GigaDevice Semiconductor Inc.

GD32G5x3 FFT 模块使用指南

应用笔记

AN248

1.0 版本

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1. 前言

本文是专门为基于 GD32 MCU 开发的工程设计人员提供，主要介绍了 GD32G5x3 系列器件内 FFT 模块的内部结构、功能配置、以及使用时的注意事项，旨在帮助 GD32 MCU 开发者正确快速的使用 FFT 模块，缩短开发周期。

2. FFT 模块简介

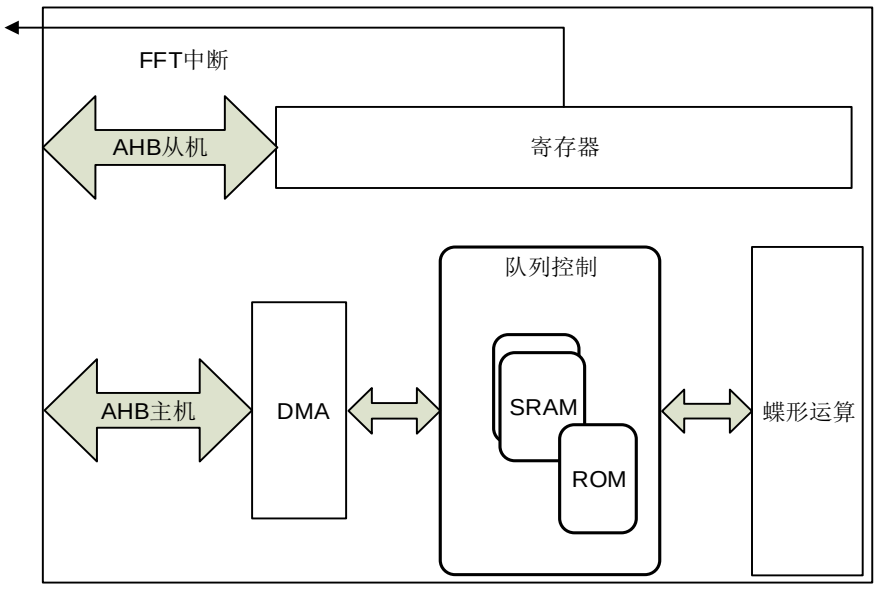
快速傅里叶变换（FFT）是离散傅里叶变换（DFT）的高效计算方法。该模块可以进行 FFT 运算，减轻了 CPU 负担。与软件实现相比，该模块可以加速了 FFT 的计算时间。该模块支持 6 个可配置的 FFT 点数，最多 1024，输入和输出数据应为 IEEE-754 单精度浮点复数。

FFT 模块主要特性如下：

- 支持1024/512/256/128/64/32点FFT；
- 支持IFFT模式；
- IEEE-754单精度浮点复数输入和输出数据；
- DMA主机加载和存储数据；
- 支持在内存中配置的窗函数功能；
- 支持输入下采样。

2.1. 运行过程

图 2-1. FFT 模块框图



FFT 模块有 DMA 主机、队列控制子模块、蝶形运算子模块和寄存器组成，如*图 2-1. FFT 模块框图*所示。该模块是使用的基-2 FFT 算法。先从存储中加载 IEEE754 单精度浮点格式的输入数据（包含实部和虚部）和窗函数数据，经过窗函数运算和输入位反运算之后，将结果写入内部 SRAM。旋转因子已经存储在 ROM 中。

蝶形运算子模块在 FFT 计算中被重复使用，并计算 $N / 2 * \log_2 N$ 次。每次计算是相同的地址，也就是说，每次计算的输出数据被写回之前存储输入数据的相同地址。

所有蝶形计算迭代完成后，DMA 主机将输出数据从内部 SRAM 传输到内存。

2.2. 操作指南

该部分介绍 FFT 的推荐操作指南。

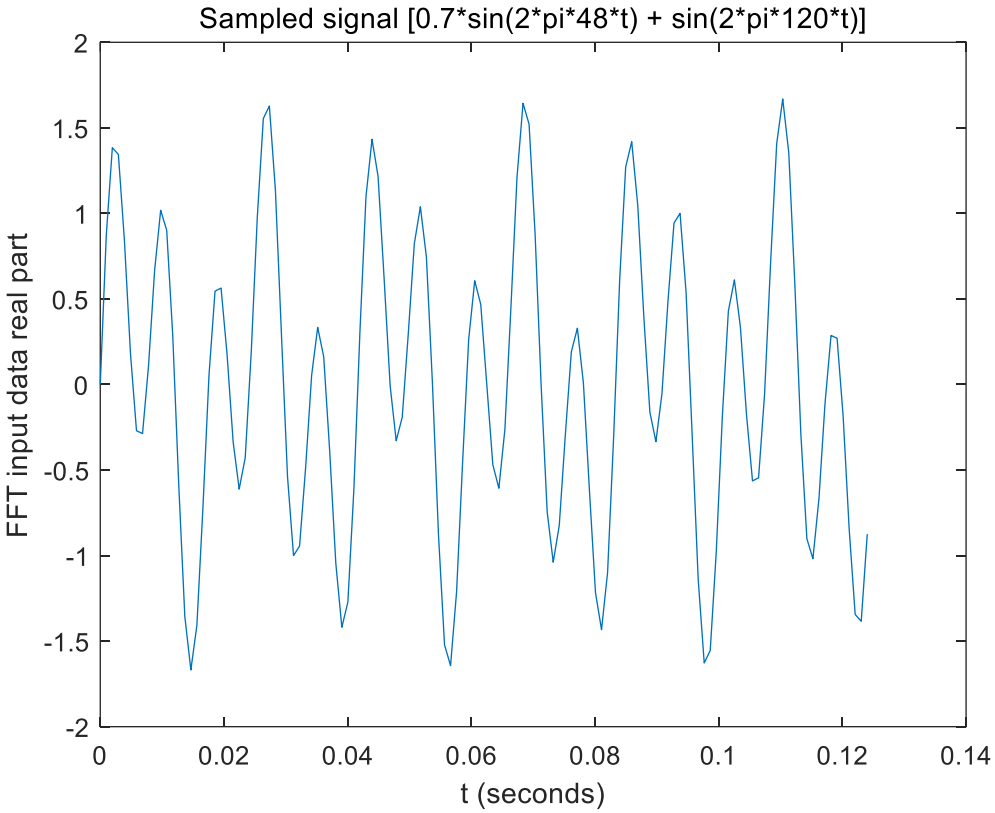
1. 如果需要，配置FFT_IMSADDR寄存器来设置FFT虚部的基地址，即虚部数据不为零。
2. 配置FFT_RESADDR寄存器来设置FFT实部基地址。
3. 如果需要，配置WINEN位和FFT_WSADDR寄存器来设置FFT窗函数的基地址。
4. 配置FFT_OSADDR寄存器来设置FFT输出结果的基地址。
5. 如果需要，配置FFT_LOOPLEN寄存器。
6. 如果需要，配置IFFTMODE。
7. 配置FFT_CSR寄存器中的NUMPT[2:0]位域来设置FFT点的数量。
8. 配置FFTEN位。
9. 等待FFTEN清零，或者CCF位置1。

3. FFT 配置代码示例

示例主要展示使用 FFT 模块进行 128 个输入数据的 FFT 变换（无加窗），FFT 模块的输入数据、窗函数和输出数据都是复数，包含实部和虚部。

128 个输入数据是从信号[0.7* sin(2π*48*t) + sin(2π*120*t)]上采集的，采集频率为 1024Hz，采样时长为 0.125s。可以明显看出，这个信号是两个正弦信号的叠加，其中一个正弦信号频率为 48Hz，幅值为 0.7；另外一个正弦信号频率为 120Hz，幅值为 1.0，如*图 3-1. FFT 实部输入数据*所示。其虚部默认是 0。

图 3-1. FFT 实部输入数据



输入数据的实部定义在数组 *fft_real_buf[FFT_DATA_LENGTH]*中，虚部默认是 0，代码如下：

表 3-1. FFT 输入数据代码

```
/* Specify the parameters of a signal with a sampling frequency of 1024 Hz and a signal duration of 0.125 seconds.Form a signal containing a 48 Hz sinusoid of amplitude 0.7 and a 120 Hz sinusoid of amplitude 1 input data = 0.7*sin(2*pi*48*t) + sin(2*pi*120*t) */
#define FERQ_SAMPLE             1024            //uint:Hz
#define PI                      3.1415926f
#define FFT_DATA_LENGTH         128U

float fft_real_buf[FFT_DATA_LENGTH] = {0};
```

```
for(index=0; index<FFT_DATA_LENGTH; index++){
fft_real_buf[index] = 0.7*sin(2*PI*48*index/FERQ_SAMPLE) + sin(2*PI*120*index/FERQ_SAMPLE);
}};
```

FFT 模块配置代码如下：

表 3-2. FFT 模块配置代码

```
/* fft parameter variable */
fft_parameter_struct fftconfig;
/* enable FFT clock */
rcu_periph_clock_enable(RCU_FFT);

/* reset the FFT */
fft_deinit();
/* initialize the FFT filter parameter struct */
fft_struct_para_init(&fftconfig);
/* setting FFT parameter */
fftconfig.mode_sel          = FFT_MODE;
fftconfig.point_num         = FFT_POINT_128;
fftconfig.window_enable = FFT_WINDOW_DISABLE;
fftconfig.downsamp_sel    = FFT_DOWNSAMPLE_1;
fftconfig.image_source    = FFT_IM_ZERO;
fftconfig.loopbuf_len     = 0U;
fftconfig.loopbuf_index = 0U;
fftconfig.real_addr         = (uint32_t)fft_real_buf;
fftconfig.image_addr       = NULL;
fftconfig.window_addr      = NULL;
fftconfig.output_addr     = (uint32_t)fft_output_buf;
/* config FFT parameter */
fft_init(&fftconfig);
/* start FFT calculation */
fft_calculation_start();
```

FFT 变换后的结果是 128 个输出数据，存储在 *fft_output_buf[FFT_DATA_LENGTH*2]*数组中，每个输出数据由两个元素表示，偶数元素是实部，奇数元素是虚部。比如第一个输出数据的实部是 *fft_output_buf[0]*，虚部是 *fft_output_buf[1]*，其他数据以此类推。输出数据的代码如下：

表 3-3. FFT 输出数据代码

```
/* output data */
float fft_output_buf[FFT_DATA_LENGTH*2] = {0};
```

通过串口可以将 FFT 变换结果输出，如下：

表 3-4. FFT 输出结果

```
FFT input data:
```

0.000000+0*i, 0.874758+0*i, 1.384084+0*i, 1.344315+0*i, 0.841806+0*i, 0.182527+0*i, -0.270391+0*i, -0.286645+0*i, 0.112291+0*i, 0.666867+0*i, 1.018484+0*i, 0.901419+0*i, 0.287692+0*i, -0.590805+0*i, -1.355038+0*i, -1.668654+0*i, -1.407107+0*i, -0.718927+0*i, 0.052364+0*i, 0.545101+0*i, 0.563592+0*i, 0.174369+0*i, -0.334832+0*i, -0.611566+0*i, -0.428905+0*i, 0.189789+0*i, 0.976833+0*i, 1.554358+0*i, 1.627501+0*i, 1.136808+0*i, 0.290884+0*i, -0.537751+0*i, -1.000000+0*i, -0.944151+0*i, -0.486918+0*i, 0.054591+0*i, 0.334070+0*i, 0.161101+0*i, -0.396262+0*i, -1.044898+0*i, -1.418853+0*i, -1.271523+0*i, -0.607962+0*i, 0.311590+0*i, 1.099346+0*i, 1.433252+0*i, 1.216425+0*i, 0.620792+0*i, -0.007105+0*i, -0.328937+0*i, -0.190983+0*i, 0.297341+0*i, 0.823447+0*i, 1.038642+0*i, 0.745359+0*i, 0.006915+0*i, -0.877654+0*i, -1.521333+0*i, -1.643492+0*i, -1.210734+0*i, -0.451630+0*i, 0.262099+0*i, 0.606286+0*i, 0.468361+0*i, 0.000004+0*i, -0.468355+0*i, -0.606285+0*i, -0.262103+0*i, 0.451622+0*i, 1.210728+0*i, 1.643489+0*i, 1.521336+0*i, 0.877661+0*i, -0.006908+0*i, -0.745356+0*i, -1.038644+0*i, -0.823453+0*i, -0.297348+0*i, 0.190978+0*i, 0.328938+0*i, 0.007110+0*i, -0.620784+0*i, -1.216419+0*i, -1.433251+0*i, -1.099350+0*i, -0.311597+0*i, 0.607956+0*i, 1.271521+0*i, 1.418857+0*i, 1.044904+0*i, 0.396268+0*i, -0.161095+0*i, -0.334071+0*i, -0.054595+0*i, 0.486914+0*i, 0.944146+0*i, 1.000000+0*i, 0.537754+0*i, -0.290873+0*i, -1.136801+0*i, -1.627500+0*i, -1.554359+0*i, -0.976842+0*i, -0.189795+0*i, 0.428903+0*i, 0.611570+0*i, 0.334841+0*i, -0.174363+0*i, -0.563589+0*i, -0.545103+0*i, -0.052370+0*i, 0.718921+0*i, 1.407099+0*i, 1.668653+0*i, 1.355043+0*i, 0.590809+0*i, -0.287685+0*i, -0.901416+0*i, -1.018487+0*i, -0.666871+0*i, -0.112300+0*i, 0.286641+0*i, 0.270392+0*i, -0.182518+0*i, -0.841798+0*i, -1.344311+0*i, -1.384085+0*i, -0.874766+0*i,

---

FFT calculation completion!

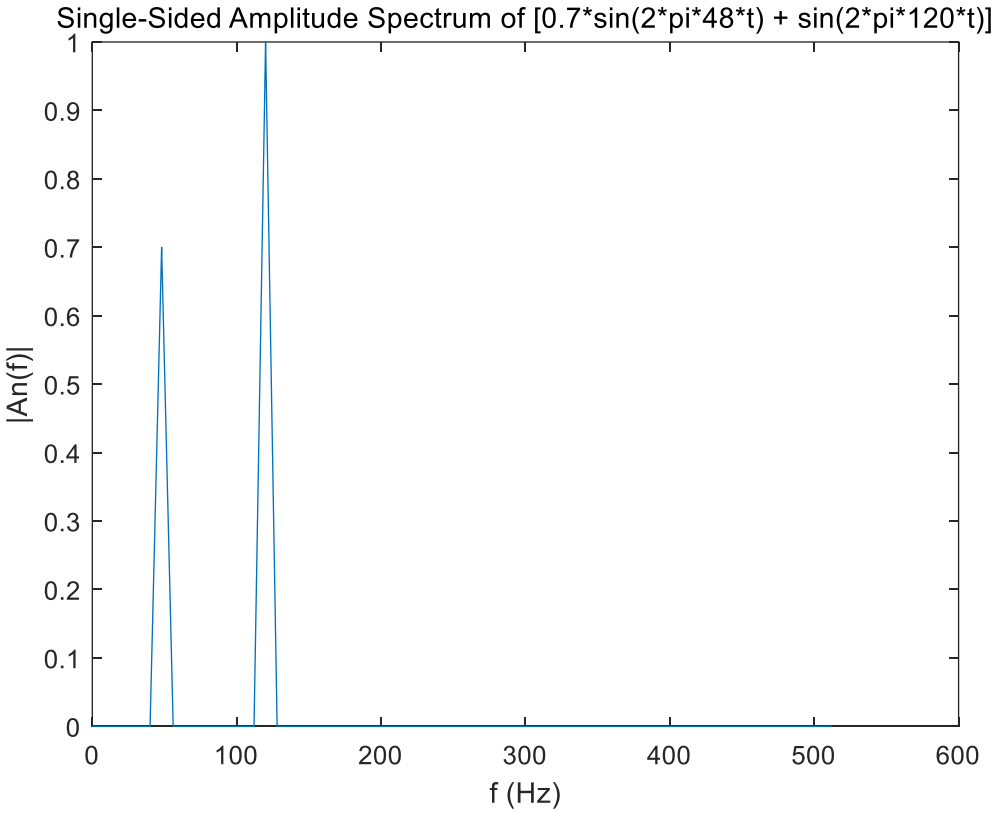
FFT calculation result:

0.000018+(0.000000*i), 0.000004+(0.000004*i), -0.000007+(-0.000003*i), 0.000009+(0.000004*i), 0.000010+(0.000009*i), -0.000001+(0.000007*i), 0.000001+(-44.799988*i), -0.000004+(0.000008*i), -0.000003+(0.000004*i), -0.000002+(0.000012*i), -0.000000+(0.000003*i), 0.000004+(0.000013*i), 0.000006+(0.000018*i), 0.000004+(0.000042*i), 0.000001+(0.000074*i), -0.000234+(-63.999992*i), -0.000004+(-0.000078*i), -0.000004+(-0.000035*i), 0.000003+(-0.000031*i), -0.000009+(-0.000018*i), -0.000018+(-0.000024*i), -0.000003+(-0.000044*i), 0.000021+(-0.000026*i), 0.000012+(-0.000005*i), -0.000001+(-0.000018*i), 0.000008+(-0.000012*i), 0.000009+(-0.000014*i), 0.000010+(-0.000004*i), 0.000012+(-0.000012*i), 0.000011+(0.000004*i), 0.000010+(-0.000008*i), 0.000001+(0.000005*i), -0.000006+(-0.000009*i), -0.000002+(-0.000003*i), 0.000011+(-0.000010*i), 0.000007+(-0.000003*i), -0.000004+(0.000004*i), 0.000002+(-0.000014*i), 0.000007+(-0.000005*i), 0.000000+(0.000011*i), -0.000007+(-0.000022*i), 0.000002+(-0.000002*i), 0.000012+(-0.000021*i), 0.000010+(0.000004*i), 0.000010+(-0.000006*i), 0.000011+(0.000003*i), 0.000007+(-0.000000*i), 0.000000+(0.000003*i), 0.000001+(-0.000003*i), -0.000009+(0.000008*i), -0.000015+(-0.000014*i), 0.000009+(-0.000026*i), 0.000026+(-0.000009*i), 0.000014+(0.000010*i), 0.000000+(-0.000004*i), 0.000011+(-0.000010*i), 0.000017+(0.000011*i), 0.000006+(-0.000000*i), 0.000002+(0.000008*i), 0.000006+(-0.000009*i), 0.000011+(0.000001*i), 0.000003+(0.000016*i), -0.000000+(-0.000003*i), 0.000001+(0.000008*i), -0.000003+(0.000000*i), 0.000001+(-0.000008*i), -0.000000+(0.000003*i), 0.000003+(-0.000016*i), 0.000011+(-0.000001*i), 0.000006+(0.000009*i), 0.000002+(-0.000008*i), 0.000006+(0.000000*i), 0.000017+(-0.000011*i), 0.000011+(0.000010*i), 0.000000+(0.000004*i), 0.000014+(-0.000010*i), 0.000026+(0.000009*i),

0.000009+(0.000026*i), -0.000015+(0.000014*i), -0.000009+(-0.000008*i), 0.000001+(0.000003*i), 0.000000+(-0.000003*i), 0.000007+(0.000000*i), 0.000011+(-0.000003*i), 0.000010+(0.000006*i), 0.000010+(-0.000004*i), 0.000012+(0.000021*i), 0.000002+(0.000002*i), -0.000007+(0.000022*i), 0.000000+(-0.000011*i), 0.000007+(0.000005*i), 0.000002+(0.000014*i), -0.000004+(-0.000004*i), 0.000007+(0.000003*i), 0.000011+(0.000010*i), -0.000002+(0.000003*i), -0.000006+(0.000009*i), 0.000001+(-0.000005*i), 0.000010+(0.000008*i), 0.000011+(-0.000004*i), 0.000012+(0.000012*i), 0.000010+(0.000004*i), 0.000009+(0.000014*i), 0.000008+(0.000012*i), -0.000001+(0.000018*i), 0.000012+(0.000005*i), 0.000021+(0.000026*i), -0.000003+(0.000044*i), -0.000018+(0.000024*i), -0.000009+(0.000018*i), 0.000003+(0.000031*i), -0.000004+(0.000035*i), -0.000004+(0.000078*i), -0.000234+(63.999992*i), 0.000001+(-0.000074*i), 0.000004+(-0.000042*i), 0.000006+(-0.000018*i), 0.000004+(-0.000013*i), -0.000000+(-0.000003*i), -0.000002+(-0.000012*i), -0.000003+(-0.000004*i), -0.000004+(-0.000008*i), 0.000001+(44.799988*i), -0.000001+(-0.000007*i), 0.000010+(-0.000009*i), 0.000009+(-0.000004*i), -0.000007+(0.000003*i), 0.000004+(-0.000004*i)

上述输出数据 *fft_output_buf* 对应的幅频图如所示

图 3-2. FFT 输出数据幅频特性



4. 版本历史

表 4-1. 版本历史

版本号.	说明	日期
1.0	首次发布	2024 年 12 月 31 日

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