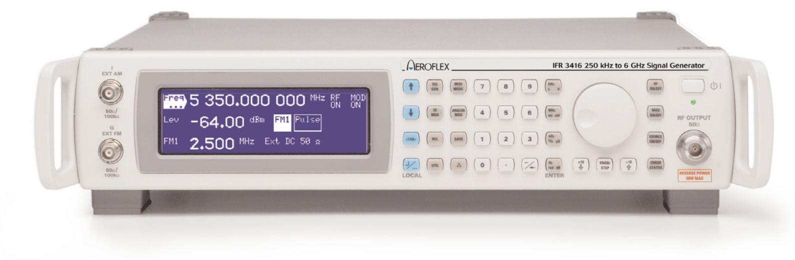
Application Note

Generating frequency chirp signals to test radar systems



Radar chirp signals can be simulated by the 3410 series signal generator using the internal arbitrary waveform generators, external IQ inputs or wideband FM/pulse capability.

Introduction

Radar systems frequently use pulse modulated signals which may also incorporate a linear frequency sweep (chirp) or frequency hopping to enhance the performance of the system. The 3410 series digital RF signal generators can be used to simulate these signals when testing the receiver and amplifier systems.

Additionally, these types of signals can be used in an EMC environment to test device susceptability to 'radar like signals' such as DFS (Dynamic Frequency Selection) enabled WiMAX devices and 802.11h WLAN. A separate application note will detail the use of pulsed signals for DFS enabled devices.

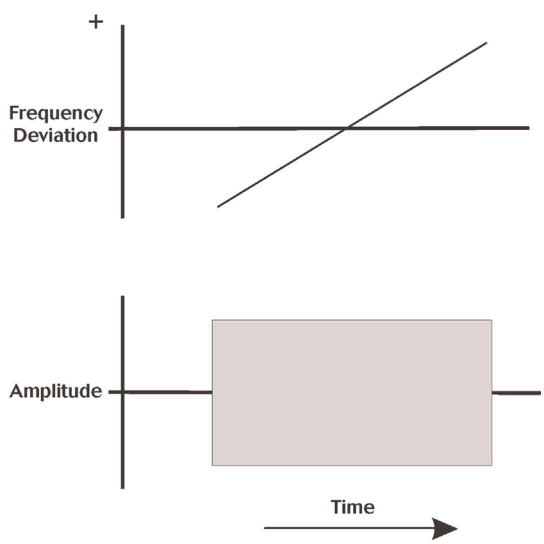


Figure 1. Typical radar chirp signal

A typical chirp radar pulse requires the generation of a pulsed RF signal where the carrier frequency is swept by several megahertz over a typical time interval of 10 to 100 microseconds. The required accuracy of the signal used to simulate the radar return varies according to the type and complexity of the radar system. Depending upon the accuracy of the signal required, three methods of generation can be used on the 3410 series digital RF signal generators.

Method 1

FM and Pulse Modulation (Analog Signal Generator)

This method is described as it is equally applicable to some high performance analog signal generators such as the Aeroflex 2030 Series.

The 3410 series digital RF signal generators have a wide band FM input which can be used to generate the frequency chirp. The FM input has a typical 3 dB bandwidth of greater than 20 MHz and is capable of deviations up to 1% of the carrier frequency. This bandwidth and deviation capability exceeds that required to generate a typical chirp signal.

To generate a chirp signal a ramp generator is connected to the FM port of the signal generator to sweep the carrier frequency and a pulse generator is connected to the Option 6 Fast Pulse Modulator to generate a pulsed RF signal. A dual-channel high speed Arbitrary Waveform Generator (ARB), such as the Tabor Instruments 8026, can be useful to provide these signals.

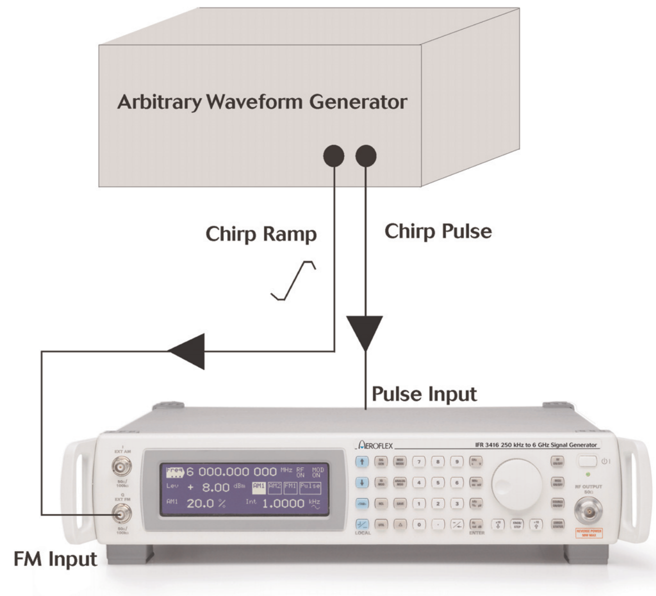


Figure 2. Using 3410 series FM input to generate radar chirps

For many systems this will produce a satisfactory signal provided factors which might effect accuracy are taken into account. The first factor to consider is that the bandwidth of the FM, although large, is not infinite. Consequently if a ramp is suddenly applied some distortion of the ramp linearity can be expected. This effect can be minimized by setting the signal generator to provide a sweep before the RF pulse is required so that transient effects have already decayed when the RF is switched on. A pre-trigger of the ramp 250 ns before the RF pulse will substantially eliminate this effect but the deviation set on the generator may need to be increased slightly in order to compensate for the effect.

The second factor to account for is that the delay between the pulse input changing the RF output and the delay in the FM system is unlikely to be the same. For pulse widths of greater than 10 microseconds the effect is not large and will only result in a small shift of the average carrier frequency of the pulse.

The accuracy of a chirp signal generated using FM is limited by bandwidth effects and the FM accuracy of the signal generator. The 3410 series FM accuracy is specified as 3%. In addition some tests require that the pulse rise and fall time of the RF pulse is controlled. This is not possible with the Option 6 Fast Pulse Modulator which is specified as having a rise time of less than 20 ns typical.

For many applications this technique provides more than adequate performance at an economical cost but if better accuracy is required or profiled pulse shaping is needed, then an alternative technique can be used which requires the use of an IQ signal generator.

Method 2

External IQ (Vector Signal Generator)

The 3410 series digital RF signal generators have the capability of providing IQ modulation which can be used to generate FM chirps. To make an IQ modulator produce a chirp the modulator needs to be configured to behave as a single side band (SSB) modulator. If a tone is applied to the SSB modulator it produces a single carrier frequency at its output whose frequency is equal to the modulator input frequency plus (or minus) the modulating tone. Clearly if the tone frequency is linearly swept the modulator output frequency will also be swept as required in a radar chirp.

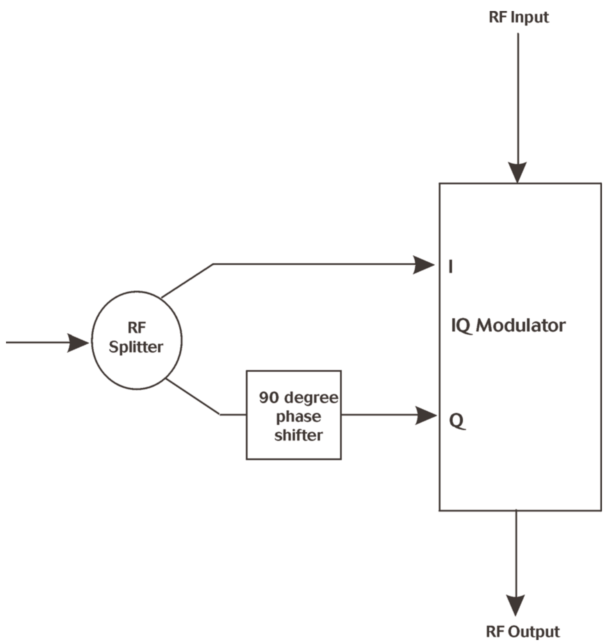


Figure 3. Using an IQ modulator as a SSB mixer

An IQ modulator can be configured as a SSB mixer by applying the modulation input to the I port and a 90 degree phase shifted version of the signal to the Q input. In practice it is difficult to make the necessary phase shifter over a broad frequency range so for generating radar chirps it is more convenient to use an ARB with two outputs where one output is computed to be phase shifted by 90 degrees. To generate the I and Q drives the simplest approach is to use an ARB whose output can be fixed by a mathematical formula over given time intervals.

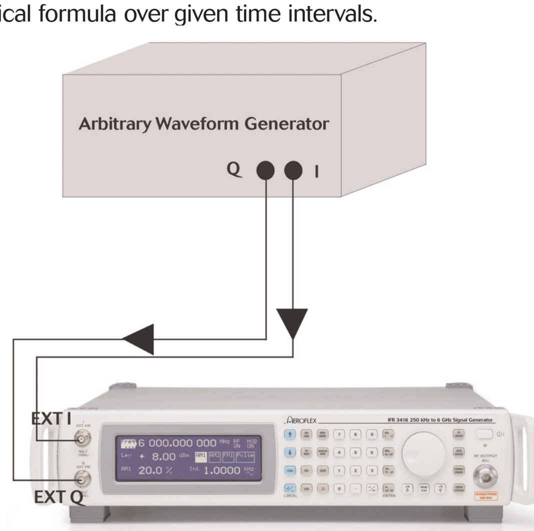


Figure 4. Using 3410 series external I and Q inputs to generate radar chirps

For a radar chirp required to sweep over a frequency range of + / - 2.5 MHz in a time interval of 20 microseconds the I port of the ARB needs to generate an output given by the formula:

I Output = $A \times \cos \pi (-2.5 \times 10^6 + t \times 2.5 \times 10^{11})t$

Where t = elapsed time during the pulse

A = required output amplitude

The "-2.5×10^6" term is the starting frequency of -2.5 MHz and the "2.5×10^{11}" term is the rate of change of the required carrier frequency with time (0.25 MHz per microsecond) .

To generate the Q drive the second output needs to be computed from the formula:

Q Output = $A \times \sin \pi (-2.5 \times 10^6 + t \times 2.5 \times 10^{11})t$

The "Sin" term replaces the "Cos" term to produce a 90 degree phase shifted version of the I signal. In this case the formula has been chosen to sweep the ARB frequency from -2.5 MHz through DC to +2.5 MHz. This method is chosen since it minimizes both the maximum ARB frequency and the bandwidth of the IQ modulator required by sweeping the frequency symmetrically from the nominal center frequency.

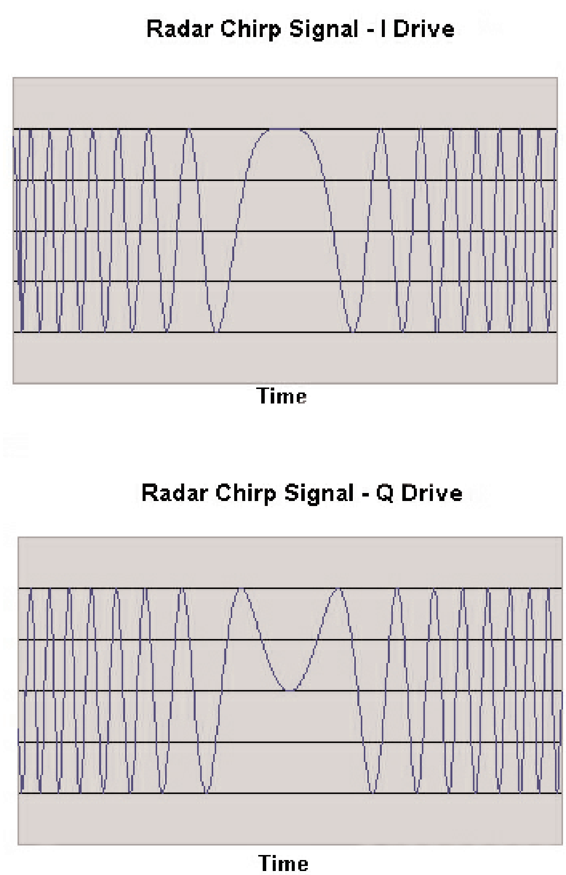


Figure 5. Typical base band I and Q drives for a radar chirp signal

The computed signal can be further refined to include the required rise and fall time characteristics of the RF pulse. If the amplitude term, A, is defined as being time dependent the I and Q drives can be varied in amplitude to produce a RF pulse.

The frequency accuracy of the output pulse will be much better than the FM technique since it is controlled by the ability of the ARB to produce a synthesized frequency. To produce a clean ARB output signal the clock rate of the ARB should be at least 4 times the peak frequency deviation of the chirp and the anti-alias filter bandwidth should be set to be at least 50% more than the peak frequency deviation.

Chirp Errors

A potential source of error in the chirp signal is that it is essential to maintain phase quadrature on the external I and Q signals. The I and Q inputs to the 3410 signal generator are carefully matched so that they will maintain phase quadrature between the front panel connectors and the modulator but the external ARB can easily introduce unacceptable errors. If the signals are not in phase quadrature some phase and amplitude distortion will be introduced into the chirp. For a 2.5 MHz chirp the period of the highest frequency from the ARB is 400 ns which requires that the I and Q drives are matched to within a few nanoseconds to maintain quadrature. In practice although the two waveform generators can be digitally synchronized to the required accuracy, the analog processing circuits inside the ARB may exhibit some mismatch. This may require that some delay compensation is introduced to match the two channels. Some care should be taken to ensure that asymmetric cable lengths are not included in the two drives from the external ARB if the best accuracy is to be maintained.

A qualitative assessment of the ARB balance can be obtained by setting the ARB to repeatedly generate the chirp and to display the I and Q outputs on an XY oscilloscope display. If the two outputs are in quadrature during the chirp the display will be a circle with a constant amplitude. Care should be taken to ensure that only a high speed scope is used for this test otherwise the scope circuits will introduce errors.

If the ARB does not generate a satisfactory circle on the oscilloscope or digitizer display it may be necessary to correct the ARB output. If the ARB is set to produce identical sine waves on its outputs at frequencies over the range of interest the relative phase of the two outputs can be plotted using a high performance oscilloscope to measure the signals. Once a plot of the phase error versus frequency has been established then the chirp signal can be corrected to remove the errors. If the phase varies linearly as a function of frequency (increasing with increasing frequency) the error is the equivalent of a time delay between the two channels. This can be corrected by introducing a time offset into the ARB waveform formula. In general the higher the clock frequency of the ARB relative to the maximum chirp frequency the fewer the errors that are likely to be introduced into the chirp.

Controlled Rise and Fall Time

A potential problem of using the ARB to define the rise and fall characteristics of the chirp signal is that an IQ modulator will have only a finite carrier leak. Consequently the effective pulse on/off ratio is likely to be limited to around 40 to 60 dB. As an example the IQ inputs on the 3410 series digital RF signal generators require the application of a 0.5 V signal, for nominal output level. A small DC offset at the output of the ARB of 5 m V will result in the generation of -40 dB of carrier leak. The constraints on the ARB can be eased by ensuring that the output of the ARB is operated at a high level and a passive attenuator is used to attenuate both the signal and any DC offset. The availability of a selectable 100 kΩ input impedance on the 3410 signal generator can significantly ease the problem of using the ARB in this way.

If significantly better isolation is required the on/off ratio can be further improved by using a pulse modulator to turn the RF on and off in order to increase the isolation provided by the ARB.

Method 3 - Using 3410 internal ARBs (Digital Signal Generator)

The 3410 family of digital signal generators can include Option 5, Dual-Channel Arbitrary Waveform Generator. This is in fact a dual-channel baseband IQ source that is programmed as required using the IQCreator software. This method is essentially the same as method 2, but uses internal ARBs rather than external ARBs. The main benefits are that the two channels are matched to maintain phase quadrature and there are no DC offsets to affect carrier leak. This provides an inherently better method than method 2. The I and Q waveforms can be generated as described in method 2, using Visual Basic, Excel or a math tool. The waveform data files can then be packaged using IQCreator and downloaded into the ARB. The advantage of this method is that rise/fall profiles can also be defined as well as multi-level pulses.

Time (us)	Sub-math	I	Q
0.015625	-0.124755859	-0.382021678	0.924153363
0.03125	-0.249023438	-0.705006025	0.709201315
0.046875	-0.372802734	-0.921274982	0.388911825
0.0625	-0.49609375	-0.999927161	0.012069471
0.078125	-0.618896484	-0.930955086	-0.365133711
0.09375	-0.741210938	-0.726151601	-0.687534619
0.109375	-0.863037109	-0.416807225	-0.908994905

Figure 6. IQ data for chirp

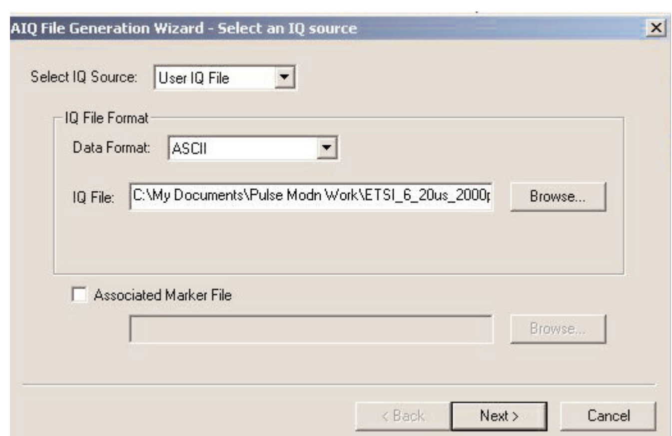


Figure 7. IQCreator packager

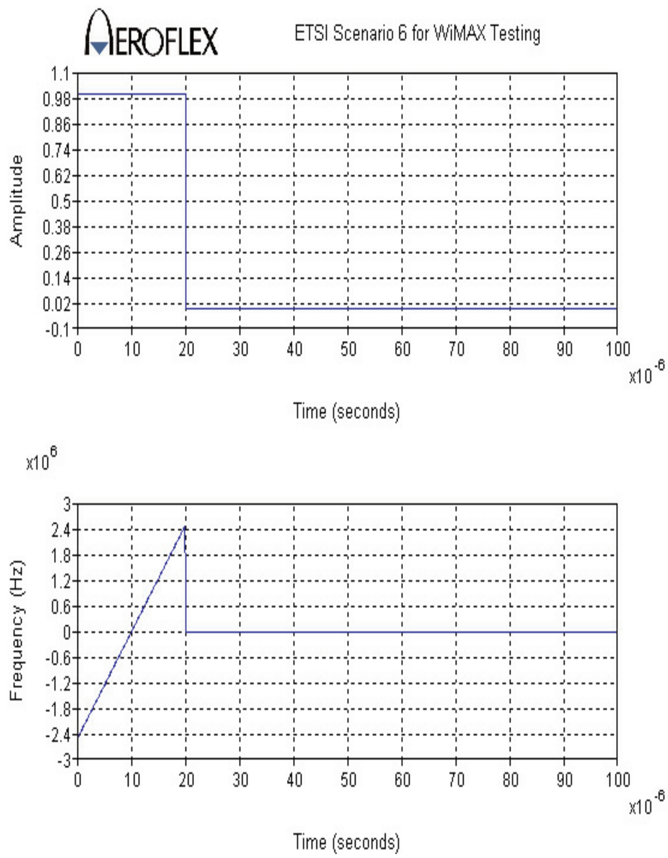


Figure 8. IQCreator simulation results

If the on/off ratio needs to be improved, this method can be used in conjunction with Option 6, Fast Pulse Modulator to provide better isolation. In this case, a “Marker” signal is embedded in the ARB file and the rear panel Marker output drives the Fast Pulse Modulator input. This will improve the on/off ratio from typically 55 dB to better than 80 dB.

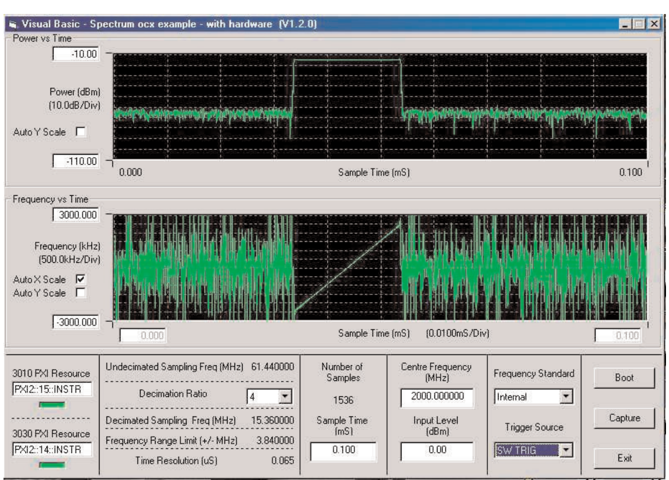


Figure 9. Amp v time and Freq v time from Aeroflex PXI RF analyzer

Choice of Solutions

The availability of the FM input and Digital and Vector Modulation modes makes the 3410 series digital signal generators ideal for generating radar chirp signals at an economical cost. The recommended solution uses the 3410 with Option 5 Dual-Channel Arbitrary Waveform Generator. If an improved on/off ratio of 80 dB is required then Option 6 Fast Pulse Modulator can be utilized. For non-critical applications the FM method provides the most economical solution while more demanding applications can be satisfied by using the 3410 series Digital and Vector Modulation capability.

CHINA Beijing
Tel: [+86] (10) 6467 2716
Fax: [+86] (10) 6467 2821

CHINA Shanghai
Tel: [+86] (21) 6282 8001
Fax: [+86] (21) 62828 8002

FINLAND
Tel: [+358] (9) 2709 5541
Fax: [+358] (9) 804 2441

FRANCE
Tel: [+33] 1 60 79 96 00
Fax: [+33] 1 60 77 69 22

GERMANY
Tel: [+49] 8131 2926-0
Fax: [+49] 8131 2926-130

HONG KONG
Tel: [+852] 2832 7988
Fax: [+852] 2834 5364

INDIA
Tel: [+91] 80 5115 4501
Fax: [+91] 80 5115 4502

KOREA
Tel: [+82] (2) 3424 2719
Fax: [+82] (2) 3424 8620

SCANDINAVIA
Tel: [+45] 9614 0045
Fax: [+45] 9614 0047

SPAIN
Tel: [+34] (91) 640 11 34
Fax: [+34] (91) 640 06 40

UK Burnham
Tel: [+44] (0) 1628 604455
Fax: [+44] (0) 1628 662017

UK Stevenage
Tel: [+44] (0) 1438 742200
Fax: [+44] (0) 1438 727601
Freephone: 0800 282388

USA
Tel: [+1] (316) 522 4981
Fax: [+1] (316) 522 1360
Toll Free: 800 835 2352

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www.aeroflex.com
info-test@aeroflex.com

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