

### Overview of Circuit

The S-band vector modulator is based on the AD8341 RF Vector modulator. The evaluation board for the AD8341 is used.\* This circuit gives Cartesian phase and amplitude control. Inputs are I and Q control voltages. The AD8341 is specified up to 2.4 GHz, and we are using it at 2.856 GHz. That and its non-ideal performance are reasons that it needs to be linearized.

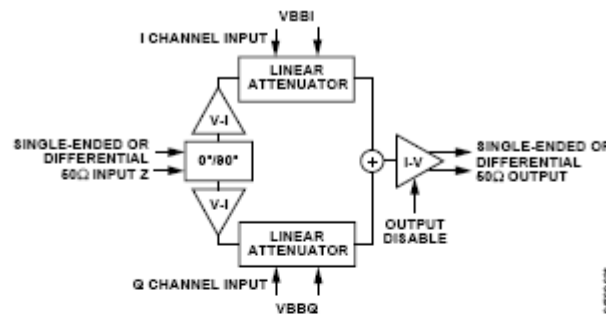


Figure 26. Simplified Architecture of the AD8341

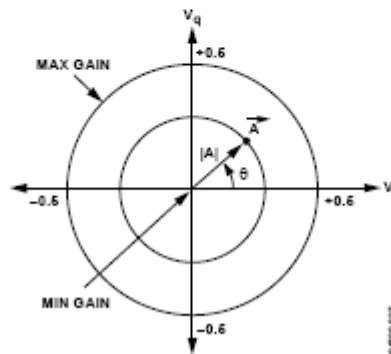
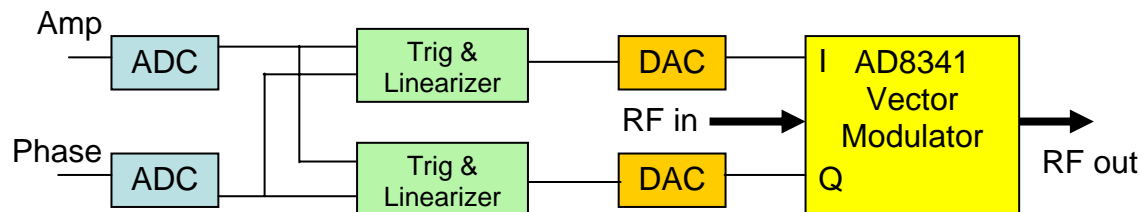


Figure 27. Vector Gain Representation

A sketch of the S-band vector modulator circuit is below. Amplitude and Phase control voltages are input from the control system. These are digitized (ADC's), and the outputs of the ADC's address two "Trig and Linearizer" circuits that are EPROM's programmed to perform trig (sine and cosine functions) and to take account of any departure from ideal of the vector modulator. The outputs of the Trig and Linearizer Circuits address DAC's that apply the control voltages to the AD8341.



### Circuit Details

\* Note that SW1 must be in the A position for the output to be enabled.

- The amplitude is digitized into 9 bits ( $0, \dots, N_H = 511$ )
- The phase is digitized into 11 bits ( $0, \dots, N_H = 2047$ )

Consider either the amplitude or phase inputs. Let  $V$  be the control voltage,  $\varepsilon$  = some tolerance,  $n$  = address, and  $V_L$  and  $V_H$  as defined below

$$\begin{aligned} V = V_L + \varepsilon &\Rightarrow n = 0 \\ V = V_H - \varepsilon &\Rightarrow n = N_H \end{aligned} \quad (1)$$

where  $N_H$  is the maximum address value (= 511 for the amplitude).<sup>\*</sup> Then the ADC output for any arbitrary control voltage is

$$n = \frac{(N_H + 1)(V - V_L)}{V_H - V_L} + O(\varepsilon) \quad (2)$$

- The trig and linearizer circuits are AT27C080PC EPROM's with 20 input address bits corresponding to the amplitude and phase data. The amplitude data forms the lowest 9 bits of the addresses.
- Two AT27C080PC's are employed in each trig and linearizer circuit, and the output is a 14 bit address to the DAC's, which generate the I and Q control voltages.
- The AT27C080PC's are programmed using a SuperPro Z EPROM burner starting with data tables that are converted to Intel hex format using *write\_intel\_hex.m*.
- The Trigger and Linearizer Circuits (Chips U9, U10, U11 & U12) are AT27C080PC EPROM's with 20 bits of input address. The circuit functions are

CIRCUIT	FUNCTION
U9	MSB's for the I control voltage DAC
U11	LSB's for the I control voltage DAC
U10	MSB's for the Q control voltage DAC
U12	LSB's for the Q control voltage DAC

### MATLAB & LABVIEW Software

*The latest versions of this software are on the ARDB group disk in \E163\S-band RF System\S-band vector modulator. The LABVIEW programs are intended to be run on ARDBW53, which has a GPIB interface and a National Instruments PCI6722 I/O board.*

Programming the vector modulator depends on a number of MATLAB and LABVIEW programs. Brief descriptions follow

MATLAB script or function	Description
read_lvm	f=read_lvm(file_name) read lvm file written by labview without comment header but with a single time column
Sband_analysis	Analysis of network analyzer data – described in detail below

<sup>\*</sup> The measured values for the amplitude circuit were  $V_L = -7.40$  V and  $V_H = 7.86$  V, and the measured values for the phase circuit were  $V_L = -7.43$  V and  $V_H = 7.90$  V.

Sband_burn	Program for burning EPROM's for linearized vector modulator data – described in detail below
Sband_readin	Read in of network analyzer data taken with <i>AD8341_ctrl.vi</i> – described in detail below.
Sband_straightthru_eprom_program	Straight thru linear burn – described in detail below
write_intel_hex	f=write_intel_hex(DATA,file_name) Extended address records for addresses for more than 16 bit addresses

LABVIEW 7.1 vi	Description
AD8341_ctrl.vi	Takes data giving the response of the AD8341 to amplitude and phase control inputs – described in detail below.
HP8753x	Instrument library for HP8753 network analyzer
HP34970a	Instrument library for HP34970 voltmeter
AD8341_loop.vi	Utility program to loop and set the I and Q voltages to control the AD8341 – described in detail below
AD8341.vi	Utility program to set the I and Q voltages to control the AD8341 – described in detail below
quad_voltages	Converts amplitude and phase to I and Q control voltages

### *Sband\_straightthru\_eprom\_program.m*

This program generates the AT27C080PC files for a “straight thru” EPROM burn. AD8341 data taken with U9, ..., U12 burned straight thru, as defined below, are part of the trig and linearization procedure. Let  $s_\theta$  and  $s_A$  denote the addresses calculated with eq. (2) (neglecting the  $O(\varepsilon)$  term), then the straight thru amplitude and phase are

$$A_s = \frac{s_A}{511} \times 8191.5 \quad (8191.5 = (2^{14} - 1)/2) \quad (3)$$

and

$$\Theta_s = \frac{s_\theta}{2047} \times 2\pi \quad (4)$$

The I and Q functions that are burned into the EPROM are

$$I = [A_s \cos \Theta_s]; Q = [A_s \sin \Theta_s] \quad (5)$$

where

$$[x] = \text{uint16}(\text{round}(x)) \quad (6)$$

The remainder of the MATLAB program uses masking and bit shifting to process I and Q for AT27C080PC EPROM programming.

The phase and amplitude measured with this array of I and Q inputs provides the reference that is used to correct for the non-ideal nature of the AD8341.

There is a set of chips U9ST051104 – U12ST051104 in the vector modulator that have the straight thru burn on them. The burn files for these chips on the ARDB group disk in \E163\S-band RF System\S-band vector modulator.

***Sband\_readin.m***

- Data are written in an eight column array by *AD8341\_ctrl.vi*. The columns are

Phase set point (V)	Amplitude set point (V)	Phase read back (V)	Amplitude read back (V)	Measured phase (deg)	Measured amplitude (db)	I voltage (V)	Q voltage (V)
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- Cuts are placed on the minimum and maximum phase and amplitude set points. The values of these cuts are coded as part of the script, and presently are set to -7.40 V & 7.86 V for the amplitude and -7.43 V & 7.90 V for the phase circuit.
- Phases are unwrapped,
- Various diagnostic plots are generated
- The data are written into a file for subsequent processing by *Sband\_analysis.m*

***Sband\_analysis.m***

This program is intended to analyze data taken with straight thru EPROM's. The purpose is to determine the deviation from ideal performance.

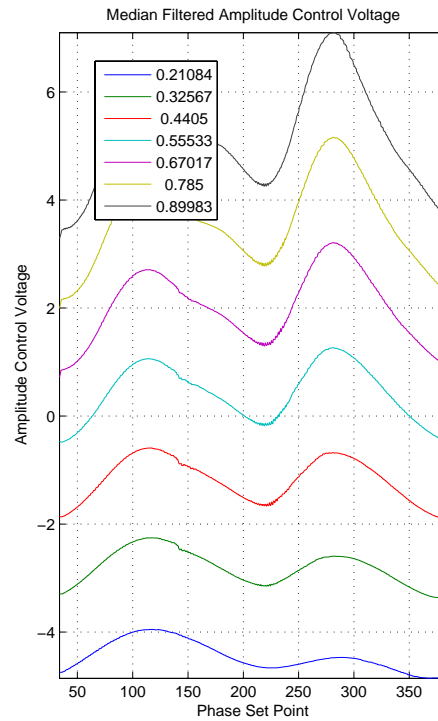
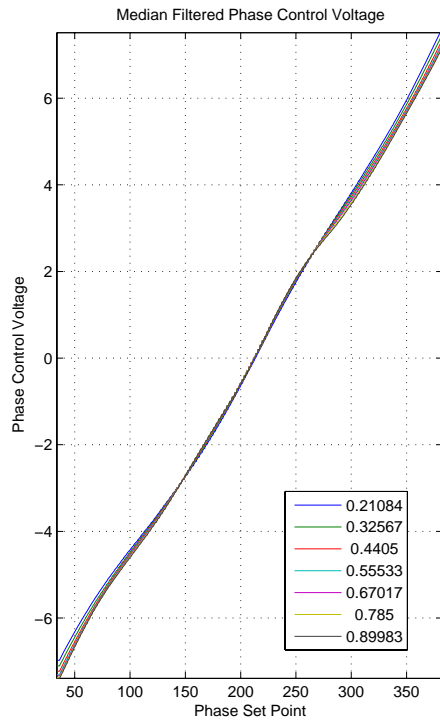
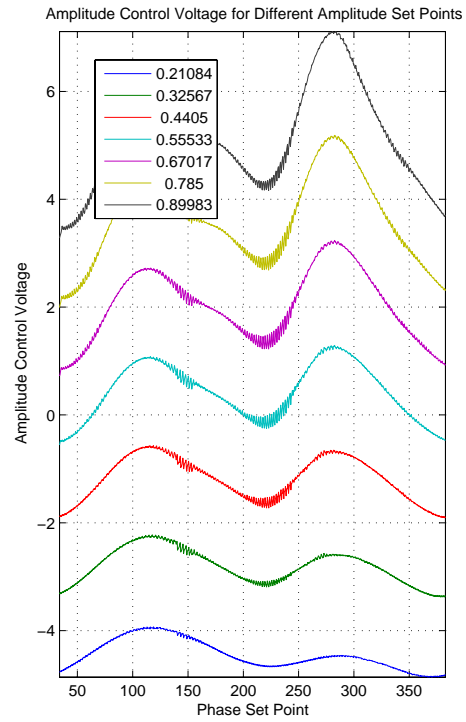
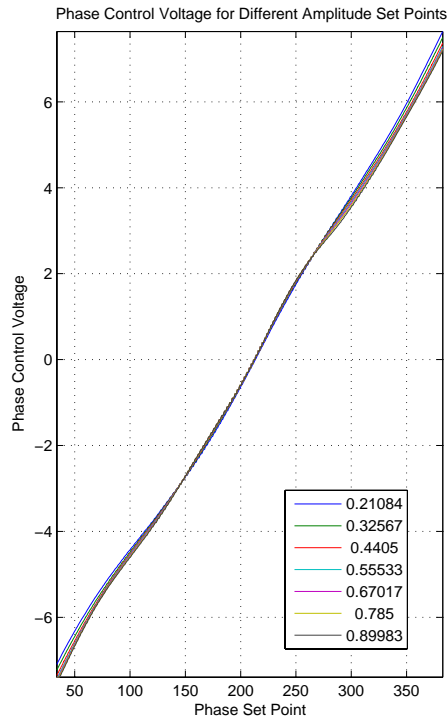
- Control voltage, ADC ranges, slopes and intercepts for conversion etc. are coded in the program and will need to be changed if other values are desired.
- Bad data are rejected
- Various diagnostic plots are generated.
- The phase and amplitude data are processed in the way described below. (It is first done for a limited set of amplitude control voltages for the purpose of generating graphics to be sure the process is reasonable. Then it is done for a fine grid of amplitude control voltages to determine the EPROM programming.)
  1. A two dimensional array [phase, amplitude] is interpolated for different values of the phase and amplitude set points. The amplitude and phase data are approximately, but not exactly evenly spaced on a grid, and the interpolation is performed using the MATLAB routine *griddatan*. The interpolation results are presented as a plot of the phase control voltage as a function of the phase set point for different values of amplitude set points. (The set point units are linear units not db.) See below
  2. A two dimensional array [amplitude, phase] is interpolated for different values of the phase and amplitude set points using *griddatan*. The interpolation results are presented as a plot of the amplitude control voltage as a function of the phase set point for different values of amplitude set points. See below.
  3. The data are median filtered to remove noise using *medfilt1*. A filtering window of 27 out of a full range of 2048 is used. This filtering window is coded into the script. Results are shown below
- They are for 7 values of the amplitude set point spanning the full range of set points (248 to 416 in this example).\*

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\* The plots were generated for straight thru EPROM's.

- The process is repeated for every value of amplitude set point in this range, and the results are saved.

The results can be interpreted in the following way. The required [amplitude control voltage, phase control voltage] is known for each pair [amplitude set point, phase set point]. The EPROM's should be programmed to give these results. Referring to the system figure: The set points are digitized by the ADC's that address the EPROM's in the "Trig & Linearizer" circuits. The outputs of these circuits are the DAC inputs that generate the required I and Q voltages for the AD8341.



***Sband\_burn.m***

This program takes the output of *Sband\_analysis.m*, converts it the appropriate digital values and writes Intel hex format files for EPROM burning. The phase,  $n_\Theta$ , and amplitude,  $n_A$ , addresses are determined by the phase and amplitude control voltages using eq. (2). The outputs of the phase and amplitude EPROM's are then determined by

$$\Theta = \frac{2\pi}{2047} \times \frac{2048}{V_{H\Theta} - V_{L\Theta}} \times (V_\Theta(n_\Theta, n_A) - V_{L\Theta}) \quad (7)$$

where  $V_{H\Theta}$  and  $V_{L\Theta}$  are the high and low input voltages for the phase control (see eq. (1)) and  $V_\Theta(n_\Theta, n_A)$  is the required phase control voltage as determined from plots such as the left hand one above. Similarly the amplitude is given by

$$A = \frac{8191.5}{511} \times \frac{512}{V_{HA} - V_{LA}} \times (V_A(n_\Theta, n_A) - V_{LA}) \quad (8)$$

Quantities are defined analogously to those for eq. (7) above. The I and Q functions that are written into the data file for burning into the EPROM are

$$I = [A \cos \Theta]; Q = [A \sin \Theta] \quad (9)$$

where the [] function is given by eq. (6).

The areas outside of the  $n_\Theta$  and  $n_A$  ranges that are used are filled with values for neighboring calculated values. This was found to be important to prevent abrupt changes in behavior if the control voltages are set outside the linear control ranges.

***AD8341\_ctrl.vi******This is the data taking program.***

This vi takes data using the HP 8753 network analyzer and Agilent 34970A multimeter. The apparatus connections and setup are

<b>NI PCI6722 I/O board</b>	Channel 0 = Amplitude Input
	Channel 1 = Phase Input
	These channels should be connected to the vector modulator through inverting, unity gain, low output impedance amplifiers. This is needed to drive the low input impedance of the control inputs. The assumed gain of the amplifiers is -1.048.
<b>GPIB Addresses</b>	34970A Multimeter: 1
	8753 Network Analyzer: 2
<b>34970A Multimeter Connections</b>	Channel 1 = amplitude
	Channel 2 = phase
	Channel 3 = I voltage
	Channel 4 = Q voltage
<b>8753 Network analyzer setup</b>	Centered at frequency of interest Span = 10 MHz 201 points 25% smoothing aperture

The picture below shows the instruction box with the same information that is on the front panel of the vi. (Old, outdated versions do not have this instruction box.)

## Operating Instructions

1) PCI 6722 analog output card: channel 0 = amplitude, channel 1 = phase

The outputs of the PCI 6722 are to be connected to the control inputs through unity gain, low output impedance amplifiers because of low input impedances of control inputs

2) Agilent 34970A: channel 1 = amplitude, channel 2 = phase,  
channel 3 = I voltage, channel 4 = Q voltage

3) The network analyzer should be centered on the frequency of interest, span = 10 MHz, 201 pts, 25% smoothing aperture

The vi generates a data table shown in the picture below from the front panel of the vi.

[illegible]

This table is saved as a Labview .lvm file, which is to be read in by *Sband\_readin.m* for analysis.

*AD8341.vi & AD8341\_loop.vi*

These v's are *Utility Programs* for understanding the performance of the AD8341 board.

The instrument setup is

<b>NI PCI6722 I/O board</b>	Channel 0 = I channel input
	Channel 1 = Q channel input
	These are set using <i>quad_voltages.vi</i>
<b>GPB Addresses</b>	34970A Multimeter: 1
	8753 Network Analyzer: 2
<b>34970A Multimeter Connections</b>	Channel 1 = I voltage
	Channel 2 = Q voltage
<b>8753 Network analyzer setup</b>	As desired for measurement

The difference between *AD8341.vi* and *AD8341\_loop* is that AD8341 is intended to be called once while AD8341\_loop is intended to be called in a continuous loop.

*AD8341\_loop* calls *AD8341.vi*.

## Notes from January 2007

The evaluation board failed and had to be replaced, so the procedures above had to be used. The following were found

- 1) The need for the low output impedance buffer amplifiers was not included in the original note. The most important consequence was that the NI PCI6722 I/O board

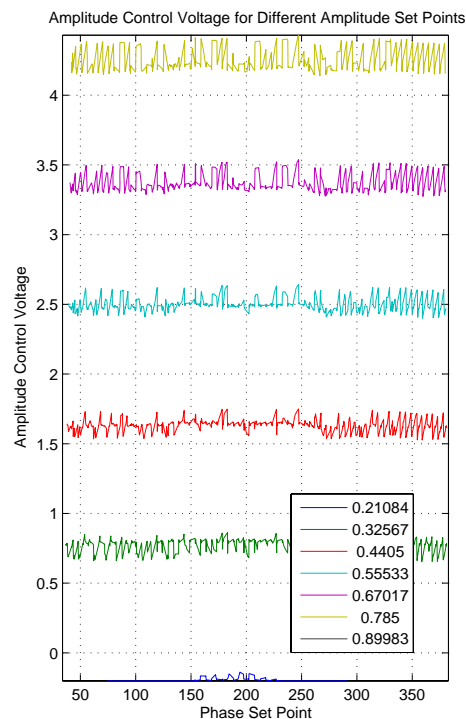
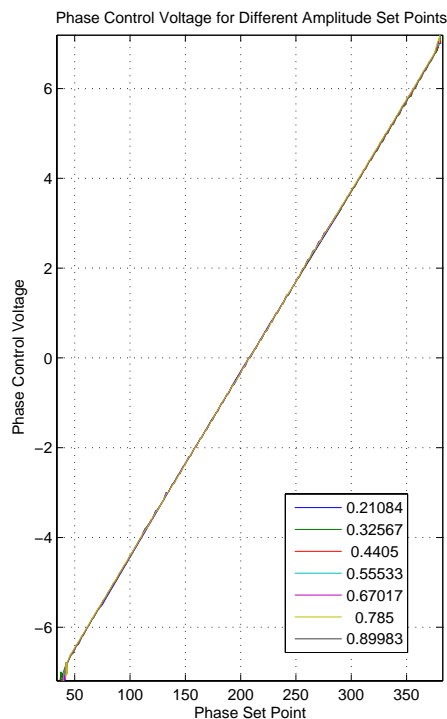


could not make the command voltage when it was  $|V| > 5$  V. In addition, the polarity of the command and NI PCI6722 I/O board output was opposite because the amplifiers used are inverting. The need to use the buffer amplifiers has now been included in the procedure.

- 2) The evaluation board had failed. Indication was 40 – 50 db of loss across the board and failure to respond to control voltages
- 3) The I & Q voltages with the straight thru chips did not have a constant quadrature sum  $\sqrt{V_I^2 + V_Q^2}$ . This problem went away when the evaluation board was replaced.

Paul Stiles may have seen and repaired something when he replaced the evaluation board or the problem may have been another manifestation of evaluation board failure.

- 4) Small software problem associated with MATLAB 2006b. Had to change `set(0,'Units','normalized');` to `set(0,'Units','pixel');`.
- 5) Straight thru burn was made with the U9ST051104 – U12ST051104 chips.
- 6) The burn files for the new chips are U9\_070125 to U12\_070125
- 7) The result using these chips is shown below for design phase control range of -7.00V to 7.00V and design amplitude control range 0V to 5.0V



The different labels correspond to different RF gains ranging from 0.21 to 0.90.