Errata

Document Title: Vector Modulation Measurements (AN 343-1)

Part Number: 5954-6365

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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.

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›lication Note 343-1

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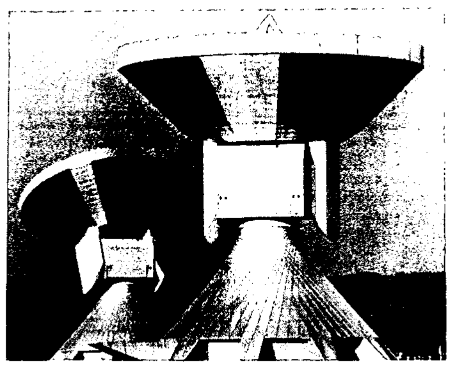

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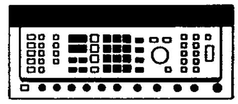
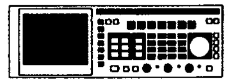


HP 8980A Vector Analyzer



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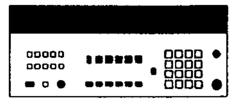
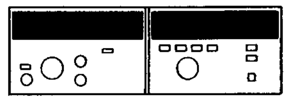


HP 8671B Synthesized Signal Generator



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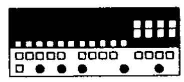

HP 3782A Error Detector
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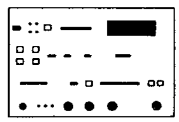
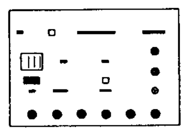


HP 3781B Pattern Generator
(BELL Compatible)



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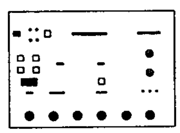

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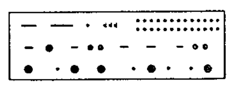
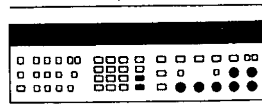
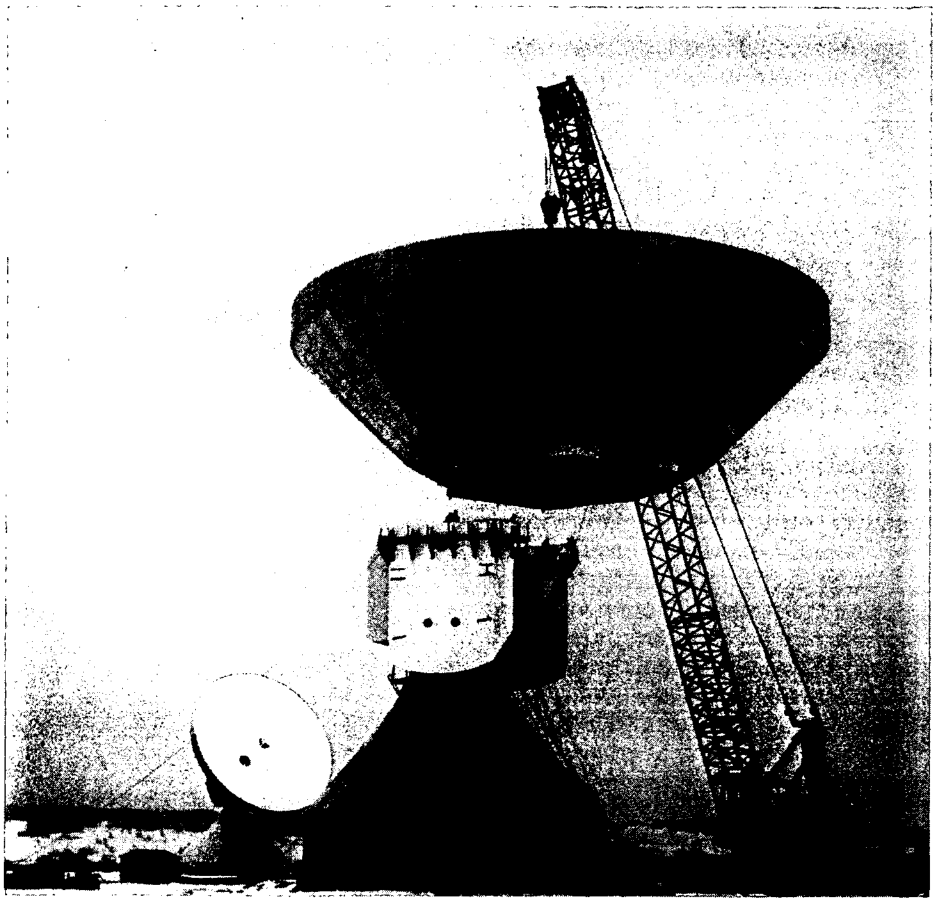


HP 3708A Noise and Interference Test Set



HP 9000 Series Controller

Introduction



Courtesy of Siemens

Digital microwave radios are increasingly chosen for both satellite and terrestrial communication. With more frequent use of digital modulation types, there is a growing need to characterize digital radios, their components and the signal environments they work in.

This Application Note outlines some of the measurements and test procedures important to measuring the analog signals in digital microwave radio (DMR) applications. Component tests and more elaborate tests like multipath fade simulation are not rigorously addressed, but the fundamentals of such tests are covered. Component tests are discussed in detail in another Application Note (AN 343-2) dedicated to vector measurements on system components (Dynamic Component Test Using Vector Modulation Analysis).

This Application Note assumes a certain familiarity with the field of DMR. For those interested in a more tutorial approach, a digital communications tutorial program and manual (I·Q Tutor, HP 11736A/B) are available from your Hewlett-Packard Sales Representative.

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

Ask for:
HP 8780A-1 Product Note
(lit. #5954-6368)
HP 8980A-1 Product Note
(lit. #5954-6369)
HP 8780A Data Sheet (lit. # 5954-6363)
HP 8980A Data Sheet (lit. # 5954-6364)

Digital Microwave Radio

The world of communications is being revolutionized as the information demands of customers reach new heights. With these higher standards come new levels of technology to satisfy the demands. Increasingly, digital techniques are called on to help cope with modern communications requirements. Digital techniques improve today's communications by providing increased information carrying capacity, higher quality of communication and reduced system complexity.

To the engineers and technicians who work with microwave communications this means designing radios with efficient digital modulation schemes, inventing ways to cope with new kinds of distortion, and discovering methods for measuring and testing their systems. This Application Note deals with the last of these challenges.

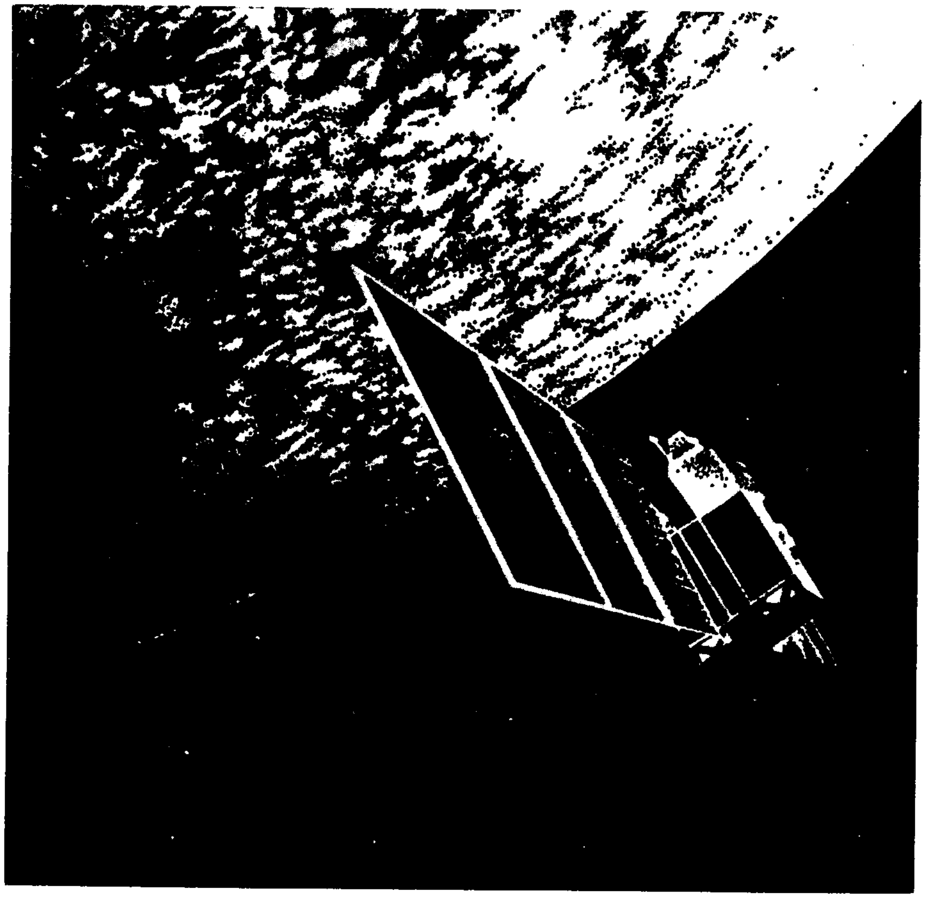
Accurate measurements are of paramount importance in digital radio. Modern DMRs offer many improvements over traditional communications systems, but to work at all, they must be aligned and tested to very strict standards. Indeed, the advancement of high speed digital communications is often limited by the measurement capabilities available.

Digital Microwave Radios are distinguished from traditional microwave links in that they use phase modulation, such as QPSK (quadrature-phase-shift-keying), or quadrature-amplitude-modulation (QAM). These modulation schemes are very different from their analog predecessors in the way in which they accomplish communication and their tolerance to various real-world impairments.

Regardless of the specific type of QAM or PSK modulation chosen for a DMR, most radios use I/Q or "vector" modulation and demodulation to put the information on and take it off of the carrier. Since the I and Q signals are derived from the phase and magnitude of the radio signal, they are also valuable analysis tools. These signals combined with the appropriate measurement instruments can be valuable in analyzing a transmission path, characterizing an amplifier's performance, or troubleshooting a radio.

Applications

Most DMR applications can be divided into two major categories: satellite communications, and terrestrial communications. The objectives of both are similar: economical long haul communications. Although there are differences in the specific requirements of these two applications, many of the same measurement principles apply to both. Because of this, except for the section immediately following, most of the Application Note will be organized by measurement types rather than by application.



Satellite DMR

When DMR signals are sent through a satellite, one of the most important concerns is the power budget. This is because the size of the satellite and therefore the output power of its transmitter are limited, and the signal undergoes a large path loss. These two things mean that the received signal at the earth is usually small and there is often a low SNR (signal-to-noise-ratio) at the output of the first stage of amplification. To combat this, satellite communication systems use simple modulation formats like QPSK which are less susceptible to noise. Because the viability of a satellite link is so dependent on its tolerance to noise, it's important to be able to measure the radio's performance under noisy test conditions.

Another major concern when using satellites for DMR communications is that the amplifier on the satellite must operate at a high level to provide enough power to complete the link back to the earth. Operating the amplifier at a high level causes its performance to be somewhat nonlinear. The types of distortion introduced by a nonlinear amplifier include AM to PM (amplitude modulation to phase modulation conversion), AM to AM (amplitude modulation to amplitude modulation conversion), and non-flat frequency response characteristics.

One of the degradations experienced by satellite DMR communications is Doppler frequency shift. I/Q modulation techniques combine phase and amplitude modulation to transmit information, so they are particularly susceptible to any phase shifts introduced in transmission. As the satellite moves with respect to the earth station, a Doppler frequency shift can be introduced which can complicate carrier recovery for the earth station receiver. Simulating this effect is important in some high speed communications applications.

Some other measurements important to satellite systems include: adjusting modulator and demodulator quadrature and amplitude imbalances, BER (bit error rate) testing, measuring filter response, aligning predistorters to optimize a link, and simulating flat and dispersive fades.

In this context, it's not difficult to understand why accurate measurements are a must in DMR design for satellite communications systems. Many of the most important measurements have been complicated by the lack of equipment dedicated to their solution. This Application Note addresses some of these problems with the use of new vector modulation products designed to expand DMR measurement capabilities.

Terrestrial DMR

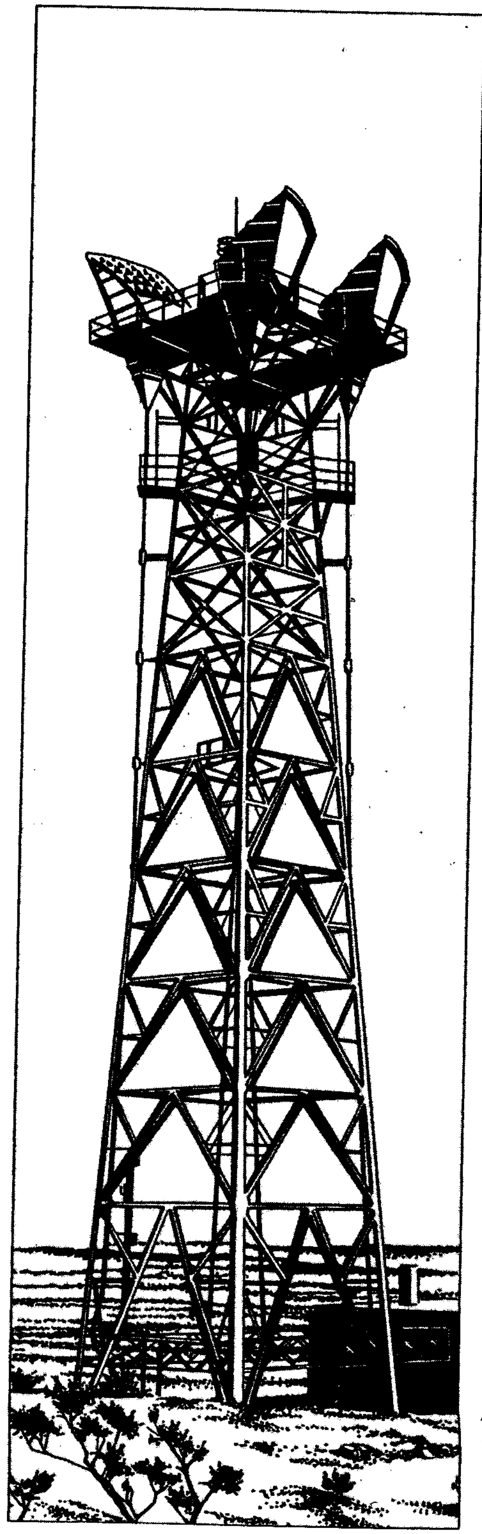
Terrestrial microwave communication is usually transmitted between two elevated antenna towers separated by 20 to 50 km. These systems are susceptible to very different degradations from those of satellite communications.

Since the distance that must be covered by terrestrial links is much shorter, having sufficient power is less of a concern than it is to satellite communications. This allows terrestrial radios to use much more complex modulation schemes to achieve channel efficiencies unheard of in satellite communications. With the advent of very high complexity modulations like 256QAM, the need for accurate measurements is greater than ever.

Some of the more common measurements important to terrestrial communications are the same as those for satellite communications. BER testing is still the standard measure of performance; although, different values of BER may be tolerated in each type of system. Quadrature and amplitude balance must be measured and aligned even more accurately than in satellite communications because the more complex modulations are far less tolerant to small errors. Clock jitter is cumulative in terrestrial links which have many stages of repeaters, and receivers must be carefully designed to tolerate it. Many of the baseband measurements are common to both satellite and terrestrial applications since they both deal with digital signals, data filters and clock recovery.

The most dramatic distortions in terrestrial communications using DMRs result from multipath fades. A multipath fade results when there are propagation paths of different length from the transmitter to the receiver. This occurs when there are reflections from surrounding objects or other diffractive paths through the air. The resulting signal which arrives at the receiver has considerable distortion and must somehow be corrected. There are a variety of methods for coping with the distortions of multipath fades; however, it's beyond the scope of this Application Note to address the measurement concerns of multipath fade in detail.

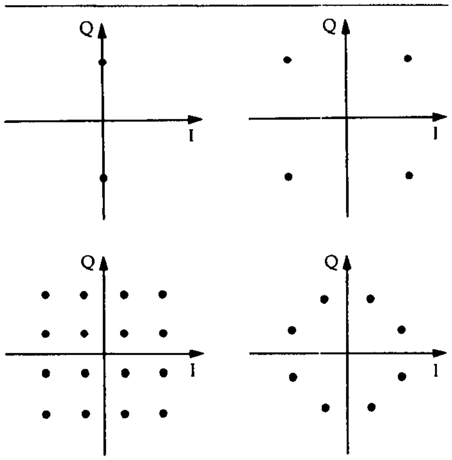
These are given only as examples of the types of measurement problems which have to be faced in terrestrial DMR. This Application Note describes the principles of accurate I/Q measurements in the fields of DMR. In the sections that follow, several basic measurements are outlined along with a description of their design rationale.



Fundamentals of DMR Measurements

Measurements of digital radios involve not only the techniques of traditional microwave measurements but also some concerns unique to DMR. This section describes the most fundamental aspects of DMR measurements.

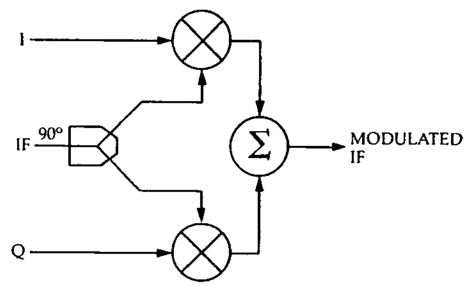
One of the most important contributions to traditional communications measurements was the spectrum analyzer. The spectrum analyzer let communications engineers and technicians see signals in the way they thought of them. No longer was the frequency spectrum of an FM signal just a theoretical abstraction: it was something that they could see and measure about real signals.



Now the field of digital radio is in a similiar transition. Many of the measurements traditionally made by spectrum and network analyzers are now being challenged by new techniques. Vector modulations are most clearly understood when represented on a phase plane where the I and Q channel information as well as the carrier phase and magnitude can be seen. There are also traditional network analysis measurements, like characterizing a data filter's response, which are better done in the time domain since the shape of the frequency spectrum may not be as important as the ISI (inter-symbol interference) introduced by the filter. These new measurement demands are now met with the use of vector measurement instruments.

I/Q Modulation

DMR measurements require accurate sources as well as analysis instruments. There are many situations that require the accurate generation of precisely modulated test signals of calibrated levels and stability. The most natural tool for doing this is the one already used in most radios: the I/Q modulator. The I/Q modulator generates signals in terms of the I and Q components inherent in most DMRs, so it seems to be an ideal choice for the generation of signals to characterize a digital radio. The modulators built for radios are built to perform within a certain range of tolerances to ensure the correct operation of the radio, and these tolerances may or may not be tight enough for specific measurement requirements. In situations like simulating degradations, adding noise, or varying signal levels, a more versatile modulator is required.



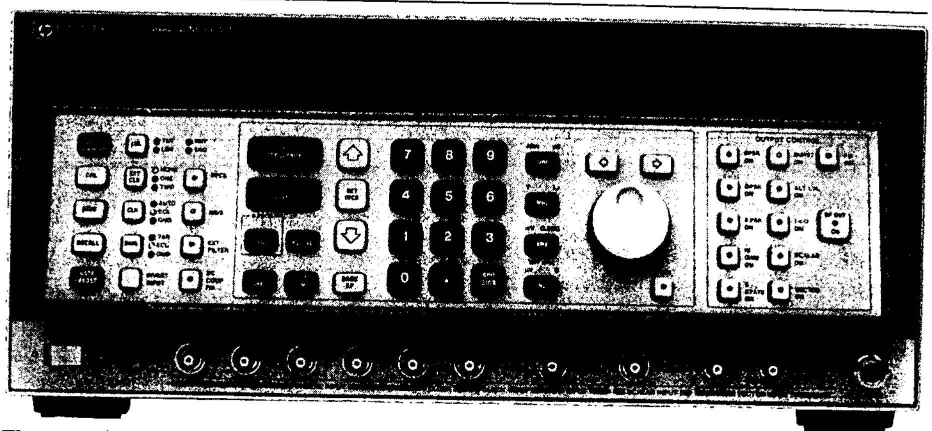
Simplified vector modulator.

The most important requirement of an instrumentation quality modulator is extremely accurate quadrature and amplitude balance. After this, it is important that the modulator have a high degree of linearity to provide precise I/Q modulations for receiver testing and demodulator calibration. The modulator's output should be very clean and free of spurious signals in the modulation bandwidth so sensitive measurements of receiver noise won't be masked by the modulator's noise.

The HP 8780A Vector Signal Generator is such a source. Capable of generating a variety of QAM and PSK modulation types with only digital signals for input, it serves as a benchmark transmitter as well as a reference I/Q modulator with analog I and Q signals input. Since it is a full function signal generator, traditional FM and AM modulated signals can be generated, as well as simultaneously with digital vector modulations.

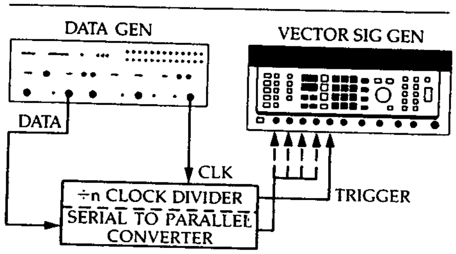
In many cases, accurate I/Q modulation measurements require a vector signal generator. The vector signal generator's primary contribution to DMR measurements is the inclusion of a very precise I/Q modulator which can provide accurate test signals for the characterization of DMR system components. In addition to analog I/Q modulation capabilities, the vector signal generator can produce many standard vector modulations with only digital signals for input. This eliminates many of the concerns associated with generating accurate I and Q baseband signals to drive an I/Q modulator.

To take advantage of the built-in modulation capabilities, several external digital signals are required. The vector signal generator inputs are parallel and will require more driving signals for more complex modulations: exactly four data lines for 16QAM, three for 8PSK, two for QPSK and only one for BPSK. The relationship between the data at the inputs and the modulated states is partially controllable by selectable inversion of the individual parallel data line inputs. In addition to these data lines, the digital inputs may also be clocked to eliminate the possibility of data skew. For more complex signal generation, other digital inputs are available for switching the output on and off (burst) and changing the output level (Alt-level).



The HP 8780A Vector Signal Generator.

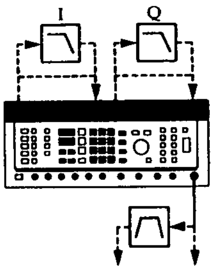
To generate the parallel data required by the vector signal generator for more complex modulations, the capabilities of available data generators will have to be augmented by the addition of a serial-to-parallel converter. If the data is to be clocked, the data generator clock will also have to be divided by the number of parallel lines generated. This will be indicated in the block diagrams as shown, but solutions to these problems will have to be handled on an individual basis.



The HP 8780A data inputs are parallel and may require serial-to-parallel conversion for use with data generators.

One requirement of vector modulated test signals that may not be met by the vector signal generator is filtering. When testing devices which exhibit performance variations as a function of frequency, such as demodulator calibration, it is particularly important to keep the test signal bandwidth appropriately limited.

To be general purpose, the generator output is relatively unfiltered. There are built-in filters to keep the modulation bandwidth from exceeding the output frequency, but in most cases this is much wider than the main lobes of the generated signals. This means that external filters or special settings of the generator's internal filters will be required to generate signals of limited bandwidth. To accommodate the widest range of filter requirements, the vector signal generator allows either direct filtering of the modulated output or filtering of the I and Q baseband signals prior to the I/Q modulator.



Flexible filtering options provide proper band-limiting for the application.

Because digital communications and the vector signal generator use phase in such a meaningful way, much more attention to phase differences in measurement systems is called for. Line lengths can cause dramatic phase differences due to differences in propagation times, even at IF frequencies. When designing measurement systems for DMRs, it's best to keep the length of transmission line the same for coherent signals and to keep them short. The shortness reduces the amount of phase shift introduced by small changes in frequency, temperature and mechanical vibration. By the same token, a long line may be used to achieve a tunable phase shift using small changes in frequency, provided that a frequency-tunable source like the vector signal generator is being used.

I/Q Demodulation

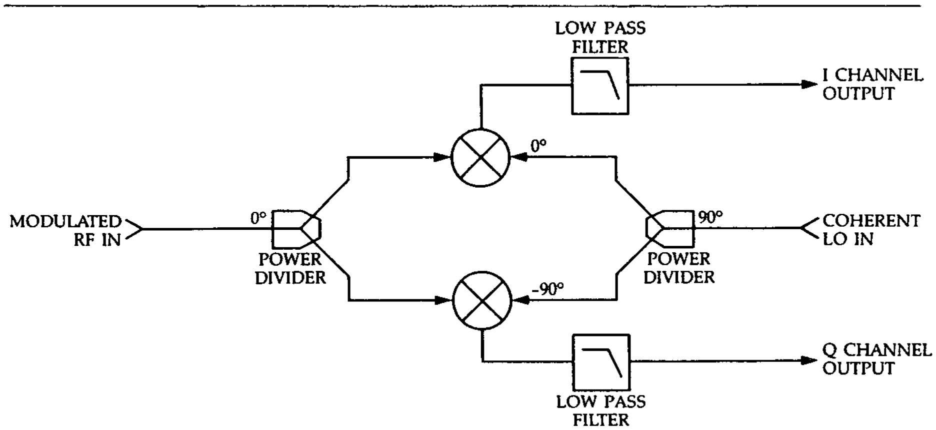
Perhaps the most fundamental difference between DMR measurements and traditional communications measurements is the use of the I/Q demodulator as an analysis tool. In a measurement role, it can be used to gain valuable information about the phase and magnitude of any signal. This information is useful in identifying the causes of degraded system performance. Almost all DMR receivers contain I/Q demodulators, but their suitability as measurement tools can vary. The design concerns can vary dramatically depending on the intended use of an I/Q demodulator, and for this reason, instrumentation-quality demodulators will often be required for measurements. We will call these vector demodulators.

The vector demodulator is an I/Q demodulator capable of complex modulation analysis. Although the demodulators in many receivers provide a significant analysis capability by themselves, in some instances a more accurate or separate demodulator will be required. One example of this need is in separating receiver errors from transmitter errors in back-to-back tests.

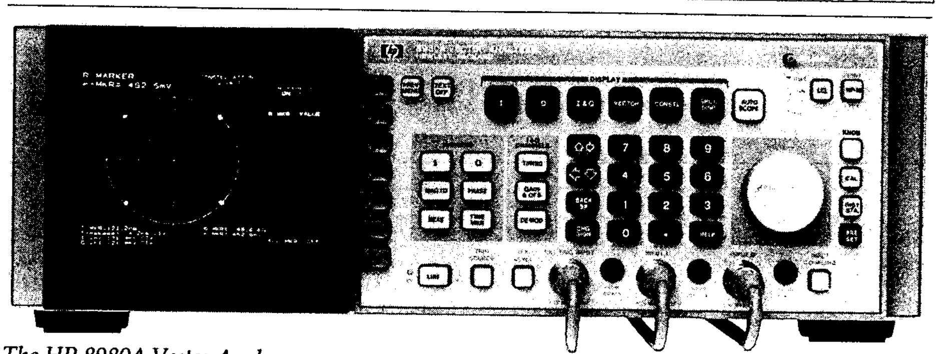
Basically the I/Q demodulator consists of two double-balanced mixers and a 90 degree hybrid connected as shown. For analysis, the characteristics which are important in an I/Q demodulator are precise quadrature, amplitude balance and linearity. Any imperfections in these measures of performance will result in erroneous measurements of I, Q, amplitude and phase.

Other practical considerations which limit the demodulator's performance include things like LO and sum-frequency feedthrough and dc I and Q offsets. Where no coherent reference LO is available, carrier recovery will also be necessary in a vector demodulator.

See the Demodulator Alignment section of this Application Note for further details on vector demodulators.



Simplified vector demodulator.



The HP 8980A Vector Analyzer.

Vector Modulation Analysis

Although I/Q demodulation has long been used in DMR as well as other receivers, the meaning of these signals has often been hidden by the displays used to show them. Usually I and Q channels have been viewed on normal dual display oscilloscopes, with one signal above the other and time along the horizontal axis. This is fine for observing eye diagrams, but the relationship between I and Q is lost in this type of representation. To understand digital modulations, and to see the relationship of I, Q and phase, the I and Q signals need to be viewed in an X vs. Y fashion.

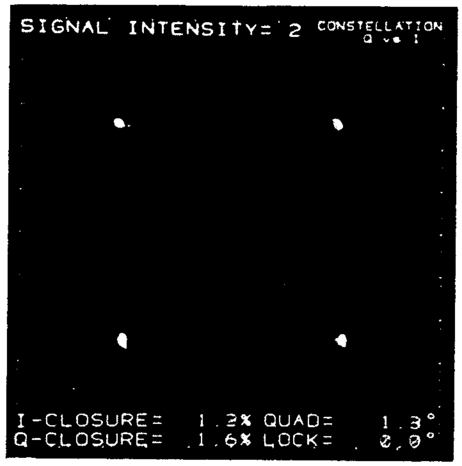
The reason that I and Q have not been displayed in this X vs. Y or vector diagram before is that traditional oscilloscopes have much lower X bandwidths than Y bandwidths. These limitations have been overcome with the introduction of the HP 8980A Vector Analyzer.

In addition to the vector analyzer, there is another instrument capable of displaying eye and constellation diagrams. The HP 3709A Constellation Display is especially suited for radio installation and maintenance applications.

The vector analyzer allows baseband DMR signals to be displayed in either a time or vector representation, allowing either their data or phase and magnitude information to easily be seen. Not only can the I and Q signals be displayed in X vs. Y fashion to represent the I/Q phase plane (a vector diagram), but special software functions allow the addition and removal of phase and amplitude offsets for calibrating out errors in demodulator quadrature or amplitude. This represents a tremendous advance in ease of use when measuring phase and amplitude modulated signals.

Eye diagram.

Vector diagram.



Constellation diagram.

There are three fundamental display modes of the vector analyzer: it can display either of its two inputs or both simultaneously vs. time, display both inputs in X vs. Y fashion (a vector diagram), or display both inputs in X vs. Y fashion only at a specified time instant (a constellation diagram).

Since the vector analyzer will almost always be connected to I and Q signals in the measurement systems described in this application note, it is important that I and Q test points are available. It is also important that the test point impedance match the 50 or 75 Ohm input impedance of the analyzer. If there is an impedance mismatch, external high impedance probes or adapters may be used to condition the I and Q signals.

When analyzing high bandwidth signals with the vector analyzer, it is important to limit the measurement bandwidth where possible. One of the drawbacks to using an I/Q demodulator is the presence of LO and sum-frequency signals on the I and Q signals. These spurious signals must be adequately filtered out for accurate measurements. This is especially important when looking at the demodulated I and Q signals on a high bandwidth display such as the vector analyzer. If not sufficiently attenuated by the low pass filters at the demodulator outputs, these signals can substantially degrade the demodulated I and Q signals making them look noisy.

For more technical information on the HP 8780A Vector Signal Generator, the HP 8980A Vector Analyzer or the HP 3709A Constellation Display, ask your Hewlett-Packard Field Engineer for the following literature:

HP 8780A Vector Signal Generator
Product Note 8780A-1 (5954-6368)
Technical Data Sheet (5954-6363)

HP 8980A Vector Analyzer
Product Note 8980A-1 (5954-6369)
Technical Data Sheet (5954-6364)

HP 3709A Constellation Display
Technical Data Sheet (5954-2028)

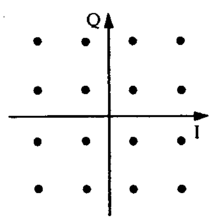
I/Q Modulator/Demodulator Alignment

The I/Q modulator and demodulator are at the very heart of modern DMRs. They are the fundamental tools which enable the transmitter and receiver to send and receive information. The assurance of their correct operation is essential. Two of the most important measures of modulator and demodulator performance are quadrature error and amplitude balance.

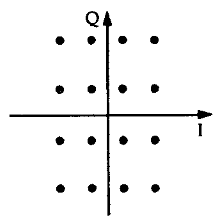
It should be noted that in some instances, I and Q channels are intentionally out of balance to simplify reception or increase one channel's tolerance to noise. These systems can also be aligned using the following methods, but the desired outcome will be slightly different.

The Effects Of Alignment Errors

Amplitude imbalance in a modulator occurs when the I or Q channel has a different gain than the other channel. This results in both erroneous phase and magnitude of the output modulated signal. If we take the example of a 16QAM signal which is generated by a modulator with amplitude imbalance (in this case $I < Q$), then we see that the resultant modulated constellation appears compressed in the horizontal direction and the states are no longer equally spaced. For the case of the 16QAM modulator, the transmitted signal's tolerance to noise may be reduced since the states are no longer in their proper locations and more likely to be misinterpreted by the receiver in the presence of noise.



I/Q states input to modulator.

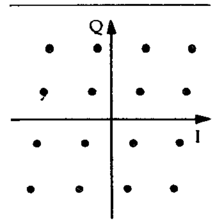


Modulated states with modulator amplifier imbalance.

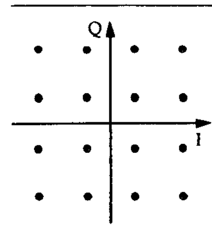
Quadrature errors have an even more insidious effect on the modulator output. If the hybrid splitter has an effective phase difference of 85 degrees instead of 90, the output phases and magnitudes will be very different from those desired. Assuming a 16-QAM signal is to be generated, the actual in-phase and quadrature-phase components of the modulated signal will be "skewed" with respect to their desired phase and amplitude. This is easily seen on the accompanying vector diagram. Once again, in the case of transmitter modulation, the probability of error has been increased since the states are no longer in their desired positions and are instead closer to the decision thresholds. In the case of modulation for test signal generation, both the phase and amplitude of the signal will be in error.

The effects of alignment errors on the demodulator are very similiar to the effects they have on the modulator. In the case of amplitude imbalances, the output I and Q signals will look squashed when viewed on a vector analyzer compared to the actual vector modulation used to excite the demodulator.

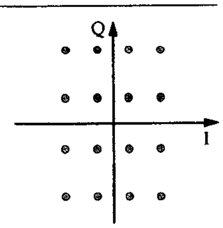
Quadrature error in the demodulator hybrid will result in a "skewing" of the represented vector diagram with respect to the input modulation. The skewing introduced in the demodulation process is in the opposite direction of that introduced in the modulation process, so equal quadrature errors in transmission and reception can partially compensate for each other when the received I and Q signals are looked at on a vector analyzer. A system which has offsetting quadrature errors is more susceptible to noise though, and won't work as well as one that is correctly aligned. This example illustrates the need for very accurate test modulators and demodulators when doing alignments.



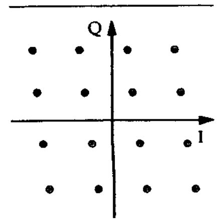
Modulated states with -5° modulator quadrature error.



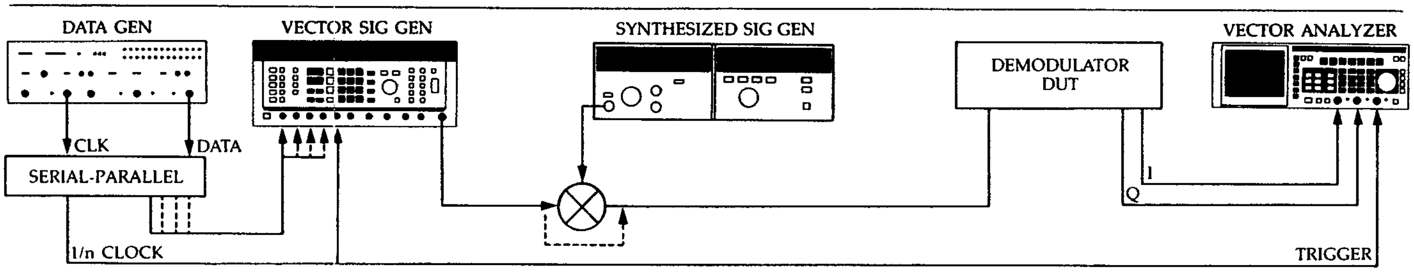
Phase/amplitude signal states input to demodulator.



Demodulated I/Q states with demodulator amplitude imbalance.



Demodulated I/Q states with -5° quadrature error.



Vector demodulator test block diagram.

Demodulator Alignment

The objective of demodulator alignment is to make sure that the output I and Q signals accurately represent the in-phase and quadrature-phase components of the signal at the demodulator's input.

Accurate demodulator alignment requires accurate test signals. The simplest way to achieve this is through the use of a vector signal generator. The vector signal generator allows the generation of a variety of test signals including many standard modulation formats for demodulator characterization. To measure demodulator performance, the vector analyzer is connected to the demodulated I and Q signals while the vector signal generator supplies the demodulator input.

It may be necessary to supplement the filters on the output of the demodulator with ones that better filter the sum and LO frequencies incident on the vector analyzer inputs. One of the biggest problems in aligning a demodulator is that of noisy signals due to insufficient filtering on the demodulator outputs.

Although a small amount of carrier feedthrough and sum frequency may be tolerated in other situations, it can be troublesome when the demodulator is used with a wide bandwidth measurement device like the vector analyzer. If there is insufficient filtering, the vector diagram will appear fuzzy and it will be difficult to measure the exact phase of particular points on the display.

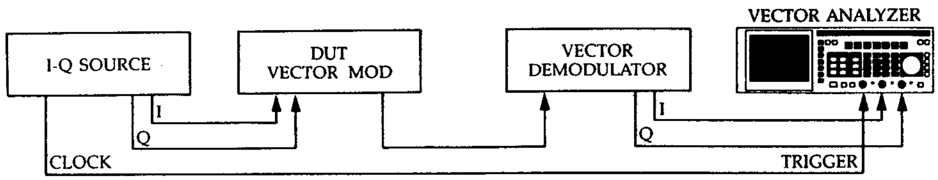
To perform the calibration, the vector signal generator should be set up to generate a test signal which is representative of the signals the demodulator normally sees and that provides a clear test pattern. In most cases, this will mean using the same modulation format, clock frequency, levels and external filtering for the same bandwidth that the demodulator will actually operate with. There is no point in simulating a representative amount of noise since it would complicate the calibration measurements.

Although static vector modulated signals could be used for the alignment, they provide a poor test signal for the demodulator. Not only do static modulations poorly represent the actual operation of the demodulator, but many demodulators have carrier recovery schemes that only work with digitally modulated signals.

The vector analyzer should be set to display a constellation since the settled values of I and Q will provide the most valuable test points for verifying quadrature and amplitude imbalance errors. Once a good constellation diagram has been generated, the demodulator can be adjusted for optimum quadrature and amplitude balance by looking at the "skewing" and compression of the vector diagram, as the demodulator's quadrature and amplitude are adjusted. There are also built-in constellation analysis functions in the vector analyzer to accurately measure quadrature and amplitude errors.

Modulator Alignment

The objective of vector modulator alignment is to make the amplitude response of the modulator to I and Q signals equal, and the quadrature of the modulator 90 degrees.



Vector modulator test block diagram.

The most obvious and straight forward way to perform a modulator alignment is with a vector demodulator and vector analyzer. The vector demodulator is a very well calibrated I/Q demodulator whose own alignment is known to be better than the error which can be tolerated in the alignment being made.

If no demodulator accurate enough for the measurement is available, the vector signal generator and vector Analyzer can be used to calibrate out errors in the quadrature or amplitude imbalance of an imperfect demodulator. To do this, use the vector signal generator at the input to the demodulator and adjust the vector analyzer to remove any quadrature and amplitude imbalances. The vector signal generator should be set up to generate a test signal typical of the signals that the demodulator will be testing. In most cases, this will mean using the same modulation format, clock frequency, levels and external filtering for the same bandwidth that the demodulator will actually operate with.

Once the demodulator has been calibrated, we can align the modulator. When aligning a modulator, I and Q input signals which simulate the actual operating environment of the modulator should be used. So, for a QPSK modulator, actual QPSK I and Q signals are best. The reason for this is that some elements of the circuit (like the mixers) have frequency response characteristics which are not flat and should be characterized over their actual operating frequencies when possible. As is the case with most measurements, the measurement will only be as good as the input signals. The I and Q input signals should be as accurate as possible. Any error in I or Q levels will show up as phase and amplitude errors on the vector analyzer and lead to difficult or incorrect adjustments of the modulator under test.

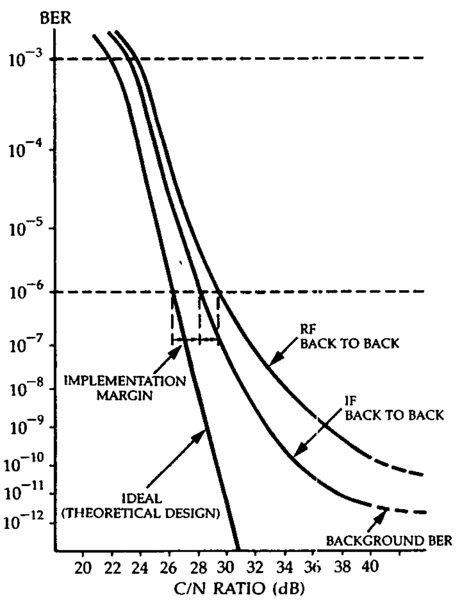
To perform the alignment using the vector demodulator method, test I and Q signals are input to the vector modulator and the output of the modulator is input to the vector demodulator. The demodulated I and Q signals are displayed on the vector analyzer in a constellation display since the settled states will be the clearest alignment points. Any error in quadrature will show up as a "skewing" of the constellation. Any amplitude imbalance will show up as rectangular compression of the constellation.

While looking at the demodulated signals, it should be easy to see improvements and degradations while adjusting the modulator quadrature and amplitude settings. Just as with demodulator alignment, the vector analyzer's built-in constellation analysis functions quickly measure remaining quadrature and amplitude errors.

BER Testing

After a radio is properly aligned (often prior to leaving the factory), it is usually given a full system test to see if it operates as well as it is supposed to. The "bottom-line" measurement in these applications is the BER test. The overall performance of digital communication systems is often described by the system's bit error rate or BER. The BER is simply the average number of bits in error divided by the number of bits transmitted. This is an appropriate measure of overall quality for a system whose primary function is the accurate communication of digital data.

Much can be learned about a DMR's performance characteristics by observing the radio's BER under a variety of degraded operating environments. The two commonly used degradations are gaussian noise and sinusoidal interference signals to provide carrier-to-noise (C/N) and carrier-to-interference (C/I) tests respectively.



Typical BER test results — BER vs. C/N curves.

The purpose of C/N and C/I testing is to determine how a radio (or its modules) departs from the theoretical or design values. The test is also useful in the laboratory for optimizing and evaluating different implementations. Some typical BER test results are shown along with their representative theoretical curves.

The measurement of BER and related statistical values like error-free seconds, error count and availability, are normally made with a pseudo-random binary-sequence (PRBS) applied to the transmitter baseband input. The PRBS pattern will usually be a CCITT recommended pattern: $2^{23}-1$ for 140 Mb/s, and $2^{15}-1$ for the lower bit-rates. The error detector synchronizes on the receiver's demodulated PRBS and makes a bit-by-bit comparison against a reference PRBS. The error accumulation can then be expressed as BER. For statistically meaningful answers, it is desirable to count at least 100 errors in the measurement period. This leads to very long gating periods at low BER values. The measurement of a 100 Mbit/s radio's residual BER of 10^{-12} would take about three days to accumulate 30 errors.

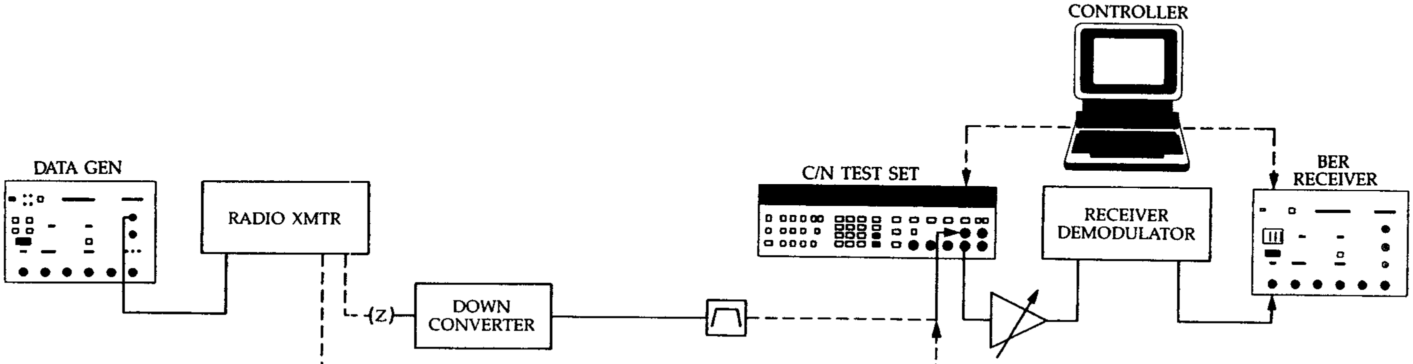
Some of the causes of higher error rates in DMR are misaligned modulator states and demodulator decision thresholds, power amplifier non-linearity, phase noise on the recovered carrier and clock in the demodulator, and thermal noise. BER tests will respond to these degradations, but will provide no information as to which causes are responsible for the effects.

BER Measurement Techniques

There are basically two different methods of making a BER vs. C/N measurement: fade simulation using an attenuator at the receiver input and the additive noise method using a noise generator. Traditionally, the first technique has been used because of the lack of dedicated equipment for the second. With the introduction of the HP 3708A Noise and Interference Test Set, this is no longer a problem and the additive noise method is preferred.

In additive noise testing, the digital radio receiver operates at normal unattenuated levels so that the effect of receiver noise figure is negligible and the possibility of synchronization loss is minimized since the AGC, amplifiers, and other components operate at their nominal levels. The IF signal in the receiver path is connected through the HP 3708A Noise and Interference Test Set which is adjusted to the appropriate system bandwidth so that high crest-factor noise can be added to the radio signal. The carrier-to-noise ratio is then accurately known and the BER is checked using the pattern generator and error detector.

One of the problems associated with BER tests is the separation of transmitter and receiver errors. Both C/N and C/I tests are usually performed on transmitter/receiver pairs whose IF or RF signals are connected "back-to-back" making it impossible to separate the BER test results of the transmitter from the receiver. Testing the transmitter or receiver alone requires a corresponding "ideal" receiver or transmitter. Isolation of receiver BER characteristics is made possible by using a vector signal generator.



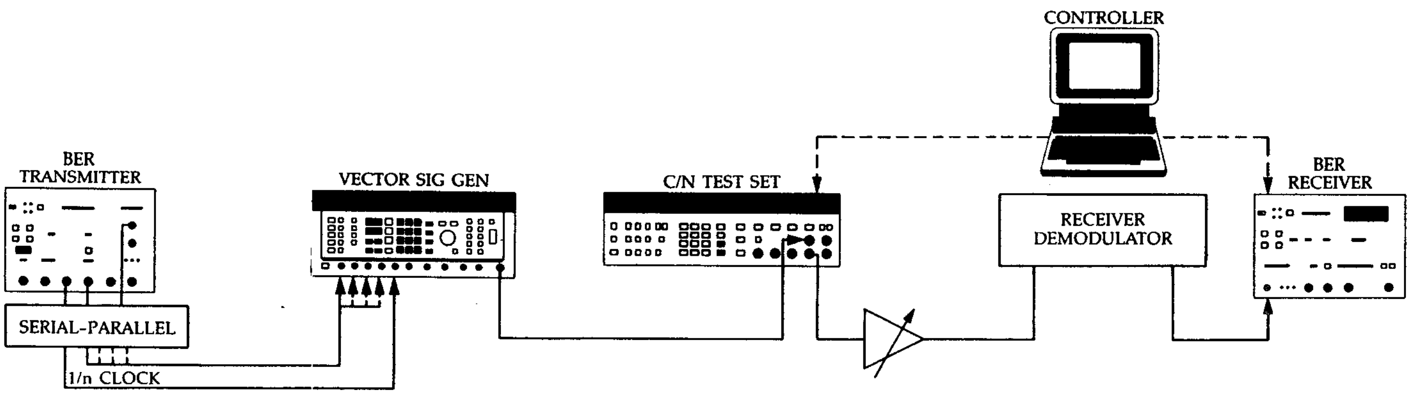
DMR transmitter/receiver BER test block diagram.

Measurement Implementation

Configurations are shown for testing C/N of transmitters or back-to-back systems using the vector signal generator, the noise and interference test set and the BER test set. The HP 3708S Noise and Interference Test Set performs automatic measurements with HP-IB controllable BER testers. The measurements can also be made manually with a wide range of nonprogrammable BER testers.

If back-to-back measurements are to be made no special calculations are required and the transmitter/receiver pair will perform the test signal generation and reception functions.

If the receiver is to be tested alone, a vector signal generator will be required. When testing the receiver alone, the output of the generator must be appropriately filtered to accurately simulate a "perfect transmitter." The quality of the filter used is extremely important since any ISI (inter-symbol-inteference) introduced by it will contribute to the BER measured. Since the generator is operating as a test transmitter, the modulation format, clock rate, and signal level as well as bandwidth should accurately represent those of the transmitter.



DMR receiver only BER test block diagram.

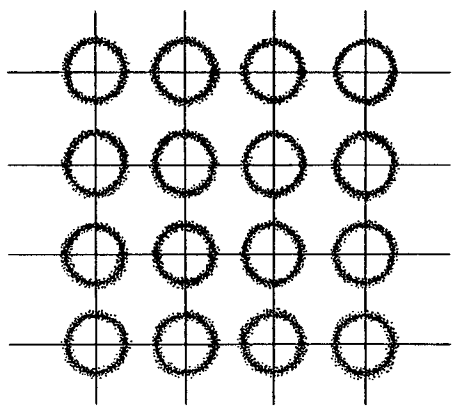
With the test setup shown, BER vs. C/N curves can be accurately and quickly plotted using the HP 3708A. The biggest remaining problem is the long gating time (maybe several days) required in the BER test to measure the very low background BER at high C/N values. Background BER refers to the BER that is due solely to imperfections and noise within the radio, and it is usually extremely low: on the order of 10^{-11} or lower. It is important to know the background BER since when many radios are cascaded, the overall error performance may become unacceptable. Clearly the test is very time consuming, particularly if a re-test is required after adjustment.

The measurement time can be substantially reduced by using a C/I test in which an interfering signal is added to produce a controlled amount of eye closure. The increased BER is then easily measured and the true background BER can be estimated.

This constellation display of a 16QAM digital radio with an interfering tone added shows clearly the reduction in space between the individual phase-states which gives the increased BER value. Estimation of the true background error ratio is made using the graphs in Product Note 3708-3 once the level of C/I and BER are known.

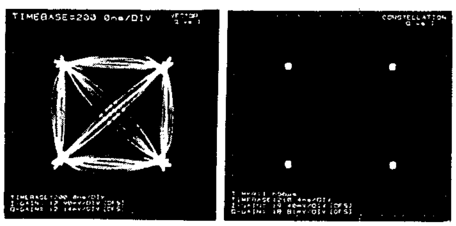
The time savings of this technique can be dramatic. For the example of a 100 Mbit/s digital radio and a residual BER of approximately 10^{-12} it would take about three days to accumulate 30 errors. The same test performed with the interfering signal would take only 2 to 3 minutes to accumulate 30 errors. This is of particular importance to high-density modulation schemes such as 16QAM and 64QAM where excessive background BER can be a significant problem.

Once a BER test has been made and the results are tabulated, very little can be said about the radio's performance. At the most we can say that the radio is as good, better or worse than expected. To analyze the radio transmitter, receiver or another system component in any greater detail requires a more capable measurement technique. Two of the most powerful analysis tools are the subject of the next section: the vector and constellation diagrams.


Constellation display of a 16QAM signal with an interfacing tone.

Vector and Constellation Diagram Analysis

The constellation diagram is a representation of the received I and Q signals at the clock instant while the vector diagram is the continuous display of the received I/Q phase plane. By looking at the constellation diagram, we can see how the received I/Q states or "symbols" look to the receiver. By looking at the vector diagram, we can see how the transitions between states occur. These two displays can tell us a lot about the quality of the transmission, filters, channel or even the demodulator's own characteristics. Many of the degradations common to terrestrial and satellite communications can be recognized from the distortions they impart to a constellation or vector diagram. This section concentrates on the identification and measurement of these degradations.



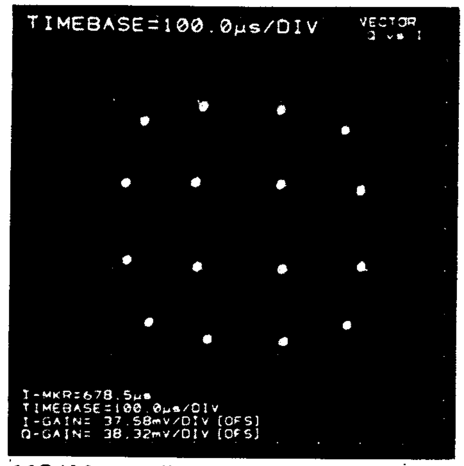
Vector and constellation diagrams of QPSK (vector diagram on left).

HPA Distortion

The distortions that result from operating a high power amplifier (HPA) at high levels where some compression is present are easily identified on the constellation diagram. If your radio has either an HPA or another nonlinear component which is driven hard, its constellation may exhibit some of the characteristics shown in the example at the right: the states no longer line up in a straight line and the corners of the constellation are rounded off and rotated.

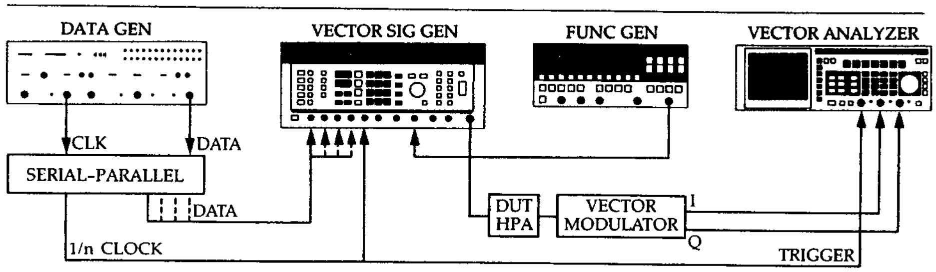
These characteristics are much easier to see on a high level QAM constellation than on a PSK constellation since the amplitude variations of the states allow a better display of compression and phase shift that occur as a function of amplitude. Not surprisingly it's PSK's tolerance to these nonlinearities that make it the choice in many satellite communication systems where HPAs are driven particularly hard. Unfortunately, these are the very systems in which we would like to be able to identify HPA distortions.

One way to make HPA distortions more evident in these systems is to artificially provide the amplitude variations necessary to excite the amplitude-dependent distortions.



16QAM constellation diagram with AM-AM and AM-PM nonlinearities.

The HP 8780A Vector Signal Generator is an ideal choice for generating this type of simultaneous modulation. By simultaneously vector modulating the signal with the appropriate PSK modulation and amplitude modulating the signal, the entire constellation will vary in magnitude as a function of the amplitude modulation. The constellation diagram produced will clearly display the amplitude modulation to phase modulation (AM-PM) conversion and compression (AM-AM) that are present due to system nonlinearities. The following diagram is an example of how such a test might be set up.

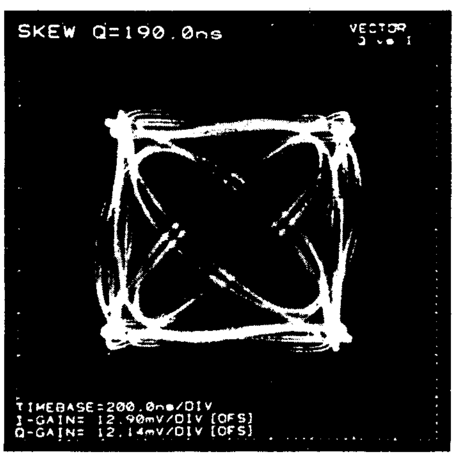


HPA nonlinearities can be dynamically characterized with simultaneous AM and digital modulation.

Examining HPA nonlinearities using this technique is not without its system dependent concerns. For example, your receiver may require a particular digital sequence to maintain lock. You may also experience difficulties with the AGC tracking out the effects of the amplitude modulation, in which case you should disable the AGC or make the amplitude modulation rate exceed the AGC bandwidth. System concerns will have to be treated individually since they are too varied to be covered here.

I/Q Crosstalk

I/Q crosstalk occurs when the I and Q modulations are not entirely independent, and it is most noticeable in a vector diagram. The reason that it is easily identified in a vector diagram is that the crosstalk causes the normal straight line transitions to bend and take on an oval shape. What actually happens is that as the I channel amplitude increases, the Q channel also experiences a small increase and vice-versa. The result is that the transitions bend as shown in the QPSK example below.



QPSK signal with oval transitions indicating I/Q crosstalk.

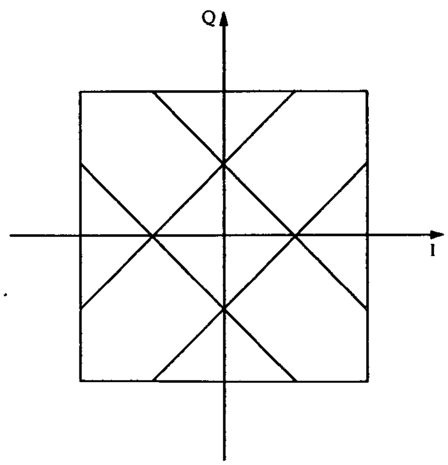
I/Q crosstalk may be caused by many things. One cause for I/Q crosstalk is the lack of isolation of the baseband I and Q signals. But crosstalk is not entirely a baseband phenomenon. I/Q crosstalk can also be caused by amplitude ripple in the IF and RF circuitry of the transmitter, receiver or even the transmission channel.

If crosstalk is detected, it will usually be observed as a dynamic problem: that is, its effects will be more dramatic as the modulation bandwidth is increased. This is just one of the reasons that modulator and demodulator measurements should be done at representative data rates and bandwidths.

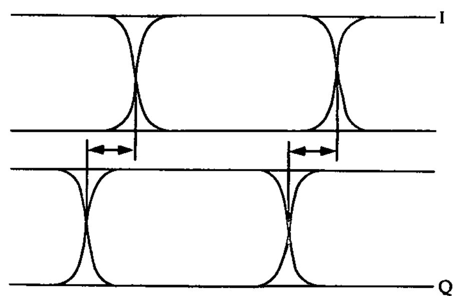
Measuring Data Skew

Data skew in DMRs refers to the time between when the I channel and Q channel switch with respect to their desired switching times. Skew can be introduced by baseband circuits, different line lengths for the I and Q channels, and a variety of other baseband elements. Since the skew is a baseband phenomenon, it is generally not caused by IF or RF components.

Data skew is important because it can substantially alter the modulator's output during the transition times as can be seen in the accompanying vector diagrams. When data skew is present, and it is no larger than a fraction of the entire symbol period, it looks a lot like I/Q crosstalk since it causes the transitions to appear bent. Depending on the degree of system filtering it may not be possible to determine whether data skew or crosstalk is responsible for the deviations.



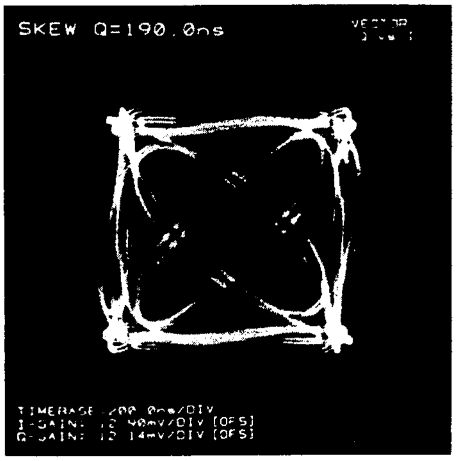
Vector diagram of QPSK with data skew.



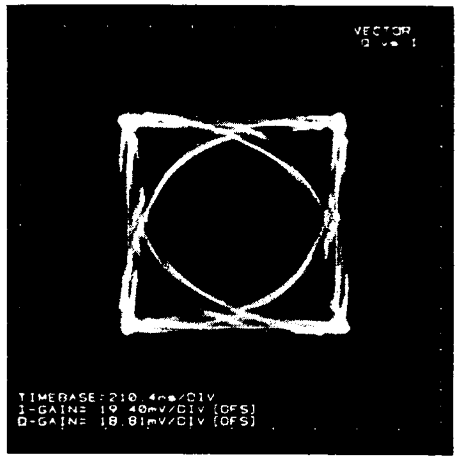
Time diagram of I/Q signals with data skew.

Not only can data skew alter the transitions between the transmitted states, but it can also effectively shorten the time that the transmitted data is valid. Where a substantial amount of skew exists, the I or Q channel may switch so much later than the other that the proper state is never achieved, introducing lots of ISI (inter-symbol interference) in the received signal.

QPSK with no I/Q timing offset.



QPSK with ¼ clock period I/Q timing offset.

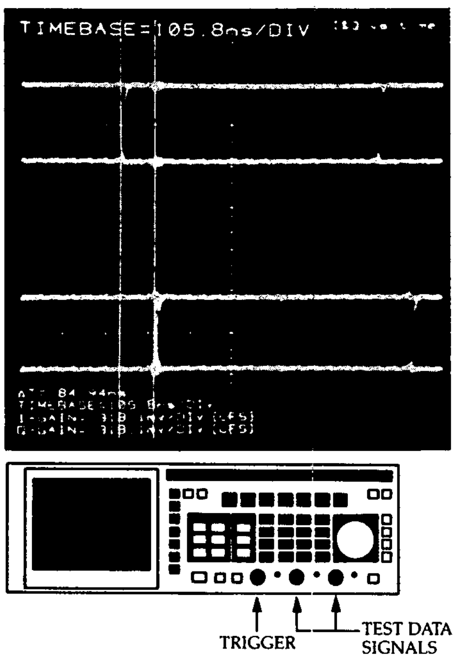


QPSK with ½ clock period I/Q timing offset.

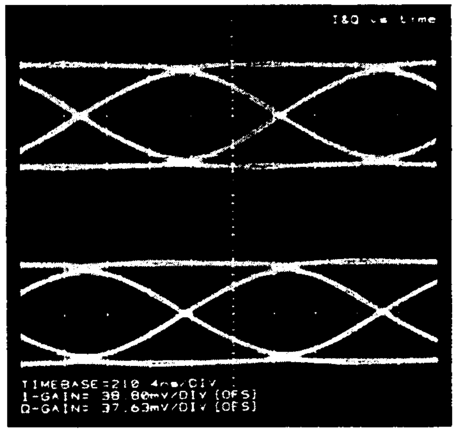
In systems which have substantially nonlinear channels, such as satellite communications, the I and Q signals may be intentionally staggered by half a clock period to avoid the large amplitude variations associated with transitions through the center of the vector diagram. In these systems it is especially important that no additional data skew or delay occur since it would cause the transitions to have greater amplitude variations which would excite the nonlinear characteristics of the channel.

In terrestrial communications, the degradations that result from data skew show up as ISI and eye closure in the constellation diagram and represent a decreased tolerance to noise.

The most obvious way to measure data skew is with a vector analyzer in its dual trace mode displaying I and Q vs. time. With this type of measurement setup it's easy to see any difference in the switching times of the two signals provided the rise times are sufficiently high. The delay between the two signal switching times can easily be measured using the time markers on the vector analyzer. By using the delay and time/div functions of the vector analyzer, the delay can be measured to ±100 picosecond resolution. One problem with doing the measurement this way is that it requires relatively square waveforms in order to visually identify the transition times. For this reason this technique is less suitable for highly filtered waveforms.

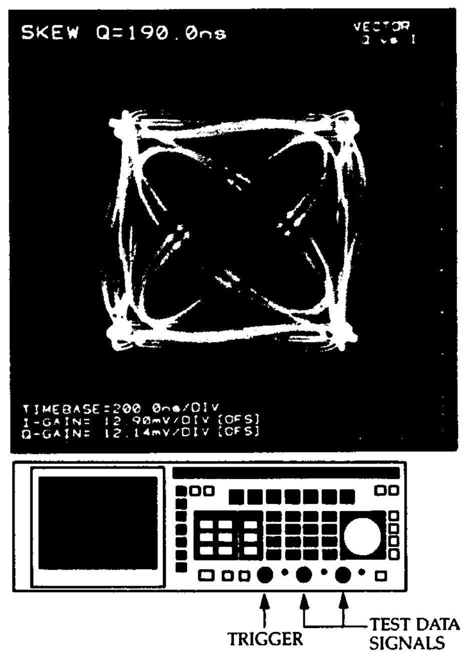


Measuring data skew of unfiltered signals with the vector display.


I/Q eye diagrams for offset QPSK.

Data skew in filtered baseband I and Q signals may be measured in a similar fashion if the vector analyzer is externally triggered and there are identifiable repetitive characteristics to the waveform. In the signals shown, the optimum eye opening is used as a point of reference, and the time at which the I channel reaches its maximum opening is compared with the time at which the Q channel reaches its maximum opening. This type of measurement assumes that the filter response is the same for both channels which may not be true. This can be checked by applying the same digital signals to both filters and comparing the outputs. Any difference in the time required to reach maximum eye opening can be calibrated out in the final measurement.

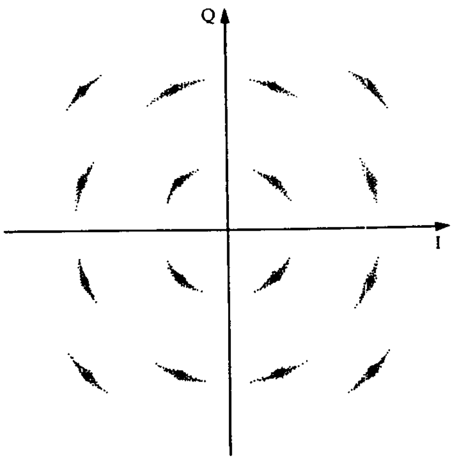
One less obvious but very sensitive way to measure data skew is to use the vector analyzer in the vector diagram mode with Q displayed vs. I. This is of particular value when looking at filtered signals whose transitions may be difficult to identify, or when an external trigger is not available. If there were no data skew at all, the displayed vector diagram would have straight transitions between all of the signal states. Any skew causes the transitions to bend as shown in the diagram below. By adjusting the vector analyzer's I or Q channel delay until the transitions do appear straight, accurate measurements of skew can be made. This technique is well suited to highly filtered signals.



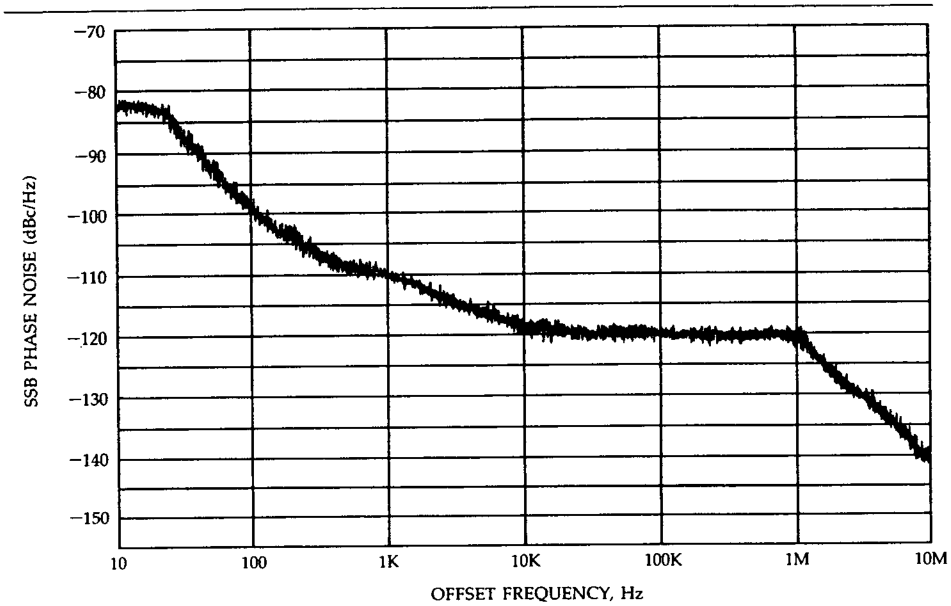
Measuring data skew of filtered signals with the vector analyzer.

Getting the Most Out of Your Radio

Although a lot can be learned from examining the vector and constellation diagrams of a DMR, often more extensive measurement techniques are required. There are many traditional communication measurements that are useful in DMR, but some techniques require special interpretation or implementation to be of value in systems that use QAM or PSK modulations. In this section, we examine some of the measurements for the first time in terms important to DMR systems.



16QAM constellation with phase noise.



Typical HP 8780A SSB phase noise.

Phase Noise in DMR Systems

Since phase noise contributes additional phase modulation to the signals in DMR systems it causes rotational jitter of the DMR signals in the phase plane. These rotations complicate the detection process and cause errors at the receiver, making phase noise important to characterize. We will concentrate on the meaning of the phase noise measurement in terms of its consequence to DMR applications. For further information on phase noise measurements and how they are made, the following Application Note is recommended: Hewlett-Packard's Application Note 207, "Understanding And Measuring Phase Noise In The Frequency Domain" (Lit. #5952-8708).

Every RF and microwave source exhibits some amount of frequency instability. This frequency instability results in unwanted phase modulation on the final signal. In DMR applications, this is most evident in the transmitter LO and the receiver carrier recovery circuits. The effect of these frequency instabilities, or phase noise, is to add a rotational jitter to the transmitted and received signal states. If the phase noise were great enough, it would cause the detected constellation to look like the one shown at left.

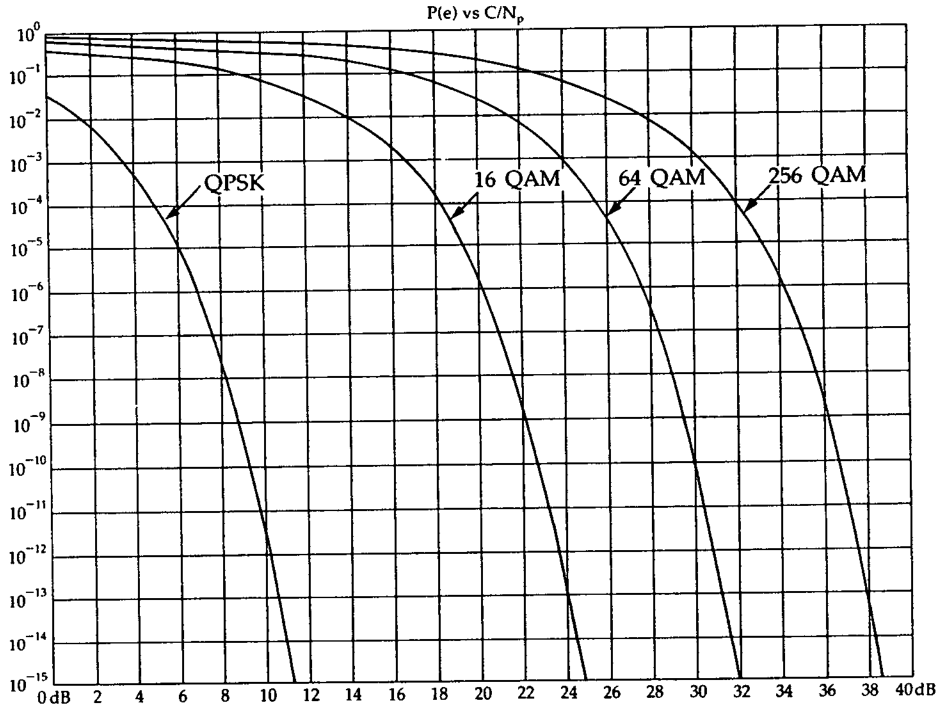
Obviously, the presence of phase noise in the system will contribute to the total number of errors incurred in the transmission process and is something to be avoided. With this in mind it's easy to understand why the measurement of phase noise is important to DMR systems.

Phase noise measurements are usually done in the frequency domain with spectrum analysis tools. The resulting data for a particular source will look like the example phase noise measurement shown. A phase noise measurement will only contain energy due to the phase noise and any residual AM on the signal will not be measured. The unit of the phase noise measurement is a matter of choice, but the most common is $\mathscr{L}(f)$. $\mathscr{L}(f)$ is the ratio of the power in one phase modulation sideband, per Hertz of bandwidth, to the total signal power, at an offset F_M Hertz away from the carrier.

$\mathscr{L}(f)$ is usually presented logarithmically as a spectral density plot of the phase modulation sidebands in the frequency domain, expressed in dB relative to the carrier per Hz (dBc/Hz), as shown in the example above.

Once the phase noise of a source has been determined, the consequence to the digital communications system under test can be ascertained. By integrating the $\mathscr{L}(f)$ curve over the channel bandwidth (both sidebands if the the receiver receives both), the amount of phase noise in the transmitted signal can be calculated. When doing this integration, only noise outside of the receiver's carrier recovery loop bandwidth should be integrated since the phase noise within this will be tracked out in the detection process. By dividing the power level of the carrier by the total phase noise power, the $(C/N)_p$ can be found. It has been shown that the P_e (probability of error) performance degradation is less than 1 dB if a carrier-to-phase noise ratio in a double-sided Nyquist bandwidth, $(C/N)_p$, is at least 10 dB higher than the carrier-to-thermal noise ratio, $(C/N)_6$, required for the probability of error performance $P_e = 10^{-6}$. If $(C/N)_p > (C/N)_6 + 20$ dB the degradation due to phase noise is negligible.[1]

In addition to this rule of thumb, P_e vs. $(C/N)_p$ curves have been calculated. Using these curves, one can determine a source's suitability for testing a particular modulation type at a given P_e provided that the source phase noise is known. As long as the P_e contributed by the source is small compared to the P_e to be measured, its phase noise should not degrade the measurement.



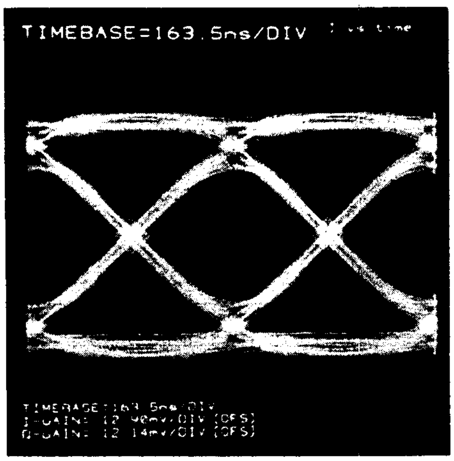
Probability of error vs. integrated double sideband phase noise.

If we look at the typical phase noise for the HP 8780A Vector Signal Generator for example, the total integral of the phase noise over a 30 MHz bandwidth, excluding the first 1 kHz for the loop recovery bandwidth, is approximately −47 dBc. From the graph of P_e vs. $(C/N)_p$ we can see that there should be no problem testing any of the modulations normally available on the instrument to P_e levels far below 10^{-15}.

[1] "Performance of Multi-Level Modulation Systems In The Presence of Phase Noise". Andy D. Kucar, Kamilo Feher, ICC 1985.

Measuring Filter Response

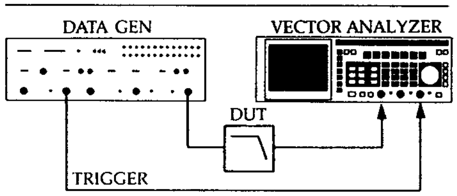
Traditionally filters have been designed and tested in terms of their frequency response. In digital communications, where filters are often called on to limit the bandwidth of digital signals, the frequency response characteristic may be less important than the time domain response. Admittedly, the data filter's primary function is to limit bandwidth, but the most important measure of its quality is how much interference is added to the desired waveform in limiting its bandwidth. This quality is expressed as either ISI (inter-symbol interference) or eye closure.



ISI is the spreading of the symbol levels at the clock instant.

Since ISI and eye closure refer to measurements of signals in the time domain, the best way to measure them is with a time domain analyzer; the HP 8980A Vector Analyzer.

The measurement of filter response should be done with a driving signal that accurately represents the signal the filter will operate with. The most important characteristics of the source are accurate frequency or clock rate and sufficient bandwidth to fully

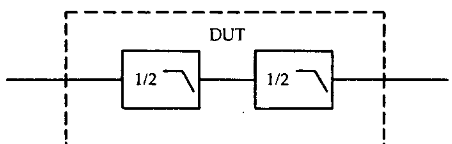


excite the filter. These two requirements are easily met by most data generators and may also be met by signals available in DMR systems.

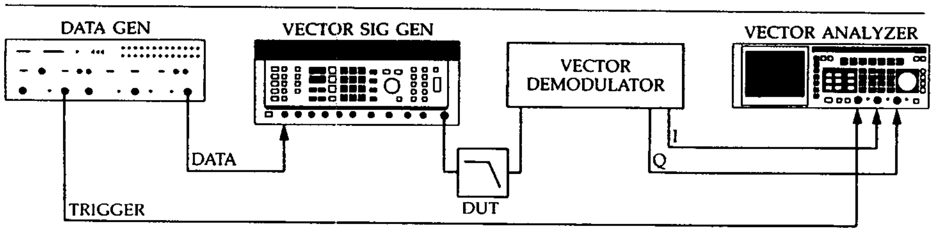
Once the measurement is set up as shown, the ISI and eye closure of a filter can easily be measured in either the time or vector diagram modes. The measurement is further simplified by the fact that the vector analyzer can analyze constellation closure and ISI on many standard QAM modulations.

This is also an excellent way to make any final adjustments while observing filter performance and comparing it to the required filter design. While watching the eye closure vary, filters can be optimized by varying component values where possible. Following this type of adjustment, the filter should be re-checked on a network or spectrum analyzer to be sure that it is still within the design frequency limits.

Often filtering is done partially at the transmitter and partially at the receiver. In these cases, it will be necessary to test both filters simultaneously to determine their combined time response, since either alone would have some ISI.

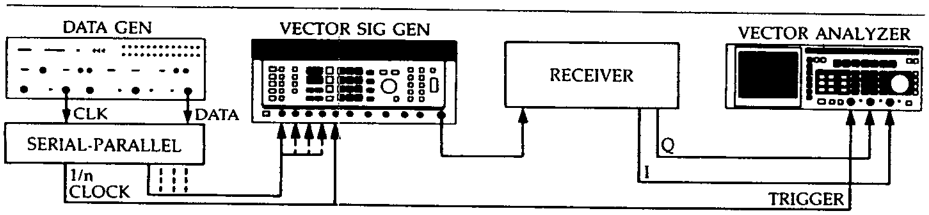


For time domain characterization transmit and receive filters often must be measured together.



IF filter test.

The above procedure is appropriate for filters that operate at baseband, but data filters are also implemented at IF. To observe the time domain response and measure ISI for IF data filters, it is necessary to construct an IF filter test set. Sometimes the filter can be tested in the radio receiver using the demodulated I and Q signals to characterize its performance. A more accurate approach is to replace either the transmitter, the receiver or both with the vector signal generator and a vector demodulator respectively still using the vector analyzer to observe eye closure or ISI.

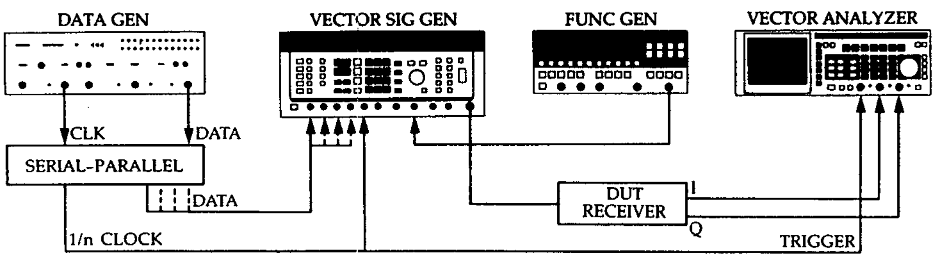


Simple AGC tests can be done by varying the vector signal generator's output level and monitoring the receiver's response with the vector analyzer.

AGC Testing

The characterization of the AGC is an important receiver design measurement. In an operating radio, the AGC control voltage may be used to record the C/N for a period of operation. Some important measures of AGC quality are dynamic range, step response and the AGC's transfer function. AGC testing is best accomplished by varying the amplitude of a test signal at the receiver input and monitoring the AGC control voltage, the I and Q baseband signals or the IF signal level after the AGC.

To test the AGC dynamic range, a modulated test signal is applied to the receiver input and adjusted in amplitude while observing the baseband I and Q signals. If a vector signal generator is used to provide the test signal, the amplitude may be varied over a wide dynamic range using the output level control. When either the top or bottom of the AGC dynamic range is reached the I and Q signals will begin to vary in amplitude along with the variations in the test signal amplitude.



Complete AGC characterization can be done by simultaneously scalar modulating and digitally modulating the test signal.

To measure the loop step response a test signal of bandwidth and dynamic range in excess of the AGCs must be applied at the input to the receiver. The vector signal generator can generate such an amplitude step by using its burst mode. The burst mode allows the output of the vector signal generator to be turned on and off by switching the burst data line. The rise time of the burst is fast enough to test AGC loop bandwidths of several hundred megahertz — more than adequate for most AGCs.

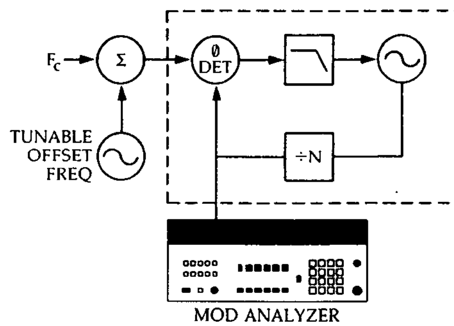
As the burst is generated, the step response of the loop can be observed on the vector analyzer by looking at the I and Q signals. The amplitude variations that result as a function of the AGC step response will show up as amplitude variations of the data stream on I and Q. For these to be clearly seen, the vector analyzer should be triggered at the same time as the burst.

Phase Locked Loop Testing

Although there are many characteristics of phase locked loops that are important to DMR design, the most important parameter is clearly the loop transfer function and bandwidth. From this one measurement much can be said about its ability to lock onto a signal and hold lock with frequency-varying signals. Another parameter worth mentioning is phase noise. The consequence of phase noise is covered in another section of this Application Note.

One method of measuring the loop transfer function is to apply a sinusoidal amplitude modulated signal to the receiver input and to monitor the amplitude of the I/Q constellation at the demodulator output. By varying the frequency of the modulation, the transfer function can be determined one frequency at a time. This can be easily done using the vector signal generator and an external sine wave generator. The setup required is shown. To make accurate constellation measurements, the magnitude markers of the vector analyzer should be used.

Since the loop bandwidth of most DMR loops is small (on the order of 1 kHz), one way to determine loop bandwidth is through a network analyzer type measurement. The diagram below outlines a measurement technique for determining the entire loop transfer function using a CW source and an HP 8901A/B. As the offset frequency of the CW source is swept through the pass band of the PLL bandwidth, the modulation analyzer monitors the modulation index of the phase detector input. As the transfer function of the loop filter is swept, the modulation index changes and is indicated on the modulation analyzer's display. If enough successive data points are measured, the transfer function can be accurately reproduced.



PLL test block diagram.

Unfortunately all of the test points required for complete characterization of the loop transfer function aren't always available. In such cases there are less complete, but simpler measurements that can be made. One such test is the measure of the loop's lock range. To test a loop's lock range, one needs only to gradually vary the frequency at the receiver's input. This can be easily accomplished using the vector signal generator since it has 1 Hz frequency settability and is very stable. Simply set up the Vector Signal Generator to generate the appropriate modulation and start tuning the frequency away from the nominal carrier frequency until the receiver breaks lock. To observe when lock is broken, either the I/Q constellation diagram may be observed (watch for rotations of the diagram), or the BER may be observed (watch for high BERs). Although a simple test, this may be useful in isolating a problem, or confirming adequate lock range.

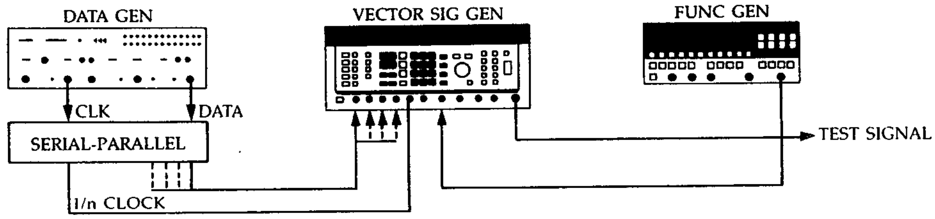
Simulating Doppler Shifts

Doppler frequency shifts result when either the transmitter or receiver moves toward or away from the other. This is particularly important in satellite DMR where the transmitter and receiver are located great distances apart and often move rapidly with respect to one another.

The frequency shift experienced due to the Doppler effect causes the vector modulated signal to experience a phase rotation. If the carrier recovery circuits in the receiver don't accurately track out the phase change, the signal will be incorrectly detected and the system P_e will increase. For this reason, it is important to characterize a satellite receiver's tolerance to Doppler FM.

The HP 8780A Vector Signal Generator is the ideal instrument for simulating Doppler shifts. Doppler shifts usually have peak deviations on the order of 1 kHz and vary at a rate on the order of 1 Hz and lower. Their simulation requires an extremely accurate source capable of vector modulation and low rate FM. Frequency stability is very important so the test signal's own phase noise is much smaller than the effects of the Doppler shift. The vector signal generator is well suited to this task with its built-in digital modulation capabilities, DC FM and 1 Hz frequency resolution. Only one additional external signal is required to simulate the degradation.

One possible simulation setup is shown. The deviation of the simulated Doppler shift can be adjusted controlling the vector signal generator FM sensitivity and FM source amplitude while the rate is directly controlled by the FM source frequency setting.



Simulating Doppler shifts with simultaneous digital and frequency modulation.

Simulating Phase Hits (TDMA)

One of the problems that TDMA systems have to deal with is the rapid phase, frequency and amplitude discontinuities that result when different radios access the system. Each radio slowly drifts in phase with respect to the other radios in the network and at a given time, they will all have unique phases and frequencies. The receivers in a TDMA system must be capable of locking quickly onto new signals in spite of these signal variations. Simulating the "phase hit" and other changes is important in characterizing the receivers designed to work in this environment.

The best way to accurately simulate the effects of multiple transmitter's phase discontinuities is with two vector signal generators.

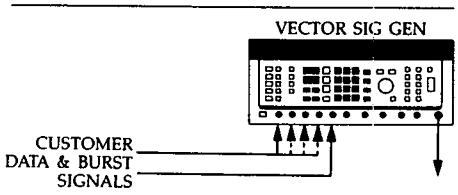
Although some of the effects of the TDMA signal can be generated using only one signal generator, to achieve a realistic phase hit that completely models all of the effects of switching TDMA systems, two vector signal generators are required. With this in mind, we will first examine the techniques required and results achievable with only one generator.

The changes that take place when changing reception from one transmitter to another include such things as amplitude, phase and frequency, all taking place very fast in a TDMA system. Using only one signal generator, all of these can be varied, but the rates of change that can be simulated are limited. The amplitude variations can be very accurately simulated using the vector signal generator alternate level modulation capability. Alt-level allows the generator output to be switched between two levels at rates as fast as the data rate. Using the FM input to the vector signal generator, the signal can be frequency modulated using a square wave to simulate the rapid frequency change, but the speed with which it can be switched is limited by the 12 MHz bandwidth of the FM circuitry.

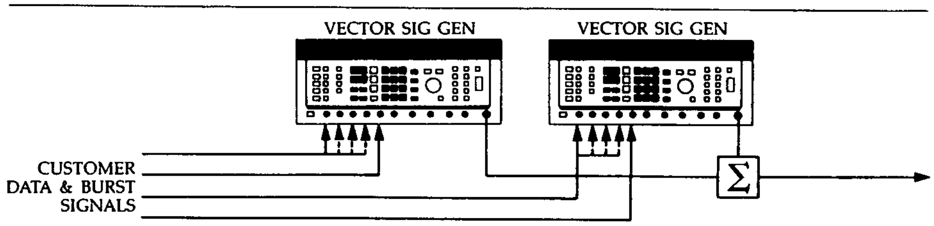
The first block diagram is an example of how a TDMA simulation might be implemented using only one vector signal generator.

If two vector signal generators are used, much more realistic signals can be generated and transitions with just phase discontinuities or phase and frequency discontinuities can be simulated.

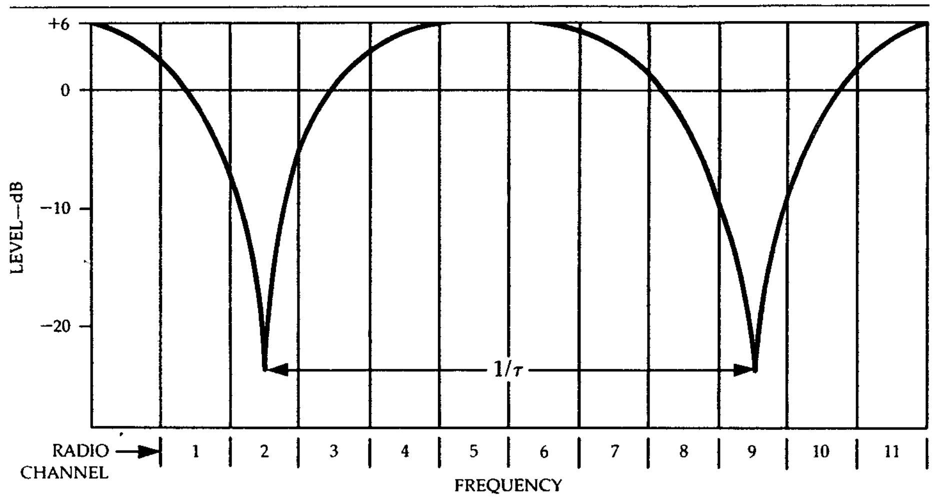
The hardware setup required is shown. Although the simulation could be done without reference locking the generators together (connecting their references), locking them ensures that any frequency offsets selected or phase differences selected will be accurate. Notice that in both examples the baseband signals are generated by the customer rather than a PRBS. This is necessary since framing information and carrier recovery information required for the receiver to properly work are different for each customer. In addition to the data generation lines, there are also burst lines to control which generator is actively transmitting. Once set up, all of the traditional signal generator conveniences are available, allowing either simultaneous or independant control of the signal levels, frequency, phase, and other simultaneous modulations.



Simulating TDMA signals with one HP 8780A.



More complete TDMA signal simulation including phase discontinuities using two HP 8780As.



Frequency spectrum of a multipath fade.

Simulating Multipath Fades

The simulation of multipath fades is of such importance to the testing of DMRs that recently much attention has been given to it in the literature. For those interested in the finer points of designing multipath simulators, there are many fine articles which expand what will be presented here.

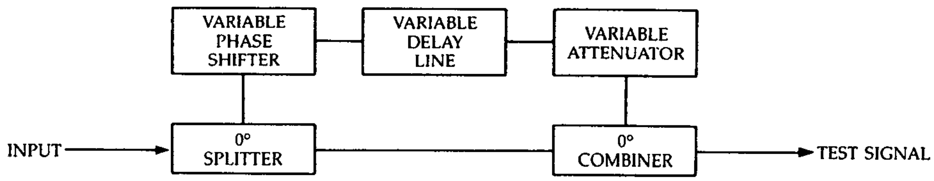
Multipath fades result when there are two or more transmission paths for a communication link. The multiple paths arise from reflections which can occur within the beam width of the antennas or fresnel bending of the radio wave propagation due to atmospheric effects. As a consequence of these multiple paths, the signal which was sent by the transmitter can appear at the receiver at different times. One part of the transmitted signal may travel the shortest path to the receiver arriving first while another part of the signal travels the widest deviation of the Fresnel path arriving much later (on the order of 5 nanoseconds later) than the first. In fact, at any one time, there are many active transmission paths for the signal to propagate on, all contributing to the signal at the receiver.

The effect of these time-delayed signals arriving at the receiver is to distort the signal: a distortion which is easiest to understand in the frequency domain. To understand the effect of multipath transmission in the frequency domain, it is important to first understand the effect of a time delay in the frequency domain. A delay in time is the same as the addition of a linear phase ramp in the frequency domain. This means that the signals which arrive delayed have been phase shifted as a function of frequency with respect with those signals which travel a shorter path.

It's not difficult to imagine then that at some frequency, the delayed signal phase change will be 180 degrees out of phase with the undelayed signal. At this point, the received frequency spectrum will contain a notch, since the two received signals will add destructively. The depth of the notch will depend on the strength of the delayed and undelayed signals. In any case, the effect of the notch will be to introduce dramatic distortions which must be corrected for the radio to continue satisfactory operation.

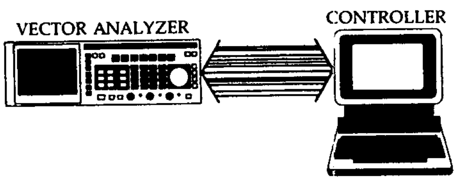
The parameters that affect multipath fades are numerous and include things as sporadic as inclement weather and temperature fluctuations in the air. It's not surprising that the fades are constantly changing and of varying severity. Their dynamic nature suggests that their simulation should also be dynamic; however, the added complexity required to simulate their dynamic nature may not be necessary depending on the system to be tested.

To test a receiver's ability to cope with multipath fades, it's necessary to simulate these degradations with some accuracy. In the real world, there are an infinite number of paths possible for propagation, but for the sake of simplicity, many effects of multipath fades can be accurately simulated accounting for only one static delay. Since the position of the resultant notch in the frequency domain is a function of carrier frequency, modulation bandwidth and delay, it is also convenient to be able to artificially control the notch position in the fade simulation.



A multipath fade simulator can be constructed using components common to DMR design. The fundamental components necessary to simulate the fade are an adjustable delay line to simulate the delay and an adjustable phase shifter to adjust the resultant notch position. In addition to these basic elements, a splitter and combiner are required to create the two separate paths and a variable attenuator is used to control the fade strength and notch depth. The basic simulator can be implemented with a range of components allowing everything from manually controlled simulators to simulators with electronically controlled phase, delay and amplitude that can accurately simulate the dynamic effects of multipath fades.

Signal Processing Applications In Vector Measurements



The purpose of this section is to stimulate some thoughts about other possible applications for the HP 8980A Vector Analyzer as an analysis tool.

One of the most challenging measurement tasks facing those who work in DMR fields is the characterization of DMR systems in the frequency domain. In the past, channels could be characterized by transmitting frequency-swept signals through them and observing the magnitude and phase of the output. The fact that many DMR receivers won't operate without continuous data signals precludes methods like these since the loss of carrier recovery renders useless any received signals that might have otherwise been used for analysis. The capabilities of the vector measurement instruments offer new solutions to these problems.

The value of the demodulated I and Q signals as analysis tools is evident: they provide not only a method for receiving the transmitted information, but they also tell us a great deal about the operating characteristics of the radio and the communication channel. The vector analyzer unlocks much of the otherwise cryptic information contained in these signals by displaying them in the I-Q phase plane with markers to indicate amplitude and phase. In addition to these capabilities, the display can digitize repetitive waveforms and send them to a controller for further analysis. This last capability opens many new measurement possibilities.

The characterization of a transmission channel is basically a network analysis measurement. It is traditionally done by exciting the channel with a sine wave and observing the channel output phase and amplitude while varying the sine wave's frequency. In many DMR channels, particularly those in satellite communications, the channel behavior varies with the amplitude of the incident signal. What's more, in some systems, the receivers won't operate without a continuous stream of framing and synchronization data and must always be tested dynamically. By using the analysis capabilities of The vector analyzer, many of these difficulties can be overcome.

If the channel must be tested dynamically, the method of analysis must be modified to accomplish the network analysis-type test in this environment. By exciting the channel input with a repeatable digital sequence, the same test measurement can be accomplished, provided that there is a method of synchronizing the vector analyzer's trigger to the repeating signal. The display can digitize the baseband I and Q signals of the receiver and send them to a controller. The controller can then calculate the transfer function of the channel provided that the channel input is known. Since the input in this case is known (it's generated by our test system), the controller can calculate the channel transfer function by first performing an FFT on the received signals and then dividing the received frequency spectra by the transmitted spectra.

Using the controller to expand the vector analyzer's capabilities offers some interesting possibilities. The analyzer's 12 bit A-D converter provides the resolution necessary for spectrum analysis measurements, and its frequency range can be extended through the de-convolution of its transfer function.

This solution is, however, not without its complications. The first practical concern is the generation of a trigger for the display at the channel output. Other concerns involve the theoretical accuracy of using an FFT and de-convolution to obtain the transfer function of a nonlinear channel. These will have to be adressed in individual situations since the concerns will vary.

Conclusions

We have investigated some of the fundamental measurements for DMRs and discussed the ways that DMR measurement needs are changing: sometimes requiring new instruments like the HP 8980A Vector Analyzer and the HP 8780A Vector Signal Generator. We have also examined the relationship that some traditional measurements like phase noise and fade simulation have to DMR systems. We hope a feeling for the rationale of designing a measurement has been communicated along with answers to some of the mysteries of DMR degradations.

What we could not do within the scope of this Application Note is explain all of the instrument-specific requirements for making the measurements. This information can be found in the Product Notes for HP's vector modulation instruments. The Product Notes not only explain some of the setup procedures necessary to make the measurements, but also typical operating characteristics that explain the capabilities of the instruments.

Although only the system measurements of DMRs have been addressed here, there are also component measurements important to DMRs. These are covered in Application Note AN 343-2, "Dynamic Component Tests Using Vector Modulation Analysis". In this Application Note the concerns of TWT and HPA testing are addressed.

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