, roughly the same magnitude can be used in the negative direction. For example, a one-byte-long SINT type will operate within the range -128 to 127, unlike the *"plain"* BYTE range of 0 to 255.

The letter "**S**" in the SINT definition stands for the word *"short"*, as the INT type is the default integer (16 bits), while SINT is short, with half the bit length—8 bits. The letter "**D**" represents the word *"double,"* with its 32 bits.

Type	Name	Bit	Minimum	Maximum	Value range HEX *	Value range DEC
SINT	short integer	8	$-(2^{7})$	$2^{7}-1$	0 .. 7F	-128 .. 127
INT	integer	16	$-(2^{15})$	$2^{15}-1$	0 .. 7FFF	-32.768 .. 32.767
DINT	double integer	32	$-(2^{31})$	$2^{31}-1$	0 .. 7FFF_FFFF	-2.147.483.648 .. +2.147.483.647
LINT	double long integer	64	$-(2^{63})$	$2^{63}-1$	0 .. 7FFF_FFFF_ FFFF_FFFF	-9.223.372.036.854.775.808 .. +9.223.372.036.854.775.807

* *Negative number ranges are not supported in hexadecimal and binary formats.*

UINT type variables

The unsigned UINT type (the letter **U** stands for unsigned) removes the hassle of dealing with negative values from the world of the INT type. It corresponds to basic types like BYTE, WORD, etc., in terms of value range, but with INT it indicates that we want to treat the contents of the variables as numeric values.

Type	Name	Bit	Minimum	Maximum	Value range HEX *	Value range DEC
USINT	unsigned short integer	8	0	2^{8}	0 .. FF	0 .. 255
UINT	unsigned integer	16	0	2^{16}	0 .. FFFF	0 .. 65.535

Type	Name	Bit	Minimum	Maximum	Value range HEX *	Value range DEC
UDINT	Unsigned double integer	32	0	2^{32}	0 .. FFFF_FFFF	0 .. 4.294.967.295
ULINT	Unsigned long integer	64	0	2^{64}	0 .. FFFF_FFFF_ FFFF_FFFF	0 .. 18.446.744.073.709.551.615

* *Negative number ranges are not supported in hexadecimal and binary formats.*

More information: TIA Datatypes: S7 data types summary table

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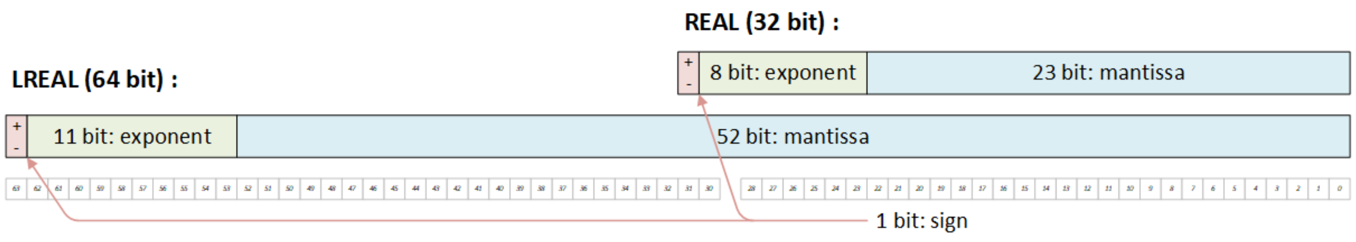
REAL type variables

REAL type variables (**REAL**, **LREAL**) are defined by the **IEEE 754** (*IEEE 754/1985 Floating Point Number Format*) standard. This is a fairly complex type that, despite its intimidating complexity, is well-suited for storing fractional numbers.

If you are interested in the definition of the type, please look it up on Wikipedia, for example, because I can't; I can't explain how this type works simply.



- **Sign**: The sign is determined by one bit (red color). This bit can be either “0” (positive) or “1” (negative).
- **Exponent**: The exponent ranges from 128 to -127.
- **Mantissa**: Only the mantissa is a fractional part of the overall value.

Type	Bit	Value range DEC
REAL	32	-3.402823e+38 .. -1.175 495e-38 .. +1.175 495e-38 .. +3.402823e+38
LREAL	64	-1.7976931348623158e+308 .. -2.2250738585072014e-308 .. +2.2250738585072014e-308 .. +1.7976931348623158e+308

In practice, REAL is suitable for handling fractions and large values. Due to its nature, it is mainly used for processing and evaluating measurements. It is important to note that, because of its structure, if a very large value is stored in it and we try to increase or decrease it by, say, a very small value, nothing will happen; the stored value will not change. The type is inherently not suitable for handling exact counters, since it handles numbers “in order of magnitude.“ INT is more appropriate for counting functions.

More information: TIA Datatypes: S7 data types summary table

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CHAR type variables

CHAR (*character*) types are suitable for storing a single letter each. The original CHAR uses codes from the ancient **ASCII** character mapping table. This table contains a mix of 255 different characters (letters, numbers, control characters, graphic symbols). Its advantage is that it requires only 1 byte, but its disadvantage is that the character set is quite limited; for example, Hungarian or Chinese accented characters are mostly excluded.

The extended version of CHAR is **WCHAR** (wide-character), which has a 2-byte length but can be used more broadly with its (**UNICODE**) *UCS-2* mapping. Up to 65,535 character mappings can be encoded with 16 bits; UNICODE does not fully utilize this range.

Type	**Name**	**Bit**	**Code table**	**Value range HEX**	**Value range DEC**	**Example**
CHAR	character	8	ASCII	0 .. FF	0 .. 255	'P', CHAR#'P'
WCHAR	Wide character	16	UCS-2	$0000 - $D7FF	0 .. 55.295	WCHAR#'Ő'

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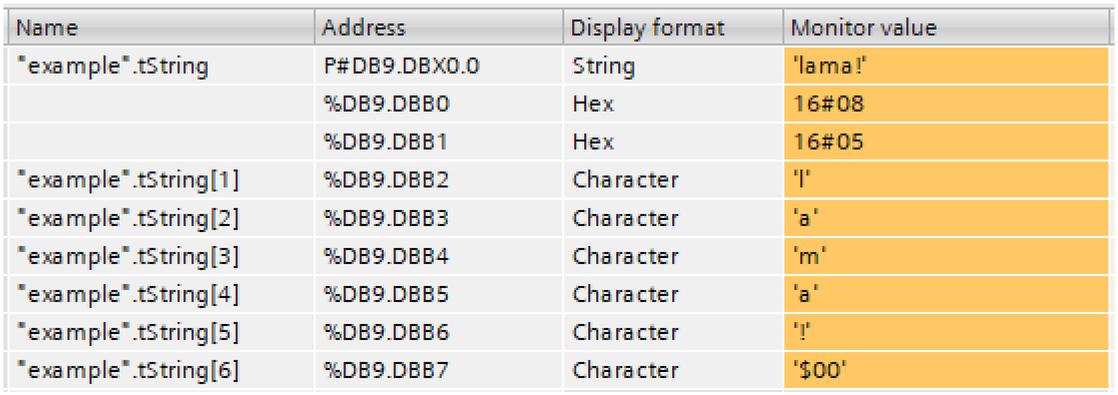
STRING type variables

STRING also has two subtypes, just like CHAR. The old, *“old-school”* STRING, which describes the text with ASCII characters, and WSTRING, which uses WCHAR characters with two bytes per character. Both types are suitable for storing text, which can be extremely useful for communication, especially in HMI connections.

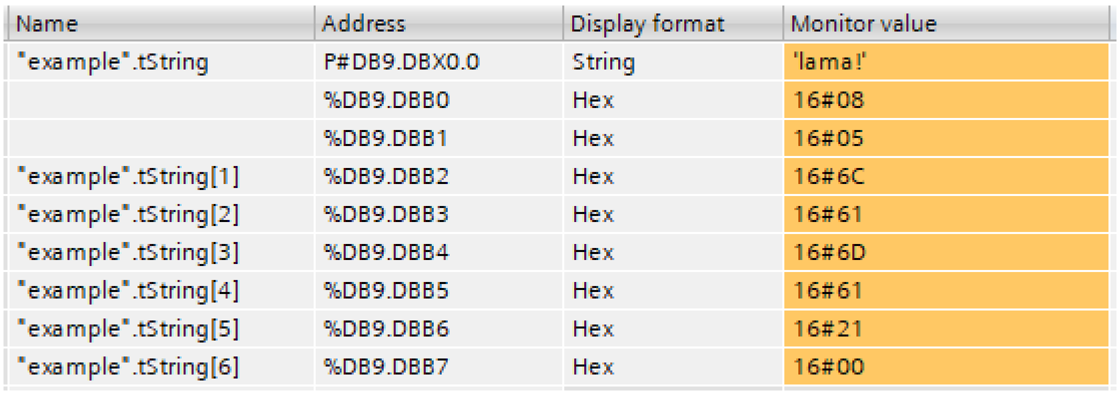
For both types, the first two positions show the maximum length of the given STRING and the current length it has been filled with. One position equals one byte for STRING, and one word for WSTRING.



Name	Address	Display format	Monitor value
"example".tString	P#DB9.DBX0.0	String	'lama!'
	%DB9.DBB0	Hex	16#08
	%DB9.DBB1	Hex	16#05
"example".tString[1]	%DB9.DBB2	Character	'l'
"example".tString[2]	%DB9.DBB3	Character	'a'
"example".tString[3]	%DB9.DBB4	Character	'm'
"example".tString[4]	%DB9.DBB5	Character	'a'
"example".tString[5]	%DB9.DBB6	Character	'!'
"example".tString[6]	%DB9.DBB7	Character	'$00'

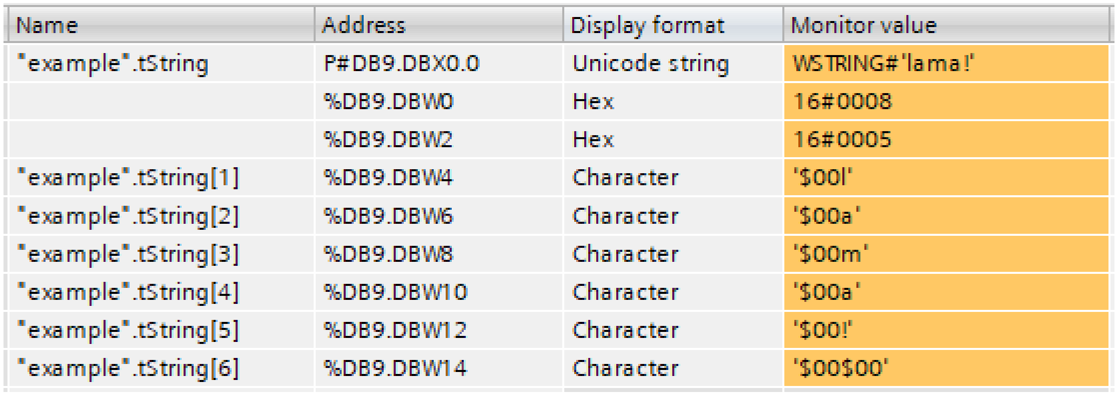
In the example above, taken from the PLC status, I entered the phrase “lama!” into an 8-byte STRING variable. The first two bytes contain the maximum length of the STRING (8) and the current length (5), followed by the phrase as our message.

If I change the display format to hexadecimal for the characters, I see the ASCII code for each letter.



Name	Address	Display format	Monitor value
"example".tString	P#DB9.DBX0.0	String	'lama!'
	%DB9.DBB0	Hex	16#08
	%DB9.DBB1	Hex	16#05
"example".tString[1]	%DB9.DBB2	Hex	16#6C
"example".tString[2]	%DB9.DBB3	Hex	16#61
"example".tString[3]	%DB9.DBB4	Hex	16#6D
"example".tString[4]	%DB9.DBB5	Hex	16#61
"example".tString[5]	%DB9.DBB6	Hex	16#21
"example".tString[6]	%DB9.DBB7	Hex	16#00

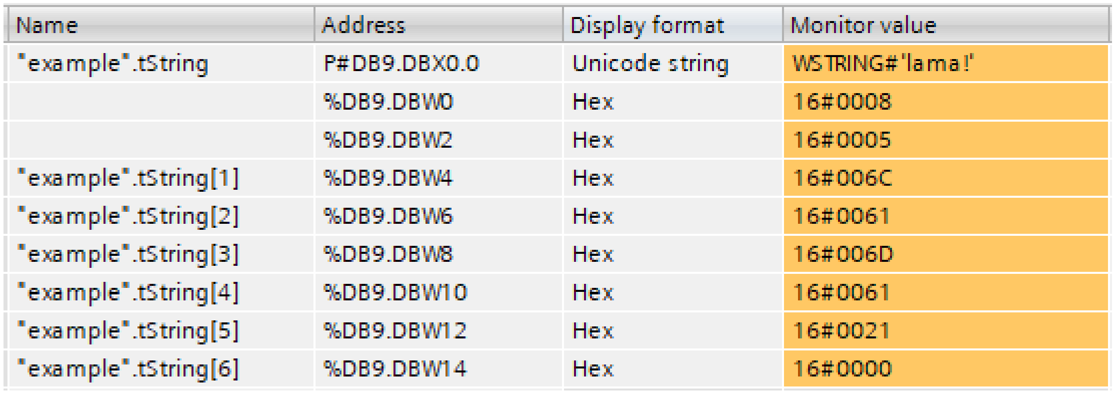
That is, the letter "l" is ASCII 16#6C, and "a" is ASCII 16#61, … For **WSTRING**, this assignment appears like this:



Name	Address	Display format	Monitor value
"example".tString	P#DB9.DBX0.0	Unicode string	WSTRING#'lama!'
	%DB9.DBW0	Hex	16#0008
	%DB9.DBW2	Hex	16#0005
"example".tString[1]	%DB9.DBW4	Character	'$00l'
"example".tString[2]	%DB9.DBW6	Character	'$00a'
"example".tString[3]	%DB9.DBW8	Character	'$00m'
"example".tString[4]	%DB9.DBW10	Character	'$00a'
"example".tString[5]	%DB9.DBW12	Character	'$00!'
"example".tString[6]	%DB9.DBW14	Character	'$00$00'

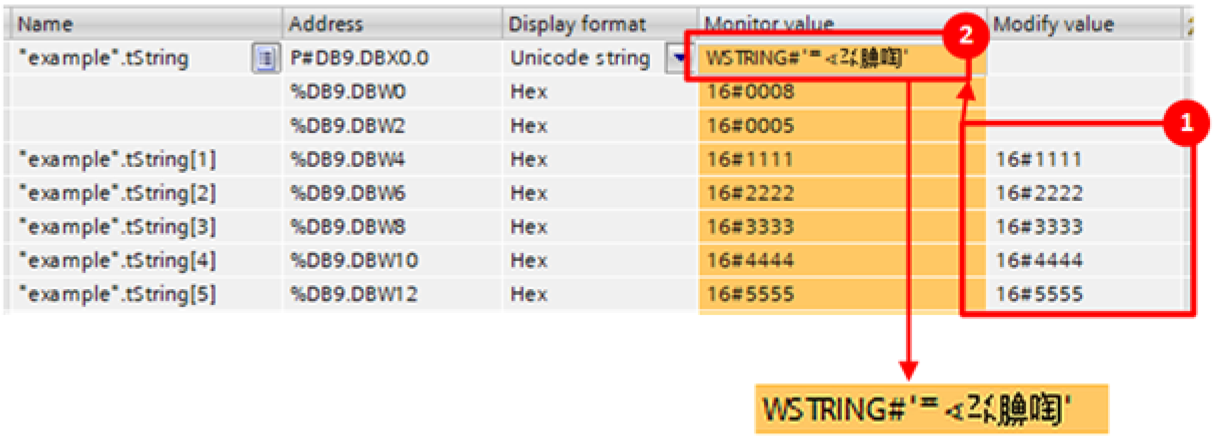
The *"$00l"* content type is due to the nature of UNICODE, as *"simple"* characters do not fill the entire UCS-2 space. It is clear that while we counted the positions per byte above, in this case each position occupies a word. The first two words here also contain the maximum length of the STRING (8) and the current length (5).

The same definition is given in hexadecimal form as follows:



Name	Address	Display format	Monitor value
"example".tString	P#DB9.DBX0.0	Unicode string	WSTRING#'lama!'
	%DB9.DBW0	Hex	16#0008
	%DB9.DBW2	Hex	16#0005
"example".tString[1]	%DB9.DBW4	Hex	16#006C
"example".tString[2]	%DB9.DBW6	Hex	16#0061
"example".tString[3]	%DB9.DBW8	Hex	16#006D
"example".tString[4]	%DB9.DBW10	Hex	16#0061
"example".tString[5]	%DB9.DBW12	Hex	16#0021
"example".tString[6]	%DB9.DBW14	Hex	16#0000

If we fully fill in the UCS-2 word field, we can see what the *"non-simple characters"* look like. In the first step, I entered longer codes in the word variables per character (1), and from this the "example" WSTRING (2) was displayed:



Name	Address	Display format	Monitor value	Modify value
"example".tString	P#DB9.DBX0.0	Unicode string	WSTRING#'=⊲²⟨鵬㖿'	
	%DB9.DBW0	Hex	16#0008	
	%DB9.DBW2	Hex	16#0005	
"example".tString[1]	%DB9.DBW4	Hex	16#1111	16#1111
"example".tString[2]	%DB9.DBW6	Hex	16#2222	16#2222
"example".tString[3]	%DB9.DBW8	Hex	16#3333	16#3333
"example".tString[4]	%DB9.DBW10	Hex	16#4444	16#4444
"example".tString[5]	%DB9.DBW12	Hex	16#5555	16#5555

To sum it all up:

Type	**Length**	**Character encoding**	**Length (characters)**	**Example**
STRING	2 byte + text	CHAR, ASCII	0 .. 254 byte / character	'lamaPLC', STRING#'lamaPLC'
WSTRING	2 word + text	WCHAR, UNICODE	0 .. 16382 word / character	WSTRING#lamaPLC

More information: TIA Datatypes: S7 data types summary table

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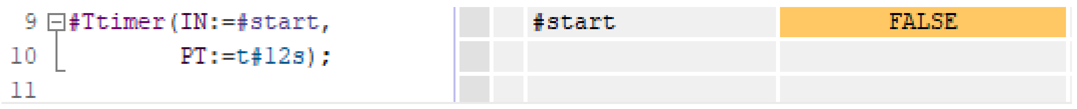
TIME type variables

TIME types mainly serve for timing purposes. The most common type in programs is simple TIME, such as in connection with IEC timings, like this:



```
#Ttimer(IN:=#start,
        PT:=t#12s);
```

#start	FALSE

These will be discussed later, but in the example above, the time (PT) is specified in TIME format, with 12 seconds written as **t#12s**.

TIME is a DINT type variable that stores time in 32 bits, measured in milliseconds. The stored value can be positive or negative, and the rules for negative integers apply, meaning negative TIME values cannot be represented in hexadecimal or binary form.

The same rules apply to the LTIME type, but it stores nanoseconds in an LINT variable, using 64 bits. Interestingly, the maximum value of LTIME is 106,751 days, or about 292 years.

The S5TIME type was included among the variables for downward compatibility; it was the default (and only) time type during the S5 PLC era.

Type	Length (form)	Value Range HEX	Value Range DEC	Example
TIME	32 bit (DINT)	0 .. 7FFF_FFFF	T#-24d20h31m23s648ms .. T#+24d20h31m23s647ms	T#12s, 16#ABCD
LTIME	64 bit (LINT)	0 .. 7FFF_FFFF_FFFF_FFFF	LT#-106751d23h47m16s 854ms775us808ns .. LT#+106751d23h47m16s 854ms775us807ns LT#12s	LTIME#12s, 16#ABCD
S5TIME	16 bit		S5T#0H_0M_0S_0MS .. S5T#2H_46M_30S_0MS	S5T#10s, S5TIME#10s

More information:
TIA Datatypes: S7 data types summary table

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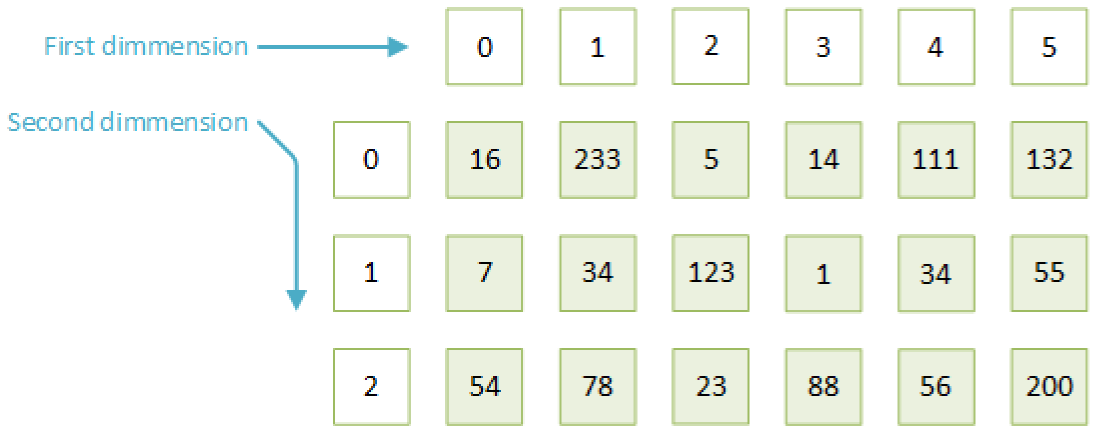
Array

An **array** is used to group data of the same type into blocks that can be easily addressed, i.e., indexed.

Arrays can be 1-, 2-, or 3-dimensional, or even 6-dimensional. The following example illustrates the structure of 2- and 3-dimensional arrays:



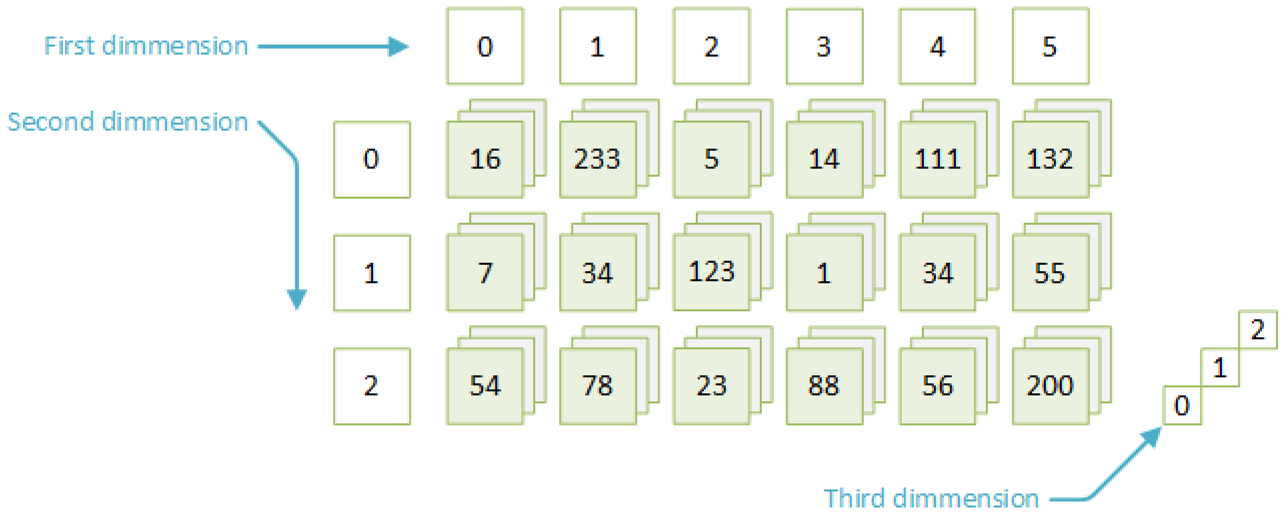
The image above displays a two-dimensional array of type “byte.” The first index represents the rows, while the second represents the columns. The value range of a byte is 0 to 255, so only values within this range are allowed. In the example above, the program's type definition is as follows:

```
arry : Array[0..5, 0..2] of Byte;
```

The assignment is displayed in the code like this:

```
tomb[3, 1] := 1;
```

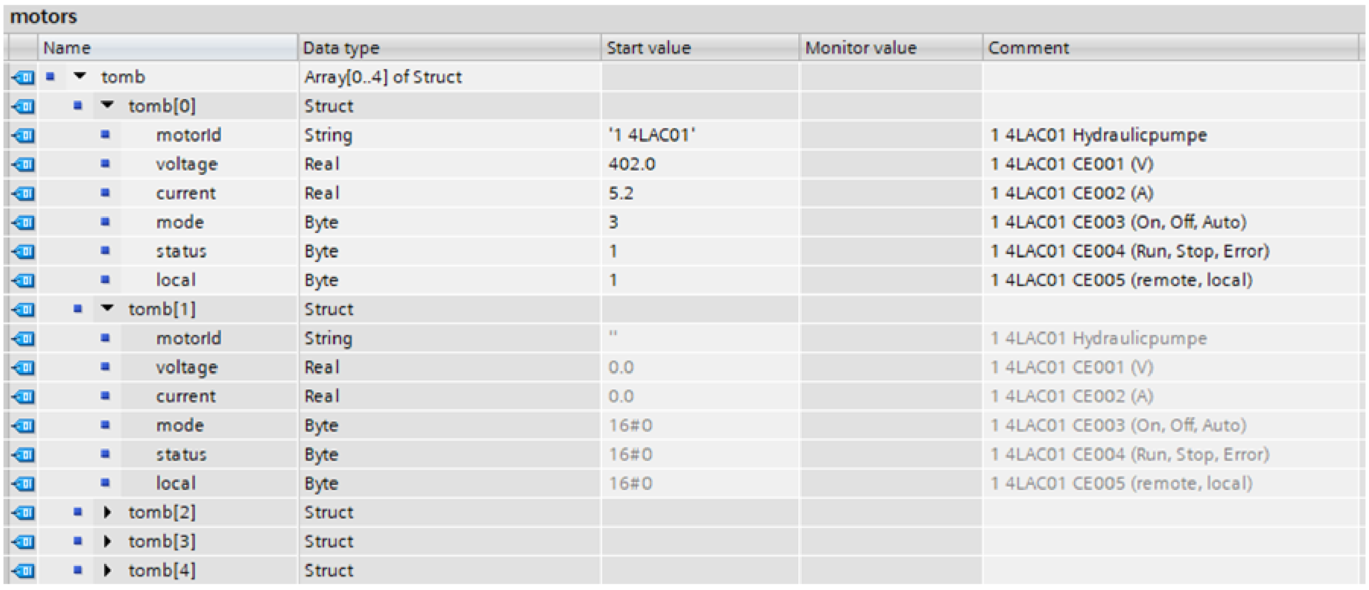
The indexing of a three-dimensional array can be illustrated as follows:



In this case, the above assignment can be defined in the program as follows:

```
tomb[3, 1, 0] := 1;
```

The elements of the array are always homogeneous, meaning their types cannot vary. However, there can be multiple instances of a single type within a single array if we define a Struct type as an array element. The hydraulic motors described as an example in Struct can also be defined as an array:



motors

Name	Data type	Start value	Monitor value	Comment
tomb	Array[0..4] of Struct			
tomb[0]	Struct			
motorId	String	'1 4LAC01'		1 4LAC01 Hydraulicpumpe
voltage	Real	402.0		1 4LAC01 CE001 (V)
current	Real	5.2		1 4LAC01 CE002 (A)
mode	Byte	3		1 4LAC01 CE003 (On, Off, Auto)
status	Byte	1		1 4LAC01 CE004 (Run, Stop, Error)
local	Byte	1		1 4LAC01 CE005 (remote, local)
tomb[1]	Struct			
motorId	String	''		1 4LAC01 Hydraulicpumpe
voltage	Real	0.0		1 4LAC01 CE001 (V)
current	Real	0.0		1 4LAC01 CE002 (A)
mode	Byte	16#0		1 4LAC01 CE003 (On, Off, Auto)
status	Byte	16#0		1 4LAC01 CE004 (Run, Stop, Error)
local	Byte	16#0		1 4LAC01 CE005 (remote, local)
tomb[2]	Struct			
tomb[3]	Struct			
tomb[4]	Struct			

In this case, I specified the type of the four-element array as “Struct”. Here, a field opens under the name of the first array element (tomb[0]), where the Struct's elements can be defined. It is important that the array is homogeneous, meaning the structure can only be set for the first element; the other elements will be copies of it without the ability to modify the structure (values, of course, can change). In the example above, the value assignment will look like this (the DB name is *“motors”*):

```
"motors".tomb[1].current := 32.2;
```

More information:
TIA Datatypes: S7 data types summary table

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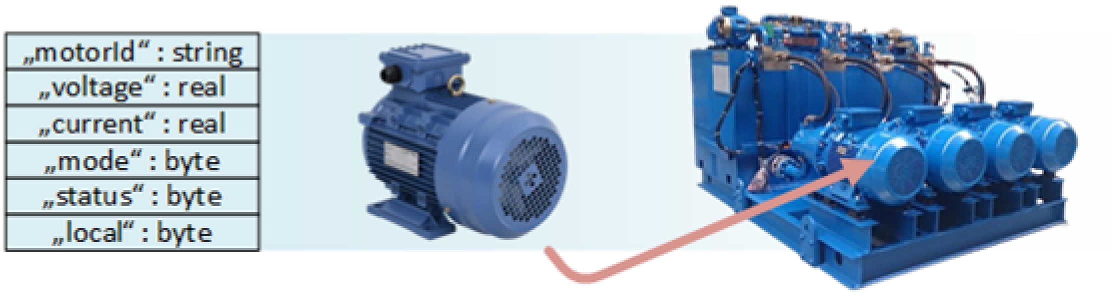
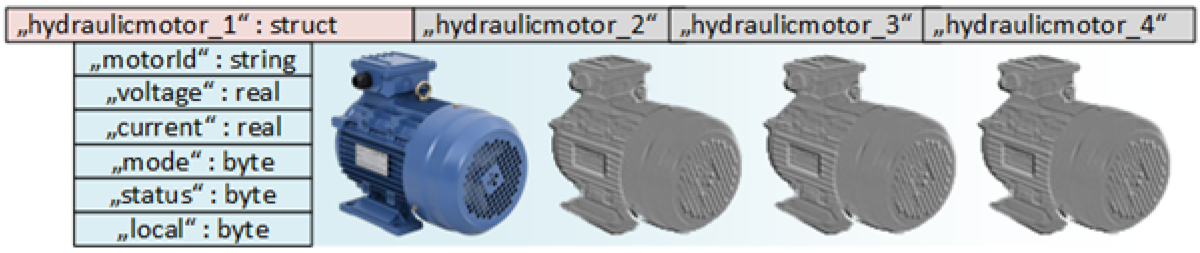
Structure

A structure is a way of organizing multiple variables, often of different types, into a group. For example, the characteristics of several devices, such as motors, can be described using the same data groups.

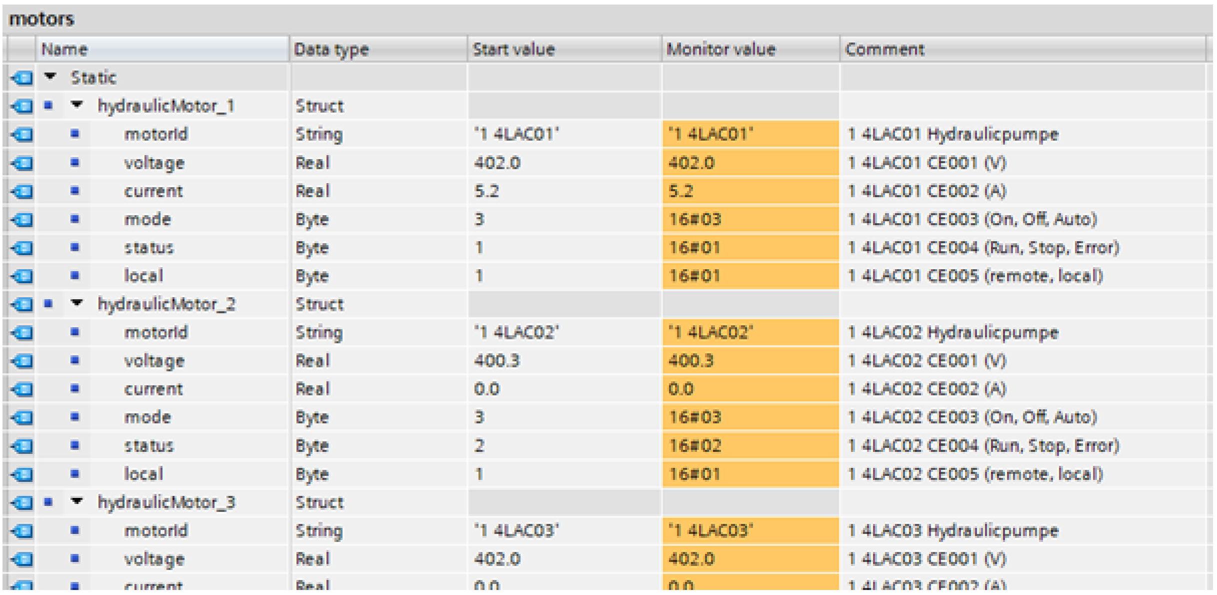
Take an electric motor, for instance. Such a motor can have many technical parameters, but for simplicity, let's narrow down the range of these parameters.



In this case, the motor has a text identifier, typically a KKS identifier in larger installations. Then there are voltage and current measurements, an operating mode, and a status indication. These data belong together and describe a motor. In the example above, this motor is, for example, the first motor of a hydraulic block. In the case of multiple motors, this structure remains—only the parameters change, as this makes it easy to handle the data uniformly:



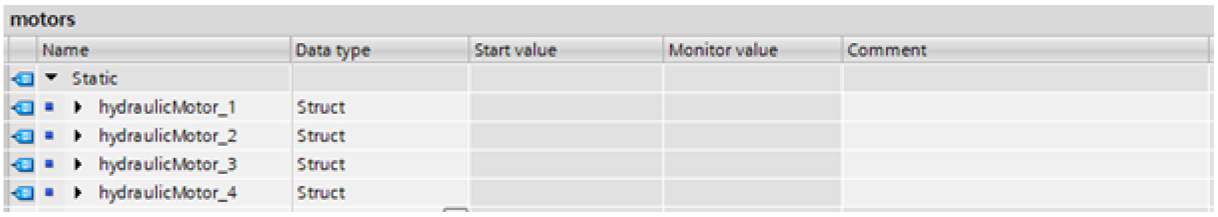
This is what it looks like in the TIA Portal when the structures are open:



motors

Name	Data type	Start value	Monitor value	Comment
Static				
hydraulicMotor_1	Struct			
motorId	String	'1 4LAC01'	'1 4LAC01'	1 4LAC01 Hydraulicpumpe
voltage	Real	402.0	402.0	1 4LAC01 CE001 (V)
current	Real	5.2	5.2	1 4LAC01 CE002 (A)
mode	Byte	3	16#03	1 4LAC01 CE003 (On, Off, Auto)
status	Byte	1	16#01	1 4LAC01 CE004 (Run, Stop, Error)
local	Byte	1	16#01	1 4LAC01 CE005 (remote, local)
hydraulicMotor_2	Struct			
motorId	String	'1 4LAC02'	'1 4LAC02'	1 4LAC02 Hydraulicpumpe
voltage	Real	400.3	400.3	1 4LAC02 CE001 (V)
current	Real	0.0	0.0	1 4LAC02 CE002 (A)
mode	Byte	3	16#03	1 4LAC02 CE003 (On, Off, Auto)
status	Byte	2	16#02	1 4LAC02 CE004 (Run, Stop, Error)
local	Byte	1	16#01	1 4LAC02 CE005 (remote, local)
hydraulicMotor_3	Struct			
motorId	String	'1 4LAC03'	'1 4LAC03'	1 4LAC03 Hydraulicpumpe
voltage	Real	402.0	402.0	1 4LAC03 CE001 (V)
current	Real	0.0	0.0	1 4LAC03 CE002 (A)

The display of structures can be limited to just their names, with an arrow placed in front of the name to close the content:



motors

Name	Data type	Start value	Monitor value	Comment
Static				
hydraulicMotor_1	Struct			
hydraulicMotor_2	Struct			
hydraulicMotor_3	Struct			
hydraulicMotor_4	Struct			

More information:
TIA Datatypes: S7 data types summary table

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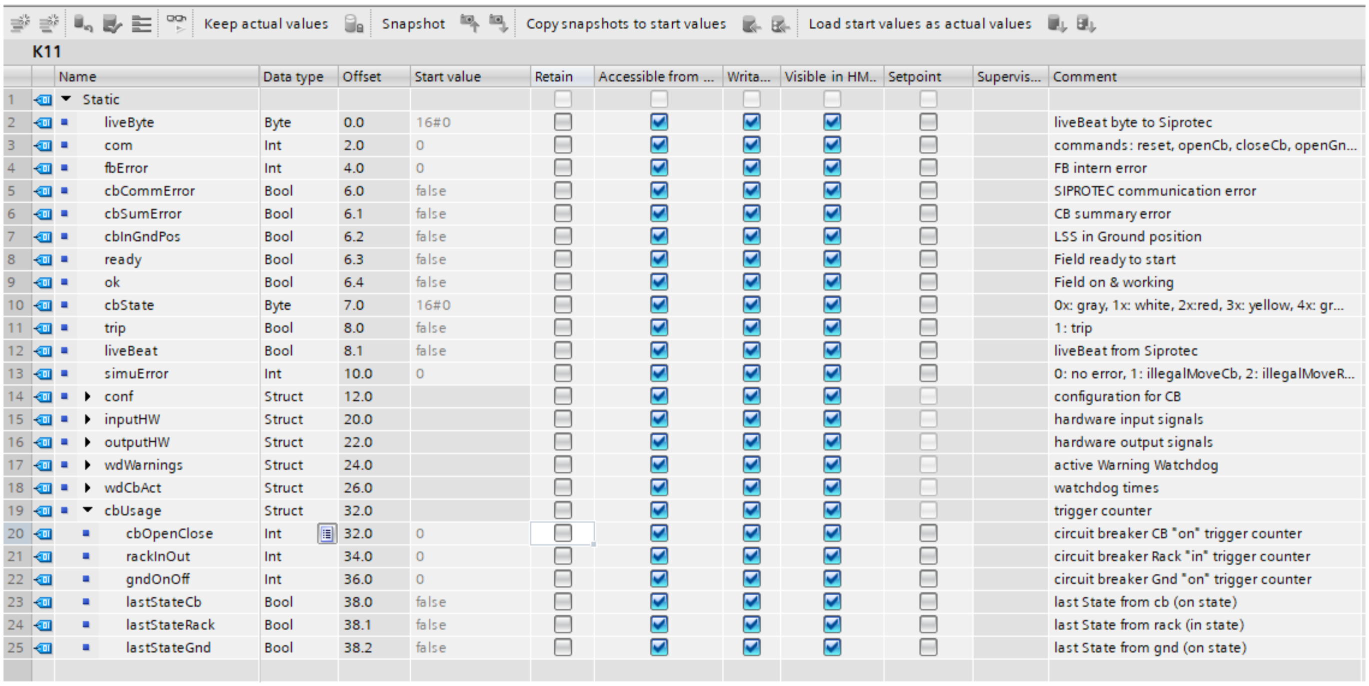
Data block (DB)

“DB” stands for DATA_BLOCK or the German term “Datenbaustein', indicating a data area. It can contain various data types permitted and defined by the specific PLC. The total size of all DBs is limited by the PLC's data capacity. Since the PLC isn't optimized for storing large data, we do not save images, music, files, or extensive text files within a DB. In the TIA-Portal, DBs are marked with a small blue barrel icon ( ). The image below shows the contents of a DB, along with some settings:


Keep actual values
Snapshot
Copy snapshots to start values
Load start values as actual values

K11

	Name	Data type	Offset	Start value	Retain	Accessible from ...	Writa...	Visible in HM...	Setpoint	Supervis...	Comment
1	▼ Static				☐	☐	☐	☐	☐		
2	liveByte	Byte	0.0	16#0	☐	✓	✓	✓	☐		liveBeat byte to Siprotec
3	com	Int	2.0	0	☐	✓	✓	✓	☐		commands: reset, openCb, closeCb, openGn...
4	fbError	Int	4.0	0	☐	✓	✓	✓	☐		FB intern error
5	cbCommError	Bool	6.0	false	☐	✓	✓	✓	☐		SIPROTEC communication error
6	cbSumError	Bool	6.1	false	☐	✓	✓	✓	☐		CB summary error
7	cbInGndPos	Bool	6.2	false	☐	✓	✓	✓	☐		LSS in Ground position
8	ready	Bool	6.3	false	☐	✓	✓	✓	☐		Field ready to start
9	ok	Bool	6.4	false	☐	✓	✓	✓	☐		Field on & working
10	cbState	Byte	7.0	16#0	☐	✓	✓	✓	☐		0x: gray, 1x: white, 2x:red, 3x: yellow, 4x: gr...
11	trip	Bool	8.0	false	☐	✓	✓	✓	☐		1: trip
12	liveBeat	Bool	8.1	false	☐	✓	✓	✓	☐		liveBeat from Siprotec
13	simuError	Int	10.0	0	☐	✓	✓	✓	☐		0: no error, 1: illegalMoveCb, 2: illegalMoveR...
14	▶ conf	Struct	12.0		☐	✓	✓	✓	☐		configuration for CB
15	▶ inputHW	Struct	20.0		☐	✓	✓	✓	☐		hardware input signals
16	▶ outputHW	Struct	22.0		☐	✓	✓	✓	☐		hardware output signals
17	▶ wdWarnings	Struct	24.0		☐	✓	✓	✓	☐		active Warning Watchdog
18	▶ wdCbAct	Struct	26.0		☐	✓	✓	✓	☐		watchdog times
19	▼ cbUsage	Struct	32.0		☐	✓	✓	✓	☐		trigger counter
20	cbOpenClose	Int	32.0	0	☐	✓	✓	✓	☐		circuit breaker CB "on" trigger counter
21	rackInOut	Int	34.0	0	☐	✓	✓	✓	☐		circuit breaker Rack "in" trigger counter
22	gndOnOff	Int	36.0	0	☐	✓	✓	✓	☐		circuit breaker Gnd "on" trigger counter
23	lastStateCb	Bool	38.0	false	☐	✓	✓	✓	☐		last State from cb (on state)
24	lastStateRack	Bool	38.1	false	☐	✓	✓	✓	☐		last State from rack (in state)
25	lastStateGnd	Bool	38.2	false	☐	✓	✓	✓	☐		last State from gnd (on state)

The columns are as follows:

Column	Desription
Name	The name of the variable within the DB. The variable names are unique, and the DB name is displayed in the upper-left corner, in this case: *K11*. The variable names are supplemented with this, e.g., *"K11".liveByte*. This also means that the DB can be copied and renamed one-for-one. That is, if this DB is copied and renamed to, for example, "K12", the above reference will be *"K12".liveByte*. In the case of a structure, for example, "*cbUsage*", the entire structure depth must be defined, for example: *"K11".cbUsage.cbOpenClose*.
Data type	The data type. Structures and arrays must be created when defining the DB by entering, for example, type Struct in the Data type field.
Offset	The offset of the variable within the DB. This appears only for non-optimized DBs. More details: optimized DB
Start value	The starting value of the given variables, which the PLC takes on when restarting. The default value can be overwritten in the cell.
Retain	Values to be retained when restarting. It can only be set for the entire DB, so it is worth grouping the values to be stored in a DB
Accessible from HMI/OPC UA/Web API	The value is accessible from external applications. For structures and arrays, the setting can only be defined for the entire block. OPC access can be enabled/disabled in the settings, see DB Properties.
Writable from HMI/OPC UA/Web API	The given value can be written from external applications.
Visible in HMI engineering	The setting disables or enables the HMI integration of the variable. In addition to disabling HMI, OPC can also be enabled, see DB Properties.
Setpoint	This allows you to initialize values in a data block (DB) online while the CPU is in RUN mode.
Comment	Description of the function of the field.

DB Limits

- You can define up to 252 structures within a single data block for S7-1200/S7-1500, regardless

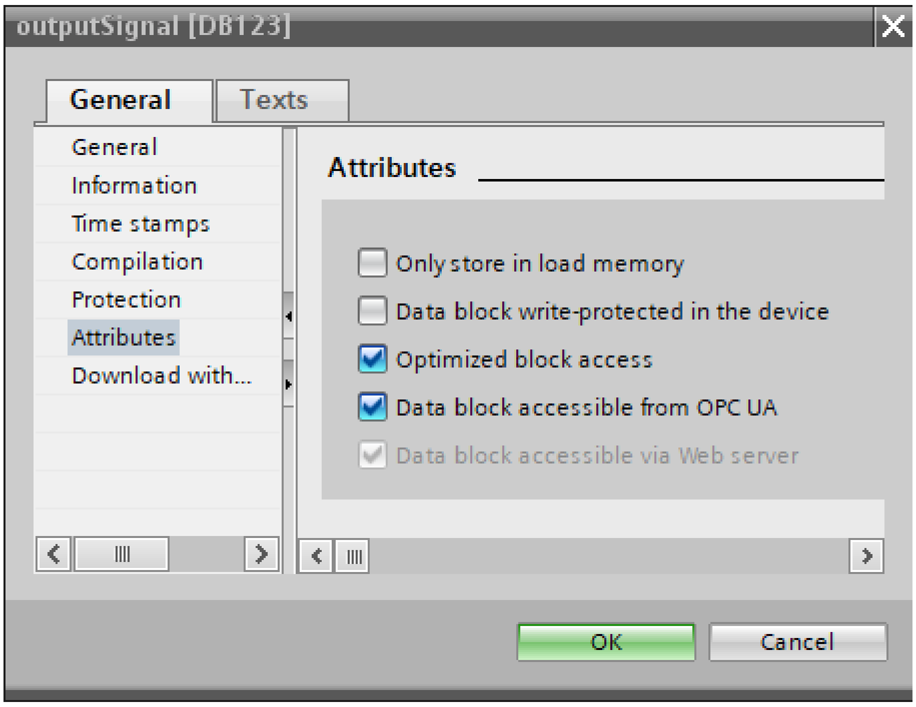
of the data types used in the structures.
- Maximum DB Number: The total number of data blocks is generally capped at 65,535, due to the common use of a 16-bit address range.
- Maximum DB Size (Standard - not optimized - Access): For older PLC models like S7-300/400 and for standard access DBs in newer models, each DB's size typically does not exceed 64 KB (65,534 bytes).
- Maximum DB Size (Optimized Access): In contrast, S7-1200/S7-1500 CPUs that utilize optimized access have a much larger size limit, which varies based on the CPU's total working memory and can reach from 1 MB up to 10 MB or more per DB.

Instant vs global DB

A **global DB** is a data block that programmers can freely create and populate with variables. These variables may include default Simatic types (INT, REAL, etc.), structures, arrays, or UDTs.

Instant DBs are implicitly created when FBs are called for the first time. This call is primarily through the instant DB. When an FB is deleted, the TIA Portal also issues a separate warning about removing the instant DB. The contents of the instant DB automatically update with changes to the FB's variable list. It can include default Simatic variables like INT, REAL, structures, arrays, and UDTs. If the FB calls other embedded FBs (e.g., TON, TOF), their instant DBs are also stored here, resulting in a **multi-instant DB**.

DB Properties


outputSignal [DB123]

Attributes

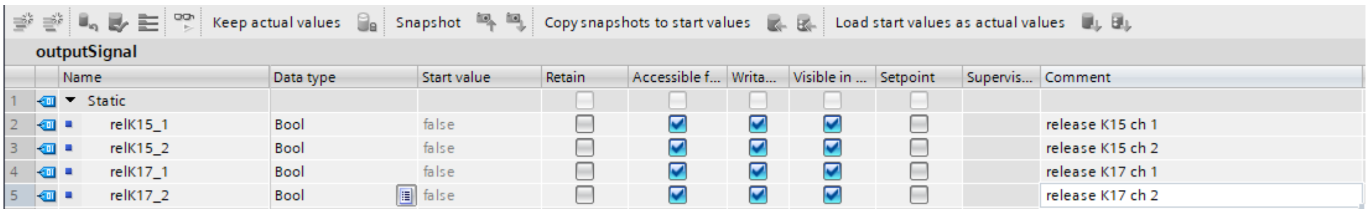
[ ] Only store in load memory
[ ] Data block write-protected in the device
[✓] Optimized block access
[✓] Data block accessible from OPC UA
[✓] Data block accessible via Web server

(*right-click on the DB → Properties..*)

Name the attribut	**Description**
Only store in load memory	This attribute is stored on the PLC's Micro Memory Card (MMC) or similar non-volatile storage, not in the CPU's working RAM, making it ideal for large, infrequently used data such as recipes or logs. It's accessed using special instructions like READ_DBL or WRIT_DBL to transfer data to/from working memory. This preserves precious working memory, but requires explicit programming to move data for active processing. The data survives power cycles but can be lost with a factory reset.
Data block write-protected in the device	Make the entire data block read-only.
Optimized block access	Optimized variable order within the DB. See below: Optimized DB.
Data block accessible from OPC UA	The data block can be accessed and published by OPC UA. See: OPC UA.

Optimized DB

Simatic groups variables in the optimized DB so they occupy as little storage space as possible. This means that it is “not visible from the outside” where a given data item is located within the storage space, i.e., in this case, the offset is not displayed in the editor window:


Keep actual values
Snapshot
Copy snapshots to start values
Load start values as actual values

outputSignal

	Name	Data type	Start value	Retain	Accessible f...	Writa...	Visible in ...	Setpoint	Supervis...	Comment
1	Static			☐	☐	☐	☐	☐		
2	relK15_1	Bool	false	☐	✓	✓	✓	☐		release K15 ch 1
3	relK15_2	Bool	false	☐	✓	✓	✓	☐		release K15 ch 2
4	relK17_1	Bool	false	☐	✓	✓	✓	☐		release K17 ch 1
5	relK17_2	Bool	false	☐	✓	✓	✓	☐		release K17 ch 2

On the one hand, this helps better utilize the PLC's storage space. Still, on the other hand, it makes operations that require direct addressing (communication modules - Modbus, direct addressing, etc.) impossible. In such cases, this option must be disabled in the settings (*right-click on the DB → Properties.. → Attributes → Optimized block access → OFF*)

Tags vs DB data

There are two basic methods for storing data in PLCs (in a simplified view). One involves placing variables in a global memory table alongside input and output variables, while the other uses data blocks (DBs). From my experience, storing data in DBs tends to be simpler and more straightforward for several reasons.

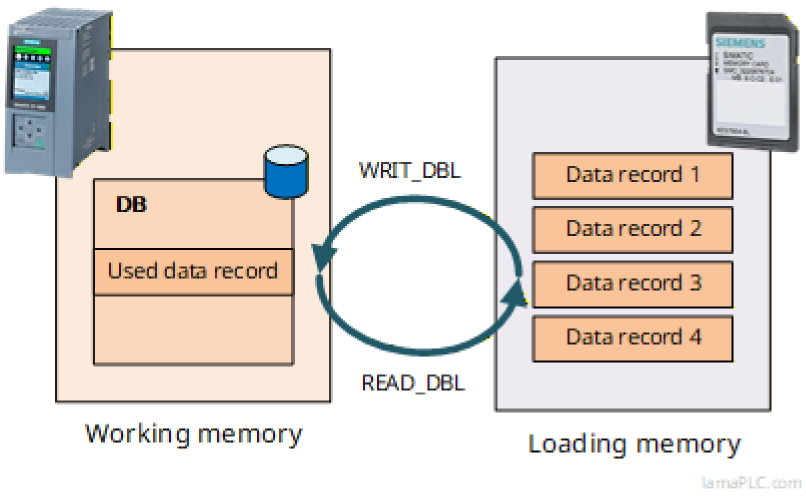
- Function-specific data can be stored in DBs. For example, the “motor1” DB contains only data for the 1st motor, but all of them (speed, load, temperature, on-off, errors, …)
- If someone wants to define a “motor2” as well, identical to “motor1” in terms of its parameters, they just need to copy the previous DB
- Cross-reference management of data immediately points to the given DB, from which we can immediately deduce their function
- If the data is already in the instant DBs assigned to the FBs, it is easy to embed them in a calling FB to use them as multi-instants.

Typically, I don't bother defining variables within the Tags; creating them directly in the databases suffices—though this is just my personal preference.

Storing DB records in the load memory

In PLCs, working memory is PLC-dependent and often very limited. We may have a lot of information that does not need to be read and written cyclically. Examples include recipe data (a list of technological components), parameter data, or database assignments that are needed only occasionally.

In these cases, one option is to store the data not in working memory but on the SD card and in load memory, and to transfer them only when needed using the “WRIT_DBL” and “READ_DBL” operations.



More information:
TIA Datatypes: S7 data types summary table

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TIA Datatypes

List of data types used by Simatic S7. The page contains the more modern TIA variable types as well as the earlier S7-classic types.

There are four data types in: Boolean, Text, Numeric, and Date/Time. Each data type defines the format of information that can be entered into a data field and stored in your database.

Datatyp	Width (bits)	Range of values	Examples	S7-300/400	S7-1200	S7-1500
Binaries						
BOOL (x) →details	1 (S7-1500 optimized 1 Byte)	FALSE or TRUE BOOL#0 or BOOL#1 BOOL#FALSE oder BOOL#TRUE	TRUE BOOL#1 BOOL#TRUE	X	X	X

Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
BYTE (b) →details	8	B#16#00 .. B#16#FF 0 .. 255 2#0 .. 2#11111111	15, BYTE#15, B#15	X	X	X
WORD (w) →details	16	W#16#0000 .. W#16#FFFF 0 .. 65.535 B#(0, 0) .. B#(255, 255)	55555, WORD#55555, W#555555	X	X	X
DWORD (dw) →details	32	DW#16#0000 0000 .. DW#16#FFFF FFFF 0 .. 4,294,967,295	DW#16#DEAD BEEF B#(111, 222, 255, 200)	X	X	X
LWORD (lw) →details	64	LW#16#0000 0000 0000 0000 .. LW#16#FFFF FFFF FFFF FFFF 0 .. 18.446.744.073.709.551.615	LW#16#DEAD BEEF DEAD BEEF B#(111, 222, 255, 200, 111, 222, 255, 200)	-	-	X
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
Integers						
SINT (si) →details	8	-128 .. 127 (hex only positive) 16#0 .. 16#7F	+42, SINT#+42 16#1A, SINT#16#2A	-	X	X
INT (i) →details	16	-32.768 .. 32.767 (hex only positive) 16#0 .. 16#7FFF	+1234, INT#+3221 16#1ABC	X	X	X
DINT (di) →details	32	-2.147.483.648 .. +2.147.483.647 (hex only positive) 16#00000000 .. 16#7FFFFFFF	123456, DINT#123.456, 16#1ABC BEEF	X	X	X
USINT (usi) →details	8	0 .. 255 16#00 .. 16#FF	42, USINT#42 16#FF	-	X	X
UINT (ui) →details	16	0 .. 65.535 16#0000 .. 16#FFFF	12.345, UINT#12345 16#BEEF	-	X	X
UDINT (udi) →details	32	0 .. 4.294.967.295 16#00000000 .. 16#FFFF FFFF	1.234.567.890, UDINT#1234567890	-	X	X
LINT (li) →details	64	-9.223.372.036.854.775.808 .. +9.223.372.036.854.775.807	+1.234.567.890.123.456.789, LINT#+1.234.567.890.123.456.789	-	-	X
ULINT (uli) →details	64	0 .. 18.446.744.073.709.551.615	123.456.789.012.345, ULINT#123.456.789.012.345	-	-	X
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
floating point numbers						
REAL ® →details	32	-3.402823e+38 .. -1.175 495e-38 .. +1.175 495e-38 .. +3.402823e+38	0.0, REAL#0.0 1.0e-13, REAL#1.0e-13	X	X	X
LREAL (lr) →details	64	-1.7976931348623158e+308 .. -2.2250738585072014e-308 .. +2.2250738585072014e-308 .. +1.7976931348623158e+308	0.0, LREAL#0.0	-	X	X
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
Times						
S5TIME (s5t) →details	16	S5T#0H_0M_0S_0MS .. S5T#2H_46M_30S_0MS	S5T#10s, S5TIME#10s	X	-	X
TIME (t) →details	32	T#-24d20h31m23s648ms .. T#+24d20h31m23s647ms	T#13d14h15m16s630ms, TIME#1d2h3m4s5ms	X	X	X
LTIME (lt) →details	64	LT#-106751d23h47m16s854ms775us808ns .. LT#+106751d23h47m16s854ms775us807ns	LT#1000d10h15m24s130ms152us15ns, LTIME#200d2h2m1s8ms652us315ns	-	-	X
Timer operations: **IEC timers**, **TON** (Generate on-delay), **TOF** (Generate off-delay), **TP** (Generate pulse), **TONR** (Time accumulator)						
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
Counters						
CHAR →details	8	ASCII character set	'A', CHAR#'A'	X	X	X
WCHAR (wc) →details	16	Unicode character set	WCHAR#'A'	-	X	X
STRING (s) →details	n+2 (Byte)	0 .. 254 characters (n)	'Name', STRING#'lamaPLC'	X	X	X
WSTRING (ws) →details	n+2 (Word)	0 .. 16382 characters (n)	WSTRING#'lamaPLC'	-	X	X
Counter operations: **CTU** (count up), **CTD** (count down), **CTUD** (count up and down)						
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
Date & time						
DATE (d) →details	16	D#1990-01-01 .. D#2168-12-31	D#2020-08-14, DATE#2020-08-14	X	X	X
TOD (tod) (TIME_OF_DAY) →details	32	TOD#00:00:00.000 .. TOD#23:59:59.999	TOD#11:22:33.444, TIME_OF_DAY#11:22:33.444	X	X	X

Datatyp	Width (bits)	Range of values	Examples	S7-300/400	S7-1200	S7-1500
LTOD (ltod) (LTIME_OF_DAY) →details	64	LTOD#00:00:00.000000000 .. LTOD#23:59:59.999999999	LTOD#11:22:33.444_555_111, LTIME_OF_DAY#11:22:33.444_555_111	-	-	X
DT (dt) (DATE_AND_TIME) →details	64	Min.: DT#1990-01-01-0:0:0 Max.: DT#2089-12-31-23:59:59.999	DT#2020-08-14-2:44:33.111, DATE_AND_TIME#2020-08-14-11:22:33.444	X	-	X
LDT (ldt) (L_DATE_AND_TIME) →details	64	Min.: LDT#1970-01-01-0:0:0.000000000, 16#0 Max.: LDT#2262-04-11-23:47:16.854775807, 16#7FFF_FFFF_FFFF_FFFF	LDT#2020-08-14-1:2:3.4	-	-	X
DTL (dtl) →details	96	Min.: DTL#1970-01-01-00:00:00.0 Max.: DTL#2554-12-31-23:59:59.999999999	DTL#2020-08-14-10:12:13.23	-	X	X
Datatyp	**Width (bits)**	**Range of values**	**Examples**	**S7-300/400**	**S7-1200**	**S7-1500**
Pointers						
POINTER (p) →details	48		Symbolic: “DB”.“Tag” Absolute: P#10.0 P#DB4.DBX3.2	X	-	X
ANY (any) →details	80		Symbolic: “DB”.StructVariable.firstComponent Absolut: P#DB11.DBX12.0 INT 3 P#M20.0 BYTE 10	X	-	X
VARIANT (var) →details	0		Symbolic: “Data_TIA_Portal”. StructVariable.firstComponent Absolute: %MW10 P#DB10.DBX10.0 INT 12	-	X	X
BLOCK_FB	0		-	X	-	X
BLOCK_FC	0		-	X	-	X
BLOCK_DB	0		-	X	-	-
BLOCK_SDB	0		-	X	-	-
VOID	0		-	X	X	X
PLC_DATA_TYPE	0		-	X	X	X

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Important and frequently used procedures and functions

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