Errata

Document Title: Vector Modulation Measurements (AN 343-3)

Part Number: 5954-6366

Revision Date: November 1986

HP References in this Application Note

This application note may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this application note copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

About this Application Note

We've added this application note to the Agilent website in an effort to help you support your product. This manual provides the best information we could find. It may be incomplete or contain dated information, and the scan quality may not be ideal. If we find a better copy in the future, we will add it to the Agilent website.

Support for Your Product

Agilent no longer sells or supports this product. You will find any other available product information on the Agilent website:

www.agilent.com

Search for the model number of this product, and the resulting product page will guide you to any available information. Our service centers may be able to perform calibration if no repair parts are needed, but no other support from Agilent is available.

Agilent Technologies

Application Note 343-3

Vector Modulation Measurements
Coherent pulsed tests of radar and electronic warfare systems

HEWLETT PACKARD

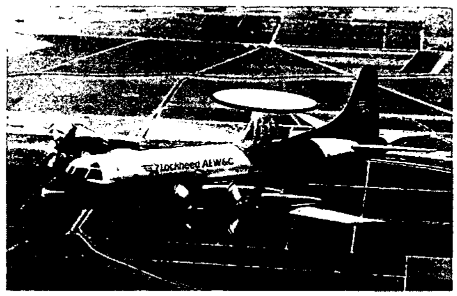
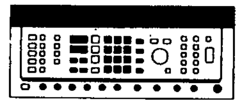


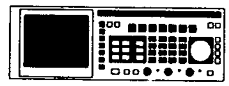
Table of Contents

Block Diagram Key

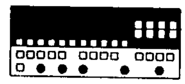
HP 8780A Vector Signal Generator



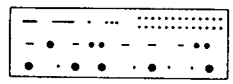
HP 8980A Vector Analyzer



HP 8116A Pulse/Function Generator



HP 3762A Data Generator



HP 300 Series Controller

Overview

Almost all radars and electronic warfare (EW) equipment coherently transmit and detect their signals. This application note will describe methods to test the microwave and IF portions of this equipment using a vector modulation test system. The proposed system will be able to perform tests with complex phase and magnitude modulation signals.

This note should give the reader the general principles and methods for making vector measurements. A vector modulation test system is introduced which uses the HP 8980A Vector Analyzer and the HP 8780A Vector Signal Generator. These instruments form the core of the system. The basics on how to make measurements with the system and instruments are covered. When finished with this application note, the reader should feel confident enough to configure and use a vector measurement system for individual testing requirements.

The application note breaks down into the following sections:

Introduction. Advancements in radar and electronic warfare technology are reviewed and related to the need for new test methods. Current testing methods are discussed with their strengths and weaknesses.

Vector Modulation Fundamentals. The vector measurement concepts are described here and compared to other test methods. Complex modulation and demodulation with In-phase and Quadrature-phase (I and Q) channels is introduced. Even if the reader is familiar with complex I and Q modulation, the section could be helpful, since a method of displaying data on a Q versus I plot is proposed.

Vector Modulation Test System. A practical implementation of a vector measurement system is introduced.

Basic Transmitter Tests. As the title implies, this sections reviews general transmitter tests. The tests focus on characterizing the transmitted waveform and its modulation.

Basic Receiver Tests. When a receiver makes a measurement, two types of errors limit the accuracy: external and internal errors.

External errors refer to measurement inaccuracies caused by factors outside the receiving system. Examples include glint, multipath reflections, atmospheric attenuation, clutter, and others.

Internal errors are caused within the receiver. The inaccuracies they cause are almost totally independent of target dynamics and tracking conditions. These errors limit the optimum accuracy and processing capability of the receiver. Examples of limits include time, frequency, and phase discriminator accuracies. Errors include phase and gain matching of different channels, quadrature error, oscillator stability, and overall signal degradation.

The "Basic Receiver Tests" section outlines tests for internal errors. Testing for internal errors requires idealized signals which are measured for degradation as they travel through the receiver.

Advanced Receiver Tests. This section briefly describes a technique for measuring the effects external errors have on receiver performance. Radar returns could be simulated for these tests.

Specific Receiver Tests. The "Basic Receiver Tests" section reviews tests which are common to all types of receivers. This section lists some specific receivers and mentions tests which apply to them directly. The receivers covered include monopulse, instantaneous frequency measurement (IFM), and compressive.

Anechoic Chamber and Radar Range Measurements. Vector techniques can greatly contribute to the design and implementation of these systems. This section reviews how vector modulation instruments can be integrated into anechoic chambers and radar ranges.

Summary.

For more specific instrument information, Product Notes, which describe the vector measurement instruments' capabilities, and technical Data Sheets are available from your Hewlett-Packard field engineer.

Ask for:

PN 8780A-1, Introductory Operating Guide for the HP 8780A Vector Signal Generator (lit. #5954-6368).

PN 8980A-1, Introductory Operating Guide for the HP 8980A Vector Analyzer (lit. #5954-6369).

HP 8780A Data Sheet (lit. #5954-6363).

HP 8980A Data Sheet (lit. #5954-6364).

HP 8980A Programming Note (lit. #5954-7342).

Introduction

Radar and EW technology has been constantly increasing in complexity. Modulation has gone from simple pulse to complex phase coding. Typically, a radar system uses the time and frequency shift of returned signals for deriving range and velocity information. The phase of a returned signal is also used to increase the accuracy of radar receivers and to derive more information about a target. The radar must coherently receive and process a return to make phase measurements. This means the receiver oscillators must be phase locked to the transmitter oscillators.

Coherent reception can reduce range ambiguities with phase tagged pulses, while range resolution can be improved with phase coding and then compressing the pulses. When integrating several pulses digitally, as moving target indicators do, the phase must be preserved so that noise will cancel and the signals will add. Synthetic aperture radars record the phase of a pulse to achieve high angular resolution.

Coherent transmission and detection adds a layer of sophistication to radar and electronic warfare systems that expands their capabilities and performance. The added layer of sophistication has been made possible by advances in both transmitter and receiver technologies.

Modern transmitters control the phase of their output signal — something the older transmitters didn't do. Older transmitters, which are typically klystrons or magnetrons, output high power at low duty cycles. While they generate pulse and chirp modulation, their phase modulation capabilities are limited. Controlling the phase of a signal coming out of a gated klystron or magnetron is quite difficult.

The block diagram of a modern transmitter usually has an exciter/amplifier configuration. The amplifiers are normally solid state or TWTs, while the exciters have a variety of standard designs. The exciters are capable of high bandwidth phase, frequency, and amplitude modulation. The rise and fall times, or switching characteristics of modern transmitters are typically much faster than older transmitters.

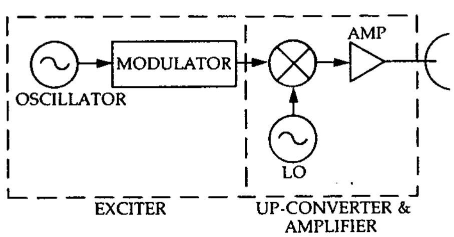


Figure 1. General modern transmitter block diagram. The modulation typically takes place before the power amplifier and at a lower frequency than RF. Older transmitters, tubes and cavity magnetrons would modulate at RF.

Older test systems weren't designed to test complex modulated signals. For older transmitters it is usually sufficient to diode detect the coupled output. This measures PRF, pulse width, rise/fall times and also peak power. A frequency counter measures the transmitter frequency. Receivers are tested by applying a pulsed signal to the input and measuring how the receiver responds. The frequency, delay, and amplitude of the pulse are varied for standard tests. With the advent of high bandwidth, coherent modulation, different methods of testing are required.

The sophistication of the radar and electronic warfare (EW) systems places a burden on test instruments. Typically the testing capabilities limit the performance of current systems. Testing capability must match the increased complexity to utilize the full potential of radar and EW equipment.

The signal a transmitter produces must be explicitly characterized. In addition to the PRF, duty cycle, amplitude, and frequency, the phase of the carrier during the pulse must be measured. The accuracy with which a receiver detects and measures the phase of a returned signal must also be characterized to find out how well the radar will perform. A test system must be able to generate a phase modulated signal, and must also be able to analyze the phase modulation on a signal.

Test Techniques

Various techniques are presently being used to test complex signals. The following paragraphs review current test techniques and then propose a new way of testing with a vector modulation test system.

A network analyzer is the most common way to make coherent tests. If the testing only requires a CW signal, this method will give the most accurate and reliable results. If, however, a modulated signal is needed to excite the system under test, other methods must be used.

A variety of reasons exist for why a test signal should be modulated, and specifically, pulse modulated. Many components in the receiver will behave differently for pulse modulated signals than CW signals because of power dissipation and nonlinearities. The radar typically will be used under pulsed conditions. Thus, the effects of pulsed signals should be taken into account during testing.

Devices in the receiver are normally designed for pulsed operation and will dissipate less energy than when a CW signal of an equivalent power level is used. This heating effect prevents the use of high power CW signals. Many radar components will burn out with a high power CW signal. But high peak power tests are needed to characterize the performance at or above the 1 dB compression point of the radar components. Nonlinearities can be tested using a pulsed, high peak power signal without overheating devices.

The pulse response of a receiver can be derived with a network analyzer by doing an inverse FFT on measurements made over a wide frequency range. This method, however, doesn't take into account the heating and nonlinear effects described. The method is also slow because the measurements must be made at each frequency over the frequency range and then processed with an inverse FFT.

Another measurement technique tests a radar transmitter with the receiver and tests the radar receiver with the transmitter. During a transmitter test, the receiver characterizes the transmitter's signal. During a receiver test, the transmitter excites the receiver and the receiver response is recorded.

This method is quite convenient and does test the ability of the radar's transmitter and receiver to operate together in a system. The transmitter and receiver are designed to work as one unit, and need to be tested as such. The modulated signal generated by the transmitter must correspond to the way the receiver processor operates, while the receiver usually contains matched filters corresponding to the frequency spectrum of the transmitted signal.

Overall system testing is necessary, but it's not very useful for isolating faults. Errors would be identified but it would be ambiguous which caused the error: the transmitter or the receiver. A complete test system must isolate the error sources all the way down the component or module level in a radar or EW system.

Radar and EW systems need to be tested under pulsed conditions with instruments which have greater performance capabilities than the system being tested. The system can then be specified to the limit of its performance, rather than having the specifications limited by the test equipment.

Having a complete test system, which includes a signal simulation source and a signal analysis device, speeds up the design cycle. Being able to isolate faults and simulate a signal right from the start of a project greatly reduces the time needed to design a full system.

Vector Modulation Fundamentals

An effective, coherent test system could be built based on the principles used in coherent transmitters and receivers. These principles, vector principles, allow a signal to be either synthesized from two orthogonal components or analyzed by breaking the signal down into two orthogonal components.

Most modern radars and some EW systems receive and downconvert signals into two orthogonal components. With the components a receiver can easily determine the phase and magnitude of the signal. This allows them to perform complex Doppler processing.

Vector principles can be used as a powerful test and analysis tool in modern systems. The two orthogonal components, or the I (In-phase) and Q (Quadrature-phase) signals, are very sensitive to system errors or degradations. Hence, test equipment specially designed to process the I and Q signals (or generate precisely modulated signals) can open up a new dimension in system performance analysis.

A vector modulation system employing I and Q channels appears in Figures 2a and 2b. This system performs coherent, pulsed tests with high modulation bandwidth signals.

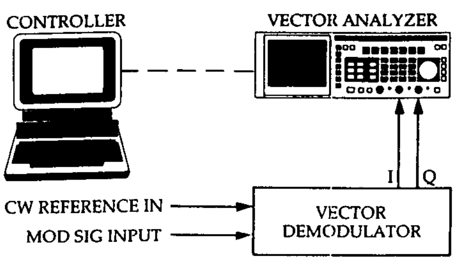


Figure 2a. This section of a vector measurement system can analyze a signal by breaking it down into quadrature components. The system reveals the signal's phase and amplitude.

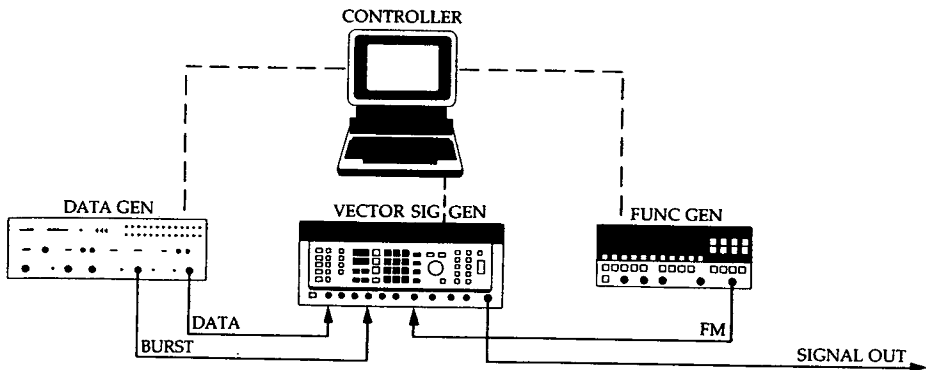


Figure 2b. This section of a vector measurement system generates complex modulated signals, including pulsed, phase coded, Barker coded, chirped, Doppler shifted, and many others.

The vector modulation test system measures the receiver at several points to locate a problem. With the high bandwidth, the system analyzes much faster rise and fall times than typical test systems can. As the block diagram in Figure 2b indicates, the test system can generate complex modulated signals for receiver tests. Complex signals can be analyzed in both the transmitter and receiver. The test system will also directly examine I and Q channels.

The rest of this section reviews the basics of vector modulation techniques and explains what the I and Q channels are used for. The next section then reviews the proposed vector measurement system and outlines its operation and capabilities.

Vector techniques are basically a method for generating and analyzing complex modulated signals.

Radar systems using I and Q channels generate and process coherent waves with sophisticated phase and amplitude modulation.

The easiest way to understand the techniques is to first see what a signal looks like on a vector diagram and then to see how a coherent receiver breaks a signal into I and Q components. After that it is easy to understand how a signal can be generated with vector techniques.

A vector diagram presents the modulation of a signal on a polar display. The vector diagram shows the time-varying amplitude and phase of the signal. The phase displayed is referenced to an arbitrary CW carrier of the same frequency which is usually provided from the transmitter. The magnitude of the vector from the origin to a displayed point on the vector diagram represents the amplitude of the signal, while the angle of the vector represents the phase of the signal.

A vector diagram of a simple pulsed signal appears in Figure 3. This diagram doesn't display just one time instant; instead, a time interval is displayed. Notice the cluster of points at the origin which represent when the pulsed carrier is off with no signal amplitude. The cluster of points on the positive I axis represents when the pulsed carrier is on. Since the points appear on the I axis, the phase of the signal is zero. The points in between the two clusters represent the transition between pulse on and off states. Notice that the transitioning points do not stay exactly on the I axis indicating that the signal's phase varies during switching due to incidental phase modulation.

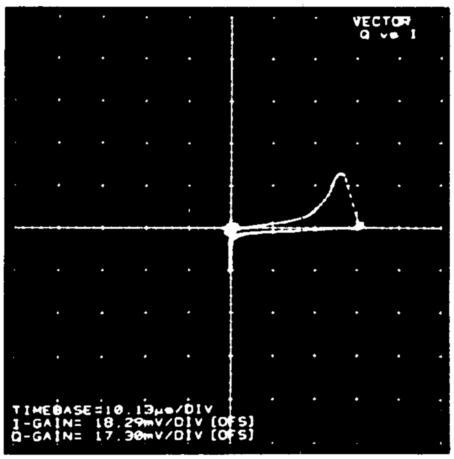


Figure 3. This vector diagram displays a simple pulse signal. The two dot clusters represent the on/off states of the pulse. The incidental phase modulation is shown during transitions.

Every radar will typically have its own unique vector diagram. Even if the modulation is the same, the incidental phase modulation will usually be different. By viewing the vector diagram then, a radar's signature can be seen quite easily. The vector diagram precisely reveals the modulation of a radar signal.

A coherent receiver produces a vector diagram with a vector demodulator. An incoming signal is demodulated into two baseband channels, the I and Q channels. The channels comprise the vertical and horizontal components of a vector diagram. By using two channels instead of just one, as older receivers did, all the modulation information, phase and amplitude, is preserved.

The vector demodulator section of the receiver is what actually breaks the signal down into I and Q components. Figure 4 outlines the basic block diagram of a demodulator. A modulated IF signal enters at the left while a CW reference signal at the same frequency as the IF carrier enters at the right. The reference and modulated signal are split into two channels. A quadrature hybrid shifts the phase of one of the reference channels by 90°. The reference and modulated signals are mixed together into two baseband channels. Thus, the two output baseband signals are 90° apart. The channel with the added phase shift is called the Q or Quadrature-phase channel and the channel with no added phase shift is called the I or In-phase channel. By connecting the two channels to an X versus Y display, a vector diagram is obtained. An analysis appears in Block 1 on page 10 which explains why an X versus Y display of the I and Q channels produces a vector diagram.

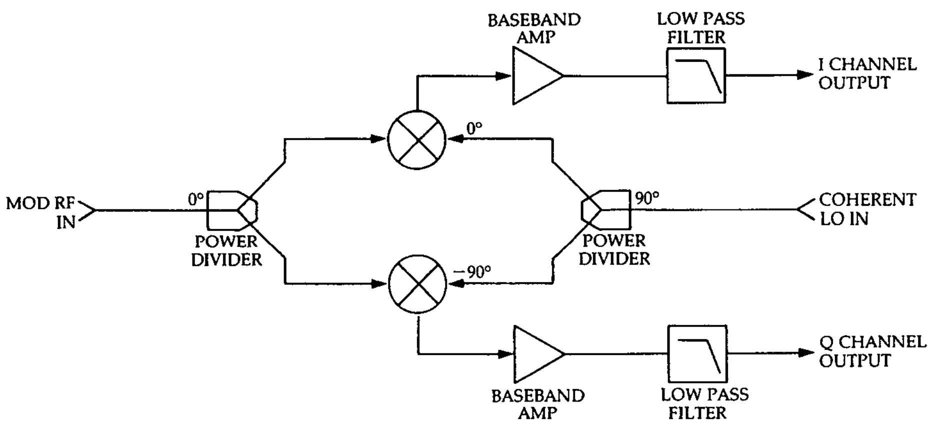


Figure 4. A vector demodulator reveals the phase between two inputs and the magnitude of the inputs. The phase, magnitude, and time information is contained on the two baseband output channels, I and Q.

Block 1: Vector Demodulator I and Q Outputs

The following analyzes why a Q versus I display represents a vector diagram of a signal's modulation. The analysis is based on the demodulator block diagram in Figure 4.

Let the RF Input equal
$A(t)\cos[\omega t+\phi(t)]$.

where: $A(t)$ = amplitude modulation
$\phi(t)$ = phase modulation
ω = carrier angular frequency.

The LO input will equal $\cos(\omega t)$. The I and Q mixer outputs are:

$A(t)\cos(\omega t+\phi)$ ⊗ $\cos(\omega t)$ → I channel

$$= \frac{A(t)}{2}\cos(2\omega t+\phi) + \frac{A(t)}{2}\cos(\phi)$$

$A(t)\cos(\omega t+\phi)$ ⊗ $\cos(\omega t-90°)$ → Q channel

$$= \frac{A(t)}{2}\cos(2\omega t-90°+\phi) + \frac{A(t)}{2}\cos(\phi+90°)$$

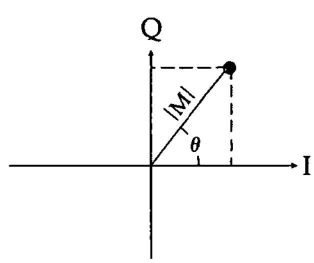
After the $2\omega t$ product is filtered out by the baseband low-pass filter, the output is:

$$I_{volt} = \frac{A(t)}{2}\cos\left[\phi(t)\right]$$

$$Q_{volt} = \frac{-A(t)}{2}\sin\left[\phi(t)\right]$$

The Q channel must be inverted either with an inverting amplifier or in the processing or display unit.

When the I and Q outputs are displayed in an X versus Y mode, the amplitude and phase of the vector to a point can be calculated as follows:



$$|M| = \sqrt{I^2+Q^2} = \frac{A(t)}{\sqrt{2}}$$

$$\theta = \mathrm{Tan}^{-1}\left(\frac{Q}{I}\right) = \phi(t)$$

Thus, a Q versus I plot represents a vector diagram of a signal's modulation.

A modulated signal can be generated using the same principles of a vector demodulator. A vector modulator, which is basically the reverse of a vector demodulator, can impose arbitrary phase and amplitude modulation on a CW carrier. Instead of breaking a signal down into I and Q components, a vector modulator synthesizes a modulated signal from baseband I and Q components. Figure 5a contains a simplified block diagram of a vector modulator.

A CW signal goes into the reference carrier input, while baseband signals go into the I and Q inputs. The modulated signal then exits from the RF output port. The correct I and Q values needed to produce the desired modulation can be calculated with the same formulas used in Block 1 for the demodulator.

The operation of a vector modulator can be visualized with Figure 5b. Here a signal is split into two paths. One path is shifted 90° and then both paths pass through variable attenuators. Finally, they are summed and output. The output is the vector sum of the two quadrature components as shown in the adjacent vector diagram.

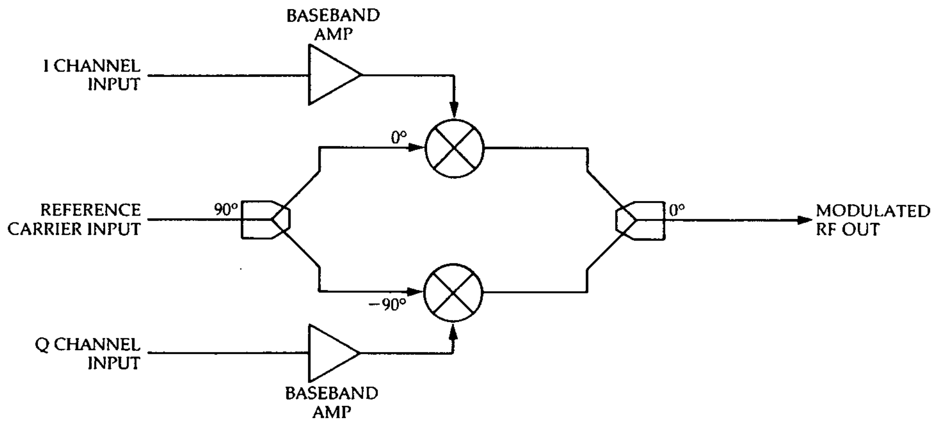


Figure 5a. A vector modulator synthesizes a complex modulated signal from baseband I and Q inputs and a CW carrier input.

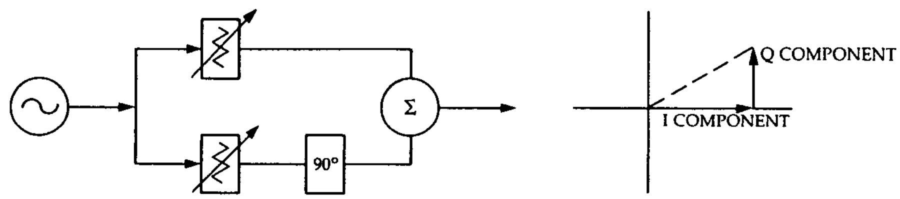


Figure 5b. Conceptual diagram of how a vector modulator operates. The incoming signal is split and passed through variable attenuators. One channel is given a 90° phase offset, then the two channels are summed. The two channels represent the quadrature components of the output signal. By varying the attenuation levels, the output phase and amplitude can be controlled.

Since the vector diagram of Q versus I doesn't show the modulation versus time, rise and fall times can't be discerned. But Q and I can each be displayed over time and the phase and magnitude can be calculated from Q and I at any instant of time. If I and Q are digitized, a computer can do the calculations and then plot the phase and amplitude versus time. These plots will give the rise and fall rates.

Figure 6 displays I and Q versus time for the simple pulsed RF example while Figure 7 displays the calculated phase and amplitude plots. Notice how the phase temporarily jumps when the pulse turns on. The change in power level causes the frequency of the oscillator generating this signal to initially change, a phase lock loop then corrects it. This effect could uniquely describe this radar's signature. The signature can then be used to identify the radar in EW systems.

Vector modulation techniques provide a comprehensive way to perform radar and EW tests. A vector diagram can display the modulation of a carrier in one plot which is easy to visualize and comprehend. Phase and amplitude envelopes over time can also be viewed by calculating them from the I and Q channels. I and Q channels can also be used to generate any desired amplitude and phase modulation.

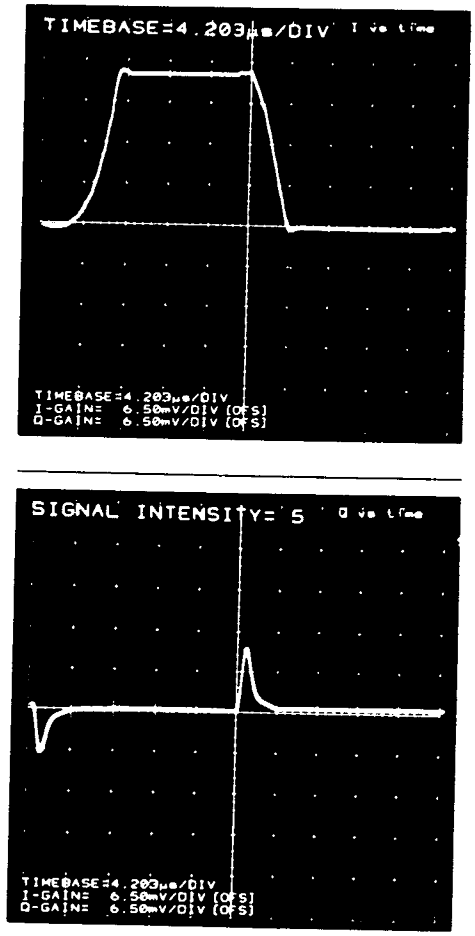


Figure 6. The I and Q channels versus time for the simple pulse in Figure 3.

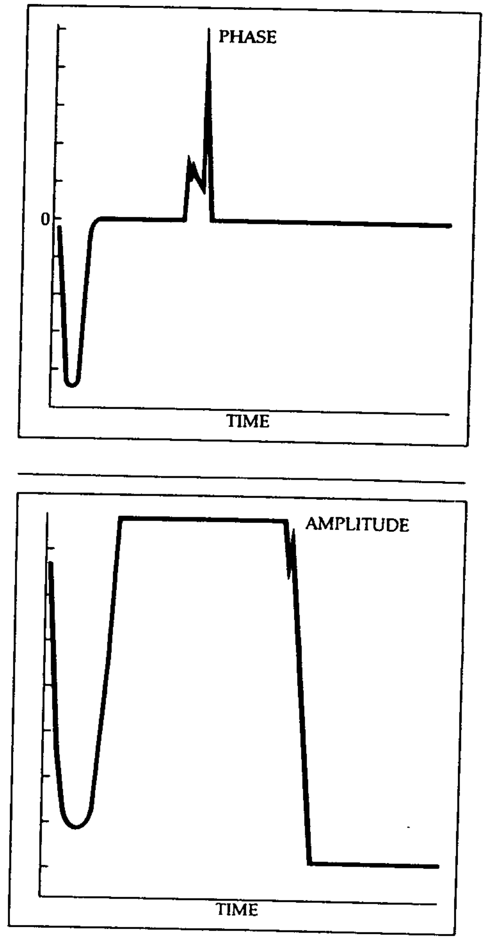


Figure 7. Phase and amplitude versus time of the pulse in Figure 3. The values have been calculated from I and Q values at each sampling time instant. These plots represent the radar's signature.

Vector Modulation Test System

Figures 2a and 2b on page 8 show the general block diagram of a practical vector modulation test system. The measurement system performs two basic functions: generating complex modulated signals and analyzing complex modulated signals. Practically all tests will rely on these two functions. The rest of this section describes the generation capabilities of the vector measurement system and then describes the analysis capabilities. This is followed by sections which explain tests the vector modulation test system can perform.

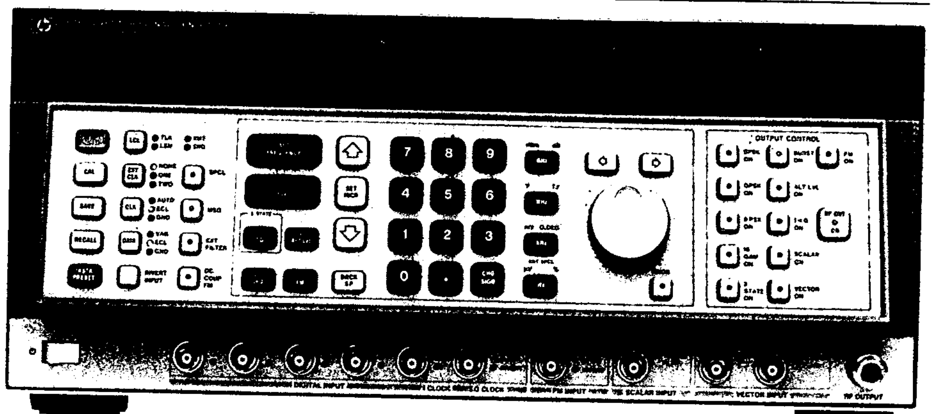


Figure 8. The HP 8780A Vector Generator.

HP 8780A Vector Signal Generator

The HP 8780A Vector Signal Generator forms the heart of the generation portion of the system. The HP 8780A is a synthesizer with extensive modulation capabilities. The HP 8780A output frequency spans from 10 MHz to 3 GHz in 1 Hz steps to allow for testing at most intermediate frequencies. The 2 to 3 GHz range can be easily upconverted for testing at microwave frequencies.

The output signal can be modulated with an internal vector modulator by providing baseband signals into the I and Q inputs. In addition to the arbitrary modulation capability afforded by the I and Q inputs, special modulation functions are available from the data, burst mode, scalar, and FM inputs.

The FM can provide peak-to-peak deviation of greater than 200 MHz for wideband chirp simulations.

The burst mode input will pulse modulate the output. The pulses have approximately 1 ns rise and fall times with an on/off ratio typically of about 50 dB; pulse widths of a few nanoseconds can be simulated. If a greater on/off ratio is needed, an external pulse modulator can be used. Variable rise time, or arbitrarily shaped pulses are easily obtained by using one of the analog I or Q inputs.

The data inputs (TTL or ECL compatible) provide a convenient new way to modulate signals. They can be used to simulate complex phase coded pulses quite easily. The data inputs represent a binary word which switches the output between predetermined phase and amplitude states. The modulation states are selected by the modulation format (BPSK, QPSK, 8PSK, 16 QAM) chosen on the front panel of the HP 8780A. For example, if BPSK is chosen, a single data input line can switch the output carrier between two phase states, 0° and 180°. The data inputs make it easy to simulate phase-coded signals such as Barker codes and Frank codes. Product Note 8780A-1 contains detailed information on operating the vector signal generator.

The HP 8780A Vector Signal Generator, in conjunction with a data generator and function generator, can simulate most types of complex modulated signals used in radars. These signals include simple pulse with no AM to PM distortions, binary phase-coded signals with almost ideal phase transitions, chirp, FM-CW, and several other polyphase-coded signals. The data generator typically controls phase, PRF, and pulse width. The function generator controls the FM and scalar inputs. The PRF and pulse width can also be controlled by running the clock output of the data generator through a divider into the burst mode input. This will set the pulse width to some multiple of the phase state width.

The HP 8780A is capable of generating a much wider variety of signals than the ones just mentioned. The analog I and Q inputs can be used for generating almost any type of arbitrary modulation desired.

HP 8980A Vector Analyzer

The HP 8980A Vector Analyzer forms the basis of the analysis portion of the vector modulation test system. Conceptually the HP 8980A consists of a specialized, high speed, 2-channel sampling oscilloscope. The HP 8980A takes I and Q inputs and displays them over time or in a vector diagram (Q versus I). The vector diagram capability sets the analyzer apart from conventional oscilloscopes since up to 350 MHz bandwidth signals can be displayed. Most scopes have severely limited X-axis bandwidth when in the X versus Y mode.

The I and Q inputs are also digitized with 12-bit resolution, so that the values can be transferred to a computer for statistical analysis. The analyzer is therefore very useful for viewing and analyzing a signal's modulation. Phase and amplitude errors can be very accurately measured by using the markers contained in the vector analyzer.

The HP 8980A captures data by sampling repetitive waveforms. This technique allows pulsed RF signals with very fast rise and fall times (< 1 ns) or signals with very wide modulation bandwidths (up to 700 MHz) to be analyzed. Repetitive waveforms must be used, however.

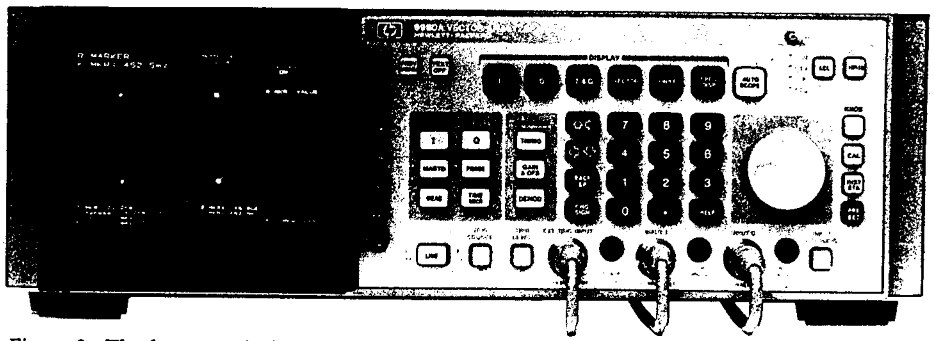


Figure 9. The front panel of the HP 8980A Vector Analyzer.

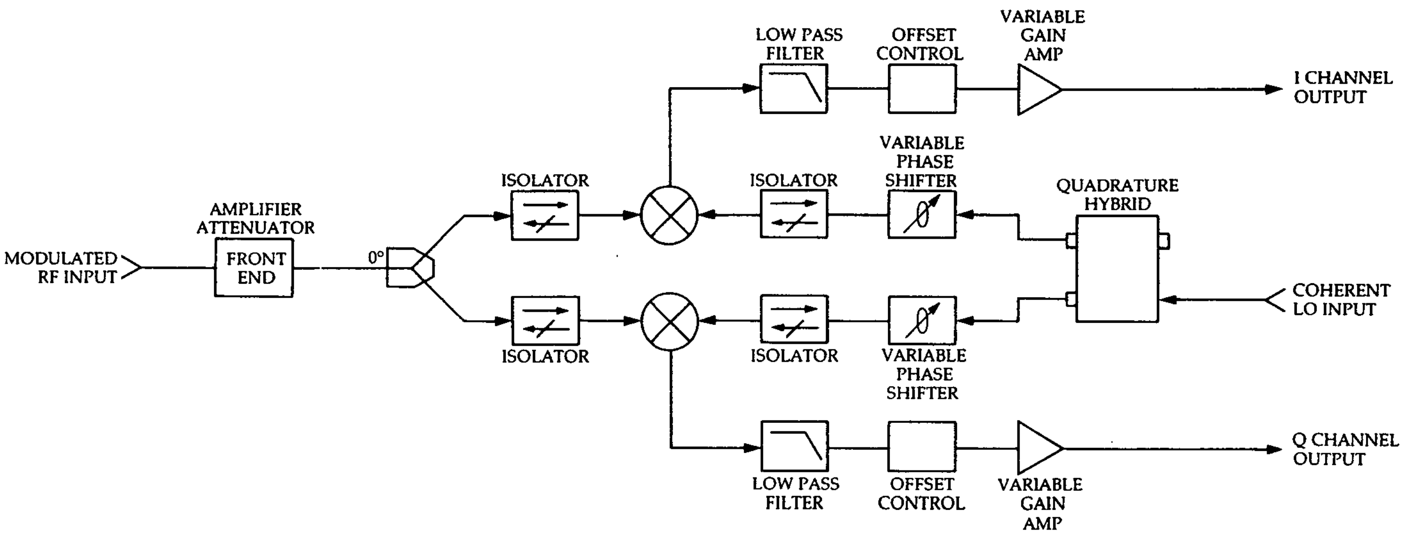
The specialized functions of the analyzer make performing measurements quite convenient. Quadrature error in a vector demodulator can be quantified and quadrature offsets can be added to the vector display. A vector alignment function rapidly switches the vector diagram display between Q versus I and I versus Q. This makes it easy to see quadrature and gain errors in a demodulator. Phase shifts can be easily inserted. A 3-D function rotates the display along the I, Q or time axes.

Usually, the HP 8980A will directly analyze receiver baseband signals because most receivers break a signal down into I and Q channels. For transmitter tests though, a vector demodulator must be added to examine the modulated carrier.

Block 2 outlines the basic considerations in building a vector demodulator. It should be tailored to the system which will be tested.

If phase and amplitude of a signal versus time are desired, a computer can calculate them from the digitized I and Q signals. These plots can then be displayed on the computer screen.

Overall, the vector measurement system with the HP 8980A and the HP 8780A can perform coherent tests under pulsed, dynamic conditions. The HP 8780A will synthesize microwave signals with complex modulation, while the HP 8980A can precisely analyze the detected modulation on a carrier. The following sections describe how to use the system to make measurements.



Block 2: Building A Vector Demodulator

One of the key instruments in a vector modulation test system is a demodulator. If the system under test doesn't have one, one can be built.

Many factors should be considered when building a demodulator. The ideal demodulator shown in Figure 4 must contain several other components in order to operate accurately. A practical block diagram of a demodulator appears above.

The major sources of errors occurring in this demodulator can be summarized as:

- DC offsets. Any offsets will carry through to the output. Some method of controlling or calibrating the offsets is needed.
- Quadrature phase. The quadrature hybrid used should split the phase by precisely 90°, otherwise the phase imbalance will cause errors. Different line lengths in the I and Q channels will also cause quadrature errors. An adjustable phase shifter or delay line should be included in the signal path for calibration. Care should be taken, though, to make sure the phase adjustment will be the same for all the frequencies used in the demodulator.
- Gain matching. The gain in the two channels must be matched. The gain matching can be calibrated by using a variable gain amplifier or attenuator in at least one of the channels.
- Carrier leakage or image frequencies. The input signals will leak through the mixer into the I and Q output channels. Second-order products and images will also leak through. Good filters at the mixer outputs will attenuate these signals.
- Impedance matching. The impedance at all the different connections should be matched as accurately as possible. This helps reduce amplitude ripple. The isolators in the block diagram help reduce reflections caused by impedance mismatches.
- Frequency response of the components. Typically, the demodulator will be used at a fixed frequency, with signals of a given bandwidth. All the components should be specified to operate over the desired frequency range. A network analyzer can be used to characterize the components over the frequency range.
- The absolute phase is completely arbitrary in a vector demodulator and it depends on the total phase relationship between the reference carrier and the modulated input signal. There must be some way, therefore, of adjusting the absolute phase of the demoduated I and Q outputs to correspond with the reference used in the radar's processing unit. An adjustable length of line between the reference carrier and the quadrature hybrid is an easy way to accomplish this.

If the demodulator will be used exclusively with the HP 8980A Vector Analyzer, the analyzer can be adjusted to take into account many of the demodulator errors. For instance, dc, quadrature phase, and gain errors can all be compensated for. This makes accurate measurements possible even when the demodulator contains these errors.

More information on testing and calibrating vector demodulators appears in the "Basic Receiver Tests" section.

Basic Transmitter Tests

The vector modulation test system just described is ideal for testing modern coherent transmitters. A sophisticated test system is needed to measure the high bandwidth, complex modulated signals being transmitted today. This section will outline tests using the vector modulation system. Examples are given using some radar signals.

A transmitter needs to have its different components and modules characterized. Each module should be adjusted for optimal performance. Then overall performance of the transmitter must be characterized.

The power of vector modulation measurements is that transmitter tests can be made by just viewing a waveform. To test the components or modules, a signal must be input and then the output signal must be viewed to see how the signal was affected. For example, amplifier modules have many specifications which describe the degradation a pulsed signal experiences as it travels through the amplifier. The specifications usually include preshoot, overshoot, undershoot, settling time, ringing, droop, insertion phase, and phase ripple.

The insertion phase and phase ripple are important measurements in coherent systems. The insertion phase must be taken into account when generating or processing a phase code. Measuring the phase during a very short pulse, however, can be exceedingly difficult. Many times a vector system is the only viable method for measuring the phase in narrow pulses.

Overall performance tests involve characterizing the output waveform of a transmitter. Many times reasonable guesses can be made about the source of errors by looking at the output. The characterization is also used to verify that the receiver is matched to the transmitted signal. Optimum accuracy calculations the whole radar will operate on must take into account the non-ideal nature of the transmitted signal.

Figures 10 and 11, respectively, show a vector measurement system connected to the IF and RF portions of a transmitter. The test system can characterize a signal by recording the signal's amplitude and phase envelopes (amplitude and phase versus time).

Several examples are given of commonly transmitted radar waveforms. The examples used should cover the majority of the waveforms being used today; any others can be characterized using the same techniques.

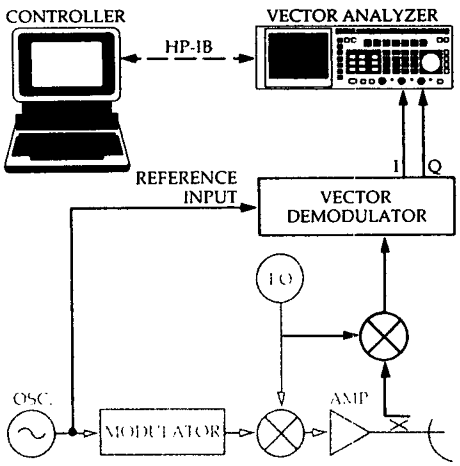


Figure 10. Vector measurement system for testing a transmitter at RF. The system will perform signature analysis of the signal's modulation.

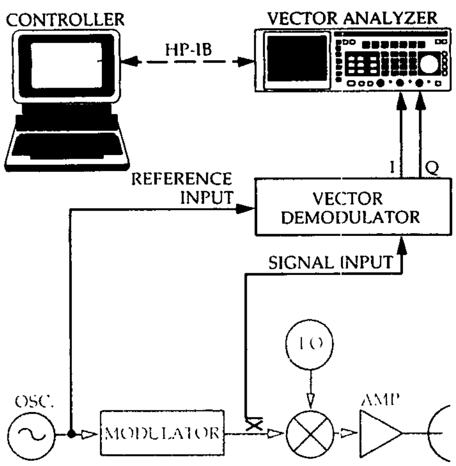


Figure 11. The vector measurement system testing the transmitter at IF. The RF and IF tests can be compared to determine the performance of the upconversion and amplification.

Let the simple coherent pulse in Figure 3 represent a transmitted radar pulse. The sudden incidental phase distortions on this signal could cause measurement errors in a Doppler receiver. If the Doppler shift of the returned pulse was analyzed during the phase bump, errors will result. The sudden jump in phase would be interpreted as a large Doppler shift. The radar receiver designer would need to accurately know what the transmitted signal was to avoid these errors. In this case the radar processor would have to ignore the pulse data during the phase bump.

The transmitter designer could be using a vector display to help adjust for these sudden phase distortions. The vector analyzer could be displaying the signal while the transmitter was being adjusted to minimize the phase bump.

Different types of modulation can also be displayed on a vector diagram. Consider a simple phase-coded pulse, which has a 13-bit Barker code on it. The phase shifts between 0° and 180°. The Q versus I plot in Figure 12 shows the three states of the signal: off, 0°, and 180°. A cluster of dots appears at each state. By using phase and magnitude markers, the general range of amplitude and phase fluctuations can be seen.

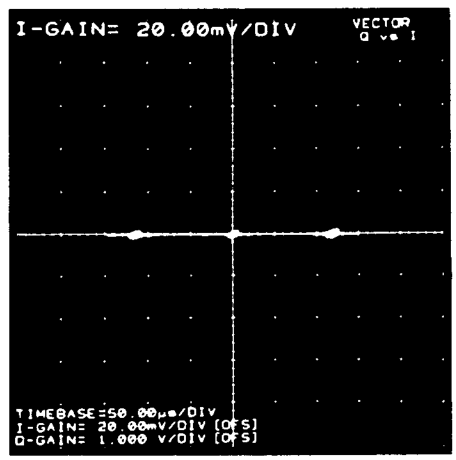


Figure 12. The vector diagram of a phase-coded pulse. The three states are displayed along with the trajectory paths taken between states. These paths indicate the signature of the radar.

Block 3: Estimating Phase and Amplitude Fluctuations from I and Q.

When data lies close to the I axis on a vector diagram, the I channel output approximates amplitude variations while the Q channel output approximates phase variations. The result can be derived using differentials.

The I channel output I_{out}, equals A/2 $\cos\phi$.

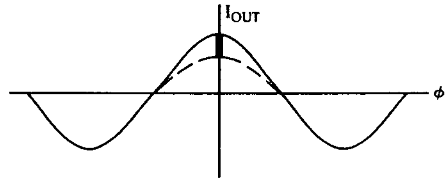
$$d(I_{out}) = d\left(\frac{A}{2}\cos\phi\right) = \frac{\cos\phi}{2}\, d(A) - \frac{A}{2}\sin\phi\, d(\phi)$$

This statement yields the following approximation:

$$\Delta I_{out} \approx \frac{\cos\phi}{2}\,\Delta A - \frac{A}{2}\sin\phi\,\Delta\phi$$

Since $\phi \approx 0$ or close to the I axis, $\cos\phi \approx 1$ and $\sin\phi \approx 0$. Thus:

$$\Delta I_{out} \approx \frac{1}{2}\,\Delta A \quad \text{or} \quad \Delta A \approx 2\Delta I_{out}$$



When $\phi \approx 0$, I_{out} is relatively sensitive to input amplitude fluctuations and relatively insensitive to phase fluctuations. The I channel operates as a linear AM detector.

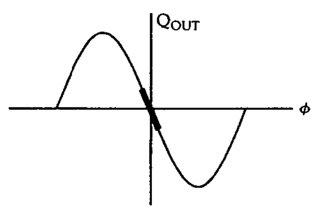
The Q channel output Q_{out}, equals A/2 $\sin\phi$.

$$d(Q_{out}) = d\left(\frac{A}{2}\sin\phi\right) = \frac{\sin\phi}{2}\, d(A) + \frac{A}{2}\cos\phi\, d(\phi)$$

which yields: $\Delta Q_{out} \approx \frac{\sin\phi}{2}\,\Delta A + \frac{A}{2}\cos\phi\,\Delta\phi$

For $\phi \approx 0$ or data close to I the axis, $\sin\phi \approx 0$ and $\cos\phi \approx 1$. Also, since the data lies close to the I axis, $A/2 \approx I_{out}$.

Thus $\Delta Q_{out} \approx I_{out}\,\Delta\phi$ or $\Delta\phi \approx \frac{\Delta Q_{out}}{I_{out}}$



When $\phi \approx 0$, Q_{out} is relatively insensitive to input amplitude fluctuations and relatively sensitive to phase fluctuations. The Q channel operates as a linear phase detector.

In this example, an expedient method for approximating phase and amplitude versus time involves just viewing I and Q over time. Block 3 shows that when the data is close to the I axis or the angle is near 0° or 180°, the I channel approximates amplitude fluctuations, while the Q channel approximates phase fluctuations. Using this, one can see on the display the general magnitude of the phase and amplitude ripples without calculating them from I and Q. Block 3 shows that the Q channel magnitude divided by the I channel magnitude approximately equals the phase deviation in radians.

The constellation mode of the HP 8980A Vector Analyzer can also be used to measure the time of phase or magnitude deviations. Suppose you wanted to measure how long the phase bump in Figure 3 lasted. You would first switch the vector diagram to constellation mode. Then only one dot will be displayed at the instant the time marker indicates. So by moving the time marker through the phase bump you can see what time it starts and ends.

To get the exact phase and amplitude envelopes, the data from the vector analyzer must be output to a computer. There the phase and amplitude can be calculated and displayed as shown in Figure 13.

Another example of a common signal which the vector system can analyze is a chirp or FM signal. The vector system can calculate the instantaneous frequency in a chirp signal at sub-nanosecond intervals. A plot of frequency versus time can be generated. These plots will characterize voltage controlled oscillators (VCOs) and measure how linear or nonlinear a chirp is.

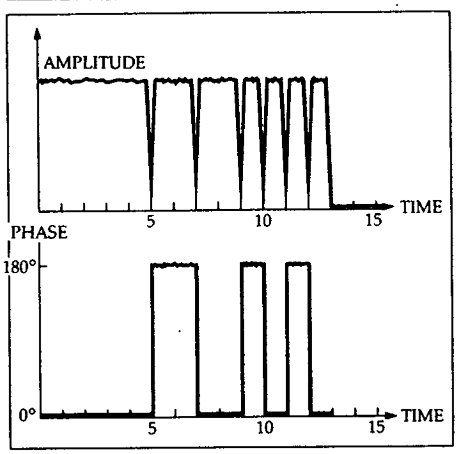


Figure 13. The phase and amplitude envelopes derived from I and Q channels of Figure 12. These plots show the phase code on the pulse.

Consider a pulsed chirp which enters a vector demodulator at an IF frequency. The reference to the demodulator is at the median frequency of the chirp. The vector diagram of the chirp appears in Figure 14. Notice how the signal sweeps out an arc while it's on. This happens because a frequency offset from a reference is equivalent to a constantly changing phase:

$$d\theta/dt = 2\pi f \text{ or } \phi = \int 2\pi f\, dt$$

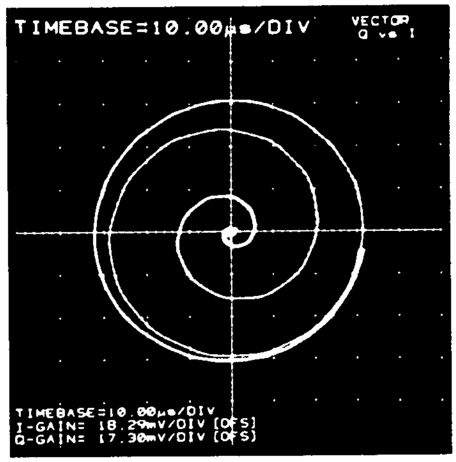


Figure 14. Vector diagram for a SAW chirp. The spiral indicates 1) changing phase due to frequency offsets compared to a CW reference, and 2) relatively slow rising and falling pulse edges.

To test the frequency linearity, the computer calculates the phase from I and Q, and then taking the derivative of the phase yields the instantaneous frequency. The frequency envelope (frequency versus time) of a nonlinear FM signal can also be derived with this technique. Figure 15 shows the plots of the chirp signal described above.

Problems do arise, though, when trying to take the derivative of sampled data. Using sampled data introduces quantization errors and taking the derivative of the data can increase the errors. Some form of averaging must be employed. The HP 8980A Programming Note (lit. #5954-7342) explores these issues and suggests an algorithm which derives frequency directly from the I and Q data.

The vector measurement system is a convenient and powerful way to characterize transmitter signals by providing a vector diagram of the signal and calculating the signal phase and amplitude. The examples above are meant to provide an understanding of the general capabilities of the vector system. The exact waveforms will be determined by the transmitter under test. How the waveform is analyzed depends on the types of errors occurring in the unit under test along with the specific test requirements.

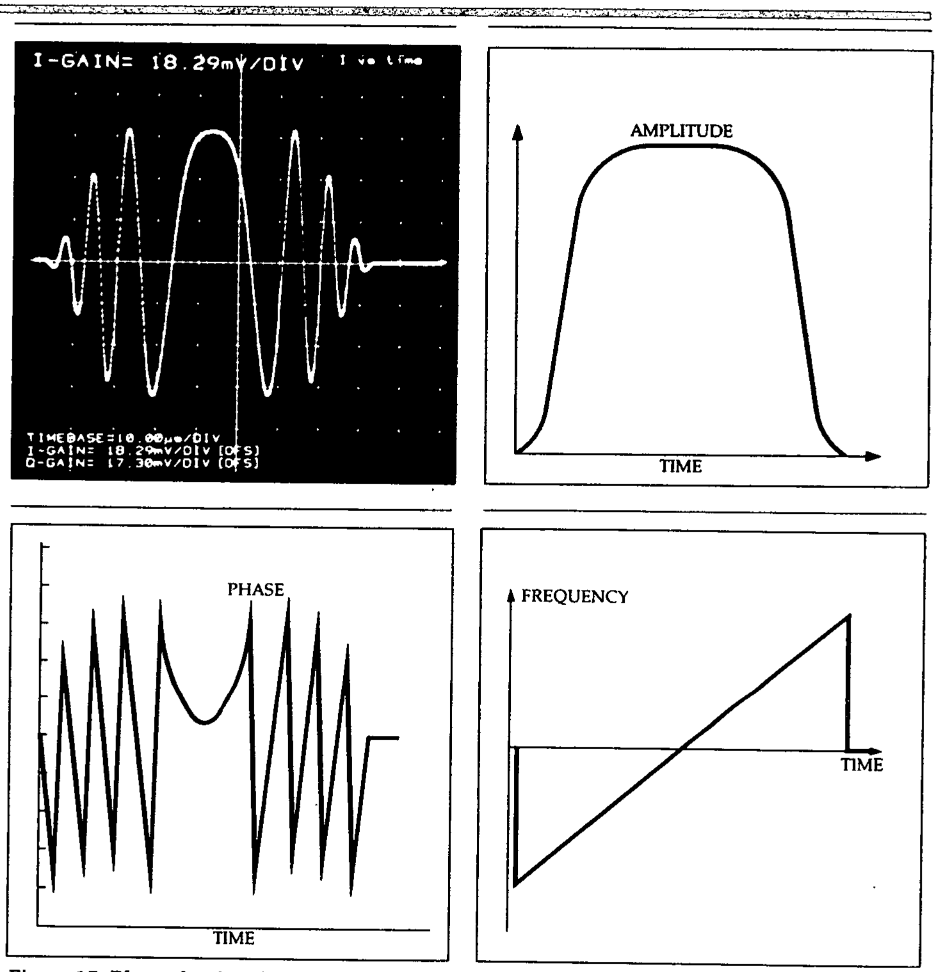


Figure 15. Plots related to the chirped signal in Figure 14. The frequency plot was calculated by taking the derivative of the phase plot. The phase plot was derived from I and Q.

Basic Receiver Tests

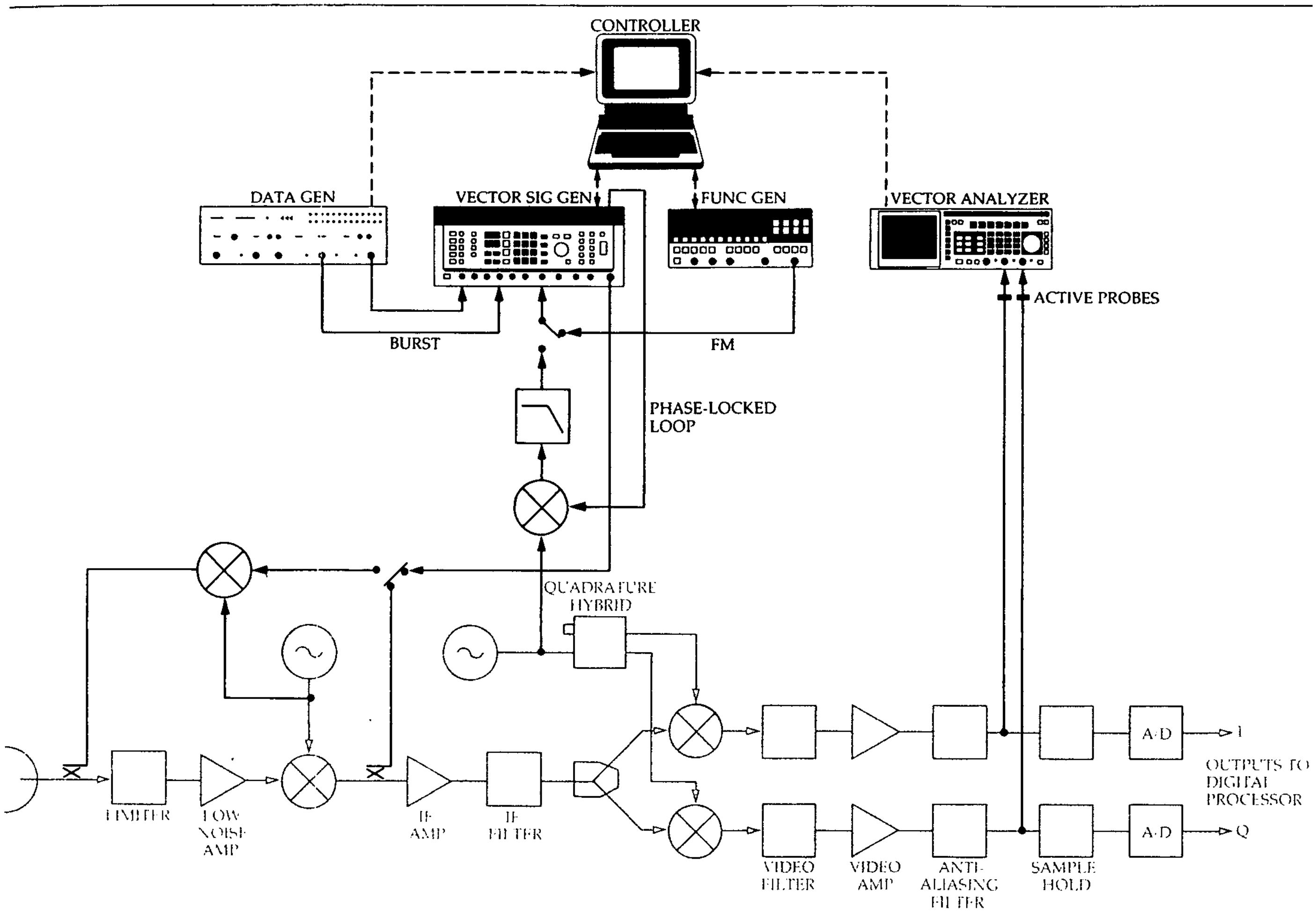


Figure 16. A vector modulation test system connected to a superhetrodyne receiver. The vector signal generator inputs a signal and the distortion caused by travelling through the receiver is analyzed with the vector display and a computer.

This section describes many tests which directly affect the optimum performance of a receiver. The first part reviews the test system. Then a very important test, demodulator accuracy, is described. Measuring signal degradation comes next, and finally some common tests are discussed. The tests described are very general and apply to most types of receivers.

A basic superheterodyne receiver is used to describe the tests. Figure 16 contains the receiver block diagram with the vector modulation test system. The vector demodulator of the receiver itself produces the baseband I and Q signals. The I and Q channels of the receiver feed directly into the HP 8980A Vector Analyzer. Care must be taken to make sure the generator output is phase locked to the receiver local oscillators. The technique used in Figure 16 establishes a phase-locked loop with the generator's coherent carrier output and FM input.

Receiver faults can be isolated by switching the injection point of the test signal from the vector signal generator and switching where the vector analyzer extracts the signal. The vector signal generator output can be upconverted to provide an RF test input or it can be directly input as an IF signal. The RF and IF portions of the receiver can be tested independently of the receiver demodulator if an external vector demodulator is supplied as in Figure 17.

The vector modulation test system will examine most of the RF and baseband portions of a receiver. The digital processor of the receiver is one section the vector system isn't optimized to test. The following paragraphs discuss some of the tests necessary in the analog portions of the receiver.

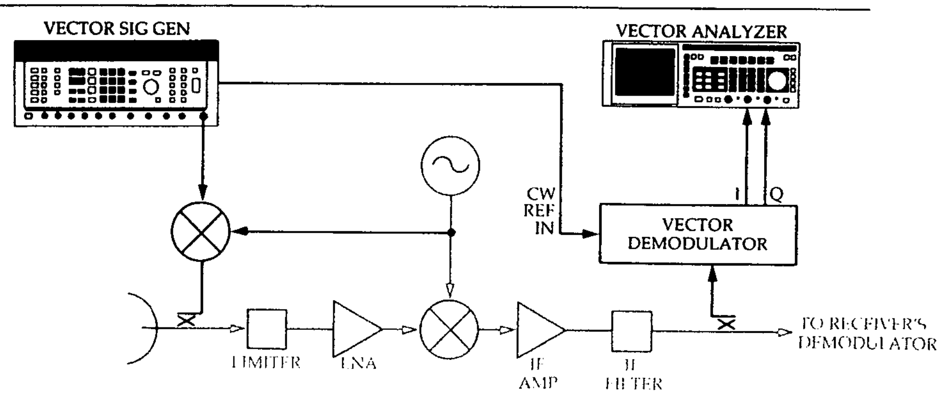


Figure 17. Basic block diagram of a vector measurement system and receiver. Just the receiver RF and IF sections are being tested.

Demodulator Alignment

Probably one of the most important tests needed on all coherent receivers is aligning and measuring the performance of the demodulator. Phase and gain errors between the I and Q channels, nonlinearities, and dc offsets cause the most problems. The I and Q channels must be split by precisely 90°, and have the same gain, otherwise these quadrature errors will result in a spurious signal at the image frequency of the input signal. The spurious signal could be interpreted as a false target or mask real targets. Clutter rejection effectiveness will also be reduced since images of the clutter returns will be produced.

Nonlinearities in the demodulator mixers or amplifiers also result in spurious signals. Reference [1] analyzes the magnitude of these errors. These errors typically aren't as significant as quadrature errors unless the input signal level approaches the 1 dB compression point of the components.

Any dc offsets will add a signal at a zero Doppler shift. The I/Q detectors, track-and-hold amplifiers, and A/D modules all exhibit dc offsets which can become significant at low signal-to-noise levels.

When choosing components for a demodulator, many factors should be kept in mind. Block 2, "Building a Demodulator," page 15, lists the main factors. A variable phase shifter and gain control should be in at least one of the channels, along with offset controls for alignment.

The demodulator can be aligned using several methods. To measure dc offsets, the demodulator should be turned on with the input terminated into a matched load. The output measured will be the dc offset. The vector analyzer is connected with high impedance probes to the I and Q channels right before the A/D modules. The HP 8980A display should be in the Q versus I display mode. Ideally, one dot will appear on the display at the origin, but if there are dc offsets, the dot might appear off center. The demodulator should be adjusted until there is no magnitude on either channel or the dot appears at the origin. This test accounts for dc offsets before the A/D module. To complete the test, the output of the A/D should be monitored. Any output corresponds to dc offsets caused by the A/Ds and they should be aligned accordingly.

Gain and quadrature errors can be tested together with one procedure. Probably the easiest method of alignment uses the HP 8780A Vector Signal Generator to input a quadrature-phase-shift-keyed (QPSK) signal into the IF of the receiver demodulator. Figure 18 shows this test setup. The HP 8780A internally generates the two data signals need for a QPSK signal. The HP 8980A Vector Analyzer should be connected to the I/Q channels right before the A/D modules. The display is in the Q versus I mode.

Ideally during the test, four clusters should appear on the display forming a square centered at the origin. The QPSK signal switches between four phase states of equal amplitude.

If there is a gain error in the demodulator, a rectangle will be displayed instead of a square. If there is a phase error, a parallelogram will be displayed. If both errors occur, a parallelogram will also be displayed. While viewing the display, the phase and gain controls of the demodulator should be adjusted until the display shows a square. The vector alignment function of the HP 8980A makes it easy to determine how well the display is a square. Since the function switches between Q versus I and I versus Q, the corners of the displayed signal will change position if a perfect square isn't being displayed.

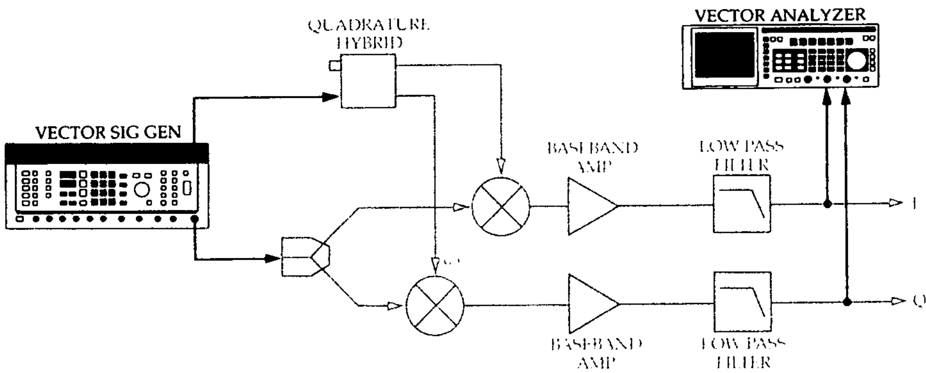


Figure 18. Calibrating a vector demodulator. The HP 8780A Vector Signal Generator inputs a test signal while the HP 8980A Vector Analyzer displays quadrature, gain, and dc errors. The demodulator can then be adjusted while watching the result on the vector display.

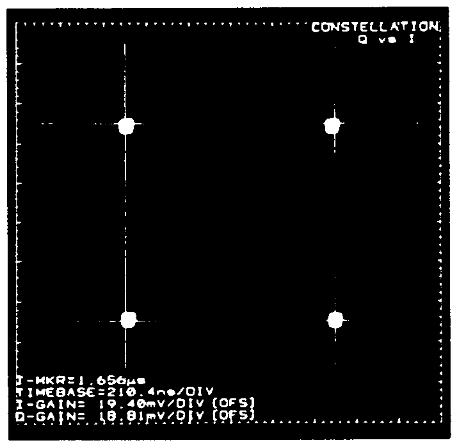


Figure 19. A QPSK signal on a vector display. The clusters form a square indicating the demodulator is in quadrature. The corners of the square determine the different signal states when the pulse is on. The lines represent the transitions between states.

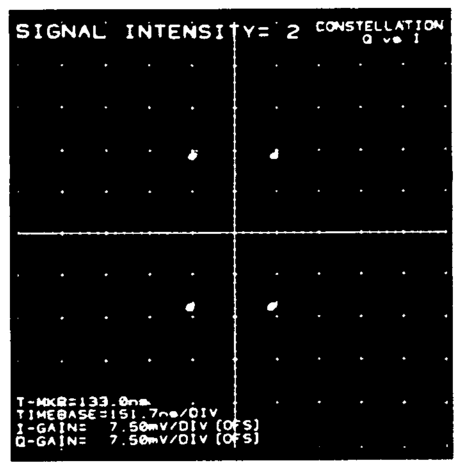


Figure 20. A QPSK signal will appear as a rectangle for gain mismatches in the I and Q channels.

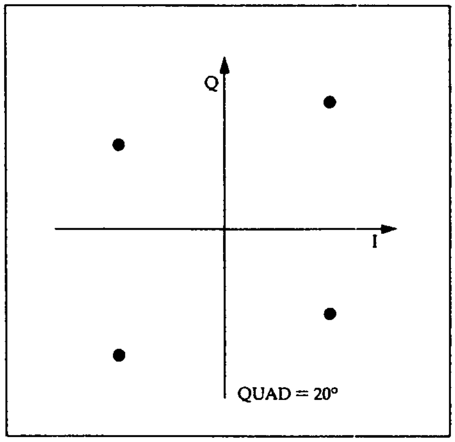


Figure 21. With both phase errors or both phase and gain errors in the demodulator, the QPSK signal appears as a parallelogram.

The sides of the square need not be parallel to the Q and I axes, since the angular position of the square is defined by an arbitrary phase shift between the radar's demodulator reference and the QPSK signal. The phase offset control of the HP 8980A can make the alignment easier by rotating the square to line up with the I and Q axes.

The HP 8980A Vector Analyzer will directly calculate quadrature error from a QPSK signal if there aren't significant gain mismatches. The vector analyzer displays the quadrature error in degrees at the bottom of the screen.

If a QPSK signal isn't available, another method can be used for demodulator alignment. Input a CW signal, which differs from the demodulator reference frequency by a few hertz, into the demodulator IF port. A perfect circle should appear on the display, since the frequency shift from the reference causes a constant phase change while amplitude remains constant. Here, amplitude and phase errors will cause an ellipse. The demodulator controls can now be adjusted until a circle appears on the display. The HP 8980A magnitude marker will be helpful when doing this. The marker draws a circle on the screen which can be used as a reference, or the vector alignment function can be used as before.

It will not always be possible to eliminate all the dc offset, gain, and phase errors through alignment. When some of these errors remain, the receiver digital processor should calibrate them out in software. To do this the errors must be accurately quantified. The HP 8980A Programming Note outlines an algorithm to run on a computer which estimates best-fit values for the errors.

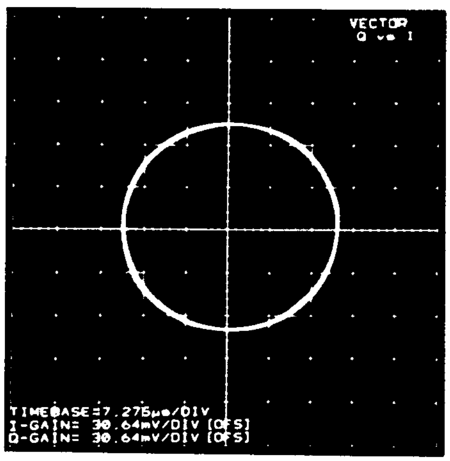


Figure 22. Vector diagram when a CW input to the demodulator has a frequency offset from the reference input. A constant frequency shift causes a constant phase change, which then plots a circle on the display. The display also represents a Doppler shifted return.

The error values can be measured without having to use a computer. A computer has been used in the past because of the difficulty in separating the quadrature errors from gain errors.

Suppose the vector analyzer displays an ellipse. A quadrature correction value should be added to the display with the HP 8980A Quadrature function. When the ellipse major and minor axes line up with the I and Q axes, then the quadrature error has been totally offset. Thus, the value of the inserted quadrature correction is the error in the demodulator. Now only a gain error remains. This can be measured with the I and Q amplitude markers.

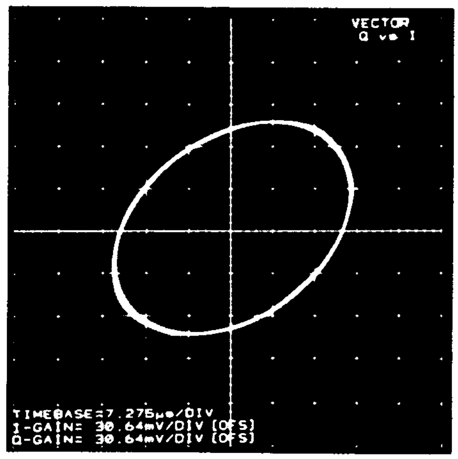


Figure 23. The vector diagram of a frequency offset will change from a circle to an ellipse when there are gain and phase quadrature errors in the demodulator.

With the errors quantified, I and Q signals with errors can be modeled as follows:

$I_m(t) = A(1+e)\cos(\theta) + a$
$Q_m(t) = A\sin(\theta+\phi) + b$

where:

e = Gain imbalance in %/100
a,b = dc offsets
ϕ = Quadrature phase error.

The receiver's digital signal processor can eliminate these errors by performing the following matrix operation:

$$\begin{bmatrix} I_c \\ Q_c \end{bmatrix} = \begin{bmatrix} \frac{1}{1+e} & 0 \\ \frac{I_m-a}{Q_m-b} \cdot \frac{\tan\phi}{1+e} & \frac{1}{\cos\phi} \end{bmatrix} \begin{bmatrix} I_m-a \\ Q_m-b \end{bmatrix}$$

I_c and Q_c are the corrected I and Q values.

If the processor of the receiver under test performs this operation, it might be desirable to view the I and Q channels without the phase, gain, and dc errors since they won't show up in the final receiver output. The display, basically, can take into account calibration procedures in the receiver's digital processor. Overall, the vector test system provides a relatively easy way to test and align a demodulator.

Signal Degradation

After the demodulator has been aligned, the test system can show how a signal degrades when traveling through the whole receiver path. One method of approaching testing of complex modulation uses an idealized signal as the front end input and then looks to see how the receiver degrades the signal. The HP 8780A in the measurement system of Figure 16 can be used to input ideal complex modulation signals into the receiver at RF or IF. The HP 8980A will then display the signal after it travels through the receiver. Degradations of the signal will become visible.

Measuring phase degradation in the receiver is as important as measuring phase degradation in a transmitter. Phase distortions, as mentioned in the transmitter section, can cause Doppler processing errors, reduce the effectiveness of pulse compression, cause errors when reading phase tagged signals, and degrade the angular resolution of synthetic aperture radars (SARs) and monopulse radars.

The causes of degradation can be isolated by looking at the signal at different points in the receiver. If it is necessary to look at the signal before it is split into I and Q channels an external demodulator can be used to provide I and Q. The types of degradation that should be looked for depend on the system under test and what types of problems the system is having. Some examples are discussed on the following page.

AM-PM and AM-AM

AM-PM and gain compression can both be measured in one convenient test with a vector modulation test system. The setup in Figure 16 uses a QPSK test signal. The output power level of the vector signal generator is varied by injecting a triangle wave into the scalar input. Figure 24 shows the vector analyzer display of this signal for a low power level. Increasing the power level causes compression in different receiver components. The gain compression and the phase distortions caused by the gain compression can be seen and measured on the vector display. Figure 25 shows how these would be measured with the markers.

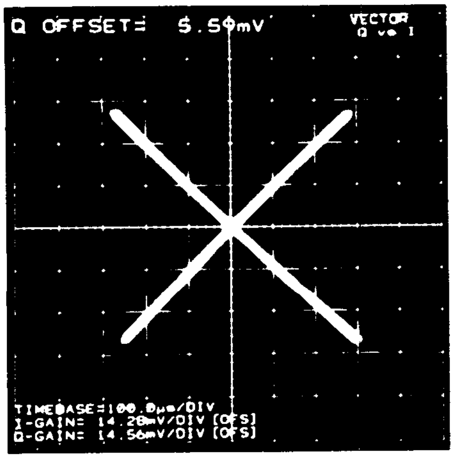


Figure 24. The vector diagram of a QPSK signal with the amplitude varying and no amplitude or phase distortions.

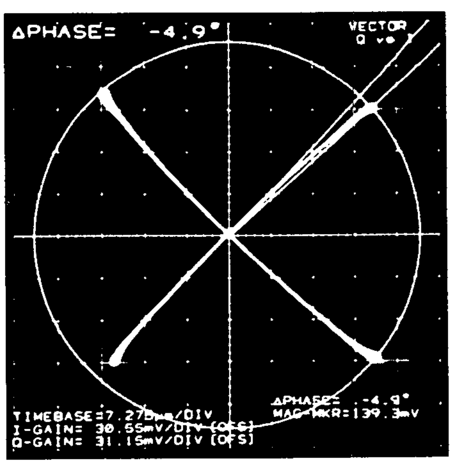


Figure 25. As the input power to the receiver is increased, gain compression and phase shifts occur. These errors can be easily measured with the magnitude and phase markers of the HP 8980A Vector Analyzer.

The QPSK signal is used since the I and Q channels might have different AM-AM and AM-PM distortions for positive and negative voltages. A QPSK signal displays the four combinations of positive and negative voltages between the I and Q channels, so any differences can be readily seen.

Figure 26 shows the same test, but instead of sweeping the output power of the vector signal generator the power is switched between two different levels. One of the power levels can be set for 1 dB compression to make a fast measurement of the phase and gain errors at this point.

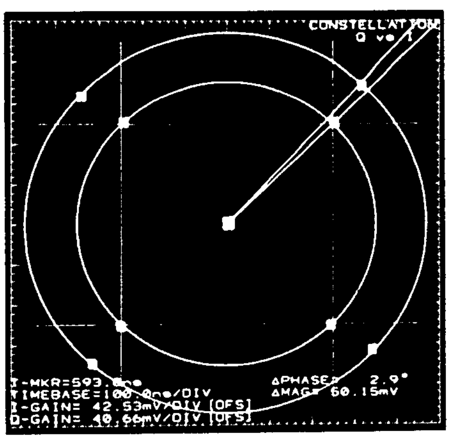


Figure 26. The HP 8780A Vector Signal Generator switches the output between two amplitude levels. The outer level is set to the 1 dB compression point to measure the AM-PM conversion.

Standard Tests

The vector modulation test system was designed to measure complex phase and magnitude. The vector test system, however, can also perform many standard tests.

For instance, to measure tangential signal sensitivity, the generator pulse amplitude can be reduced to the appropriate level while viewing the signal versus time on the display. Dynamic range can be tested in the same fashion. The 50 picosecond time resolution of the vector measurement system allows time delay and jitter to be tested quite accurately. The receiver response delay can be measured for a range of different input frequencies and power levels. Sample timing can be critical. If the sampling instant occurs before settling, errors will result. If sampling occurs too late, the pulse could be missed entirely.

Testing the performance of the overall receiver including the processor is done by supplying an input signal with the HP 8780A Vector Signal Generator to exercise as many functions of the radar as possible. In this case, the receiver's readout displays the measurement result. Shifting the generator frequency will measure the Doppler velocity accuracy and resolution. Delaying the burst mode trigger signal will measure the range accuracy, while using several narrow pulses will reveal the range resolution.

Another important test, gain and phase tracking of different paths, is discussed in the Specific Receiver section under Monopulse.

Receivers are usually tested under both idealized conditions and real environment conditions. The previous section outlined tests under idealized conditions. This section will outline a concept for testing a receiver with real environment signals.

Several methods exist for making real environment tests. These include testing out in the field, testing in an anechoic chamber with complex arrays of equipment which simulate an environment, or simulating an environment on a computer. The last method doesn't use the receiver in the test — it only predicts the receiver performance. Field testing and using an anechoic chamber are expensive alternatives to computer simulations. They also are elaborate, and time-consuming to set up.

The HP 8780A Vector Signal Generator could be used in many instances as part of an environment simulation. A technique is needed though for generating the many different phase and magnitude modulations present in radar signals. The HP 8780A has the capability to be arbitrarily modulated with I and Q inputs. The phase and amplitude of the desired output signal must be described at every time instant. The I and Q input signals must be calculated using the formulas in Block 1 to give the desired phase and magnitude of the output signal. These calculated I and Q components can be fed into the HP 8780A Vector Modulator.

A system which utilizes a vector modulator might be configured as in Figure 27. The memories contain the calculated values of I and Q which will give the desired signal. The D/A's convert the digital data from the memories into the analog I and Q inputs to the vector modulator. Two HP 8770A Arbitrary Waveform Synthesizers could provide the memory and D/A's.

Several major factors would limit a system such as the one in Figure 27; D/A resolution (number of bits), memory speed, D/A speed, and memory size. The rate by which data can be transferred from the memory and converted into analog signals determines the ultimate modulation bandwidth of the RF signal. The modulation bandwidth would have to be close to the bandwidth of the signal to simulate real environment conditions. The size of the memory limits the diversity and complexity of the signals which can be simulated. Also the memory size limits the length of the signal and consequently the lowest Doppler shift that can be simulated.

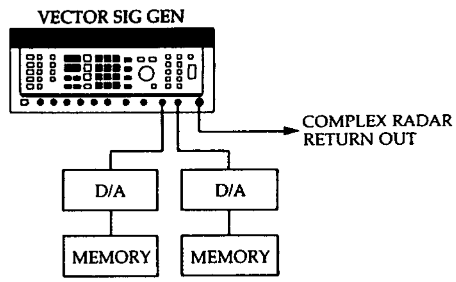


Figure 27. This system could potentially simulate different environmental radar returns. Possibilities include clutter returns, target returns, glint and scintillation effects.

Other factors which limit the system capabilities include quadrature accuracy of the modulator, stability and phase noise of the carrier source, and synchronization of the two D/A outputs. The 50 dB pulse on/off ratio of the HP 8780A might also be a limitation.

The potential exists for the simulation of many real world conditions. The conditions could include clutter returns from a variety of terrains, target scintillation, glint, and others.

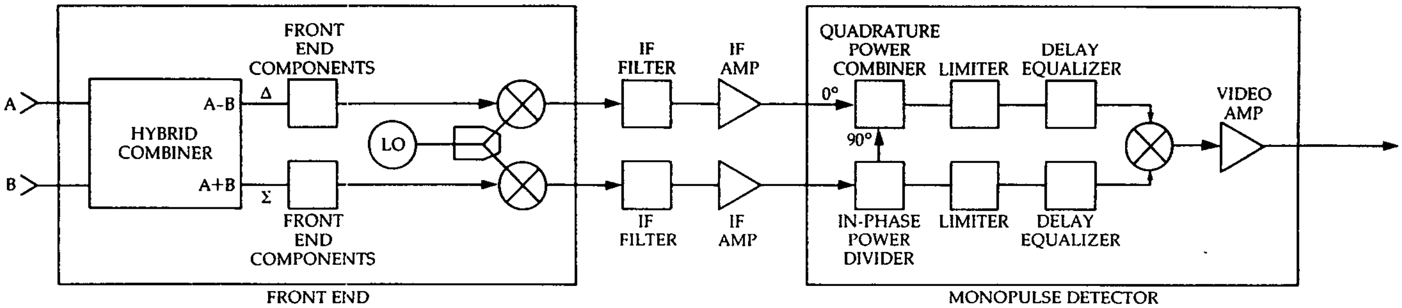


Figure 28. This monopulse receiver converts the amplitude measurement of the two channels into a phase measurement for processing.

Most receiver test measurements apply to all of the different types of receivers. Some receivers, however, require unique tests. This section will describe a few specific test measurements which apply to three types of receivers: monopulse, instantaneous frequency measurement, and compressive. The tests described may apply to other types of receivers than just the ones mentioned. Thus, the reader might want to skim this section even if it doesn't include a certain desired receiver type.

Monopulse

Monopulse receivers calculate the direction of a target off boresight by comparing either the amplitude or phase between the sum and difference channels from a multiple-feed antenna system. The receivers usually have several signal paths where the phase and magnitude between the paths must be matched. A vector measurement system is well suited to perform the special testing that monopulse processing requires.

Amplitude Monopulse

A simple block diagram of an amplitude monopulse receiver appears in Figure 28. This monopulse receiver makes an initial amplitude measurement but then converts it into a phase measurement[2]. Another type of monopulse makes a direct amplitude measurement by dividing the difference channel by the sum channel and deriving the direction of the target from the ratio. The monopulse receiver in Figure 28 will be used as an example because it requires more sophisticated testing. Phase accuracy, in addition to gain accuracy, must be measured.

The antenna horns of this radar are spaced very closely so there are no phase offsets between the sum (Σ) and difference (Δ) channels. The Σ and Δ channels should either be in-phase or 180° out-of-phase. Any phase differences introduced by the receiver between the channels will directly cause errors at the output. Gain errors between the channels will also cause errors at the output. The gain and phase matching of the channels must be tested and measured. These measurements are similar to the quadrature accuracy ones described in the previous section. Instead of testing at baseband, the testing is done at IF and the channels should be in phase, not 90° out of phase.

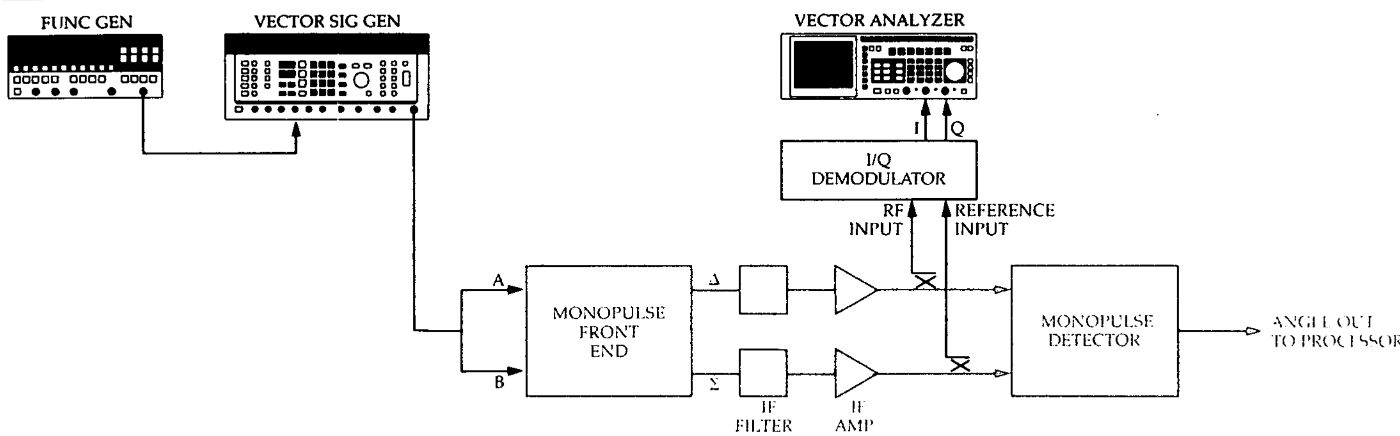


Figure 29. The vector measurement system here tests the phase matching of the sum (Σ) and difference (Δ) *channels.*

Figure 29 shows how a vector system could be configured to test the phase matching right before the signals enter the detector. The two channels are fed into a vector demodulator with one channel going into the RF input and the other channel going into the reference input. The demodulator finds the phase difference between the inputs. The HP 8980A Vector Analyzer in this case should just show a dot along the I axis which represents no phase difference.

To observe the channels 180° out of phase, the generator should be switched from the A input of the receiver to the B input. The 180° hybrid will split the signal and reverse one of the channels. The dot on the vector display will stay on the I axis but it will switch to the left of the Q axis, thus representing a 180° phase difference.

If there are any phase errors, the dot on the display will not lie on the I axis. Phase markers can be used to measure the value of the error angle. The vector modulation test system during this test doesn't actually find the phase of the receiver signals, it only compares the phase in the different channels. Phase transients during the pulse on/off transitions aren't displayed. These transients don't cause problems if each channel responds the same way or is matched.

Gain mismatches between the sum and difference channels cause errors. If the IF of the radar is within the 350 MHz bandwidth of the vector analyzer, the gain match can be measured directly. The two channels are fed into the analyzer and the amplitudes of the channels can be viewed and compared over time. If the radar IF is above 350 MHz, the demodulator can downconvert them and then each channel can be measured separately on the vector display. The radar IF signal could also be downcoverted to under 350 MHz and displayed directly over time without using a demodulator.

The vector modulation test system performs the test with good time and amplitude resolution, thus errors due to gain mismatches can be accurately quantified.

The detector portion of the amplitude monopulse receiver can be tested by inputing phase-matched signals into the Σ and Δ channels and varying the amplitudes. The output of the detector can then be compared to the ratio of the inputs to verify the correct response.

In the monopulse detector of Figure 28, the Σ and Δ channels are combined in quadrature. The sum, or D, channel's phase difference from the Σ channel determines the target direction.

The phase matching accuracy must be tested. As before, the two channels feed into a demodulator and the HP 8980A Vector Analyzer displays Q versus I. The phase difference between the D and Σ channels will cause a dot to appear off the I axis. An angle marker can then be used to determine the difference phase of the channels. The correct phase difference must be calculated by taking the inverse tangent of Σ/Δ. All the possible angle offsets will be measured by letting the difference channel, Δ, vary from 0 to Σ.

Gain can be measured separately on each channel as before. Although it's not as important to measure the gain tracking of the D and Σ channels, AM-PM conversions can cause problems. Thus the channels usually go through limiters to equalize their amplitudes.

Phase Monopulse

A phase monopulse receiver operates on a slightly different principle than an amplitude monopulse. The antenna horns are placed farther apart so there will be a phase difference between the signals picked up by each horn when the target is off boresight. Figure 30 shows how the phase between the received channels relates directly to the angle of the target off boresight when a constant frequency pulse is received.

The vector modulation system in Figure 31, which is connected to a phase monopulse receiver, shows how different angular returns can be simulated with the HP 8780A. The test is done with CW signals. The angular difference between the RF output of the HP 8780A and the coherent reference can be arbitrarily controlled with the 2-state function. Adjusting the phase simulates different angles of arrival.

Each of the two channels in this phase monopulse radar has a vector demodulator. Thus, there are two sets of I and Q channels which are digitized and sent to a processor. The processor calculates the phase difference from the two I/Q pairs.

In this system, the two channels in the RF and IF portions of the receiver need to be phase matched. Gain matching might also be valuable to ensure the components are operating with similar power levels.

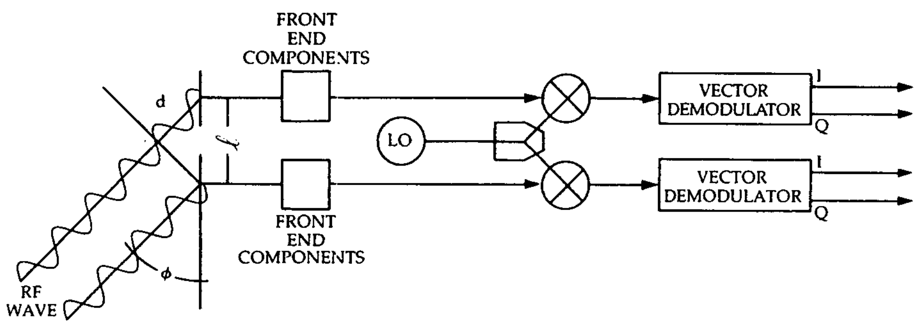


Figure 30. Phase monopulse. When a target return is off boresight, the extra distance traveled by one channel causes a phase difference.

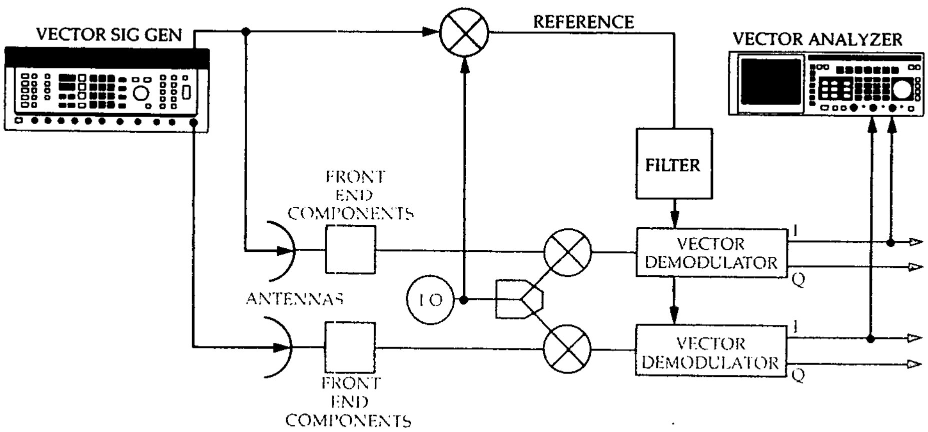


Figure 31. A phase monopulse receiver is being tested for phase matching between the channels. The delay between the returns is varied and then the phase offset can be observed at several points within the receiver.

The measurements can be made using the technique described for an amplitude monopulse, but the I and Q signals in the receiver can be used directly. The HP 8980A Vector Analyzer can display the angular and gain differences between the channels by switching its inputs between the two I/Q pairs. This would give quantitative values for the mismatches.

When making these measurements it's important to first calibrate the demodulators as described in the "Basic Receiver Tests" section. Otherwise, you will be measuring the combined phase and gain mismatches of the demodulators and the RF and IF channel paths.

The HP 8980A Vector Analyzer can also be used to visually adjust and calibrate the channels. For this test, shown in Figure 31, the HP 8780A Vector Signal Generator injects the same test signal into each antenna. The two I signals at the receiver output are applied to the vector analyzer. The test signal frequency is set several hertz higher than the demodulators' reference frequency. Thus two identical sine waves should come out of the I channels.

The vector analyzer will display a line at 45 degrees if the channels are phase and gain matched. An ellipse will be displayed for a phase mismatch and the line won't be at 45 degrees for a gain mismatch. The user can then adjust the channels while viewing the display to optimize the phase and gain matching. The Q signals should also be compared to see if they are matched.

The monopulse tests described involve measuring the phase and gain tracking of two different signals. The vector measurement system is well suited to make these tests. The techniques can be applied to a variety of receiver types but they do apply directly to monopulse receivers.

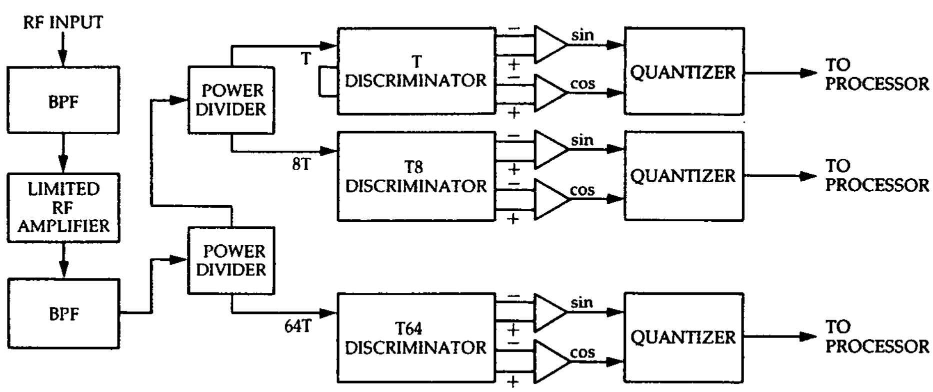


Figure 32. Digital instantaneous frequency measurement (DIFM) receiver.

Instantaneous Frequency Measurement (IFM)

IFM receivers detect a signal's frequency by measuring its phase change through a delay line. The receiver splits the incoming signal and passes one channel through a delay line. The frequency of the signal is then derived by comparing the phase difference between the channels.

A block diagram of a general IFM receiver, with three frequency discriminator modules, appears in Figure 32. Each discriminator module has a different length delay line. Using several discriminators instead of just one allows the receiver to achieve wider frequency coverage and higher resolution. Each discriminator outputs a sine and cosine function of the phase change introduced by the delay line. Both the sine and cosine outputs are necessary in order to separate the signal amplitude and phase. Reference [3] contains a detailed discussion on IFM's.

The sine and cosine discriminator outputs provide a logical place to test the receiver with a vector measurement system. With the sine output connected to the Q input of the HP 8980A Vector Analyzer and the cosine output connected to the I input, the angle can be read directly from the vector display in Q versus I mode. The phase accuracy can then be measured to make sure it falls within the range set by the resolution of the analog to digital converter. The HP 8780A can be used as the frequency input. The frequency can then be varied in order to test the receiver over its specified frequency range. The discriminators with the longer delay lines will have their angle output change faster with a changing input frequency. The rate of change of the output angle versus the input frequency can be seen by varying the input frequency and measuring the rotation of the dot on the vector analyzer.

The vector diagram will show directly any phase errors at the output of the discriminators. Several major causes of errors are noise, intermodulation products from the limiting amplifier, quadrature accuracy in the discriminators, matching of power splitters, and simultaneous signal returns. The discriminators introduce errors when they receive more than one signal. The extra signals usually come from the antenna picking up multiple transmissions. The discriminator will also see extra signals caused by intermodulation products of the limiting RF amplifier. More than one generator can be used for simulating multiple signal returns while raising the power level of the generator can cause the RF limiting amplifier to output intermodulation products.

The discriminator usually employs several quadrature hybrids and power splitters. The quadrature accuracy of the hybrids must be tested along with the power matching of the splitters. Both power splitting mismatches and quadrature errors will cause inaccuracies in the phase measurements. The procedures for these tests are the same as for the phase and gain channel matching described above in the monopulse receiver section.

In the IFM receiver, similar to an amplitude monopulse receiver, the absolute phase of the transmitted signal isn't significant but the phase changes occurring within the receiver are. Thus a coherent test system such as a vector test system is required to perform a thorough analysis under pulsed conditions of the receiver operation.

Compressive

Compressive receivers will break a signal down into its spectral components for EW purposes. The typical method used will downconvert an incoming signal with a swept local oscillator. Then the signal will travel through a frequency dependent delay line. The time when the signal exits the delay line indicates the frequency. The amplitude of the signal exiting the delay line indicates the energy contained in that frequency component of the signal. Basically, the compressive receiver performs a multiply-convolve function which derives frequency from the time a signal comes out of the receiver[4].

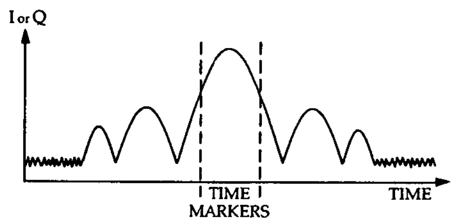


Figure 33. The output of a compressive receiver for a simple pulsed input.

The time measurement capability of the receiver must be tested for its accuracy; since errors there will result in the wrong frequency being recorded. A vector measurement system can make a contribution to this test because of the 50 picosecond time resolution available. The HP 8780A Vector Signal Generator is used to input constant frequency pulses into the receiver. The HP 8980A Vector Analyzer can then measure the time delay of the output from the delay line by triggering off the generator's pulse mode input. The delay can then be read directly from the display.

These results can be compared to the final output of the receiver, which indicates the frequency of the signal. The processor then is tested to make sure the frequency measured corresponds to the time delay the vector analyzer measures. The resolution of the system can also be determined in this manner. The test is similar to measuring the delay through a generic receiver mentioned in the "Basic Receiver Tests" section.

Anechoic Chamber and Radar Range Measurements

A vector modulation system can make many contributions to anechoic chamber and radar range systems. These systems make measurements under tightly controlled conditions with precisely controlled test signals. The HP 8780A Vector Signal Generator can provide the test signals with the modulation needed.

Many times, anechoic chambers or radar ranges are used to perform closed, hardware-in-the-loop tests. These tests simulate the scenarios a radar or EW system will operate in.

Figure 34 shows a closed, hardware-in-the-loop test for characterizing the flight performance of a missile guidance system. The test simulates the different received radar pulses the missile would see in an actual combat situation. The guidance system decides which way to turn the missile based on the radar return. The next radar return then is determined by which way the missile turned. Thus, the test system forms a closed feedback loop.

The test system transmits a radar pulse to the missile receiver. The missile then decides which way to turn. The decision is sent to a computer which calculates what the modulation of the next radar pulse return should be. The Doppler shift, magnitude, phase offset, and time delay are all calculated by the computer based on the relationship of the missile and target. The computer sends the modulation in the form of digital I and Q values to two D/A's, where analog I and Q values are generated as inputs to a vector modulator.

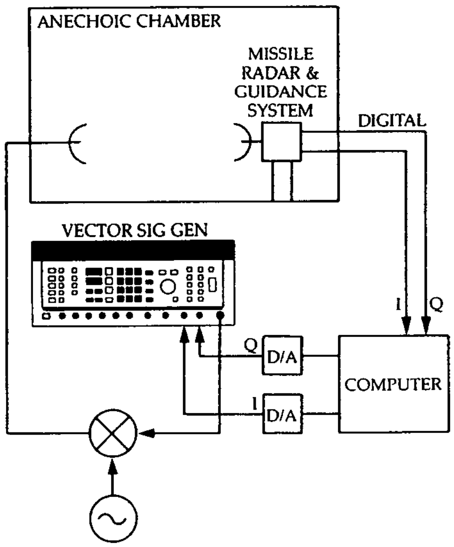


Figure 34. A closed hardware-in-the-loop test system. The HP 8780A Vector Signal Generator provides the I/Q modulator which allows the amplitude, phase, and frequency of the signal to be varied. The computer continuously calculates the Doppler shift, time delay, and amplitude of each pulse in terms of I and Q modulating signals.

The HP 8780A Vector Signal Generator includes both a vector modulator and synthesized frequency source and can thus provide an off-the-shelf instrument for closed loop testing. The vector signal generator can also provide a source for open loop testing in anechoic chambers and radar ranges. It could be used to simulate a variety of threat signals for EW receiver testing and to illuminate a target for target classification measurements.

The HP 8980A Vector Analyzer can also be included in an anechoic chamber or radar range when repetitive signals are used. The vector analyzer provides a visual display of a signal and can also collect I and Q data.

The vector analyzer can provide a visual display of a signal's polarization. For instance in Figure 35, the two antennas receive vertically and horizontally polarized waves. The received signals are coherently downconverted to a few megahertz. These two signals are then used as the I and Q inputs for a vector display of the polarization. Linear polarization will appear as a straight line, circular polarization will appear as a circle, and elliptical polarization will appear as an ellipse.

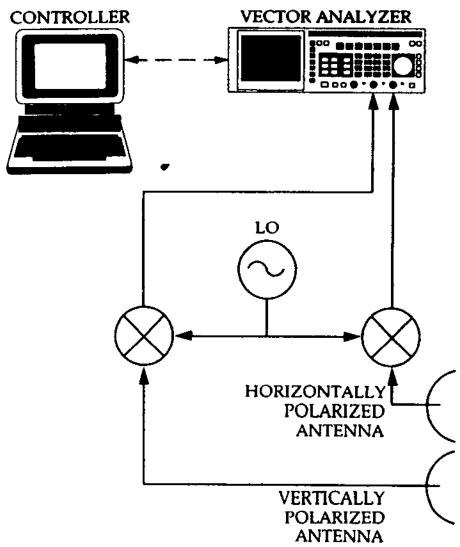


Figure 35. Displaying a signal's polarization with the HP 8980A Vector Analyzer.

Summary

Modern radar and electronic warfare systems now utilize the phase information of waveforms. Controlling a transmitted signal's phase, and processing the phase of a received signal have added a new layer of capability and complexity to systems.

The added complexity has put a greater burden on testing instruments. Simple pulse techniques are no longer sufficient to characterize the modern radar and electronic warfare systems. New testing techniques are needed.

Some techniques currently being used were reviewed but they have major drawbacks.

A new approach, using a vector modulation system has been introduced. It overcomes the drawbacks of the other test techniques and provides the capabilities needed to test modern coherent radar and EW equipment, by performing coherent tests under pulsed, dynamic conditions. General test procedures were discussed and tests were listed for some specific receivers and applications.

Hopefully the reader now has a clear idea of the concepts behind a vector modulation system and realizes the power it affords. A vector modulation system overcomes many limitations of previous test systems and allows a user to test his system for maximum performance.

References

[1] V. Gregers Hansen, *Microwave Journal*, March 1984, "Topics in Radar Signal Processing."

[2] Theodore W. Stone, *Microwave Systems News*, August 1980, "Monopulse Receiver Design Depends on IF Processor Success."

[3] P.W. East, *IEEE Proceedings*, Vol. 129, No. 3, June 1982, "Design Techniques and Performance of Digital IFM."

[4] G.L. Moulem, *IEEE Proceedings*, Vol. 129, No. 3, June 1982, "SAW Compressive Receivers for Radar Intercept."

For more information
Call your local HP sales office listed in
the telephone directory white pages.
Ask for the Technical Measurements Department
Or write to Hewlett-Packard:

United States:
Hewlett-Packard
P.O. Box 10301
Palo Alto, CA 94303-0890

Europe:
Hewlett-Packard
P.O. Box 529
Startbaan 16 1180 AM
Amstelveen, The Netherlands

Canada:
Hewlett-Packard Ltd.
6877 Goreway Drive
Mississauga, L4V 1M8 Ontario

Japan:
Yokogawa-Hewlett-Packard Ltd.
3-29-21, Takaido-Higashi
Suginami-ku, Tokyo 168

Elsewhere in the World:
Write to Hewlett-Packard Intercontinental
3495 Deer Creek Road
Palo Alto, CA 94303-0890, U.S.A.

Data Subject to Change
November 1, 1986

Printed in U.S.A.
5954-6366