Products: Vector Signal Generator SMIQ

SMIQB60
Arbitrary Waveform Generator
for SMIQ

Application Note

The SMIQB60 option is an internal two channel arbitrary waveform generator based on the modulation coder SMIQB20. SMIQB60 uses an innovative interpolation filter technique to increase memory capacity. Waveforms can be calculated and transmitted with the external PC-Software WinIQSIM™ and stored in the non volatile memory of SMIQ. Stored waveforms can be recalled by SMIQ without using WinIQSIM™.

ROHDE & SCHWARZ

Contents

1   Introduction

The SMIQ option SMIQB60 is an internal 2 channel arbitrary waveform generator (ARB) based on the modulation coder SMIQB20. Waveforms can be calculated and transmitted with the external PC-Software WinIQSIM™ and stored in the non volatile memory of SMIQ. Stored waveforms can be recalled by SMIQ without using WinIQSIM™. SMIQB60 provides arbitrary I/Q signals to drive SMIQ's I/Q modulator. This is the main purpose of SMIQB60, although the I/Q signals are also available at SMIQ's I and Q outputs. SMIQ is based on a concept providing considerable improvements compared to conventional arbitrary waveform generators. This concept is outlined in section 2. Sections 3 and 4 describe SMIQB60 operation and applications.

2   Function Principles of SMIQB60

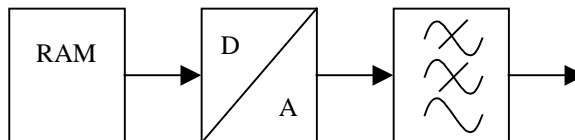## Conventional arbitrary waveform generators

Fig. 2-1   Conventional ARB

A conventional arbitrary waveform generator (ARB) basically consists of an output-memory, a D/A-converter and an analog filter (see Fig. 2-1).
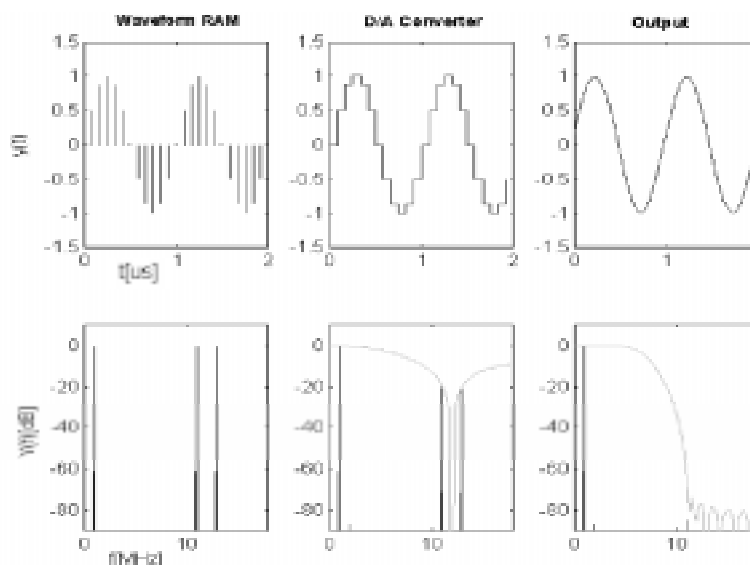

Fig. 2-2   Building a sinewave with a conventional ARB. Upper row: time domain. Lower row: frequency domain.

Fig. 2-2 shows how a signal is generated with a conventional ARB. A sinewave with frequency 1 MHz is taken as example.

The sinewave is represented by a sequence of sample values stored in the waveform RAM. Mathematically, this is described as a sequence of weighted Dirac pulses. The time interval between two consecutive sample values is given by $T_{sample}= 1 / f_{sample}$, with f_{sample} being the sample rate. This time signal and the resulting frequency spectrum are shown in the left column of Fig. 2-2 A sequence of Dirac pulses in time domain gives a sequence of Dirac pulses in frequency domain. The fundamental at f_{mod} (modulation frequency) is repeated at $f_{sample} \pm f_{mod}$, $2*f_{sample} \pm f_{mod}$, and so on. These repetitions are called aliasing products. As the sample rate is 12 MHz, and f_{mod} = 1 MHz, there are aliasing products at 11 and 13 MHz, 23 and 25 MHz, and so on.

Actually, this is not quite the signal coming out of the D/A converter. As we want a continuous output signal, every sample value has to be held for T_{sample}. Thus, the signal from the D/A converter is a sequence of rectangles with amplitudes

given by the sample values and widths T_{sample}. This leads to an additional $(\sin f_{sample}) / f_{sample}$ factor in the spectrum, as shown in the middle column.

As the fundamental contains all necessary information about the signal, the aliasing products are normally suppressed by low-pass filters to reduce the bandwidth of the signal chain, see the right column in Fig. 2-2. In our example, the filter cutoff has to be at 11 MHz at maximum to suppress all aliasing products (see Fig. 2-3).
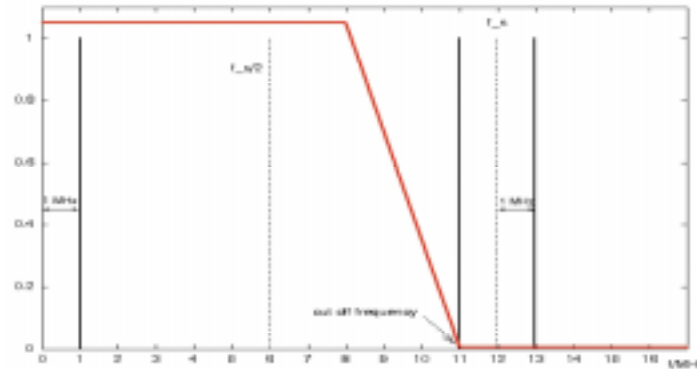

Fig. 2-3   1 MHz sinewave signal with 12 MHz sample rate and 11 MHz filter cutoff.

Usually, the antialiasing filters in ARBs are hardware filters with fixed passband and stopband range, the signal calculation has to be adapted to the filter characteristics. (In our example, the sample rate *has to be* at least 12 MHz to make use of the 11 MHz filter.) This can lead to high oversampling values and therefore to a large amount of sample values using up RAM capacity.

The ARB concept has been significantly improved in the SMIQB60 option. The core of this improved concept is using a digital interpolation filter.
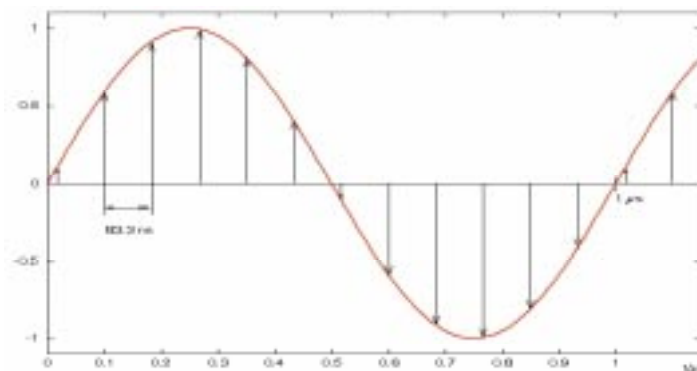
Functioning of an interpolation filter

Fig. 2-4   1 MHz sinewave with 12 MHz sample rate (time domain)

Let us have a closer look at how an interpolation filter works with a simple example. In Fig. 2-4 a 1 MHz sine wave signal is shown. This waveform is sampled with a 12 MHz sample rate, which means, a value every 83.3 ns.
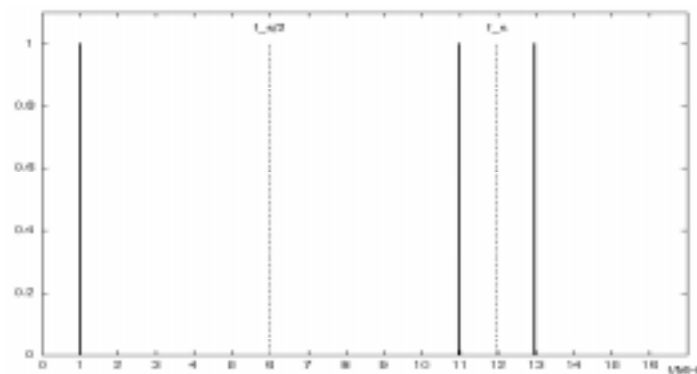
Fig. 2-5   1 MHz sinewave with 12 MHz sample rate (frequency domain)

In Fig. 2-5 the resulting frequency spectrum is displayed, consisting of the fundamental at 1 MHz and the aliasing products symmetric to multiples of the sampling frequency. The aliasing products are located at (12 ± 1) MHz, (24 ± 1) MHz, and so on.

Fig. 2-6   1 MHz sinewave with 3 MHz sample rate (time domain).
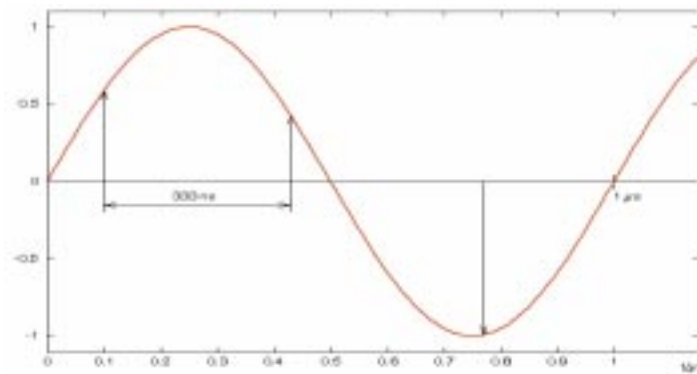
Fig. 2-6 shows the same 1 MHz sine wave signal. This time it is sampled with a sample rate of 3 MHz, a value every 333 ns.
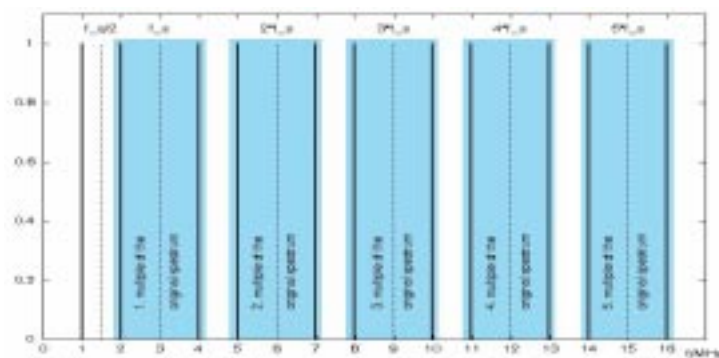

Fig. 2-7   1 MHz sinewave with 3 MHz sample rate (frequency domain)

This results in a spectrum as shown in Fig. 2-7. The fundamental is still at 1 MHz, but the aliasing products are now at (3 ± 1) MHz, (6 ± 1) MHz, and so on.
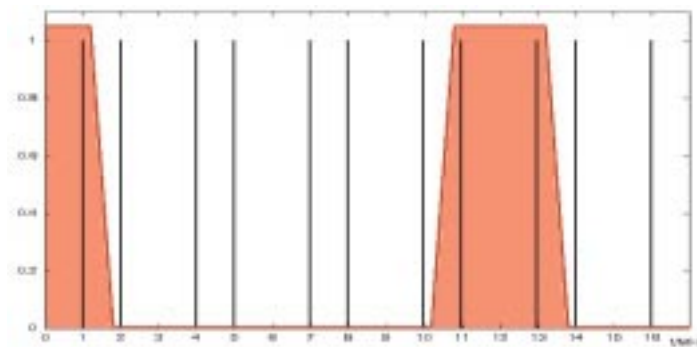
Fig. 2-8   The interpolation filter suppresses a part of the aliasing products.

By applying a digital interpolation filter, all unwanted aliasing products are suppressed (see Fig. 2-8). In this example only the frequencies within the marked area are passing the filter, which means, that the filter provides an oversampling of 4 (3 MHz * 4 = 12 MHz).
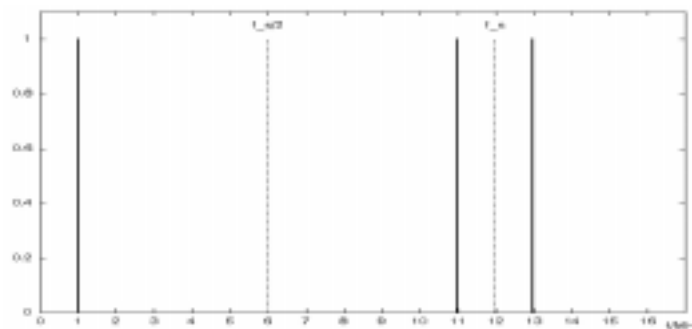
Fig. 2-9   Spectrum of the 1 MHz sinewave with 3 MHz sample rate, after applying the interpolation filter from Fig. 2-8.

As result we have exactly the same frequency spectrum[1] as for a 12 MHz sample rate (compare Fig. 2-9 with Fig. 2-5).

The frequency spectrum of Fig. 2-9 leads to the time signal displayed in Fig. 2-10, looking exactly like the sine wave with a sample rate of 12 MHz (see Fig. 2-3).
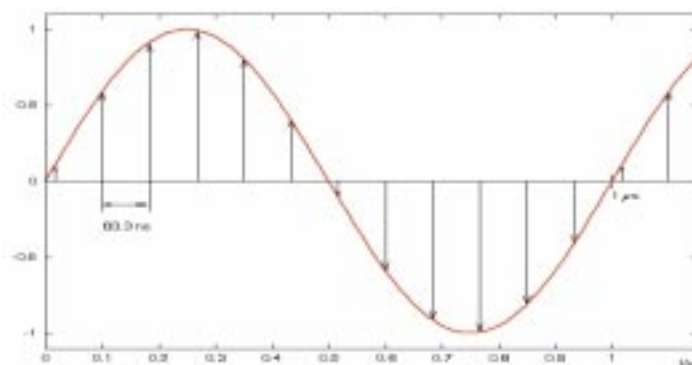

Fig. 2-10   1 MHz sinewave with 3 MHz sample rate in time domain, after applying the interpolation filter of Fig. 2-8.

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[1] Actually, the interpolation filter takes away some signal energy. However, we are still in the digital world, so this problem can be eliminated with sufficient calculation accuracy.

The interpolation filter increases the "effective" sample rate by a factor of four. To put it another way: we can obtain an effective sample rate of 12 MHz by sampling with 3 MHz, applying the interpolation filter and using up four times less samples.
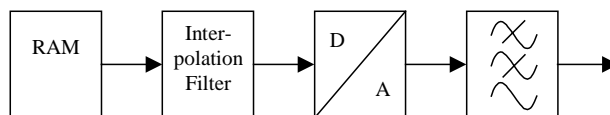
SMIQB60 concept

Fig. 2-11   Schematic of the SMIQB60 ARB

In the SMIQB60 ARB the interpolation filter is inserted between the RAM and the D/A converters. It has two functions:

- The interpolation filter allows low nominal sample rates, which uses up less RAM capacity.

- The interpolation rate of the filter is automatically set in a way that aliasing products of the signals are shifted into the stopband range of the antialiasing filters.
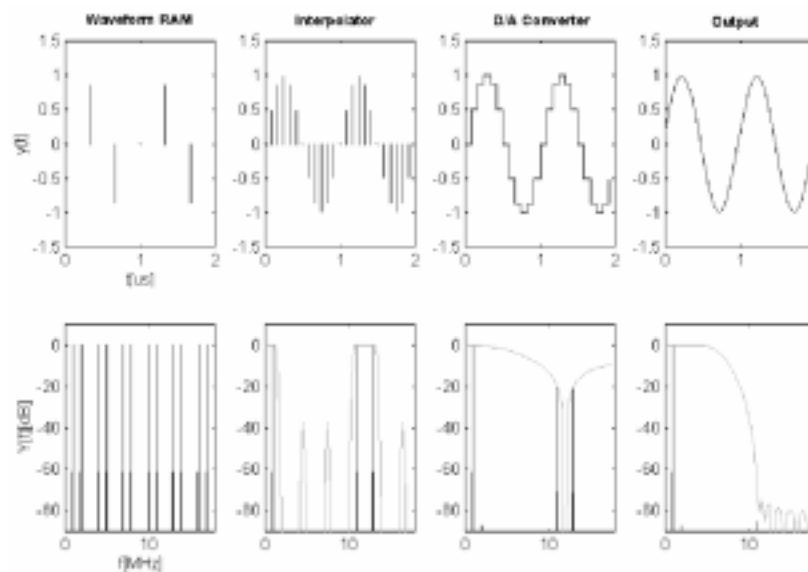
Fig. 2-12   Building a sinewave with SMIQB60. Upper row: time domain. Lower row: frequency domain.

In Fig. 2-12 the function principle is shown for a 1 MHz sinewave signal. In the leftmost figure the 1 MHz sinewave and the aliasing products resulting from the sample rate of 3 MHz are shown. The digital interpolation filter suppresses parts of the aliasing products, which leads to a higher effective sample rate and therefore more values in the time domain. The D/A conversion weights the signal with a (sin f_{sample}) / f_{sample} function. The analog filter suppresses the remaining aliasing products.

The interpolation filter technique significantly saves memory. It usually leads to lower oversampling values than with conventional ARBs.

The interpolation filter is designed in a way that it starts suppressing at 0.375 f_{sample} (See Fig. 2-13). The sample rate f_{sample} is set by choosing an oversampling value O, as $f_{sample} = O \cdot f_{sym}$, where the symbol rate of the

modulated signal is defined by the application. Choosing O sets both the sample rate and the passband range of the interpolation filter.
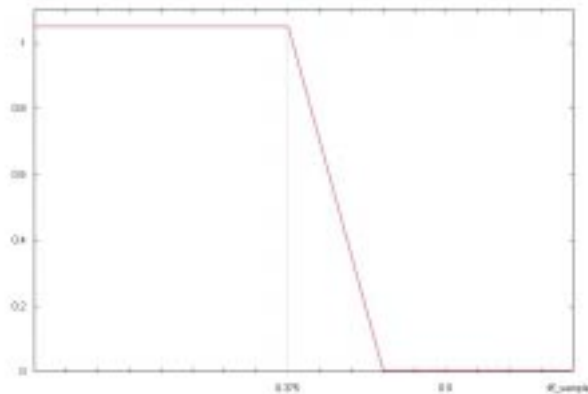
Fig. 2-13   Schematic characteristics of the interpolation filter in SMIQB60

In general, oversampling has to be selected so that the bandwidth of the interpolation filter W_I exceeds that of the modulated signal W_S.

$$W_I \geq W_S$$

This leads to the following equation (for derivation see the mathematical appendix provided with this application note):

$$O \cdot \frac{W_I}{f_{sample}} \geq \frac{W_S}{f_{sym}}$$

The following value is obtained for the digital standard W-CDMA with the baseband filter $\sqrt{\cos}$, $\alpha = 0.22$:

$$\frac{W_S}{f_{sym}} = \frac{1+\alpha}{2} = 0.61$$

thus (with $W_I / f_{sample} = 0.375$)

$$O \geq \frac{0.61}{0.375} = 1.63$$

Due to the reduced oversampling, the duration of the signal increases with a constant number of sampling values. Accordingly, the number of sampling values decreases with constant signal duration. Usually, with conventional ARBs, the minimum oversampling is limited to 4. Then a W-CDMA frame with 38400 chips requires 153600 samples. A conventional ARB with 512 ksamples memory could take signals with up to 3 frames. In SMIQB60, WCDMA signals with up to 8 frames are possible (512k / (38400 · 1.63) = 8.375…).

Fig. 2-14 shows the basic block diagram of the SMIQB60 ARB.
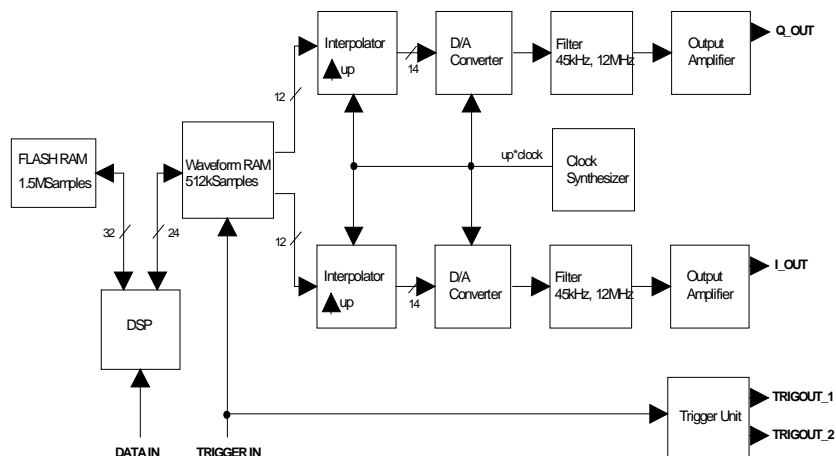
Fig. 2-14   Basic block diagram of SMIQB60.

The I/Q samples are loaded by the host computer via the DATA IN interface to the DSP which passes them into a non-volatile FLASH RAM. The latter is organized in 22 blocks of 64ksamples, each. At least one block is occupied by each waveform.

If a waveform is selected, the I/Q samples are loaded into the output memory. They are convolved with a correction filter, which compensates in particular the Si frequency response of the D/A converter.

The maximum absolute value of the I/Q output signal is 0.5 V at 50 Ω (= 0 dB) in Normal mode. This is the nominal output of the I/Q modulator. The output level can be varied in Manual mode between -6 dB and 3 dB in order to optimize the ACP in various channel offsets. For measurements in alternate channels, the output signal can be increased above 0dB to slightly overdrive SMIQ's I/Q modulator. This may produce more intermodulation distortion, but intermodulation will mostly affect the adjacent channels. In ther alternate channels the performance will be better, because signal-to-noise ratio is increased. The range above 0 dB is not specified, signal frequencies above 10 MHz may lead to a limitation.

The internal calibration of the SMIQB60, which is performed automatically with calibration of the vector modulation, corrects offset and gain errors to a minimum.

3   SMIQB60 Operation

Generating waveforms with WinIQSIM™

SMIQB60 is supported by WinIQSIM™ from version 3.30. Waveforms can be loaded via the IEC/IEEE bus into the FLASH memory, an individual operating menu can set numerous SMIQ parameters. WinIQSIM™ provides predefined settings for bit and symbol clock for generating trigger signals, slot and frame trigger and the restart signal for the Bit Error Rate Tester (SMIQB21). Waveforms generated for AMIQ can also be loaded into SMIQB60.

Calculating signals in WinIQSIM™ works as usual (see the WinIQSIM™ user manual or online help system for details). Communication with SMIQB60 is done via the SMIQ(ARB) menu. The different functions of this menu are also described in the WinIQSIM™ documentation. Here, we shall only mention two functions. If the waveform contains too many samples for the SMIQB60 RAM, WinIQSIM™ gives a warning when the transmission to SMIQB60 is started.

- If the original oversampling value is bigger than 2, WinIQSIM™ suggests a new value, and the transmission is aborted.

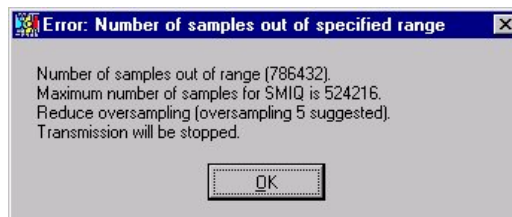Fig. 3-1   WinIQSIM™ recommends lower oversampling if the number of samples is too high for SMIQB60 RAM

- If the original oversampling value is 2, WinIQSIM™ offers downsampling to a value between 1 and 2 (remember that the effective sample rate is increased by SMIQB60's interpolation filter method).
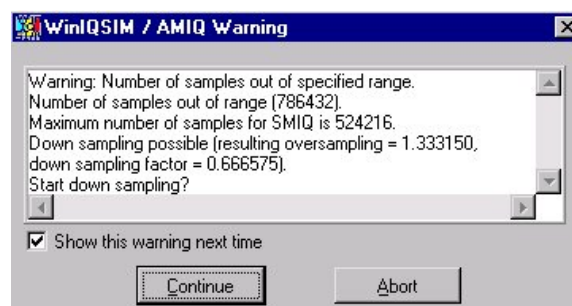

Fig. 3-2   If the number of samples is too high and oversampling is already 2, WinIQSIM™ offers downsampling.

ARB menu in SMIQ

Stored waveforms can be handled via the SMIQ user interface without any external device. In addition, ARB hardware parameters such as operation mode, outputs or clock rate can be set. The CCDF of a loaded waveform can also be displayed.

Furthermore, triggers can be programmed manually. The trigger generator consists of programmable counters which generate a periodic sequence with a pulse duty cycle of On Time / Off Time with settable start delay. The settable resolution for this trigger is the sample rate ($1/t_a$).


```
┌──────────────────────────────────────────────────────────────────────────┐
│ FREQ  2.000 000 000 0  GHz        │ LEVEL        -30.0  dBm │
│                                   │ PEP          -30.0  dBm │
├────────────────────────────────────────────────────────────────────────────┤
│ VECTOR                                                         ALC-S&H      │
│ FREQUENCY    STATE                                                          │
│ LEVEL        TRIGGER M    TRIGGER OUT1 POL                      POS   NEG    │
│ ANALOG MOD               TRIGGER OUT2 POL                      POS   NEG    │
│ VECTOR MOD   TRIGGER..    TRIGGER OUT1 DELAY                        0  Clk   │
│ DIGITAL MOD  SELECT WA    TRIGGER OUT2 DELAY                        0  Clk   │
│ DIGITAL STD  DELETE WA    TRIGGER OUT1 MODE...      CURRENT:    USER         │
│ ARB MOD      SET SMIQ        ON TIME                                1  Clk   │
│ NOISE/DIST   CLOCK FRE       OFF TIME                               1  Clk   │
│ FADING SIM   CLOCK...     TRIGGER OUT2 MODE...      CURRENT:    USER         │
│ BERT         IQ OUTPUT       ON TIME                                1  Clk   │
│ LF OUTPUT    CCDF ►          OFF TIME                               1  Clk   │
└──────────────────────────────────────────────────────────────────────────┘
```
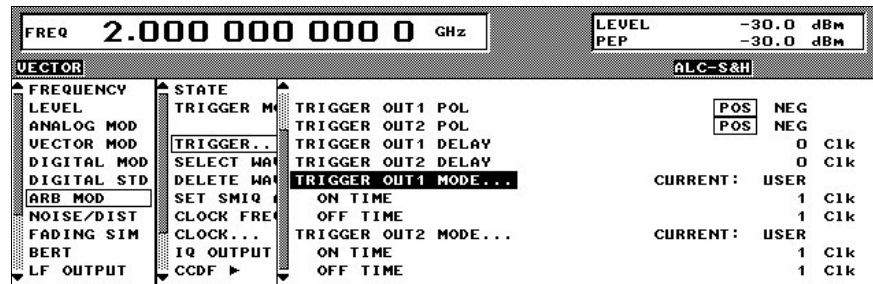
Fig. 3-4   Trigger settings in ARB menu of SMIQ

For example, to generate a slot trigger for a W-CDMA signal with 3.84 Mcps, the following values have to be set:

t_{Slot} =   Slot time

t_{Chip} =   Chip time

t_a =   Sample time

ov =   Oversampling

A W-CDMA frame is 10 ms long. As this system has 15 slots each slot has a length of 666.67 µs. The chip rate multiplied by the frame length gives the number of chips per frame = 38400. This divided by the number of slots gives the value for chips per slot = 2560.

ov $= 2$

t_{Chip} $= ov \bullet t_a$

t_{Slot} $= 2560 \bullet t_{Chip}$

$\Rightarrow$ $t_{Slot} = 5120 \bullet t_a$

On Time = 500 (for example) $\Rightarrow$ Off Time = 5120 − On Time = 4620

The trigger signals can be delayed with respect to the waveform by setting the parameter TRIGGER OUT 1 (or 2) DELAY in the ARB menu. This can be used for compensating different delay times for the signal and control paths of a measurement setup, for example.

Fig. 3-5   Trigger delay, on and off times for SMIQB60 trigger.

4   Applications

CW multi carrier signals

A "classical" application for an arbitrary waveform generator is the generation of CW multi carrier signals. As there is no modulation present, the sequences can be kept rather short. With its maximum clock rate of 40 MHz, SMIQB60 can cover a wide range of signal scenarios. The well balanced I and Q channels lead to signals of high quality.

CW carriers with offset from the RF center frequency ω_0 can also be taken for evaluating the signal quality produced by SMIQB60. If a carrier is generated at $\omega_0 + \omega_M$, spurious signals at $\omega_0 - \omega_M$ are caused by deviations from the ideal balanced I/Q signal, i.e. different magnitude and/or group delay for I and Q. These deviations can result either from not totally balanced outputs of SMIQB60 or from imbalance of the I/Q modulator itself. The measurement cannot distinguish between the two cases. Actually, the I/Q modulator's contribution is much smaller than SMIQB60's. The SMIQ data sheet states the following values:

I/Q imbalance	
Magnitude (up to 10 MHz)	typ. 0.05 dB
Group delay (up to 10 MHz)	typ. 0.5 ns

These values contain both the contributions from the ARB and the I/Q modulator.

The non-ideal I/Q signal for a CW carrier at $\omega_0 + \omega_M$ can be described by:

$$
\begin{aligned}
I(t) &= \cos \omega_M t \\
Q(t) &= (1+\epsilon)\sin(\omega_M t + \varphi)
\end{aligned}
$$

with ϵ, φ << 1.

This leads to the following result for the RF signal:

$$
s(t) = \cos(\omega_0 + \omega_M)t - A\sin[(\omega_0 - \omega_M)t + \phi]
$$

where the second term describes the spurious signals. The parameters A, Φ are:

$$
\begin{aligned}
A &= \frac{1}{2}\sqrt{\epsilon^2 + \varphi^2} \\
\tan\phi &= \frac{\varphi}{\epsilon}
\end{aligned}
$$

A and Φ can be obtained from the data sheet values for imbalance – magnitude and group delay. They depend on the frequency offset from the center frequency.

The complete calculation can be found in the mathematical appendix provided with this application note.
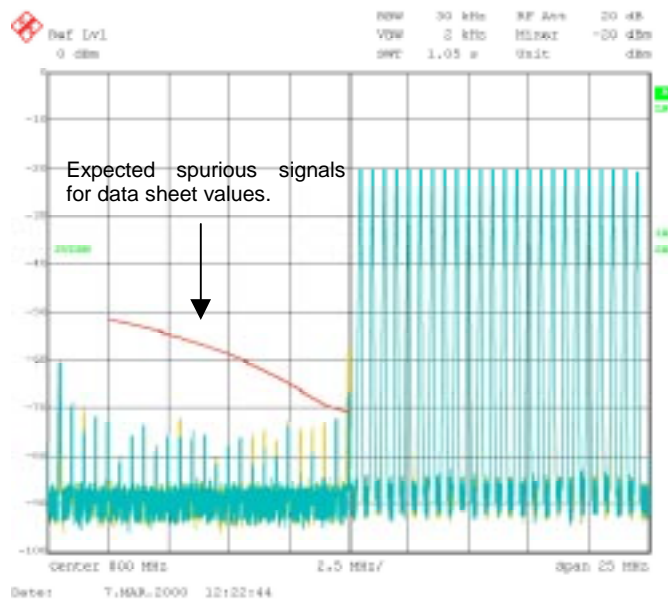
Fig. 4-1   A CW multi carrier signal with 24 carriers, carrier spacing 0.5 MHz, all carriers placed on the right of the center frequency.

Fig. 4-1 shows an example CW multi carrier signal with 24 carriers. The carrier spacing is 0.5 MHz. The signal has been calculated so that all carriers are placed on the right of the center frequency. The SMIQ I/Q modulator converts this signal to 800 MHz center frequency, where it is measured with an FSIQ signal analyzer. The line in Fig. 4-1 marked with an arrow shows the expected level of the spurious signals for the data sheet values. As can be seen, typical values are well below this limit.

Digital standards

For modulated signals, the sequence length of the stored signal plays an important role. In many cases, the signal contains a large number of symbols, for bit error tests and similar measurements, for example. For spectral measurements the number of symbols is less important. For multi carrier signals, however, large bandwidths require high sample rates, and this is memory consuming.

Especially for multi carrier signals, AMIQ with its large RAM capacity might be the better solution in general. Nevertheless, SMIQB60 can be successfully used in many situations where digitally modulated signals are required.

The following tables give an overview of SMIQB60's capacity for different digital communication standards.

GSM/EDGE

Symbol rate	270.833 ksps
Symbols per frame (4.616 ms)	1250
Channel spacing	200 kHz

Number of carriers	maximum number of frames
1	209
2	76
3	60
4	49
5	42
max. 98	1 frame (Limitation through max. clock rate of 40 MHz)

NADC

Symbol rate	24.3 ksps
Symbols per frame (40 ms)	972
Channel spacing	30 kHz

Number of carriers	maximum number of frames
1	269
2	83
3	60
4	47
5	38
max. 217	1 frame (Limitation through memory size of 512 kSamples)

cdmaOne (IS-95)

Chip rate	1.2288 Mcps
Chips per Frame (80 ms)	98304
Channel spacing	1.25 MHz

Number of carriers	maximum number of frames
1	2
2	1 (Downsampling used; Limitation through memory size of 512 kSamples)
3	1 (Downsampling used; Limitation through memory size of 512 kSamples)

cdma2000 1X/3X

Chip rate	1.2288 Mcps (3.6864 Mcps)
Chips per frame (80 ms)	98304 respectively 294912
Channel spacing	1.25 MHz (3.75 MHz)

1X mode (like cdmaOne)

Number of carriers	maximum number of frames
1	2
2	1 (Downsampling used; Limitation through memory size of 512 kSamples)
3	1 (Downsampling used; Limitation through memory size of 512 kSamples)

3X multi carrier mode (superoversampling 2)

Number of carriers	maximum number of frames
1* 3X	1 (Downsampling used; Limitation through memory size of 512 kSamples)

3X direct spread mode

Number of carriers	maximum number of frames
1	1 (Downsampling used; Limitation through memory size of 512 kSamples)

W-CDMA (3GPP FDD)

Chip rate	3.84 Mcps
Chips per frame (10 ms)	38400
Channel spacing	5 MHz

Number of carriers	maximum number of frames
1	6
2	2
3	1
4	1 (Downsampling used; Limitation through max. clock rate of 40 MHz)
5	1 (With superoversampling 1 and baseband oversampling 4)

5   Additional Options related to SMIQB60

Fig. 5-1 on the next page shows the SMIQ option policy related to SMIQB60. The hardware options SMIQB20 (Modulation Coder) and SMIQB11 (Data Generator) are prerequisite for installing SMIQB60.

SMIQB60 itself can be activated by keycode and contains the WinIQSIM™ software.

There are five additional keycode options for generating signals according to special digital communication standards.

- cdmaOne or IS-95 (option **SMIQK11**) is a common CDMA standard in the U.S. and in Korea.

- cdma2000 (option **SMIQK12**) is a 3G standard proposed by some big U.S. manufacturers. It is a CDMA system with one or three carriers and is backward compatible with IS-95.

- Option **SMIQK13** contains the TDD mode of W-CDMA 3GPP.

- TD-SCDMA (option **SMIQK14**) is a special W-CDMA standard that has been developed for the Chinese market.

- Option **SMIQK15** covers several OFDM-based standards, such as HiperLAN/2 and WLAN 802.11a. The option contains the WinIQOFDM software for calculating OFDM signals. WinIQOFDM is used together with WinIQSIM™.

All those signals can be calculated with WinIQSIM™ (+ WinIQOFDM for OFDM) right away. However, the keycode options are required if the signals are downloaded to SMIQB60.
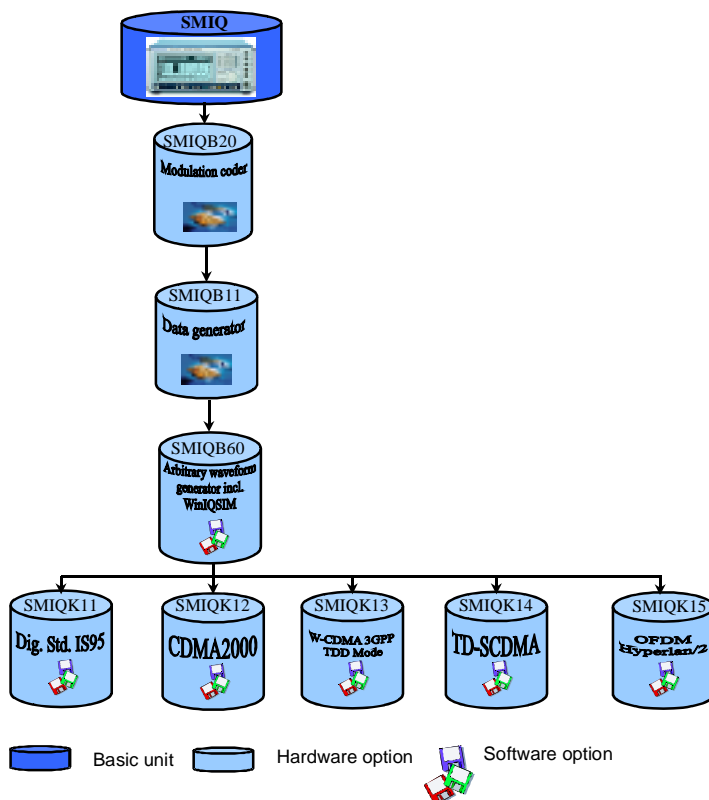

Fig. 5-1   Excerpt from SMIQ options map: SMIQB60 and related options.

6 References

[1] Vector Signal Generator SMIQ, Data Sheet, Rohde & Schwarz, 2000, PD 757.2438.25

[2] Vector Signal Generator SMIQ, Operating Manual, Rohde & Schwarz, 2000, PD 1125.5610.12

7 Ordering information

Vector Signal Generator:

SMIQ02B	300 kHz to 2.2 GHz	1125.5555.02
SMIQ03B	300 kHz to 3.3 GHz	1125.5555.03
SMIQ04B	300 kHz to 4.4 GHz	1125.5555.04
SMIQ06B	300 kHz to 6.4 GHz	1125.5555.06

Options:

SMIQB11	Data Generator	1085.4502.04
SMIQB12	Memory Extension	1085.2800.04
SMIQB20	Modulation Coder	1125.5190.02
SMIQB60	Arbitrary Waveform Generator incl. WinIQSIM™	1136.4390.02
SMIQK11	Digital Standard IS-95 CDMA (for option SMIQB60)	1105.0287.02
SMIQK12	Digital Standard CDMA2000 (for option SMIQB60)	1105.0435.02
SMIQK13	Digital Standard W-CDMA Mode TDD (3GPP) (for option SMIQB60)	1105.1231.02
SMIQK14	Digital Standard TD-SCDMA (for option SMIQB60)	1105.1383.02
SMIQK15	OFDM Signal Generation, Hiperlan/2 and User definable (for option SMIQB60)	1105.1531.02

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