M8190A Arbitrary Waveform Generator

Accelerated insight into your design with Signal Scenario Generator delivering High Resolution and Wide Bandwidth

Enhance your reality

Anticipate Accelerate Achieve

Agilent Technologies
Drivers for Target Markets

**Realistic testing, today and tomorrow**

<table>
<thead>
<tr>
<th>Radar</th>
<th>Communication</th>
<th>R&amp;D and Research</th>
<th>General Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly realistic signal scenarios</td>
<td>More data, faster</td>
<td>Simulate real-world imperfections</td>
<td>Head-room for the future</td>
</tr>
<tr>
<td>• Simulate with the most realistic signal to avoid expensive life tests</td>
<td>• Cram more information into existing bandwidth</td>
<td>• Ensure flexible adoption to new distortion requirements</td>
<td>• Keep programs on spec, on budget and on time</td>
</tr>
<tr>
<td>• Need for low phase noise to detect slower moving targets</td>
<td>• New standards require 100 times wider modulation bw than existing standards</td>
<td>• Mimic the analog real world imperfections</td>
<td>• Never-ending changing environment calls for new innovation</td>
</tr>
</tbody>
</table>

Transmitter signal, $f_0$

Phase noise

Clutter signal

Reflection from target

Radar scenario diagram

Communication scenario diagram

R&D and Research scenario diagram

General Purpose scenario diagram
Differences M8190A Rev 1 and Rev 2

There’s obviously a difference ….

Revision 1 configuration: B02
- 2 channel version
- 14 bit
- 2 GSa memory

Revision 2 offering
- Advanced Sequencer
- DC and AC Amplifier
- Fast switching (export control for 12GSa/s)
- Calibration ISO 17025 or Z54
- 1 channel or 2 channel
- 14 bit / 8 GSa/s or 12 bit / 12 Gsa/s
- 128 Msa or 2 GSa memory per channel
M8190A Arbitrary Waveform Generator

Accelerated insight into your design with Signal Scenario Generator

- Reliable, repeatable measurements
  - Low phase noise
  - Excellent SFDR and low harmonics

- Optimize the output to match your application
  - Three software selectable amplifier for different signal characteristics (DAC, AC, DC)

- Create complex signal scenarios – efficiently
  - Up to 2 Gsa memory per channel
  - Advanced sequencer

- Flexibility to stress your device to its limits
  - Generate multi-level signals with programmable ISI and jitter up to 3 GB/s

- 88 dBc, 555 MHz, 12 GSa/s DAC
- 110 dBc @ 10 kHz DAC
M8190A AWG - Reliable, repeatable measurements from precise signal simulation

- 88 dBc, 555 MHz, 12 GSa/s DAC

- 63 dBc, 2 GHz multi tone, DAC

- 110 dBc @ 10 kHz (typ)

8 GSa/s; f_{OUT} = 1 GHz; internal sample clock

Excellent SFDR ensures that tones stand out from distortion even with hundreds of tones
Optimize the Output to match your application
Three Selectable Amplifiers!

**Best SFDR, HD & phase noise**
- Root phase noise: -110dBc @10kHz (typ)
- Direct DAC
- Single-ended or differential
- Amplitude 350 mV_{pp} to 700 mV_{pp}
- Offset -20mV … +20mV

**High bandwidth & power**
- 2 V_{pp} (SE)
- AC amplifier*:
  - Single-ended
  - Amplitude (SE) 200 mV_{pp} to 2.0 V_{pp}
  - 50 mHz to 5 GHz (3 dB) (typ)

**Low jitter**
- 5 GHz
- Eye measurement 12 GSa/s, 3 Gb/s
- ~ 7 ps_{pp} Jitter
- 50 ps transition time
- Voltage window: -1.0 ... + 3.3

* AMP option

More details

Agilent Technologies
M8190A AWG

Create complex signal scenarios – efficiently

Waveform Memory
- 2 GSa memory
- 1/6 s playtime at highest sampling rate

Best Memory Usage Through Sequencing
- A sequence consists of a list of waveform segments
- Each segment can be looped up to $2^{32}$ times
- A sequence can contain up to 512 k steps

Real-time Memory Access
- The dynamic control port on the front panel allows you to select one of $2^{13}$ ($2^{19}$)
  segments / sequences dynamically at runtime by applying a digital pattern to the connector

Long playtime and long signal scenarios for highly realistic testing

More Details
M8190A AWG

Flexibility to stress your device to its limits

- Ensure flexible adoptions to new distortion requirements by just adopting the waveform itself
- Mimic the analog imperfections that occur in real-world environments by a mathematical description in tools like Matlab
- Reduce test costs through realistic signal simulations that minimize the need for additional hardware like power combiners
Synchronization of more than 2 channels

1. Set up an external trigger generator to generate a one-shot pulse synchronous with its clock input.
2. Observe the skew between the marker outputs on the scope on recurring runs; make sure it is always the same skew. If not, see next slide.
3. Adjust the waveforms and output delays to compensate the skew.

Four M8190A channels in sync:

- Waveforms consist of a pulse (to show perfect alignment) followed by a sinewave (to show that channels are independent).
- In a real application, the waveform can of course be completely arbitrary.

Zoom-in on rising edge:

Skew can be adjusted to < 1ps.
Flexible signal generation that enables testing of FHSS devices

Carrier frequency is rapidly changed across a wide range of frequency channels. A special receiver knew the frequency-hopping pattern.

- **Interference, noise:**
  - Spread-spectrum signals are highly resistant
  - Only a small piece of data is affected by interference because the frequency changes all the time, so error correction is much more successful.

- **Secure transmission:**
  - The next carrier frequency is not known, so nobody can listen in

- **Efficient use of bandwidth**

- **Transmission occurs only on a small portion of this bandwidth at any given time**

- Spread-spectrum signals add minimal noise to the communication,

---

**Frequency switching characteristics**

<table>
<thead>
<tr>
<th>Effective output frequency</th>
<th>( f_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option: -14dB</td>
<td>( f_{\text{max}} = 3.2 \text{ GHz} )</td>
</tr>
<tr>
<td>Option: -126</td>
<td>( f_{\text{max}} = 4.8 \text{ GHz} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effective frequency switching time</th>
<th>( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option: -14B</td>
<td>313 ps (= 1 / ( f_{\text{max}} ))</td>
</tr>
<tr>
<td>Option: -126</td>
<td>No option: FSW 210 ps</td>
</tr>
<tr>
<td>Option: -126</td>
<td>Option: FSW 208 ps (= 1 / ( f_{\text{max}} ))</td>
</tr>
</tbody>
</table>

1. Effective output frequency \( f_{\text{max}} \) is determined as \( f_{\text{max}}/2.5 \)
2. Determines the minimum time to switch between selected segments in sequence mode
3. Option FSW does not affect switching time in 14 bit mode (Option 14B)
Key characteristics of a Radar Pulse

- Get up to 14 bits resolution and more than 5 GHz analog bandwidth per channel simultaneously
- Build long, realistic scenarios with 2 GSa memory per channel and a sophisticated sequencer
- Push radar designs farther with highly realistic signal scenarios
- Identify deviation from the desired waveform to avoid degradation of radar performance

Typical Test Setup
New features in Rev. 2 available with SW 2.1

• Output Formats (NRZ, DNRZ, RZ, Doublet)
  • For RF applications, select mode based on desired frequency response
  • For time-domain applications, NRZ provides better pulse performance
  • For frequency-domain apps, DNRZ provides better SFDR

Frequency response (Fs=7.2 GHz)

More details
M8190A Programming Structure

- **MATLAB**
  - .mdd
- **LabView**
  - LabView driver
- **User Program**
  - User specific software & application software
  - SCPI
  - IVI-COM
  - IVI-C
  - Firmware & driver
    - Firmware
    - Runs on external PC
    - OR
    - AXIe embedded controller
  - VISA HiSLIP protocol
    - *or* raw TCP/IP on Port 5025
    - (same or different host)
- **PCIe**

**More details**

**Measurement Hardware**
- Instrument M8190A

**SystemVue**
- Wideband Waveform
M8190A Operation with all leading software platforms
Waveform libraries provide quick and easy access to both common (sine, square, triangle, ramp, pulse, exponential) and complex signals.

Free-hand, point, and line-draw modes to create custom shapes.

Equation editor allows you create waveforms with exact polynomials.

Advanced math functions provide additional flexibility for more complex signals.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Basic</th>
<th>Pro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Waveform Library</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cut, copy, past with Excel</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Waveform math</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Free hand</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Line draw</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Advance waveform library</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Equatation editor</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Point draw</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>FFT, CCDF, and contstallation diagrom</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Filters</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Windowing functions</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Dual-channel operation</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Basic version is part of M8190A shipments.
MATLAB software for the M8190A available directly from Agilent for making your own arbitrary waveforms (multi-tone signals, pulsed radar signals, and multi-carrier modulated waveforms), measurement and analysis routines, and instrument applications.

Examples can be modified and are downloadable from the web:

www.agilent.com/find/81180_examples
Accelerate “Design to Test” for Complex Waveforms
SystemVue + Agilent’s M8190A

- Radar Models
- Clutter, noise, and interference
- SystemVue
- BB Pattern Generator
- BB Arb. Waveform Gen
- RF Signal Generator

Design

Validate

Test

- Digital I/Q
- Analog I/Q
- Modulated UWB RF

- UWB Radar
- EW
- SDR

- WiFi
- 802.11ac
- 802.11ad

- MIMO
Introducing New 802.11ad Signal Creation and Signal Analysis Software or WWC

**Compliant** testing for Wireless HD, WiGig and IEEE802.11ad

**Complete** transmitter and receiver testing with the Wideband Waveform Center

Wideband Waveform Creator: **Keep it simple** with drag & drop waveform creation

Wideband Waveform Analyzer: Modulation analysis **at a glance** of fully coded signals

Wireless HD version 1.0
Supports HRP and PRP
Supports all transmit codes
WiGig & IEEE802.11ad
Fully compliant waveforms
Supports CPHY, SCPHY, OFMDPHY, LPSCPHY

Wideband Waveform Creator for transmitter testing:
- General features:
  - IQ impairments and gaussian noise addition
  - Pre-distortion: complex and \( \sin(x)/x \)
  - Output direct to Agilent AWG
  - Single-tone, two-tone and multitone
  - QPSK, 8-PSK, 16-QAM, GMSK, Pi/2BPSK
- Configurable baseband filtering
- 1. Drag & drop waveform
- 2. Assign attributes
- 3. Add predistortion for uplink compensation
- 4. Set sample rate and download waveform to the instrument

Wideband Waveform Analyzer for receiver testing:
- Color-coded composite constellation display
- Multiple dockable windows, each independently configurable to display one of 13 measurement results

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Agilent 60 GHz PHY Test Solution

Controlling PC
(Could be Desktop, Laptop or Embedded)

81199A Wideband Waveform Center (WWC)

M8190A Wideband AWG (I/Q Generation)

8267D-520-016 (I/Q Modulation)

N5152A 5GHz/60GHz U.C.

N5183A-520 MXG (Tx LO)

N5183A-520 MXG (Rx LO)

N1999A 60GHz/5GHz D.C.

DSO90404A Infiniium Real-time Oscilloscope

Wfm Data

Acq'd Signal

DUT

More details
The new AWG picture

Do you care about waveform resolution?

- Radar, EW & Satellite with modulation bandwidth ≤ 1 GHz ≥ 5 GHz
- Communications with a bandwidth need ≤ 1 GHz ≥ 5 GHz
- Education and Research looking for flexible, reliable signal generation
- Serial Standards, which need to mimic analog imperfections up to 3 Gbit/s

SFDR 1)

- Agilent M9330A
  - Up to 80 dBc SFDR
  - 5 GHz analog Bandwidth

- Agilent 81180
  - Up to 50 dBc SFDR
  - 7.5 GHz analog Bandwidth

1) SFDR across Nyquist range with $f_{\text{out}} = 150$ MHz
2) Bandwidth of a single channel AWG output
Arbitrary Waveform Generator
Ongoing Innovation

Agilent Labs & high speed digital R&D designed a disruptive technology through BiCMOS silicon geranium process takes us years ahead.

M8190A revision 1 - breakthrough performance: up to – 80 dBc SFDR & 5 GHz analog bw
- Build a strong foundation for highly reliable Satellite Communications Excellent SFDR ensures that tones stand out from distortion even with hundreds of tones
- Push Radar design farther with highly realistic signal scenarios with 2 GSa memory per channel

M8190A revision 2 -
- Advanced sequencer allows even longer radar playtime
- Low phase noise of – 110 dbc/Hz improves detections of moving targets

M8190A data formats
- Optimize signal performance through data formats

Wideband Waveform Center & M8190A
- New test tools for 60 GHz wireless: support of modulation bandwidth 100 times wider than 802.11n
- Complete and compliant test solution for wireless HD, IEEE802.11ad

Agilent 81180 Agilent M9330A Same Quality & wider BW

Agilent M8190A

Optimize signal performance through data formats
AXIe infrastructure

- M9502A: Two-slot AXIe chassis with ESM
- M9505A: Five-slot AXIe chassis with ESM
- M9045A and M9045B: PCIe laptop card adapter Gen 1 x4
- M9047A: PCIe desktop card adapter Gen 2 x8
- Y1200A: x4 – x8 PCIe cable
- Y1202A: x8 – x8 PCIe cable
- M9536A: Embedded AXIe controller

Accessories

- M8190A-801 Microwave phase matched balun, 6.5 GHz, max SMA jack
- M8190A-805 Low pass filter, 2800 MHz, max SMA, VLF 2850+
- M8190A-806 Low pass filter, 3600 MHz max SMA, VLF 3800+
- M8190A-810 Cable assembly coaxial-50 Ω, SMA to SMA, 457 mm length
- M8190A-811 Cable assembly coaxial-50 Ω, SMA to SMA, 1220 mm length
- M8190A-815 Dynamic control input cable
- M8190A-820 Connector-Rf, SMA termination, plug straight, 50 Ω, 12.4 GHz, 0.5 W
Configurations

5-slot AXIe chassis

- fits up to 2 M8190As + system controller + ESM module
- Only a monitor is needed to form a complete instrument

2-slot AXIe chassis

- Fits one M8190A + ESM module
- Requires PC or Laptop with PCI-Express interface card to control it
Backup
Typical Setup
Signal Generation Setups

IQ Modulation

- Differential I/Q signals
- RF/IF out
- Marker output → Pulse mod. input
- M8190A
- E8267D, Opt. 016
- Modulation BW up to 2 GHz
- RF up to 44 GHz
- IF/RF up to 5 GHz
- Modulation BW up to 2 x (4.5 GHz – IF)
- Data up to 3 Gb/s

Direct IF/RF

- RF/IF/ DATA out
- IF/RF up to 5 GHz
- Modulation BW up to 2 x (4.5 GHz – IF)
- Data up to 3 Gb/s

PCIe

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Agilent Technologies

September 19, 2012
Enhance your Reality

- High Resolution
- Wide Bandwidth

Step 1
High Resolution

M9330A / N8241A
15 bit, 1.2 GSa/s

Step 2
Economic Version

81180A
12 Bit, 4.2 GSa/s AWG
Released April 2010

Step 3
High Resolution and Wide Bandwidth

M8190A
14 bit 8 GSa/s / 12 bit 12 GSa/s

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Enhance your Reality with a Source of Greater Fidelity

- Breakthrough performance
- 30 dB better dynamic range
- 30X deeper memory
- 5 GHz analog bandwidth
- Operation with all leading software platforms
Analog vs. Digital Up-Conversion

Analog I and Q signals are generated using an AWG. An (analog) I/Q modulator generates the IF or RF signal.

In digital I/Q modulation, the multiplication with a carrier signal is performed digitally – either in real-time or in software.
Delivering High Resolution and Wide Bandwidth simultaneously

Bandwidth is limited by DAC sample rate

Accuracy is limited by all analog components

Performance mostly depends on DAC

Sample after transient is settled

Resampling switch

Final DAC output

Shifting and adding 2 DAC’s for more power and area

DAC output

T/2

T/2

= Analog output

DAC output

Digital data

DAC

clk
Expansion into Signal Scenario Generators

Signal Scenario Generator

- **Precision AFG**
  - 81150A
  - 81160A
  - January 2009
  - January 2011

- **Precision AWG**
  - 81180A
  - 81190A
  - April 2010
  - March 2011

**Expand**

- **Flexible but precise**
  - 81104A + 81105A
  - 81130A + 81131A
  - 81133A

- **Flexible but precise**
  - 81101A
  - 81104A + 81105A
  - 81110A + 81111A + 81112A

- **Flexible but precise**
  - 81130A + 81131A + 81132A
  - M8190A

**Precise but flexible**

- **50 MHz**
- **80 MHz**
- **165 MHz**
- **330 MHz**
- **400 MHz**
- **660 MHz**
- **3.35 GHz**

**Anticipate — Accelerate — Achieve**

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M8190A Software Structure

VISA HiSLIP protocol - or - raw TCP/IP on Port 5025 or VXI-11 (only Rev. 2 FW)

SCPI | IVI-COM | IVI-C

Firmware

LabView

User Program (C++, C#, .NET)

Signal Studio, Benchlink WWC, etc.

Matlab

LabView driver

Can run on the same or different PC than firmware

LAN

VISA Address: TCPIP0::xxx::hislip0::INSTR or TCPIP0::xxx::5025::SOCKET

Can run on the same or different PC than firmware
Or embedded PC

VISA Address PXIn::nnn::nnn

Remember:

- You can only communicate with the M8190A through the firmware. Make sure it is running and connected to the hardware...

- The firmware acts as a LAN instrument. Do not attempt to connect your user software to PXIn:nnnn:nnnn

Back
M8190A AWG - Reliable, repeatable measurements from precise signal simulation

Excellent SFDR ensures that tones stand out from distortion even with hundreds of tones

- 45 dBC, 3 GHz 1000 tones, 8 Gsa/s, DAC
- 63 dBC, 2 GHz, 100 tones, 12 Gsa/s, DAC

8 GSa/s; f_{out} = 1GHz; internal sample clock
-110dBC@10kHz (typ)
M8190A Block Diagram

- PCI-Express Link from external PC or embedded controller
- Module FPGA
- Ext. Ref Clk
- Sample Clk In
- Int. Clk
- Clock Generation
- Sync Clk In
- Trigger In

Clock Generation:
- Ext. Ref Clk
- Sample Clk In
- Int. Clk

FPGA:
- Sample Memory (up to 2 GSa)
- Sequence Memory (512 K entries)

DAC:
- Amplified Out
- DAC Out
- AC Amp.
- DC Amp.

Sample Clk:
- Sync Clk
- Sample Clk

Sync Clk:
- Sync Clk In
- Sync Clk Out (= sample clock/48 or sample clock/64)

Sample Marker:
- Channel 1
- Sample Marker

Var. delay:
- Trigger In

interface, transferring 48 or 64 samples per SYNC clk

Sync Marker:
- Channel 2

(used with multi module sync)
Agilent Amplifier

Amplitude in Vpp

Bandwidth in GHz

-1 V - +3.3V voltage window
M8190A without sequencing

- Only a **single** waveform segment is available
- Waveform segment can be up to 2 GSamples long

Infinite loop
Sequence

- A **sequence** consists of a list of waveform segments
- Total size of waveform segments can be up to 2 GSamples
- Each segment can be looped up to $2^{32}$ times
- A sequence can contain up to 512K steps
Scenario

- A **scenario** consists of a list of sequences
Advancement modes
Advancing from one segment/sequence to the next can be…

• **Automatic**
  - Loop N times, then go to next segment/sequence (un-conditional)

• **Conditional**
  - Loop until an event occurs, then go to next segment/sequence

• **Repeat**
  - Loop N times, then wait until an event occurs before going to the next segment/sequence

• **Stepped**
  - Same as “Repeat”, but wait for an event on every loop

All transitions are “seamless”. Event can be an external signal or a software command
Selection of segment/sequence to be generated

Selection of segment/sequence can be determined by…

• Pre-defined sequence
  – If the order of waveform segments is known ahead of time, it can be set up as a “sequence”

• Dynamic Control Port
  – The dynamic control port on the front panel allows you to select one of $2^{13}$ ($2^{19}$) segments/sequences dynamically at runtime by applying a digital pattern to the dynamic control port connector

• Software
  – Instead of applying a digital pattern to the dynamic control port, you can also select a segment/sequence using software by sending a command to the firmware

In all cases, transitions are “seamless” – without any gaps
Trigger modes

All of the previously mentioned cases can be combined with the following trigger modes. This applies to **segments** or **sequences**.

- **Continuous**

- **Triggered**
  - Each edge of the trigger signal starts the selected segment/sequence

- **Gated**
  - Segments are always completed
...and how does it work internally?

In this example, 3 sequences are defined using a total of 6 steps.

Multiple steps can point to the same segment.
81199A Wideband Waveform Creator (GUI)

Create a library of individually configurable waveform segments...

Select waveform segment format from (WiHD, WiGig etc.)

Fully parameterized encoding

...drag and drop to create required composite waveform in the editor

Add noise and user-definable predistortion (e.g. for uplink compensation)

Set final sampling rate to match AWG

Download direct to AWG or to File
81199A WiGig / 802.11ad Modulation Analyzer

Multiple dockable windows, each independently configurable to display any mix of:

- Spectrum
- Main Time
- Error Summary
- Decoded Payload Data
- LDPC Codeword Display
- Correlator Output
- Channel Estimation
- IQ Data
- Error Vector Spectrum
- Error Vector Time
- OFDM EVM vs symbol
- OFDM EVM vs subcarrier
- Carrier Tracking
- Phase Error
- Power vs. Time

Flexible graphing, including image cut/paste for easy documentation

Detailed tabulation of numerical results.

Colour coded composite constellation display

Full remote control using SCPI over LAN/Telnet/Sockets
WiGig Alliance is focused on mmWave/60 GHz technologies

WiGig 1.1 Specification

802.11ad

Board of Directors

Anticipate Accelerate Achieve
802.11ad Technology

- Single Carrier OFDM
  - For Preamble and Data
  - Bandwidth: 1.76 GHz
  - Modulation: \(\frac{1}{2}\)-BPSK, \(\frac{1}{2}\)-QPSK, 16-QAM

- OFDM
  - For Higher Data Rates
  - Bandwidth: 1.825 GHz
  - Modulation: SQPSK, QPSK, 16-QAM, 64-QAM

- 57 – 66GHz Unlicensed, globally available
- 7 Gbps Data Rates
- Wider channels, enabling higher data rates over short distances (1m – 10m)
- First commercial devices expected to be announced at CES in Jan 2012 (covert meetings occurred at CES2011 last January)
Why New Test Tools for 60 GHz Wireless

**mm Technology**
- Performance taken for granted at lower frequencies not so easy to achieve
- Mismatch, skew, cable lengths matter

**Baseband Modulation & Demodulation**
- 2 GHz Modulation BW
  - Data rates up to 7 Gbps
  - 100 times wider modulation bandwidth than 802.11n.
  - 1.5 times wider than 802.11ac
- Traditional sources and analyzers lack BW
- Complex frequency response (flatness) difficult

**No connectors at 60 GHz**
- Built-in multi-element antennas lack test connection
- No place to insert 1.85mm connectors
- Over-the-air (OTA) testing required
- Multi-path intrinsic in performance and in measurement environment
Agilent Participation in the WiGig Alliance

In the Alliance and Participation in the PlugFest

- Agilent representatives have chaired the WGA Interoperability Working Group (IWG) for the last two years.
- Agilent exclusively provided the test equipment for the PlugFest

From WiGig Alliance Press Release

"Key test instrumentation for the PlugFest is being provided by Agilent Technologies, the leader in test and measurement and the only commercial provider of signal creation and modulation analysis SW and HW solutions for the WiGig Standard."
Triggering of M8190A modules
Definition: Trigger latency

Trigger latency is the amount of time it takes from the (active) edge of the trigger input to the start of the output signal.

- The trigger latency can typically be broken down into:
  - a **fixed amount** (due to the delay in cables & asynchronous circuits)
  - a certain **number of clock cycles** (due to internal flip-flop stages)
    - e.g., 2.6 ns + 7680 clk cycles, +/- 24 clk cycles
  - an amount of **uncertainty** (see next slide)

- Nominal values for the M8190A in 14-bit mode:
  - 2.6 ns + 7680 clk cycles, +/- 24 clk cycles
Definition: Trigger uncertainty

Trigger **uncertainty** is the worst case variation of trigger latency that can be observed on recurring trigger events.

- Without any precautions (= asynchronous trigger input), the trigger uncertainty in the M8190A is **+/- 3 ns** @ 8GHz sample rate. At slower sample rates proportionally more!!
- While the fixed and clock-dependent amounts of trigger latency can easily be compensated by the system setup, a large **trigger uncertainty** might be **not acceptable** for many applications.
Why does the M8190A have a large trigger uncertainty? (when using asynchronous triggering)

• Inside the M8190A, the trigger input is **sampled** with the SYNC clock. 
  [SYNC clock = Sample clock divided by 48 (64) in 14-bit (12-bit) mode]

• Now consider two different scenarios of when a trigger input can occur **relative** to SYNC Clock

  ![Diagram showing two scenarios of trigger input relative to SYNC Clock]

  - **Trigger case #1**: Trigger is sampled with the next rising edge of SYNC Clock
  - **Trigger case #2**: Trigger is sampled with next rising edge of SYNC Clock

  ![Diagram showing trigger latency in both cases]

  - **Trigger latency in case #1**
  - **Trigger latency in case #2**

  → Different Trigger latencies are observed by the user
How can the trigger uncertainty be avoided?

Make sure the trigger input is synchronized with the SYNC Clock Output of the M8190A. This reduces the trigger uncertainty to an excellent $\pm 5 \text{ ps (typ.)}!!$

...of course this only works if the DUT can operate at the SYNC clock frequency (= M8190A sample rate divided by 48 or 64(*))

(*) SYNC clock = Sample clock divided by 48 in 14-bit mode, divided by 64 in 12-bit mode
How to use synchronous triggering at other frequencies?

Use the device’s clock output to drive the Ref.Clk Input of the M8190A. This works under the following conditions:

- M8190A sample clock is set to the Ref.Clk Input frequency times 48 or 64(*) divided by an integer ≥ 1. (Example: Ref.Clk = 100 MHz, Sample Clk = 4.8 / 2.4 / 1.6 / 1.2 GHz, etc. in 14-bit mode)
- The other device generates its output synchronous to its Clock Output
- The Clock Output frequency is a multiple of 1 MHz in the range 1...200 MHz

(*) SYNC clock = Sample clock divided by 48 in 14-bit mode, divided by 64 in 12-bit mode
...or use an external Reference Clock

Use an external Ref.Clk to drive both the device’s clock input and the Ref.Clk Input of the M8190A

- M8190A sample clock must be set to the Ref.Clk Input frequency times 48 or 64(*) divided by an integer \( \geq 1 \)
- The other device generates its output synchronous to its Clock Input
- The Ref.Clk. frequency is a multiple of 1 MHz in the range 1…200 MHz

(*) SYNC clock = Sample clock divided by 48 in 14-bit mode, divided by 64 in 12-bit mode
Synchronization of two or more M8190A modules
Synchronization of two or more M8190A modules

- Timeline

- Synchronization between **two** M8190A modules (up to 4 channels) will be officially supported in fall 2012
  - The current plan is to support the synchronization without any hardware changes – just an FPGA / Firmware update and a sync cable

- Synchronization between **more than two** M8190A modules (more than 4 channels) is on the roadmap to be supported at a later date
  - This will require an extra “clock distribution” module. Other than that, the plan is to work without any hardware changes to the modules

- **In the meantime, the approach that is described on the following slides can be used as a work-around to synchronize two or more modules**
What does it exactly mean to “synchronize” two or more M8190A modules? (1)

Synchronization requires two things:

1. Frequency Synchronization
   - This is to make sure that the modules run at the same sample rate which must be derived from the same master oscillator for all modules
   - This can easily be achieved in one of two ways:
     - Feed all modules with a common reference clock. In case of two modules in the same AXI chassis, this is the default
     - Feed all modules with a common sample clock. The common sample clock can either come from an external generator or one module acts as a master and the clock is daisy chained to the other ones

2. (see next slide)
What does it exactly mean to “synchronize” two or more M8190A modules? (2)

2. All modules must be started at the same time and run with a repeatable skew

- Starting the modules at the **exact same time** is practically impossible without the means that will be implemented inside the modules later
- Starting the modules with a **repeatable skew** is possible.
  - Repeatable skew means it stays the same across multiple “runs” and waveform downloads - as long as the sample rate and other operation modes are unchanged
  - The procedure is to download “test waveforms” that are used to measure the skew between the outputs of multiple modules during a “test run”.
  - Once the skew values are known, the waveforms and delays can be adjusted to compensate for the measured skew
  - Finally, the adjusted waveforms can be downloaded and the modules started again – this time with zero skew between the outputs
Why is it so difficult to start multiple modules at the exact same time?

- Consider the Sync Clock timing of two or more modules. Even though they are both derived from the same sample clock, they can have 1 of 48 (or 64) different phase relationships to each other.
- An asynchronous start signal might be sampled by the different modules in different order every time → no repeatable skew → useless
- A start signal that is synchronous to the first module’s SYNC Clock is better but might violate setup/hold times of other modules – depending on their phase alignment.

![Diagram](image)
Synchronization setup
(shown for two M8190A, but can be extended to more)

1. Set up the M8190A in “armed” mode; load waveforms to all modules that contain a marker at the start of the waveform; start all modules
2. Set up an external trigger generator to generate a one-shot pulse synchronous with its clock input
3. Observe the skew between the marker outputs on the scope on recurring runs; make sure it is always the same skew. If not, see next slide
4. Adjust the waveforms and output delays to compensate the skew
What if the skew is not repeatable?

• …then you have a setup or hold-time violation on one of the modules
• identify which module does not generate a repeatable timing (expect the skew to “jump” by SYNC clk period)
• Change the sample rate of the module to a different sample rate and change it back to the original sample rate. This will cause the sync clock divider to find a new (random) phase. Go back to the previous step

• With a little programming effort it should be possible to automate this procedure
• Note: After every power cycle / change of sample rate / change of 12-/14-bit mode, synchronization is LOST
Example

Four M8190A channels in sync

Waveforms consist of a pulse (to show perfect alignment) followed by a sinewave (to show that channels are independent)

In a real application, the waveform can of course be completely arbitrary
Example

Zoom-in on rising edge:
Skew can be adjusted to < 1ps
Other considerations for multi-module operation

• **Two** M8190A modules can be plugged into a 5-slot AXI frame (plus an optional embedded controller). That’s the simplest configuration, since the sample clock can easily be shared between the modules.

• **Three or four** M8190A modules will have to be split up into two AXI 5-slot chassis. In order to run such a configuration, you will either need
  – One compatible PC with **two PCIe slots** (we don’t know if that exists) or
  – **Two separate, compatible PCs** or embedded controllers (which is expensive, but probably OK for someone who can afford 3 or 4 modules)

• If a customer wants two M8190A modules in two separate 2-slot chassis (e.g. because he wants to use them separately as well as together), the same applies.