



Using the STR91xFA DMA controller

Introduction

This application note provides information on how to use and take full advantage of the STR91xFA DMA controller. It is intended for anyone getting started with DMA.

While it is impossible to cover every possible control scenario of each peripheral DMA transfer, those considered to be the most typical and useful are described.

Software is available with this application note and can be downloaded separately from www.st.com.

Contents

1	DMA unit	4
1.1	DMA features	4
1.2	Peripheral DMA support	5
1.3	DMA request signals	6
1.4	DMA transfer properties	7
1.4.1	DMA channel	7
1.4.2	Source and destination addresses	7
1.4.3	Source and destination data width	7
1.4.4	Flow control	7
1.4.5	Transfer type	8
1.4.6	Transfer size	8
1.4.7	Source and destination burst size	8
1.4.8	Incrementing source/destination address	8
1.4.9	Terminal count interrupt	9
1.4.10	DMA linked lists	10
1.5	Programming the DMAC using the STR9 software library	12
2	DMA transfer examples	14
2.1	Memory to memory transfer	14
2.1.1	Transfer properties	14
2.2	Memory to SPP transfer	14
2.2.1	SSP DMA interface overview	14
2.2.2	Memory to SSP example	14
2.2.3	Transfer properties	15
2.2.4	Hardware connection	15
2.3	UART to memory transfer	15
2.3.1	UART-Rx DMA interface	15
2.3.2	UART to memory example	16
2.3.3	Transfer properties	16
2.3.4	Hardware connection	16
2.4	Memory to UART transfer	16
2.4.1	UART-TX DMA interface	16
2.4.2	Memory to UART example	16

2.4.3	Transfer properties	17
2.4.4	Use of linked lists for DMA transfer	17
2.4.5	Terminal count interrupt generation	17
2.5	DMA transfer triggered by external DMA request	18
2.5.1	External request example	18
2.5.2	Transfer properties	18
2.6	Timer to memory transfer	18
2.6.1	Timer DMA interface overview	18
2.6.2	Timer to memory example	18
2.6.3	Transfer properties	19
2.6.4	Use of linked lists for DMA transfer	19
2.6.5	Hardware connection	20
3	Revision history	21

1 DMA unit

The STR91xFA DMA controller (DMAC) is an AMBA AHB module, and connects to the Advanced High-performance Bus (AHB). It allows devices to transfer data to or from the system's memory and registers without the intervention of the CPU. While the transfer takes place the CPU is free to do other things. As a result, the STR9 core is not overloaded to serve all peripherals and there is an overall speed-up in CPU operation chiefly when transferring a large amount of data.

1.1 DMA features

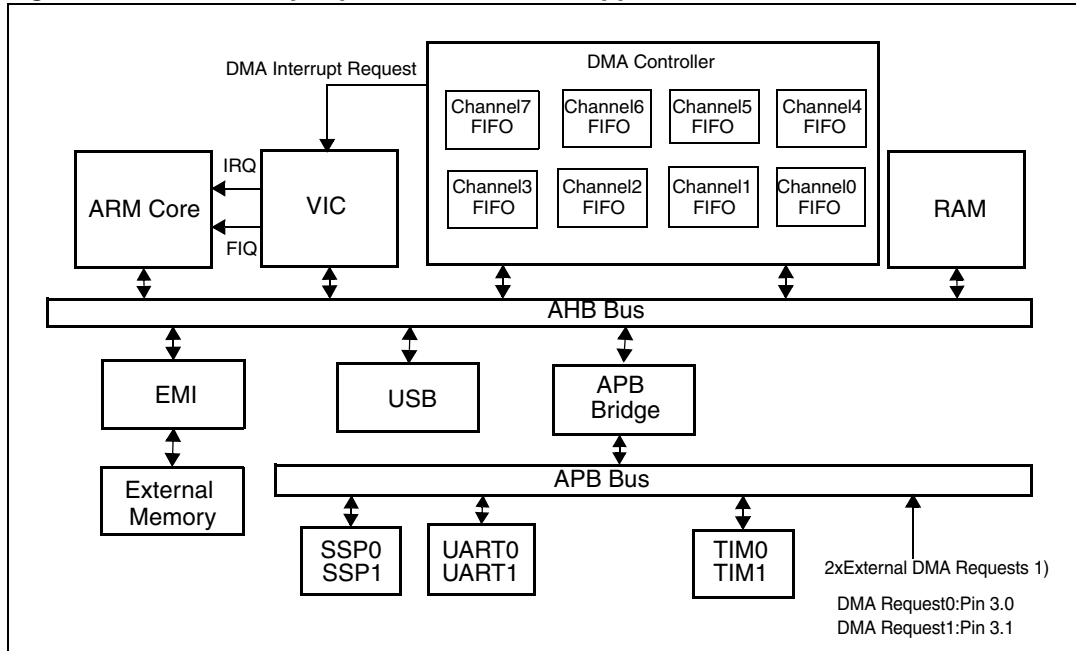
The DMAC offers:

- Eight DMA channels. Each channel can support a unidirectional transfer.
- Hardware DMA channel priority. Each DMA channel has a specific hardware priority. DMA channel 0 has the highest priority and channel 7 has the lowest. If requests from two channels become active at the same time, the channel with the highest priority is serviced first.
- The DMAC provides 14 peripheral DMA request lines (refer to [Table 1](#)).
- Single DMA and burst DMA request signals. Each peripheral connected to the DMAC can assert either a burst DMA request or a single DMA request. Note that peripherals without FIFO inside can not generate a DMA burst request.
- Programmable DMA burst size. The DMA burst size can be programmed to transfer data more efficiently. Therefore, up to 256 data per block can be reached (note that the data width can be configured to byte, half-word or word).
- Support for memory-to-memory, memory-to-peripheral, peripheral-to-memory, and peripheral-to-peripheral transfers.
- Incrementing or non-incrementing addressing for source and destination.
- DMA Linked list support: the DMAC is able to perform a chained list of DMA transfers without need for CPU intervention
- Separate and combined DMA error and DMA Terminal Count interrupt requests: An interrupt can be generated to the processor on a DMA error or when a DMA count has reached 0 (Terminal Count event, usually used to indicate that a transfer has finished).

1.2 Peripheral DMA support

Peripherals supporting the DMA are shown in this block diagram:

Figure 1. DMAC and peripherals with DMA support



Note: 1 An external DMA request can be generated from 2 GPIO pins going to high levels.

The DMAC requests and triggering events are summarized in the following table:

Table 1. STR91x DMA requests

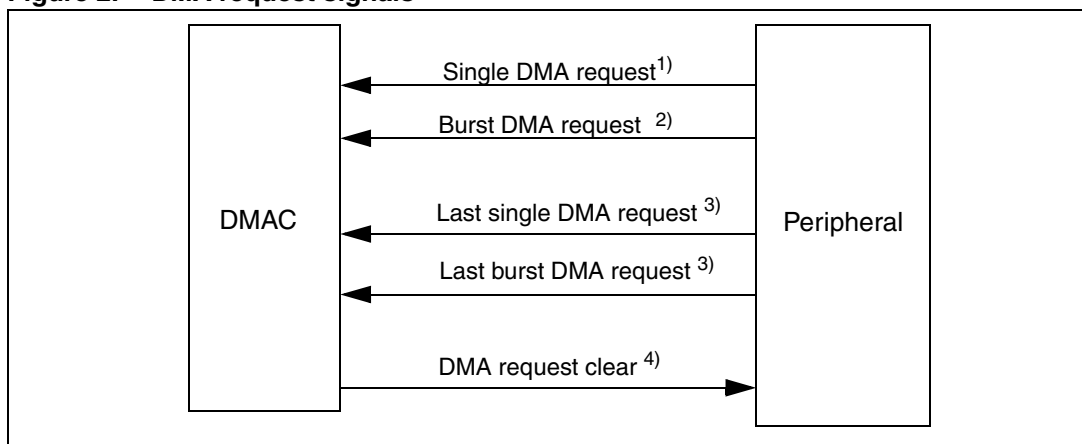
DMA request signal	Associated peripheral function	DMA trigger
0	USB RX	USB correct transfer event
1	USB TX	
2	TIM0	Input Capture and Output Compare events
3	TIM1	
4	UART0 RX	FIFO watermark level reached
5	UART0 TX	
6	UART1RX	
7	UART1TX	
8	External DMA Req0	Rising edge of P3.0
9	External DMA Req1	Rising edge of P3.1
10	-	Reserved
11	-	

DMA request signal	Associated peripheral function	DMA trigger
12	SSP0 RX	Half FIFO level reached
13	SSP0TX	
14	SSP1RX	
15	SSP1 TX	

1.3 DMA request signals

The following figure describes the signals used for peripherals to request a DMA transfer:

Figure 2. DMA request signals



1. *Single DMA requests* are asserted when the peripheral has to transfer one data item.
2. *Burst DMA requests* are asserted when the peripheral has multiple data items to transfer. Note that the single and burst requests are not mutually exclusive, they could be asserted together by the peripheral.
3. *Last burst and last single requests* can be asserted only when the peripheral is the flow controller in order to indicate the last transfer request to the DMAC (in STR91xFA, only the USB has these signals).
4. *DMA request clear* is asserted by the DMAC to indicate to peripheral that the request has been serviced.

1.4 DMA transfer properties

A DMA transfer is characterized by the following properties:

- DMA Channel
- Source and destination addresses
- Source and destination data width
- Flow control
- Transfer type
- Transfer size (only when DMAC is the flow controller)
- Source / destination burst size
- Source / destination address incrementing or non-incrementing
- Terminal count interrupt generation
- Next linked list item address

In the following paragraphs, a detailed description of each DMA transfer property is provided.

1.4.1 DMA channel

A DMA channel needs to be allocated by the user (8 channels are available) for the DMA request. The choice of the channel depends on the required priority (0 to 7) and on the availability of the channel (not already allocated to another request).

1.4.2 Source and destination addresses

A DMA transfer is defined by a source address and a destination address. Both the source and destination should be in the AHB or APB memory ranges.

1.4.3 Source and destination data width

Data width for source and destination can be defined as:

- Byte
- Half word (16-bit)
- Word (32-bits)

1.4.4 Flow control

The flow controller is the unit that controls the data transfer length and which is responsible for stopping the DMA transfer.

The flow controller can be either the DMAC or the peripheral.

- With DMAC as flow controller:

In this case, it is necessary to define the transfer size value.

When a DMA request is served, the transfer size value decreases by the amount of transferred data (depending of the type of request: burst or single).

When the transfer size value reaches 0, the DMA transfer is then finished and the DMA channel is disabled in case of no next linked list item, otherwise a new linked list descriptor will be fetched from SRAM into DMA registers.

For further details about linked lists, refer to [Section 1.4.10](#).

- With the peripheral as flow controller:

In this case, the transfer size value is ignored.

In fact, it is up to the peripheral to signal the end of transfer by using Last Burst or Last single request lines.

In the STR91xFA, only the USB peripheral supports these two signals (Last Burst and Last single requests). For other peripherals when used as flow controller, peripheral interrupts can be used to stop a transfer, by halting the DMA channel.

1.4.5 Transfer type

The transfer type could be:

- Memory to memory
- Memory to peripheral
- Peripheral to memory
- Peripheral to peripheral

- Note:*
- 1 *In memory to memory transactions, the DMAC should be the flow controller and DMA transfer is started without any request.*
 - 2 *In memory to peripheral transactions under DMAC flow controller only the DMA burst requests are monitored by the DMAC.*

1.4.6 Transfer size

As described in [Section 1.4.4](#), the transfer size value has to be defined only when the DMAC is the flow controller, in fact this value defines the number of data to be transferred from source to destination.

Depending on the received request: burst or single, the transfer size value is decreased by the amount of transferred data.

1.4.7 Source and destination burst size

For burst transfers (when supported), it is necessary to define the burst size value. This value defines how much data is to be transferred when a burst request is received.

Depending on the type of the transfer, the following need to be defined:

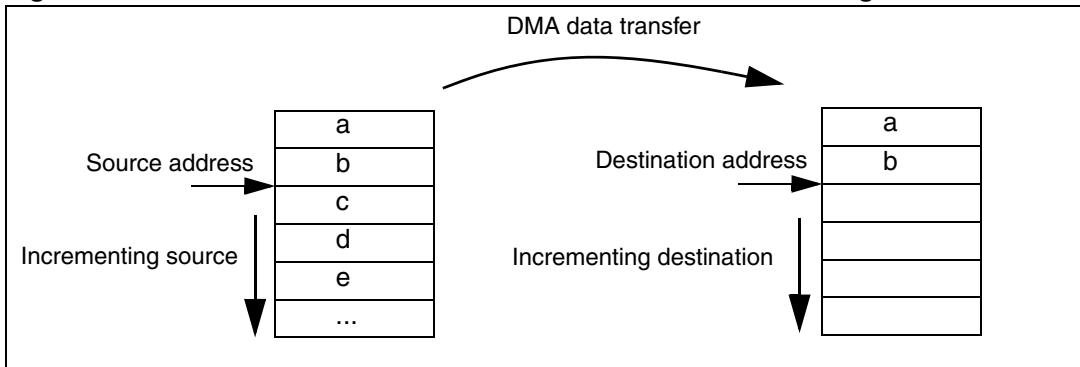
- The source burst size when doing a *peripheral to memory* transfer
- The destination burst size when doing a *memory to peripheral* transfer

- Note:*
- If the DMAC is the flow controller and burst size value is not 0, then two cases are possible:*
- *Current Transfer size value is greater than burst size value. In this case the DMAC will monitor and serve only the burst requests.*
 - *Current Transfer size value is less than burst size value. In this case the DMAC will monitor single DMA requests until the transfer size value reaches 0. An exception to this is when the transfer is from memory to peripheral, in this case only burst requests will continue to be monitored.*

1.4.8 Incrementing source/destination address

It is possible to configure the DMAC to automatically increment the source or/and destination address after each data transfer.

Figure 3. DMA source address & destination address incrementing



1.4.9 Terminal count interrupt

The DMAC can be configured to generate an interrupt: “the terminal count interrupt” at the end of the DMA transfer.

Also when using linked lists, a terminal count interrupt can be generated at the end of each linked list transfer.

1.4.10 DMA linked lists

DMA linked lists are used in order to perform a set of DMA transfers without need for CPU intervention.

The first DMA transfer properties should be programmed in the DMAC registers. The next transfers properties are stored in SRAM as “descriptors”.

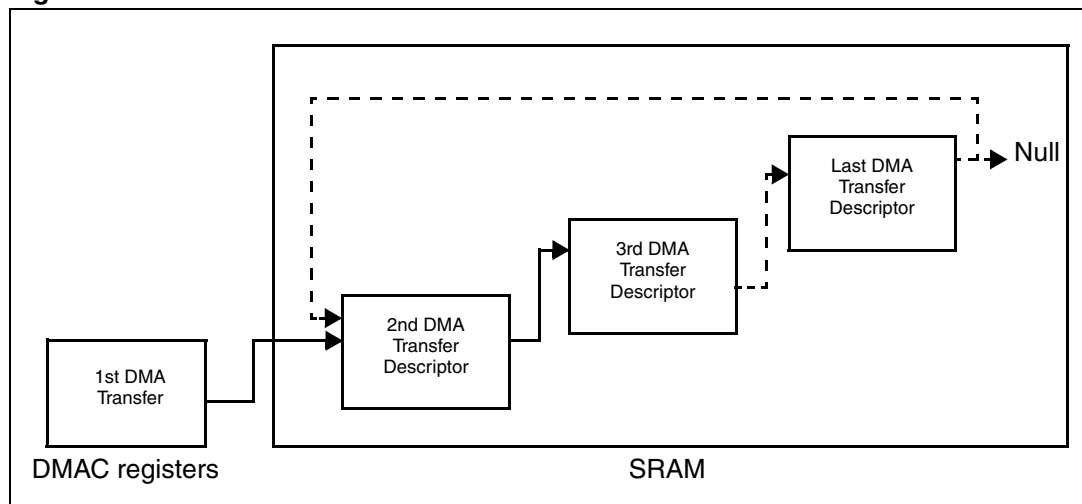
Each DMA descriptor has a pointer to the next linked list item.

The last linked list item points to Null or can point the first (or other) descriptor in order to form a chained linked list.

After finishing a transfer, the DMA will automatically fetch the next linked list descriptor from memory in order to perform the next transfer.

When finishing the last linked list transfer and there is no next descriptor to fetch, the DMA channel will be disabled.

Figure 4. Linked lists



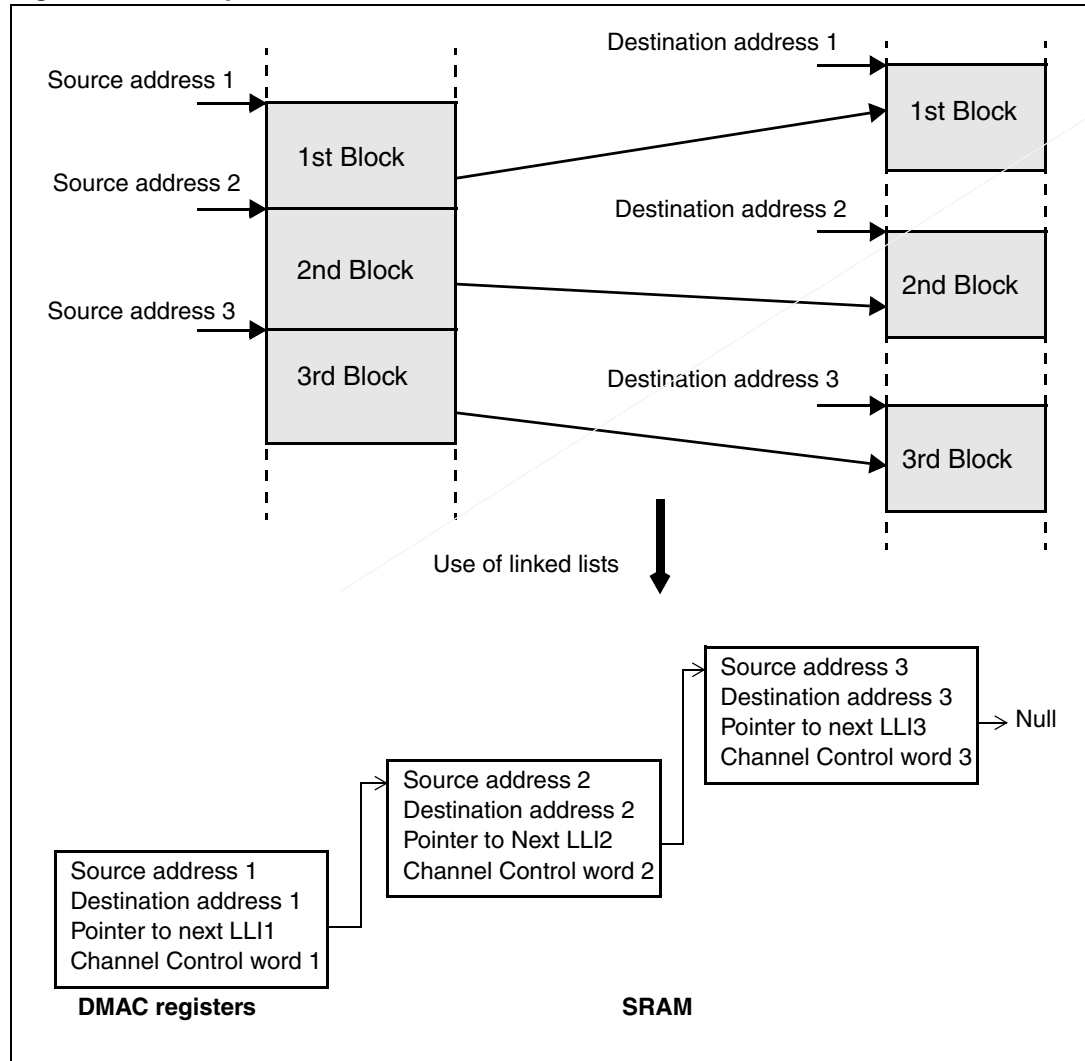
As explained above, in order to use linked lists, the first transfer parameters must be programmed in the DMA registers. This configuration should include the address of the first linked list item in SRAM.

The SRAM descriptors must then be programmed. These are in the form of a structure with the following four 32-bit words organized as follows:

- Source address
- Destination address
- Pointer to next LLI (Linked List Item)
- Control word: This 32-bit word has the same bit fields as the DMA_ChannelControl register DMA_CC.

An example use of DMA linked list is the “scattering” of contiguous blocks into different areas in memory.

Figure 5. Example use of DMA linked lists



As shown in figure above, the DMA linked lists are used in order to transfer 3 data blocks to three different areas in memory.

The first block transfer is done using the first descriptor programmed in DMA registers, and the 2nd and 3rd transfers are done using linked list descriptors in SRAM.

Depending on the “Channel Control word” TCIE bit (see DMA_CC register), the user can choose to generate or not a Terminal Count interrupt at the end of each linked list transfer.

1.5 Programming the DMAC using the STR9 software library

Some software considerations must be taken into account when programming the DMAC, (Refer to section 9.4 in the *STR91xFA Reference Manual*).

The STR91xFA software library DMAC driver provides an easy way to configure the DMAC registers.

In order to configure the DMA transfer properties for a DMA channel, the following structure needs to be used:

```
typedef struct
{
  u32 DMA_Channel_SrcAdd; /* DMA transfer source address */
  u32 DMA_Channel_DesAdd; /* DMA transfer destination address */
  u32 DMA_Channel_LLstItm; /* DMA next linked list address */
  u8 DMA_Channel_DesWidth; /* Destination data width */
  u8 DMA_Channel_SrcWidth; /* Source data width */
  u8 DMA_Channel_DesBstSize; /* Destination Burst size */
  u8 DMA_Channel_SrcBstSize; /* Source Burst size */
  u16 DMA_Channel_TrfsfSize; /* Transfer size value */
  u8 DMA_Channel_FlowCntrl; /* Flow controller & transfer type */
  u8 DMA_Channel_Src; /* DMA request source */
  u8 DMA_Channel_Des; /* DMA request destination */
} DMA_InitTypeDef;
```

The following explains the required steps to program the DMAC:

1. Enable the DMAC clock and exit it from Reset state
2. Enable the DMAC:

```
DMA_Cmd(ENABLE);
```

3. Fill a structure of type `DMA_InitTypeDef` with the correct configuration parameters:

```
DMA_struct.DMA_Channel_SrcAdd = .. ;
DMA_struct.DMA_Channel_DesAdd = .. ;
DMA_struct.DMA_Channel_LLstItm = .. ;
DMA_struct.DMA_Channel_DesWidth = .. ;
DMA_struct.DMA_Channel_SrcWidth = .. ;
DMA_struct.DMA_Channel_SrcBstSize = .. ;
DMA_struct.DMA_Channel_TrfsfSize = .. ;
DMA_struct.DMA_Channel_FlowCntrl = .. ;
DMA_struct.DMA_Channel_Src = .. ;
```

4. Choose and free DMA channel with the required priority. DMA channel 0 has the highest priority and DMA channel 7 the lowest priority and update DMAC registers:

```
DMA_Init(DMA_Channelx, &DMA_struct);
```

5. Use incrementing or non-incrementing addressing depending on source and destination region:

```
DMA_ChannelSRCIncConfig (DMA_Channelx, ENABLE);
DMA_ChannelDESIncConfig (DMA_Channelx, ENABLE);
```

6. Enable DMAC channel:

```
DMA_ChannelCmd (DMA_Channelx, ENABLE);
```

7. A DMA terminal count interrupt or a DMA error interrupt can be generated:

```
DMA_ITConfig(DMA_Channelx, ENABLE);
DMA_ITMaskConfig(DMA_Channelx, DMA_ITMask_ITC, ENABLE); /* TC int */
DMA_ITMaskConfig(DMA_Channelx, DMA_ITMask_IE, ENABLE); /*Error int*/
```

The following part of the code example shows how to configure the UART-TX DMA interface on channel0 with interrupt generation when DMA count reach 0.

```

/***** Example DMA Config *****/

/* No next linked list item*/
DMA_struct.DMA_Channel_LLstItm= 0;

/* Source address of the DMA transfer */
DMA_struct.DMA_Channel_SrcAdd=(u32) (&TxBuffer0[0]);

/* Destination address of DMA the transfer is UART Data reg*/
DMA_struct.DMA_Channel_DesAdd=(u32) (&UART0->DR);

/* Source data width is Byte */
DMA_struct.DMA_Channel_SrcWidth= DMA_SrcWidth_Byte;

/* Destination bus width is Byte */
DMA_struct.DMA_Channel_DesWidth= DMA_DesWidth_Byte;

/* DMAC is The flow controller*/
DMA_struct.DMA_Channel_FlowCntrl=DMA_FlowCntrl1_DMA;

/*The DMAC is triggered by the SSP_DMA_Transmit request.*/
DMA_struct.DMA_Channel_Des= DMA_DES_UART0_TX;

/*Transfer size of 12 data */
DMA_struct.DMA_Channel_TrsfSize =12;

/* Update the DMA channel0 registers with DMA_struct values */
DMA_Init(DMA_Channel0,&DMA_struct);

/* Enable Source increment */
DMA_ChannelSRCIncConfig (DMA_Channel0, ENABLE);

/*Enable the Terminal Count interrupt*/
DMA_ITConfig(DMA_Channel0, ENABLE);
DMA_ITMaskConfig(DMA_Channel0, DMA_ITMask_ITC, ENABLE);

/*Enable the DMA channel0*/
DMA_ChannelCmd (DMA_Channel0,ENABLE);

```

2 DMA transfer examples

2.1 Memory to memory transfer

This example shows how to program a DMA channel for memory-to-memory transfers. When enabled, the DMA channel starts to transfer data from the source buffer to the destination buffer.

The DMA transfer starts just after enabling the DMAC without any DMA request. When the transfer is finished, the DMA terminal count interrupt is generated.

2.1.1 Transfer properties

In this example:

- The DMAC is the flow controller.
- Burst DMA transfers are used.
- DMA source and destination incrementing are used

2.2 Memory to SSP transfer

2.2.1 SSP DMA interface overview

A programmable DMA channel may be assigned by CPU firmware to service each SSP unit for fast and direct transfers between the SSP and SRAM with little CPU involvement. Both DMA single-transfers and DMA burst-transfers are supported for transmit and receive.

During data reception by SSP, single DMA transfer request are asserted when the receive FIFO contains at least one character. Burst DMA transfer request asserted by the SSP when the receive FIFO contains four or more character.

During data transmission single DMA transfer requests are asserted when there is at least one empty location in the transmit FIFO. Burst DMA transfer requests are asserted by the SSP when the transmit FIFO contains four or less characters.

2.2.2 Memory to SSP example

This example described communication between two SSPs: SPP0 and SSP1.

SSP0 is configured as master and SSP1 as slave. The Motorola frame format "SPI" is the used protocol for communication.

1. "SSP0_Buffer_Tx" buffer has to be transferred from SPP0 (master) to SSP1 (slave).
2. Data is received by SSP1 peripheral and stored in the SSP1_Buffer_Rx. A comparison is then made with the expected values of the transmitted buffer. The result of this comparison is returned in the "TransferStatus1" variable.

In this example the DMAC is used for transferring "SSP0_Buffer_Tx" data from SRAM to SSP0 transmit FIFO.

2.2.3 Transfer properties

In this example:

- The flow controller is the DMAC.
- The DMAC is triggered by the SSP_DMA_Transmit request.
- No linked lists are used.
- Since the SSP has a FIFO, burst transfers can be used.
- Only the source address incrementing is used.

2.2.4 Hardware connection

To run this example, please connect both SSP0 and SSP1 pins as follows:

- Connect SSP0_SCLK(P2.4) to SSP1_SCLK(P3.4).
- Connect SSP0_MISO(P2.6) to SSP1_MISO(P3.5).
- Connect SSP0_MOSI(P2.5) to SSP1_MOSI(P3.6).
- Connect SSP0_nSS (P2.7) to VCC through a pull-up resistor.
- Connect SSP1_nSS (P3.7) to GND.

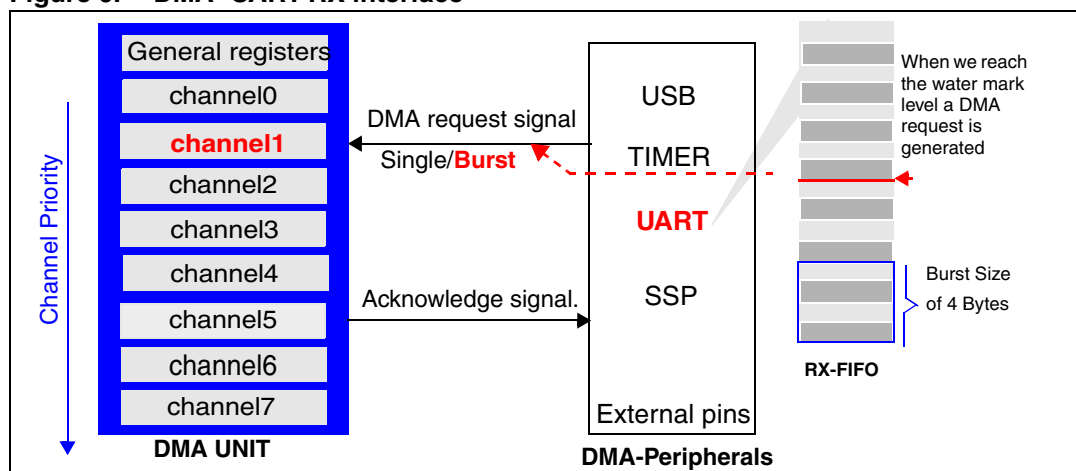
2.3 UART to memory transfer

A programmable DMA channel may be assigned by firmware to service channels UART0 and UART1 for fast and direct transfers between the UART and SRAM with little CPU involvement.

2.3.1 UART-Rx DMA interface

The DMAC is triggered when the receive FIFO level reaches the defined watermark level. The burst transfer and single transfer request signals are not mutually exclusive, they can both be asserted at the same time. When there is more data than the watermark level in the receive FIFO, the burst transfer request and the single transfer request are asserted (refer to [Figure 6](#)). When the amount of data left in the receive FIFO is less than the watermark, only the single request is asserted. This is useful for situations where the number of characters left to be transferred in the stream is less than a burst.

Figure 6. DMA- UART-RX interface



2.3.2 UART to memory example

In this example data is transferred from a PC using the *HyperTerminal* application to the UART0 receive FIFO.

UART0 waits for a string to be entered from HyperTerminal. Each byte tapped through this utility is received by the UART0.

The data received in the UART-RX FIFO is transferred to SRAM "RxBuffer" using DMA.

Note: The received buffer has a maximum size of RxBufferSize (bytes).

2.3.3 Transfer properties

In this example:

- The flow controller is the DMAC.
- The transfer type is peripheral to memory.
- The DMAC transfer is triggered by the UART_DMA_Receive request.
- The burst size is 4 bytes.
- No DMA linked list are used.
- Only the destination address incrementing is used.

2.3.4 Hardware connection

Connect a null-modem RS232 cable between the DB9 connector of UART0 and PC serial COM port.

2.4 Memory to UART transfer

2.4.1 UART-TX DMA interface

A single character DMA transfer request is asserted by the UART when there is at least one empty location in the transmit FIFO. A burst DMA transfer request is asserted by the UART when the transmit FIFO contains less characters than the watermark level.

The following examples provide a basic communication between UART0 and HyperTerminal using DMA capability.

2.4.2 Memory to UART example

The DMA transfers data from TxBuffer0, TxBuffer1, TxBuffer2 to UART0 Tx FIFO. Each source buffer has a fixed size. The transferred data can then be shown in the HyperTerminal utility.

The CPU is applied to generate an interrupt after each amount of data to be transferred by DMA.

2.4.3 Transfer properties

In this example:

- The flow controller is DMAC.
- The transfer type is memory to peripheral.
- DMAC is triggered by the UART_DMA_Transmit request.
- Burst transfers are used and burst size is 4 bytes.
- Linked mode is used (see next section for details).
- Only the source address is incremented.

2.4.4 Use of linked lists for DMA transfer

In this example there are three different buffers which need to be transferred to a fixed destination: the UART transmit FIFO.

This transfer can be done using the linked list:

- The first LLI (Linked List Item) is programmed into the DMAC registers and next transfer linked lists are programmed as descriptors in SRAM.
- Each LLI controls the transfer of one block of data, and then optionally loads another LLI to continue the DMA operation, or stops the DMA stream.

To determine the appropriate control information for each linked list item, refer to the *DMA_CCRx* register bit fields:

Figure 7. DMA_CCRx register

Reset Value:0000 0000h															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TCIE	PROT 2	PROT 1	PROT 0	DI	SI	0	0	DWIDTH			SWIDTH			DBSize[2:1]	
r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DB Size0		SBSize[2:0]			TransferSize[11:0]										
r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w	r/w

2.4.5 Terminal count interrupt generation

To generate an interrupt request at each LLI termination, follow the procedure below:

- Enable the TC interrupt for each linked list by:
 - Enabling TC interrupt for first transfer use DMA_ITConfig function
DMA_ITConfig (DMA_Channel1, ENABLE);
 - Enabling this interrupt in the second and third linked list items: set bit “TCIE” in each control word of the linked list descriptors (see [Figure 7](#))
- Enable global TC interrupt for the current channel using DMA_ITMaskConfig function.
DMA_ITMaskConfig (DMA_Channel1, DMA_ITMask_ITC, ENABLE);

2.5 DMA transfer triggered by external DMA request

A DMA transfer can be triggered by an external pin:

- External DMA Req 0: When pin P3.0 goes high
- External DMA Req 1: When pin P3.1 goes high

Only one burst transfer is done after pin is driven to high state.

2.5.1 External request example

This example illustrates how to make a memory to memory DMA transfer (Buffer0 to Buffer1) triggered by the External DMA Req 0.

A terminal count interrupt is generated at the end of the transfer.

The memory to memory transfer is triggered by pulling high pin P3.0

2.5.2 Transfer properties

In this example:

- The DMAC is the flow controller.
- The transfer type is memory to peripheral (even if the transfer is memory to memory, it is necessary to set the transfer type to memory to peripheral).
- Burst transfer of 8 bytes is used: The particularity of the external request pin is to generate only one burst request if the pin is driven to high state.
- No DMA linked lists are used.
- Source and destination address incrementing are used.
- Terminal count interrupt generation at the end of the transfer.

2.6 Timer to memory transfer

2.6.1 Timer DMA interface overview

A DMA interface is available on TIM0 and TIM1. The source can be selected to be IC1, OC1, IC2 or OC2. The timer can perform DMA requests to a DMA module and then allow a data transfer between STR9 resources using DMA.

For the timer peripheral there is no FIFO inside. So the IP can't generate a DMA burst request to the DMA controller for burst transfer. Therefore the Timer need only a single transfer to service the counter.

As a result, when the data path is from memory to Timer it is not possible to use the DMAC as flow controller because the availability of DMA burst request is mandatory. This explains why the Timer is used as flow controller in this case of transfer.

In the case of a data path from the Timer to memory, the DMA burst request is not mandatory so either the DMAC or the Timer can be used as flow controller.

2.6.2 Timer to memory example

The following example shows how to use the TIM peripheral to measure the frequency and the pulse width of an external signal.

TIM0 is configured in PWM input mode. At each Input Capture1 event a transfer from registers IC1R and IC2R to memory will occur.

To store ICR1 and ICR2 related to the same input capture event, use two channels; channel0 to transfer the IC1R value and channel 1 to transfer the IC2R value.

A pattern can be used as the external signal to be sure that their pulse widths and periods correspond with those stored in the memory.

TIM1 configured in PWM mode can generate such a pattern if its period and pulse width are modified every output compare interrupt with the desired values.

To obtain the time values:

$$\text{Period} = \frac{\text{IC1R} \times \text{tPRESC}}{\text{fPCLK}}$$

$$\text{Pulse} = \frac{\text{IC2R} \times \text{tPRESC}}{\text{fPCLK}}$$

Where:

fPCLK = Internal clock frequency

tPRESC = Timer clock prescaler

2.6.3 Transfer properties

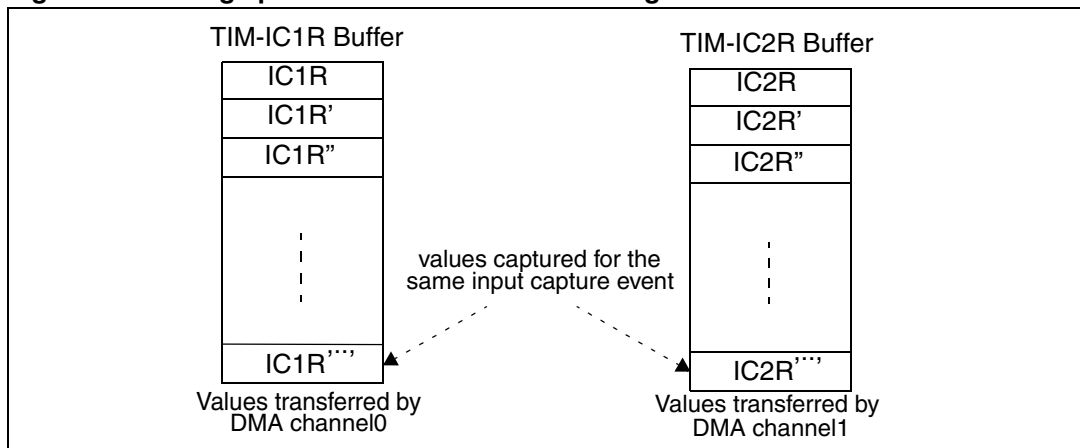
- The flow controller is DMAC.
- The transfer type: Peripheral to memory.
- DMAC is triggered by the Input capture1 event request.
- Burst transfers are not supported since there is no FIFO inside.
- Linked mode is used (see next section for details).
- Source and destination address not incremented.

2.6.4 Use of linked lists for DMA transfer

Linked lists is used due to the fact that the content of the two input capture registers changes every time depending on the external signal. It is therefore possible to save these values separately at each input capture event which gives more information about the injected signal.

One linked list is used for each channel; link1 for channel0 and link2 for channel1. Therefore linked list1 is used to transfer IC1R values to TIM-IC1R buffer and linked list2 to transfer IC2R values to TIM-IC2R buffer (refer to [Figure 8](#)).

Figure 8. Storage procedure of IC1R and IC2R registers



2.6.5 Hardware connection

The external signal comes from TM1-PWM pin to be injected in TM0-IC1 pin so:

- Connect TM1-PWM pin (**P4.2**) to TM0-IC1 pin (**P4.0**).

3 Revision history

Table 2. Document revision history

Date	Revision	Changes
08-Jan-2007	1	Initial release.
02-Jun-2008	2	Removed I2C section.

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