Errata

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HP References in this Application Note

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Application Note 343-5

Vector Modulation Measurements
Calibrated microwave system for complex arbitrary
signal simulation using HP 8780A Vector Signal Generator
and HP 8770A Arbitrary Waveform Synthesizers
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Introduction
Digital signal synthesis is a powerful tool for signal simulation. It allows simulation of arbitrary waveforms and a variety of impairments encountered in today's increasingly sophisticated systems. In many applications, arbitrary signals must be upconverted to the intermediate or radio frequencies of interest. But this upconversion process is complicated by imperfections in available mixers, LO's, filters and splitters.

Recently, Hewlett-Packard introduced all of the pieces needed to accomplish arbitrary waveform generation at RF. The system uses vector (I/Q) modulation techniques to upconvert baseband signals generated with arbitrary waveform synthesizers, hence its name: the Vector Arbitrary Waveform Synthesizer (VAWS). This note analyzes VAWS' unique capabilities as well as its basic performance. For applications requiring high-precision waveforms, the note describes a self-calibration BASIC routine designed to extract maximum performance from the system. An example illustrates the use of this routine in generating and compensating waveforms.

The VAWS System
The heart of the system is the HP 8770A Arbitrary Waveform Synthesizer or AWS. With 50 MHz of bandwidth, 12-bit resolution and 512K memory, it has already found its way into a great number of complex RF signal simulation applications. A companion product to AWS is the HP 11776A Waveform Generation Software. This software package runs on a series 200/300 computer and provides tools to create the waveforms needed to drive AWS.

The second part of the system is the HP 8780A Vector Signal Generator. It uses I/Q modulation techniques in which an RF output is created by adding two components together: the I or in-phase component whose amplitude is scaled by the I channel modulation, and the Q or quadrature component whose amplitude is scaled by the Q channel modulation input (see Figure 2). The result is a carrier signal from 10 MHz to 3 GHz whose phase and amplitude can be precisely controlled by the correct levels of I and Q. Moreover, the I and Q modulation channels have bandwidths of 350 MHz each, making possible phase and/or amplitude transitions as fast as one nanosecond.

VAWS uses two arbitrary waveform synthesizers to drive the vector generator's I and Q modulation inputs. This configuration allows arbitrary control of the in-phase and quadrature components of the carrier, and thus control of the carrier's amplitude and phase. Arbitrarily modulated RF signals can be generated this way for a wide variety of receiver test applications. An unmodulated carrier output is available for applications requiring a coherent reference.
Creating Waveforms

The process of signal simulation using the VAWS system begins with the definition, in software, of the RF signal desired. Depending on the particular application, signals will be most easily defined one of three ways:

**Vector (I/Q) Domain**
The first method is to describe a modulated RF signal in terms of the carrier's I and Q components with 50 MHz of bandwidth available in each channel. This approach would be most useful in digital communications applications where most modern transmitters and receivers use I/Q modulation techniques to process data.

**Polar Domain**
The second technique is to define the signal in terms of its amplitude and phase components. Signals created defined this way are capable of jumping from one phase/amplitude state to any another in as little as 8 nsecs. If desired, a slower, predescribed phase/amplitude trajectory can be defined instead. Since frequency modulation is merely a type of phase modulation, VAWS can also make frequency transitions in also 8 nsecs time (within its modulation bandwidth). This “polar” representation of the carrier is usually more suitable for radar systems simulation where RF pulses with precise phase trajectories are often required (e.g., chirped or phase tagged pulses).

**Frequency Domain**

Finally an RF signal can be defined in terms of its frequency content. Completely arbitrary spectrums can be defined within the 100 MHz bandwidth, including spectrums that are non-symmetrical with respect to the carrier frequency. This capability may be of special interest to EW receiver designers who need to cope with jamming signals such as broadband noise or comb lines that fill many megahertz of bandwidth.

The HP 11776A Waveform Generation Software, with its Waveform Generation Language (WGL), provides the necessary tools to create the desired signals in any of the domains described above. Once the signal has been defined, conversion between its amplitude and phase representation, I and Q representation and frequency spectrum can be done with the use of simple commands. The software allows a signal to be “modified” in a domain different from the one it was created in. For example, modulation can be initially defined in terms of I and Q components, then converted to the polar representation where phase noise can be added or amplitude compression simulated. Finally, the signal can be transformed into the frequency domain where it may be filtered before returning to the original I and Q domain. Since the VAWS hardware requires I and Q components to drive it, a conversion to the I and Q domain is always needed before downloading the waveforms into the system.

Figure 3a. VAWS generated comb line shows spurious images and carrier leakage.

Figure 3b. After compensation, the flatness is improved and the images and carrier leakage reduced.

**Calibration**

Off-the-shelf system performance will be sufficient for most applications. In some cases, however, precision attainable only from a calibrated system will be required.

Figure 3 shows the actual spectrum of a simple signal created with WGL and downloaded to the VAWS system, both before and after compensation. The signal is chosen to illustrate effects that can be caused by an uncalibrated system.
Before compensation, the signal's spectrum shows several undesired spurious components. One of them is a carrier leakage term at the center frequency. Also, you will note several other spurs in the upper half of the spectrum which are images of the desired components in the lower half of the spectrum. Finally, an uncompensated system will show noticeably more frequency response ripple than a compensated one.

For applications requiring very tight control over any of these parameters, the calibration and compensation routines provide a way to characterize and compensate the system to minimize their effects. The calibration routine characterizes the sources of errors in the system that lead to these degradations. It then generates a table of calibration factors that the compensation routine uses to predistort the I and Q WGL waveforms. The predistorted waveforms thus take into account system errors and result in a corrected output. Next we will briefly discuss the causes of the non-ideal behavior as well as how the system calibration goes about characterizing such imperfections.

**Image Rejection**

Upconverting baseband signals using vector (I/Q) modulation requires that the I and Q channel characteristics be extremely well matched. If not, spurious images are generated in the upconversion process due to the different amplitude ripple or phase responses that do not track between the two channels.

To understand why this is so, let's consider a simple example. Suppose we would like to generate a single tone at some offset frequency from the carrier. To accomplish this, we would need to drive the I channel with a cosine wave at the offset frequency and the Q channel with a sine wave at the same frequency. Figure 4 shows the process by which image cancellation is ensured for this situation. (A three-dimensional representation is necessary to follow the phase relationship between the two channels.)

First, since the Q channel is modulated with a sine wave rather than a cosine wave, its negative frequency component is shifted 90 degrees with respect to the I channel's positive frequency component. Likewise, the positive frequency component is shifted -90 degrees relative to the I channel's positive component. Secondly, the Q channel is further modulated in quadrature with respect to the I channel, thereby adding an additional phase shift of 90 degrees to the negative and positive frequency components. The result is that positive frequency components add constructively and negative frequency components add destructively as the two channels are combined at the output.

Any of the following conditions can result in less than perfect cancellation of the image terms: mismatch between the I and Q levels, phase shift between channels or quadrature error in the upconversion process (quadrature error is explained below).

Fortunately we can correct for these errors before the modulation signals are downloaded into the AWSes by predistorting in software the amplitude and phase responses. An uncalibrated system can result in images as high as -25 dBc at the higher end of the modulation band with, where the filters’ phase response changes most rapidly. With calibration, however, images can be reduced to a typical level of -60 dBc.

**Carrier Leakage**

Any DC offsets appearing at the modulation inputs of the Vector Signal Generator will show up as carrier leakage. These will affect the on/off ratio of pulses as well as the level of carrier suppression. The calibration routine iterates the I and Q AWS DC offsets until it finds a minimum feedthrough level at the vector signal generator's RF detector output. As a result, the carrier leakage performance of the system can be improved typically from about -40 dBc for the uncalibrated system to -60 dBc after calibration.

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**Figure 4. Image cancellation process in vector modulation. Q channel goes through two distinct phase shifting processes, enabling undesired images to cancel.**
I/Q Gain Imbalances vs Frequency

Gain imbalances vs frequency result from different output filter responses of the I and Q AWSes over the 50 MHz frequency range. The calibration routine characterizes this mismatch by first measuring the RF level produced by a tone in the I channel only. It then programs the Q channel to output a tone of the same frequency and adjusts its amplitude until the level at the RF detector matches that obtained for the I channel. This process is repeated at the frequencies of interest, including DC, until a complete list of level correction factors is available for the Q channel.

I/Q Phase Mismatch

As with gain imbalances, I/Q phase mismatch is also a result of differences between the I and Q AWS' output filters. In this case, however, differences in the filter's phase responses result in incorrect alignment between the Q channel sidebands and the I channel sidebands, giving rise to undesired image terms. To match the I and Q phase responses, the calibration routine programs the I channel with a cosine wave and the Q channel with a sine wave, then it varies the phase of the Q channel until a minimum level is read from the RF detector. This phase represents the mismatch between channels at the calibration frequency. As with gain imbalance, the process is repeated for all the frequencies of interest to fill a table of calibration factors.

Modulator Quadrature Error

A quadrature error occurs when the generator's LO input to the Q mixer (in Figure 2) is not shifted by exactly 90 degrees. Similar to a phase mismatch, quadrature error will rotate the Q component more or less than 90 degrees thereby impeding the alignment of sidebands required for image cancellation. The vector generator's performance excels in this area and no additional calibration is needed.

I/Q Differential Delay (I/Q Skew)

Ideally, events programmed into the Q channel AWS start and stop at the same time as events programmed into the I channel AWS. To make this happen both AWS need to be running synchronously and the next section describes a procedure to synchronize one AWS to the other. Due to cable length and propagation delay differences between the two AWS, a delay of up to 5 nsec can appear between the outputs of two synchronized AWS.

Differential delay between the modulation channels affects the image rejection figure in much the same way as phase mismatch does (since delay corresponds to a linear phase variation with frequency). Consequently, differential delay between channels will be accounted for by the phase mismatch portion of calibration. However, 5 nsec at 50 MHz translates into a phase mismatch of 90 degrees, which is more than the calibration routine can handle. It is therefore necessary to follow a manual calibration procedure to bring the phase shift due to delays within the limits of what the phase mismatch calibration can handle (approx. ±15 degrees). The manual delay calibration is discussed in the Calibration Example section and only needs to be done once, when the system is initially assembled.

Frequency Flatness

The frequency flatness of the system is limited by the flatness of the AWS' output filters. An uncalibrated system will have a frequency response ripple of no more than ±0.65 dB. Using the Vector Signal Generator's RF detector to calibrate the flatness of the I and Q AWS allows a calibrated system to keep the ripple variations under ±0.1 dB across the full modulation bandwidth.

Using Calibration

Five subroutines are used in the calibration package. "Aws_cal_..." and "Comp_..." handle the calibration and compensation tasks. The first one characterizes the system and generates a set of calibration factors accordingly. The second one uses these cal factors to compensate the I and Q driving waveforms for AWS. Both these routines can be called from WGL and the example at the end of this note shows how to use them.

The other three subroutines cannot be invoked from WGL. "HP 8780" and "Aws" are instrument drivers while "Search" is a convergence algorithm used in the process of finding minimum of functions. These three routines are used by the "Aws_cal_..." subroutine during calibration.

The parameters calibrated by this package are DC offsets, DC gain imbalance, frequency flatness match, phase response match and absolute frequency flatness. The following table summarizes measured system performance resulting from the calibration of the different parameters.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>PERFORMANCE</th>
<th>UNCAL’D</th>
<th>CAL’D</th>
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<tr>
<td>I and Q DC offsets</td>
<td>carrier leakage</td>
<td>-25 dBC</td>
<td>-60 dBC</td>
</tr>
<tr>
<td>DC gain imbalance</td>
<td>image rejection</td>
<td>-25 dBC</td>
<td>-60 dBC</td>
</tr>
<tr>
<td>Frequency flatness match</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase response match</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute frequency Flatness</td>
<td>RF modulation flatness</td>
<td>± .65 dB</td>
<td>± .1 dB</td>
</tr>
</tbody>
</table>

Table 1. Actual measurement of an HP 11755 VAWS system.

Some applications deal with performance criteria in terms of quadrature error and gain imbalance instead of image rejection. It can be shown (see Reference 1) that a -60 dBC image rejection figure corresponds to a gain imbalance of less than 0.2% and a quadrature error better than 0.15 degrees. A calibrated VAWS system can achieve this level of performance across the full modulation bandwidth.

NOTE: Because this calibration uses HP 8780's internal DACs to cancel out offsets in the I and Q AWSes it is important that HP 8780A's settings do not change between calibrations as this may reset the DACs back to their original values. Changing frequency, level or turning RF ON/OFF are allowable functions that will not reset the DACs.

Once the system has been characterized and the waveforms compensated, the performance of the system can be expected to remain fairly constant over time with the exception of the DC offsets. Carrier leakage is very sensitive to DC offsets so any perturbations in ambient temperature may significantly affect it. Once the complete system calibration is accomplished, the calibration routine will allow you to correct small variations in offsets quickly (in a few seconds) without requiring any extra waveform manipulations. This is done inside the HP 8780A and does not involve AWS. It is ideal for frequent use (every few minutes) to ensure best carrier leakage performance over time (see NOTE).
The Setup

Figure 5 shows the system setup. All hardware and software needed, including ordering information, is listed in Appendix A. Installation and power up procedures for the HP 8780A and HP 8770A are available in their respective operating manuals for first time users. The following is a step by step guide to the assembly of the system:

1) Connect the instruments to the HP-IB bus and set HP-IB addresses to the following:
   - HP 8780A 0 — 20
   - HP 8770A I channel 0 — 19
   - HP 8770A Q channel 0 — 06

   (HP-IB addresses for the AWSes are set with dip switches on the AWSes rear panel. HP-IB address for the vector signal generator is set selecting special function 25.0.)

2) Use the BNC cables to connect the signal outputs of the AWSes (labeled RF OUT in the rear panel) to the respective I and Q modulation inputs of the Vector Signal Generator. It is important that these two cables be of the same length.

3) Connect the controller HP-IB port (select code 7) to the I AWS, Q AWS and Vector Signal Generator's HP-IB ports.

4) The I AWS and the Q AWS need to be synchronized so that they share a common clock. First, connect the ECL SYSTEM CLOCKS INPUT on the I channel AWS to one of its two ECL SYSTEM CLOCKS OUTPUT (See Figure 5). Use a 1-meter SMA-SMA jumper cable provided with AWS' cable kit. Next connect the other ECL SYSTEM CLOCKS OUTPUT of the I channel AWS to the ECL SYSTEM CLOCKS INPUT of the Q channel AWS. Use the other 1-meter cable provided it is essential that these cables be matched in length. (For more information on synchronization, refer to HP 8770A's Operating Manual Section 3-18.1).

   Once the two AWSes have been synchronized, the I channel AWS (master) needs to be powered up prior to the Q channel AWS (slave) as the slave requires the master's clock to be present for correct operation.

5) Enable the vector modulation inputs on the vector signal generator by pressing the VECTOR ON key. Turn on the RF output, select its level and frequency. (Consult the HP 8780A's Operating Manual for details.)

6) Load the WGL software into the computer (Refer to the WGL Setup Guide of the 11776A Reference Manual). The WGL screen should come up indicating that the WGL system is now running.

7) Next, the application software must be loaded. Disks are available from your HP representative. Insert the Application Software disk containing the calibration application files into the disk drive slot. The following four files should be present on the disk:
   - CALSUBS, CALPROG, FREQ_DATA1 and FREQ_DATA2.
   - To load the BASIC subroutines, type:

   ```
   SYSTEM
   STOP
   LOADSUBL FROM "CALSUBS"
   RUN
   ```

8) Finally, the WGL programs used in calibration have to be brought into the WGL system's editor. Type the following commands:

   ```
   'CALPROGS' $ GET
   EDIT
   EXIT
   ```

   (use soft key for this)

Appendix B has a listing of the programs available in the CALPROG file. These include definitions that will allow system calibration to be performed with simple commands. In the following section, a calibration example illustrates how these commands are used.
An Example

Part 1. Calibrating the System

Before an accurate system calibration is possible, it is necessary to ensure that the vector signal generator has been recently calibrated. If not, press the CAL key on the HP 8780A before proceeding with the rest of the example.

The first step is to calibrate I/Q Differential delay (skew). Do so by typing,

CALSKEW

The system will characterize its own delays and display on the screen the resulting value. If the skew is less than 250 psec., the screen will display the following message:

1 vs Q SKW = <value>
TEST PASTED II! (skew <250 ps)

This indicates that the system skew is within limits. If the skew is greater than 250 psec., a set of instructions will appear on screen. It will include a list of cables (available from the HP 8770's Synchronization Cable Kit) that need to be added to the system, as well as information as to which channel to add them to. Follow these instructions and repeat the skew calibration until the resulting skew is less than 250 psec.

Section 4-12.1 in the AWS Manual describes in detail an alternative way to calibrate this parameter. Skew calibration only needs to be done once after the system has been set up.

The next step is to calibrate the DC offsets in the system. This is accomplished by typing,

CALDC

Finally, the system's frequency response needs to be calibrated. Here the calibration routine characterizes the system's frequency flatness, I/Q gain imbalance and I/Q phase mismatch. Calibration allows flexibility in which frequencies are to be calibrated. This is important since the compensation routine linearly interpolates between calibrated frequencies. Interpolation error may result if the calibrated frequencies are spaced too far apart. To run frequency calibration type,

CALFREQ1 <long version>
(or CALFREQ2) <short version>

Both these commands use information stored in WAVE files named "FREQ_DATA1" and "FREQ_DATA2" respectively to know which frequencies need to be calibrated. CALFREQ1 will calibrate the system from 0 to 50 megahertz with one megahertz spacing between calibration frequencies and will take about 20 minutes to complete. CALFREQ2 calibrates the system at approximately 5, 20, 30, 40, 45 and 50 megahertz taking less than five minutes to complete. To minimize interpolation error use CALFREQ1.

Some applications may require calibration at a different set of frequencies than the ones available in "FREQ_DATA1" or "FREQ_DATA2" to be calibrated. The CALFREQ command uses the data in the Working Wave to determine the calibration frequencies. The Working Wave should be created in the frequency domain by storing a "1" at every frequency to be calibrated (frequencies must be kept under 50 megahertz) and a "0" elsewhere.

As calibration progresses, the screen will show the system's characterization results. A "CALIBRATION COMPLETED" message indicates that calibration has been successful and the calibration factor BASIC arrays have been filled. At this point the compensation routines can be called to predistort I and Q waveforms.
Part 2. Creating a Complex Signal

Earlier we saw how we can represent a complex RF signal in one of three ways. In this example we will create a signal with a defined frequency spectrum occupying the full 100 MHz bandwidth available with VAWS. We will then observe how calibration improves the system performance. Start by executing the following commands:

```
FDOMAIN
1024 CTX
0 LOAD XY 0 LOAD 1 clear the working and aux waves
25000 CLOCK
```

The last command sets the WGL clock to 250 MHz instead of the default 125 MHz. This does not affect the clocks in the AWses. It does, however, reflect the fact that we have independent control over both sides of the spectrum about the carrier. As a consequence, we will not be able to use the TOTIME command to transform to the time domain (TOTIME presupposes symmetric spectrums), instead the IFFT (inverse FFT) command will be used instead.

For illustration purposes, we will simulate several channels of information with arbitrary shaping in one portion of the spectrum and flat noise at three different levels in another portion. We will then add a couple of interfering tones to complete the scenario over the 100 MHz of available bandwidth (see Figure 6a).

```
0 HZ 450 HZ WI RAMP 1 + NORM 4 1 creates an arbitrary
450 HZ 650 HZ WI 3 LOAD 1 channel of info.
650 HZ 1050 HZ WI RAMP NEG 1 + NORM 4
FULL 7 STORE A
```

Finally, we will add two interfering tones, one at 90 MHz and one at 100 MHz.

```
1 90 HZ STORE IN
1 100 HZ STORE IN
FULL ?
```

Now that the complete frequency spectrum has been defined, we need to take a few extra steps to arrive at the I and Q time domain waveforms required by the VAWS system. First, we must define the phase response of the signal over the frequency range. In this example, the phase will have a uniform random distribution from −180 degrees to +180 degrees.

```
XY NOISE 160 - XY 1 define phase in the auwave
DISP2 1 view magnitude and phase
```

We have chosen arbitrarily to define the magnitude of the spectrum in a log scale so it will match a spectrum analyzer’s display. The next line will convert it to a linear scale with the 0V level representing −50 dB and 1V level representing 0 dB.

```
1-50-TOLIN
```

For simplicity we have decided to let the left side of the screen represent the low end of the spectrum and the right side the high end. In reality, however, the IFFT used by WGL expects a slightly different representation of the signal one more commonly used in digital signal processing applications. Consequently, before we can execute a frequency-to-time transformation, we need to shift the spectrum to the left (with wrap-around) so that the relative position of the upper and lower sidebands is reversed.

In traditional baseband signal simulation the lower sidebands would be the mirror image of the upper sidebands. However, one of the strengths of this system is its
ability to simulate non-symmetric IF/RF modulation. To accomplish this, the complex IFFT looks at the full signal spectrum when computing the real and imaginary time components (I and Q).

The second line will set the component at the carrier frequency to zero. This is not necessary, but will be useful in demonstrating the effect calibration has on the carrier level. CTOT is a user definition (see Appendix B) which performs the complex IFFT and scales the data to ensure that the signal levels are appropriate.

In the working and auxiliary waves of WGL, we now have the I and Q components to be downloaded into the AWSes. Executing the following user definition will accomplish this.

**ILOAD**

Figure 6b shows a spectrum analyzer picture of the resulting signal (the HP 8780 level is set to 0 dBm and its frequency to 750 MHz). In comparing this spectrum to the waveform defined in WGL, you will note that undesired images, carrier leakage and frequency response ripple (most apparent in the noise section) all contribute to the degradation of the spectrum.

**Part 3. Compensating Waveforms**

We now need to compensate the I and Q waveforms to clean up the spectrum. The following user definitions will call the appropriate BASIC subroutines to perform the necessary corrections:

- **COMPFREQ**
  - Compensate frequency response
- **COMPDC**
  - Compensate DC offsets
- **ILOAD**
  - Execute ILOAD

Figure 7 now shows a spectrum free from all unwanted responses!

There is an additional command, not discussed above, that may be very useful in some applications requiring exceptional carrier leakage performance. Carrier leakage, as discussed earlier, is the only parameter that can be expected to drift with time. In some instances it is convenient to keep an extensive directory of waveforms in the AWS memory, switching from waveform to waveform by appropriate sequencing.

It would be very time-consuming to have to re-compensate all the signals in memory as the system drifts. Therefore the user definition

**QUICKDC**

provides a quick way to correct for small DC offset drifts in the system without requiring waveforms already stored in AWS to be modified in any way. The definition accomplishes this by using DAC's internal to the HP 8780A to cancel offsets.

This definition allows for two options. The first one is used when the waveforms used have already been compensated for DC offsets. In this case, the QUICKDC correction only needs to correct for drifts. The second option is used when the waveforms have not been compensated. The QUICKDC correction must then be able to handle not only the drift but also the system's initial offsets. It is recommended that the first option be used whenever possible as the HP 8780A offset DACs have a limited range, and may not be able to handle large initial offsets.
Appendix A. WGL Programs

These programs are available from your HP representative. Please contact your field engineer or local HP sales office for software or additional product information.

[These programs are saved in "CALPROGS"]

DEFINE INITIAL
( initializes HP45 addresses and more... 719 store laws
706 store gaws
720 store hp8780
( need 10 db of attn to not o.d. HP8780
-4.010;raw:10;raw:10;1* $ aaws attenuate | do gaws
aaws attenuate | do laws END

DEFINE CTOT
( does a complex ifft and scales it
tor ifft size * neg xy size * neg xy
tdomain
top max / tor ( normalize to 1 END

DEFINE CALFREQ1
size store tctx
"FREQ_DATA1" $ get calfreq
? tctx ctx

DEFINE CALFREQ2
size store tctx
"FREQ_DATA2" $ get calfreq
? tctx ctx

DEFINE CALFREQ
2 caldriver

DEFINE COMPAIR
comfreq compdc igload END

DEFINE CALDRIVER
( This program calls the calibration routine. See BASIC listing for more
or store p1 initial
Gaws laws hp8780
paws_cal $ CALL xy xy swap down END

DEFINE QUICKC:
( This definition calls the DC offset drift calibration erase
"QUICK DC CAL: Select One..." 7 cr or
"1) Set AWG2 to DC-offs cal factor?cr or
"2) Set AWG2 to 0 and null carrier"7or cr
"3) Set 1 if I and Q waveforms have?cr or
"been DC compensated."7 or
"Select 0 otherwise."? or cr
"SELECT ONE (CR=ABORT)" enter store ch initial
ch of int ( cr 2 eq intre(0 0 ) ( offsets-> 0
ifalse(999 999) ( flag sub
hp8780 0
"aaws_cal $ CALL xy xy swap down )

DEFINE CALDC
( Calibrates DC offsets
erase "Calibrating DC offsets ..."? 1 caldriver END

DEFINE CALFREQ
( This calls the frequency response
( calibration routine
( It expects the wave with info on the
( frequencies to be cal'd
erase
"Frequency calibration in progress ..."?
size store tctx
2 caldriver

tctx ctx

DEFINE CALSELM
( This routine calls the skew cali-
( bration routine.
erase "Calibrating skew ..."?
1 caldriver END

DEFINE COMPRIVER
( This definition calls the compensation
( routine. SEE BASIC listing for more
store perm 0 0 perm "comp" $ CALL xy xy swap down END

DEFINE COMPRIVER
( This definition does the frequency
( compensation routine.
( It expects time domain I and Q in the
( wave and awave respectively
90 sin store angfigl (save deg/grad fig
xy xy store a xy deg (set to degrees
of 2 compdriver tot xy a xy store a xy
tof 1 compdriver tot xy a xy
angfigl 1 eq ifalse (rad) END

DEFINE COMPDC
( This routine compensates the DC offs
( It expects time domain I and Q in the
( wave and awave respectively
0 compdriver ( Comp dc

DEFINE ILOAD
( downloads I and Q from WJ and Aux Wave
( to two 8770's and sync's them,
( HP11 address should be set in INITIAL
initial
top max 1 gt iftrue cr or " WARNING " cr
( "or (.[0]) >=15 cr) result ter
or ":raw;:chan1;1:$ aaws download xy
or "raw;:chan1;1:$ aaws download xy
9279076:NOW; $ syncstart cr
"SYSTEM IS RUNNING " ? cr
END

(----------------------------------------------------------)
For more information, call your local HP sales office listed in the telephone directory white pages. Ask for the Electronic Components Department, or write to Hewlett-Packard:

**United States**
P.O. Box 10301
Palo Alto, CA 94303-0890
U.S.A.

**Canada**
6877 Goreway Drive
Mississauga, L4V 1M8
Ontario

**Europe, Africa,**
**Middle East**
Central Mailing Dept.
P.O. Box 529
1180 AM Amstelveen
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