

# Advanced Waveform Generator For Integrated Phased Array Testing

David S. Fooshe<sup>1</sup>, Kim Hassett<sup>1</sup>, William Heruska<sup>2</sup>, John Butler<sup>2</sup>, Patrick Fullerton<sup>2</sup>

<sup>1</sup>Nearfield Systems, Inc., Torrance, CA 90502 USA

<sup>2</sup>Lockheed Martin Corp., Moorestown, NJ 08057 USA

**Abstract—** This paper will discuss a highly customizable and integrated waveform generator (WFG) subsystem used to coordinate timing and command sequences between a phased array antenna and the measurement system during antenna testing. The WFG subsystem is an automated digital pattern generator that orchestrates the command and triggering interface between an NSI measurement system and a phased array beam steering computer. The WFG subsystem is controlled directly by the NSI 2000 software and allows the test designer to select and generate a sequence of up to sixteen unique synchronized timing waveforms. Test scenarios, results and data for the WFG subsystem will be presented along with plots showing the key timing characteristics of the system.

**Keywords:** phase array antenna, antenna measurements, automated test, waveform generator, pattern generator, digital waveform, beam-steering computer.

## I. INTRODUCTION

The performance of today's electronically steered array antennas (ESA) depends largely upon the speed and versatility of the integrated beam-steering computer (BSC). The ESA antenna beam is steered by individually controlling the phase of the radio waves transmitted and received by each radiating element. The ESA antenna's BSC is responsible for translating the desired deflection of the ESA beam from the broadside direction into phase commands for the individual array radiating elements [1]. There are many variations of the ESA including passive arrays, active arrays and digital beam-forming antennas. As a result, there are a variety of different configurations and interfaces which must be considered when measuring ESA antennas [2] [3] [4].

Regardless of the antenna configuration, in every case the measurement system must be capable of synchronizing the measurement process with the AUT. In the case of the ESA antenna, this implies an ability to control the timing of the beam-steering commands, and the ability to interface with the beam-steering computer.

A simple test scenario allows the measurement computer to download a list of beam steering commands to the BSC, perhaps over a LAN interface, and then provides a step command trigger at the appropriate time during the measurement process to advance the advance the BSC to the next beam. In this scenario, the measurement computer can wait a pre-determined interval, or dwell, to provide the BSC time to update the array before continuing with the measurement. This scheme works well provided the BSC

interface to the array is deterministic. Otherwise, a handshake process may be required to allow the BSC flexibility in determining when it is ready to make a measurement.

Other interface solutions include the output of parallel digital patterns to directly control the beam state, and other more complex messaging schemes. In each case, the measurement system is required to synchronize with the AUT BSC in order to coordinate the test process.

In order to meet the demands of the Lockheed Martin phased array calibration and near-field test environment, a test system that could provide a series of parallel waveform sequences at a high rate was required to update the antenna state during the near-field measurement process. In a joint effort, the waveform generator (WFG) subsystem was designed to support current and future ESA testing needs in an ever changing test environment. The WFG subsystem is an automated digital pattern generator capable of outputting multiple programmable waveforms from the NSI measurement system to the phased array and beam steering computer. The WFG subsystem is highly integrated with and controlled directly by the NSI 2000 software, and provides for a sequence of up to sixteen unique timing waveforms. The next section will describe a sample test process and how the WFG subsystem is used.

## II. SAMPLE TEST PROCESS FOR A PHASED ARRAY

In the test environment, the WFG is used as an agile signal generator to coordinate timing and commands between the main test equipment, peripheral test equipment, real-time command interfaces to the AUT, and the AUT itself. Due to its agility, the integrated WFG platform allows for tactical and non-tactical waveforms to be interwoven during test or used independently for troubleshooting purposes.

As an example, per figure 1, the WFG is used in dual roles providing an interrupt signal to the test system real-time command interface to the AUT, and timing signals to the AUT and peripheral test equipment. The measurement computer engages the WFG and loads in relevant test and/or tactical waveforms. A signal is then sent to the real-time interface to buffer tactical commands to the AUT. The triggering mechanism in the NSI software beamtable signals the WFG that an event has occurred and triggers the timing signals to the AUT, upon which the AUT will then execute the commands it was previously sent. Because the WFG has the ability to synchronize test equipment by sending redundant triggering signals to the AUT and equipment simultaneously, the test equipment and AUT can work together seamlessly to perform the test and data collection process. The process repeats until the desired test scenario is completed.

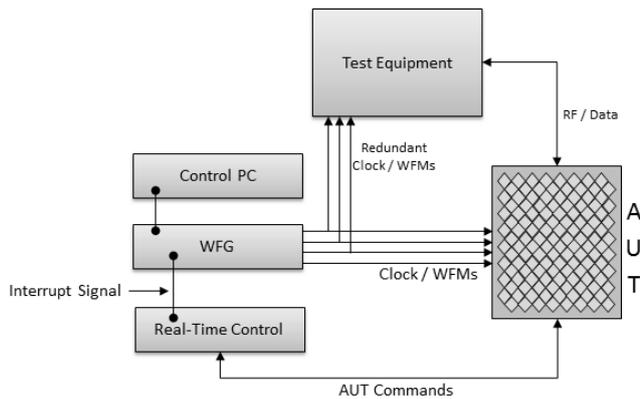


Figure 1. Test Set-Up Configuration

The flexibility of the WFG, when integrated with the NSI test system and software, allows for continuity between various test environments. A standalone system [5] is used during AUT system integration. In this case, the WFG integrated with a network analyzer provides a set of waveforms for integration and alignment to the AUT. Once the AUT moves to the near-field test environment, a WFG integrated with a Panther 9000 system provides waveforms for performing near-field performance testing. The built in efficiency and flexibility allows for the same waveforms and test software to be used in either environment reducing software development efforts and eliminating errors by having multiple versions of software.

### III. WFG SUBSYSTEM DESCRIPTION

The WFG is a system of hardware and software for generating the required signals needed to synchronize beam-steering of a phased array radar antenna with the NSI near-field data acquisition system. The WFG may be used to control the array during antenna measurements or in a standalone system during array verification and calibration.

The WFG provides the capability to generate up to sixteen unique, user-defined waveforms with a minimum pulse width of 0.1 microsecond and sample rates from 1 KHz to 10 MHz. Twelve of these sixteen waveforms are available as two identical RS-422 differential output pairs. The remaining four waveforms are available as two single-ended outputs each.

The waveform timing signals are programmable by the operator through a user interface supplied with the NSI2000 software. The waveform signal timing is generated by a 10 MHz reference signal using either the output of a signal generator or the internal 10 MHz reference. As shown in figure 2, the waveform signals are synchronized with the RF measurement system using a trigger from the NSI Panther 9000 beam controller to indicate either a beam change (BC, or T4) or frequency change (FC, or T3). An external or internal trigger may also be selected.

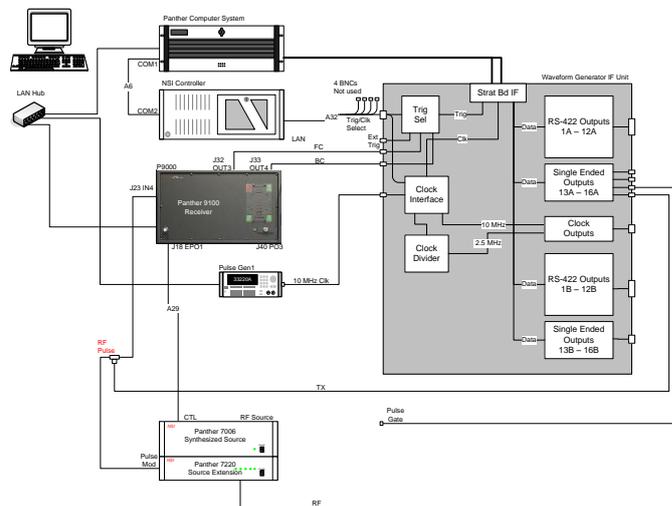


Figure 2. WFG Block Diagram

The WFG interface provides the capability to enable/disable all or individual waveform channels upon command through the UI by defining the “Off” state as either logic high or low. All WFG outputs may be disabled, or set to a predefined default state, through the use of an enable/disable switch. The enable/disable function may also be remotely switched through the use of an external cable.

In addition to the digital waveform outputs, two synchronized RS-422 clock signals are also provided. A Clock1 output is provided as a 10 MHz square-wave RS-422 signal. A Clock2 signal is provided as an additional programmable synchronous clock which is a direct divide down from Clock1. The clock signals are user controllable on/off and are synchronized with the timing signals generated by the WFG. Each of these clocks (Clock 1 and Clock 2) is available as two identical RS-422 differential output pairs, primary and redundant. The WFG outputs are synchronized to the rising edge of the clocks.

As shown in figure 3, the WFG consists of:

A 2U rack-mount WFG Interface Unit (WFG IF Unit), which provides the interface between the WFG card and the customer beam-steering computer (BSC).

A PCI waveform generator (WFG) card installed in the NSI acquisition computer.

- An Agilent 33220A pulse generator which provides the 10 MHz clock for the WFG system.
- BC/FC trigger signals, which may be generated by either the Panther high-speed beam controller or NSI controller.
- Software provided with the NSI2000 software controls the WFG setup and allow the user to set up pre-defined waveforms.

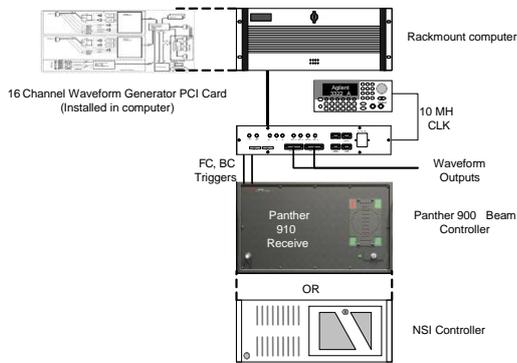


Figure 3. WFG Hardware Configuration

The WFG may be controlled through the NSI2000 software user interface or through the DLL commands available for NSI 2000 script programming.

#### A. WFG Interface Unit

The WFG IF Unit 2U rack mount front panel, figure 4, has a rocker-style power on/off switch and a power on LED. All connectors are included on the front panel to allow installation of the unit in the rear of the rack for easy access to connections.



Figure 4. WFG Hardware Configuration

The WFG IF Unit has a power-on LED and three LEDs to indicate the active trigger.

BNC connectors are provided for 10 MHz In, 10 MHz Out, External Trigger, Frequency Change (FC) Trigger and Beam Change (BC) Trigger.

Four BNC outputs (WFG Out 13A, 14A, 15A and 16A) provide single-ended BNC outputs for the four most significant of the 16 digital waveform outputs.

A DB9 connector provides an input for TTL signals to select one of the three input trigger sources (Ext, FC, BC). Two bits are provided for this purpose and are typically supplied by a cable from the NSI controller. Two additional bits are provided to independently enable or disable Clock1, Clock2 or both.

A DB25(f) connector (WFG Out 1 – 12A) provides RS-422 differential TTL signal pair outputs for the 12 least significant of the 16 digital waveform outputs.

A 2<sup>nd</sup> DB25(f) connector (WFG Out 1 – 12B) provides redundant RS-422 differential TTL signal pair outputs for the 12 least significant of the 16 digital waveform outputs. These are redundant copies of the WFG Out 1 - 12 A signals.

The WFG outputs are synchronized with the 10 MHz and related clocks as shown in figure 5.

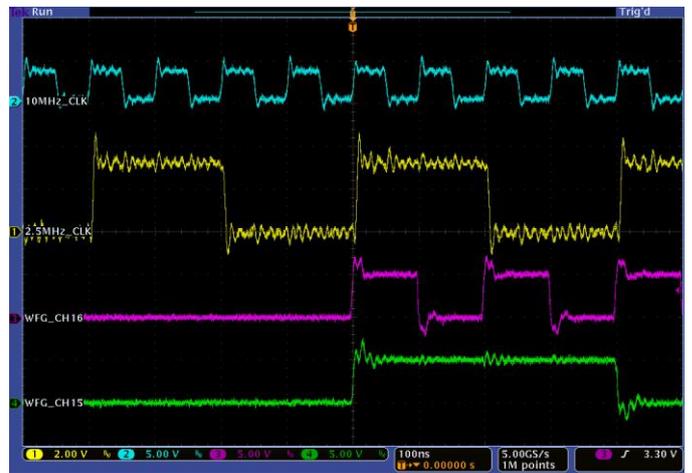


Figure 5. WFG Hardware Configuration

The DB9(f) connector, Clock Primary, provides RS-422 differential TTL signal pair outputs for Clock1 and Clock2. Clock1 is the 10 MHz clock output signal. Clock2 is the 2.5 MHz clock output signal. NOTE: Clock2 is set to 2.5 MHz at the factory in this example, but may be changed to 1.25 MHz, 5 MHz or 10 MHz using a slide switch inside the WFG IF unit.

The DB9(f) connector, Clock Spare, provides redundant RS-422 differential TTL signal pair outputs for Clock1 and Clock2.

20-pin IDC male connectors accept two ribbon cable inputs from the WFG PCI card installed in the Windows computer.

The red master enable/disable switch is used to disable or enable the WFG outputs. The adjacent connector, labeled 'Remote', is used to support an external cable allowing the En/Dis switch to be controlled remotely.

Single-ended WFG outputs are provided on the WFG Sample Test Connector. The 40-pin male test connector allows direct connection to a scope such as an Agilent 6000L rack-mount oscilloscope with integrated 40-pin input connector using a probe cable assembly available from Agilent.

#### B. WFG Control

The WFG software is an integral part of NSI2000 and provides the capability to link waveforms to specific NSI2000 scan events. For example, if a series of signals are required to initialize the BSC, a scenario of unique WFG outputs could be generated at the start of a scan to perform this function. NSI2000 events to which WFG waveforms can be assigned include acquisition start and end, scan cut start for both forward and reverse cuts, scan cut end and reference measurements.

The WFG software may be setup and run from the NSI2000 user interface or by user generated scripts. The NSI2000 scripting language may also be used to access the WFG object model.

The WFG software is provided as a NSI2000 sub controller. Access to scan parameters is included and the beam table may be used to verify configuration and timing.

### C. WFG User Interface

The NSI2000 WFG user interface provides the ability for the user to assign scene files to scan events and to specify the behavior of scenes including trigger and clock selection and the type of trigger event. Each scene file may include the specification of a waveform file. The waveform file defines the waveform that will be generated during the assigned scan event.

Waveform files are comma delimited (.csv) files that specify the digital output pattern for each WFG channel. The filename is used as the waveform identifier. The waveform files are located in a single directory that is specified in the NSI2000 WFG user interface. An example of the waveform file, 'CutFwdStart.csv' is shown in figure 6. The waveform files may be created using Excel or a text editor.

```
NSI2000 Waveform File,.....
Time, Bit 16, Bit 15, Bit 14, Bit 13, Bit 12, Bit 11, Bit 10, Bit 9, Bit 8, Bit 7, Bit 6, Bit 5, Bit 4, Bit 3, Bit 2, Bit 1
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 1, 1, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
0.100 usec, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Figure 6. WFG Waveform File

Scene files are used to specify parameters to be used with a waveform as well as the waveform to be used. Scene files are associated with scan events in the NSI2000 WFG user interface. The filename is used as the scene identifier. The scene files are located in the same directory as the waveform files. Scenes are assigned to NSI2000 acquisition events, but only one scene can be assigned to an event at a time. An example of the scene file, CutFwdStart.scn, is shown in figure 7.

```
NSI2000 Scene File,,
TriggerType,1,
TriggerEvent,1,
DateSaved,3/14/2009 4:53:49 PM,
DateBinary,3/14/2009 4:53:49 PM,
Channel_01,CutFwdStart.csv,10/11/2008 9:44:14 AM
```

Figure 7. WFG Scene File

Scene files may be generated using the NSI2000 WFG software user interface or with a text file.

During the NSI2000 acquisition, the WFG sub controller will be signaled by the following events:

- At Start and End of entire acquisition
- At Start and End of each Continuous Path or Stop Motion cut
- At Start and End of each Reference set

If a Scene has been assigned to the event, the binary pattern is loaded into the WFG and the hardware trigger configured. The Event assignment is automatically saved when NSI2000 is closed. Figure 8 shows the NSI2000 scene-to-event assignment menu.

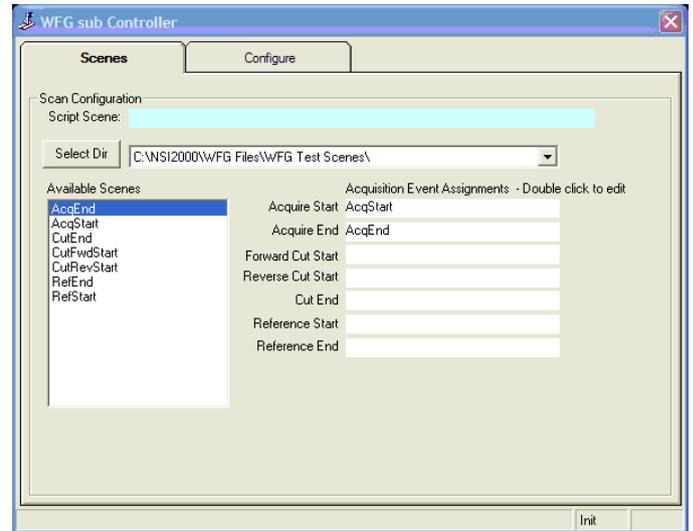


Figure 8. WFG Scenes Assigned to Acquisition Events.

Clicking on the assigned scene name field will open the scene configuration window, as shown in figure 9.

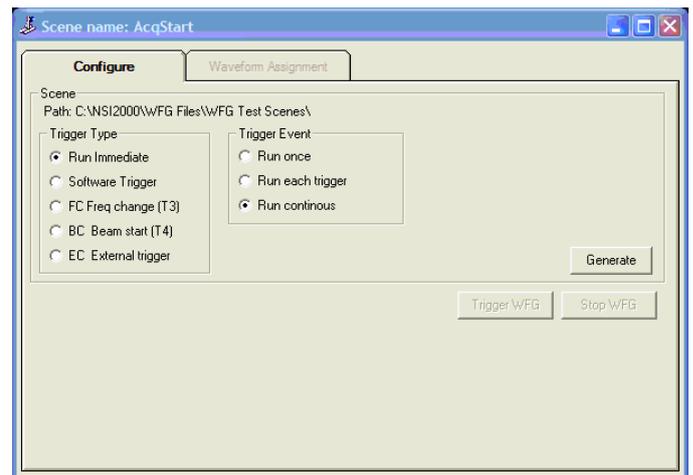


Figure 9. WFG Scene Configuration Window

The WFG scene configuration window provides a means of modifying the behavior of an assigned scene. Change the trigger type or trigger event and press the 'Generate' button to update the scene file.

Pressing the 'Generate' button will generate a binary file representing the current scene file, load the binary into the WFG and setup the waveform. If the 'Run Immediate' trigger type is selected, the waveform will begin to run. If another trigger type is selected the waveform will run when triggered.

Pressing the ‘Generate’ button activates the ‘Stop WFG’ button and places the currently running binary file in the WFG sub Controller status window along with current status, i.e. see bottom status pane showing Run state in figure 10.

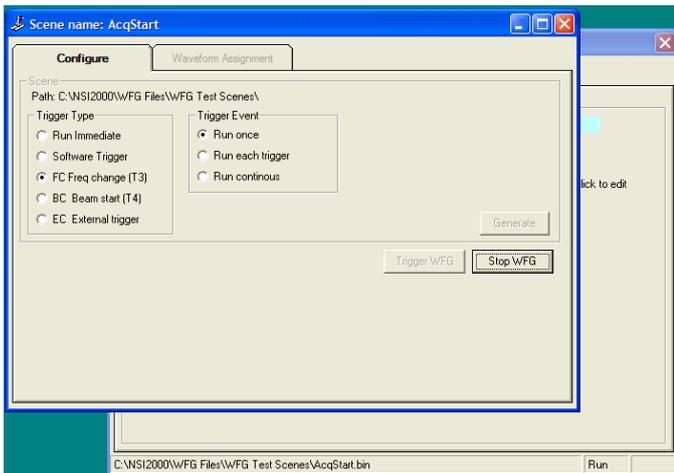


Figure 10. WFG Running

The state of the trigger type and trigger event buttons on the configuration window determine the WFG behavior at runtime. These values are read in from the scene file when NSI2000 is started.

Once the WFG scene files have been assigned to acquisition events, the designated waveforms will run when the specified acquisition event fires. Facilities are provided in the NSI2000 software to save and restore scene settings, start and stop waveforms and displaying log data.

#### D. WFG Object Model

The WFG may be controlled by software on the host computer using the WFG support object model developed specifically for the capabilities of the WFG. The WFG object model resides in a DLL allowing calls from Windows applications such as VB or NSI2000, Word or Excel.

The WFG object model allows the programmer access to the WFG services using the NSI2000 script capabilities. Properties and methods available for the WFG class are shown in figure 11.

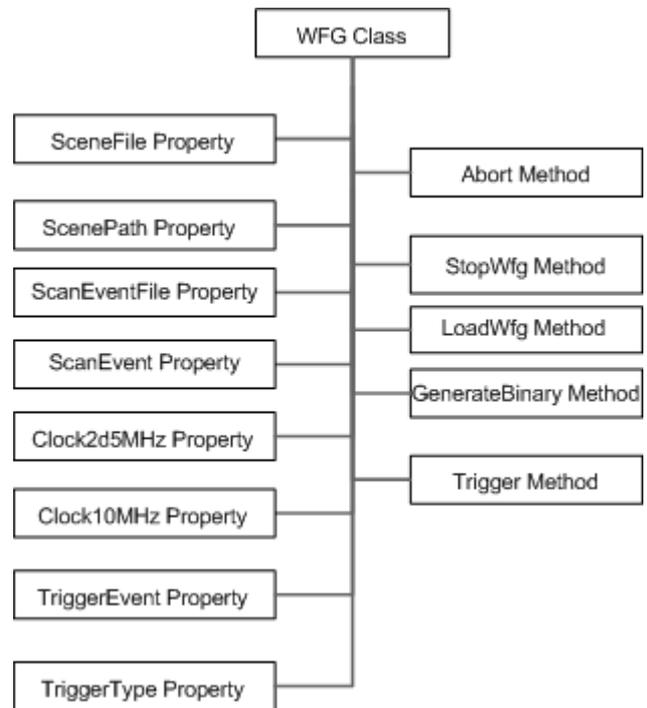


Figure 11. WFG Object Model

#### IV. SUMMARY

This paper has described a highly customizable waveform generator (WFG) subsystem intended to coordinate the ESA antenna test process. The WFG subsystem is an automated digital pattern generator that orchestrates the command and triggering interfaces between the NSI measurement system and a phased array beam steering computer. The WFG subsystem is used for the more complex beam-steering computer interfaces that require multiple programmable timing sequences.

#### ACKNOWLEDGEMENT

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