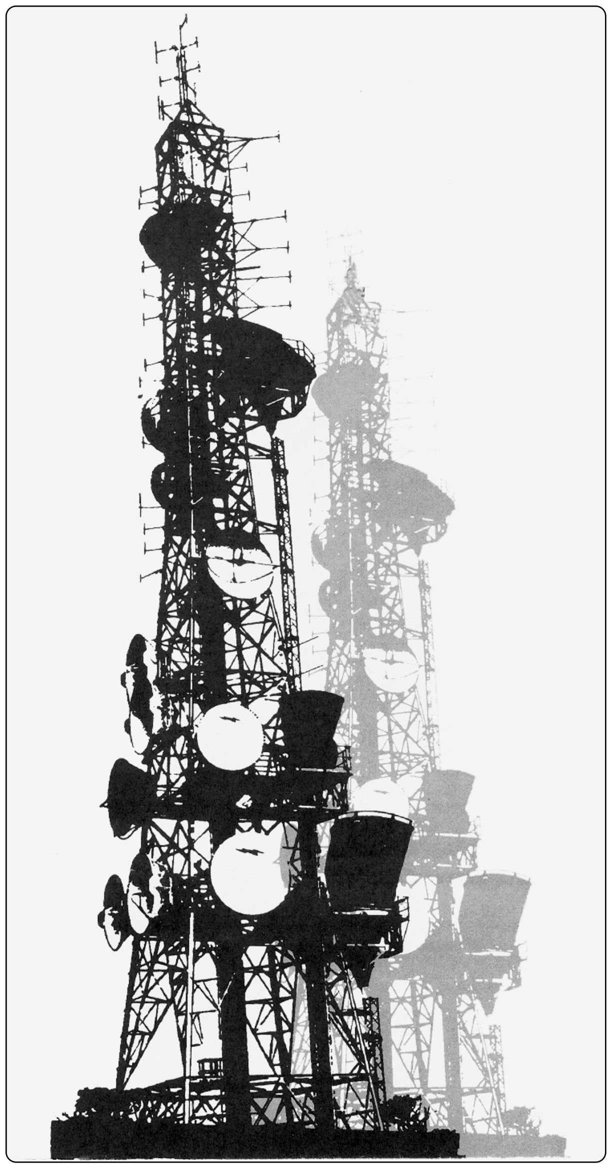
Agilent
Digital Radio Theory and Measurements

Application Note 355A



An introduction to digital radio principles, practical problems, and measurement solutions

Agilent Technologies

Table of Contents

Second Edition

This booklet replaces the four earlier seminar booklets (literature numbers 5954-2048, 5954-2049, 5954-9554 and 5952-2857). The main differences are in the second section on impairments and measurements. The changes include: updates to the error-performance standards, more comprehensive treatment of transmission impairments and the inclusion of the latest Hewlett-Packard measurement solutions and publications for Digital Radio. There has also been some editing to clarify certain points.

This booklet is divided into two parts. The first part provides an introduction to digital radio concepts and implementation. The second part reviews the impairments that may occur on a practical digital radio system and how these degradations affect the performance of a radio link. Measurement solutions to these problems are presented. The booklet is laid out as a slide storyboard so that it can be used in presentations, however the text provides sufficient information for it to be used as a normal application note.

A Note to the Presenter

In the second part of the seminar, as each measurement type is described, it is useful to demonstrate the appropriate Hewlett-Packard test equipment. In some cases a unique piece of dedicated test equipment can be presented, in other cases a range of products is available. Examples of these are: spectrum analyzers, network analyzers and bit-error rate testers. These product families are continually evolving and in the case of BER testers, different interface standards and bit-rates are used in various parts of the world. With a knowledge of the audience, select some appropriate products based on the applications information in the booklet, and include one or two product slides to support your demonstration; product slides can usually be obtained from the manufacturing division.

Part 1

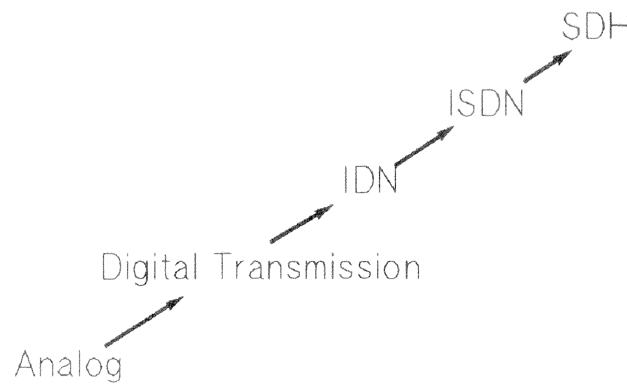
Digital Radio Theory and Implementation

- Introduction
- How a Digital Radio Works
- Noise and Distortion

DRTM0010

In this first part we will review some fundamentals of digital microwave radios. First we will see where the digital radio fits into a modern communications network. We will then discuss the radio itself and its similarities to analog microwave radios. Finally, in this section we will investigate two of the fundamental performance limiting factors in a digital radio.

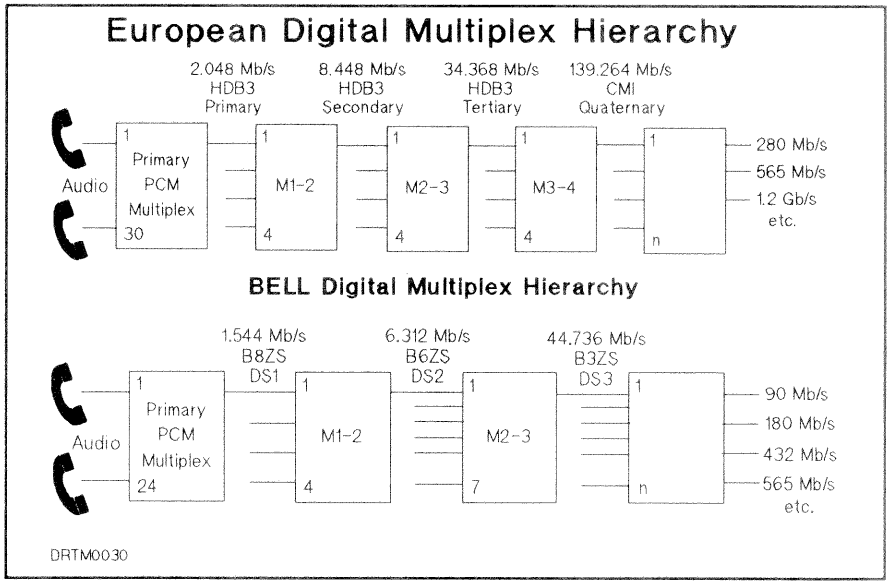
Telecommunication Network Trend



DRTM0020

Telecommunications networks worldwide are currently converting (at varying rates) from analog to digital systems with the ultimate objective being the creation of Integrated Digital Networks (ie: networks with connections provided via digital switching/transmission), Integrated Services Digital Networks (ie: multi-service networks with digital access, switching and transmission) and broadband ISDN.

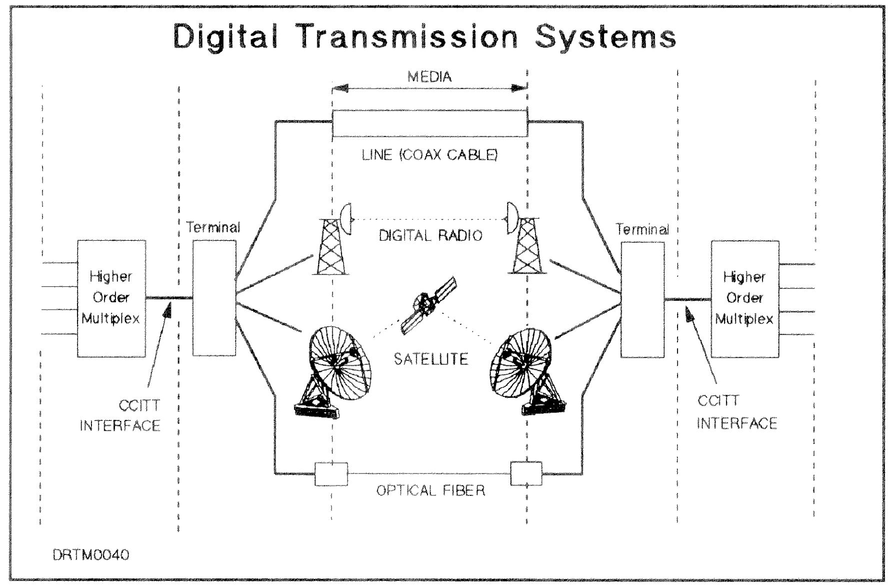
European Digital Multiplex Hierarchy



The various digital services, whether they are digitized telephony (64kb/s PCM or 32 kb/s ADPCM), data, videotex or facsimile etc., are time division multiplexed (TDM) together to form higher rate bit streams. This is done in stages as shown in this picture of European and North American digital hierarchies. These are commonly used rates. However, different hierarchies are used in Japan and in some military systems. In addition, new hierarchies are being implemented. There is the Synchronous Digital Hierarchy (SDH) and, in the US, SONET (Synchronous Optical Network). Although similar, the exact rate at each stage of these hierarchies of different than those shown here.

The output of each multiplex stage may form the tributary stream for the next stage of multiplexing or may pass directly to a transmission system. Digital microwave radios are available to transmit at any of these rates up to 139 Mb/s (3*DS3 in the US) and more recently 155 Mb/s for synchronous systems. The theory and measurements presented in this paper apply to all these radios.

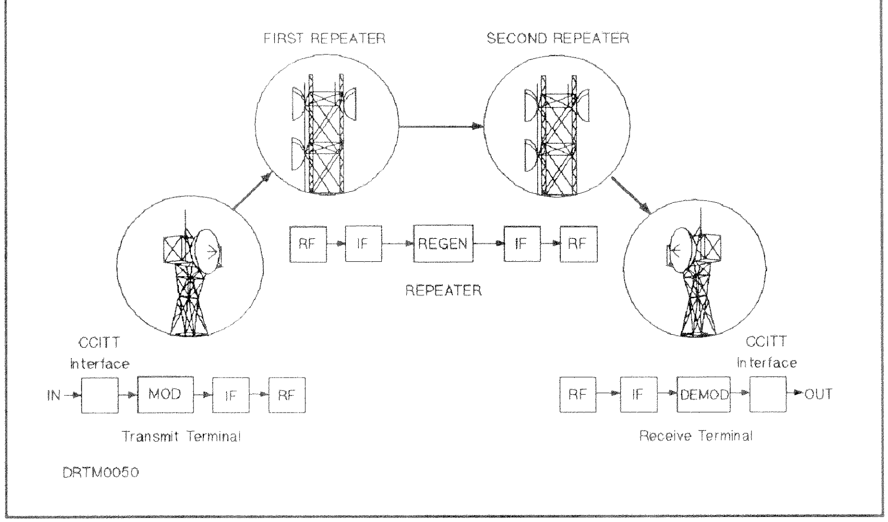
Digital Transmission Systems



The bit rates and interface codes etc. shown in the previous slide are all standardized by CCITT (International Telephone and Telegraph Consultative Committee) and are independent of the particular transmission medium used. The transmission system may carry traffic at any of the bit-rates in the hierarchy, depending on the capacity through-put requirements of the system. The testing and the performance of the system at these interfaces relates to network performance in the IDN and again is specified by CCITT (Rec. G821, G703 etc.) independent of the transmission media. These standards have been adopted by CEPT in Europe and by the ANSI/ECSA* TI Committee in North America.

This slide shows the four commonly used methods of transmission. Optical fiber is the most popular for high-capacity routes in Network Operators (PTT's, Telcos and Common Carriers) where existing routes or "way-leaves" exist. However microwave radio and satellite have many applications in lower capacity routes, in difficult terrain, in private and military communication networks and where the advantages of flexibility, security and speed of installation offered by radio are particularly valuable.

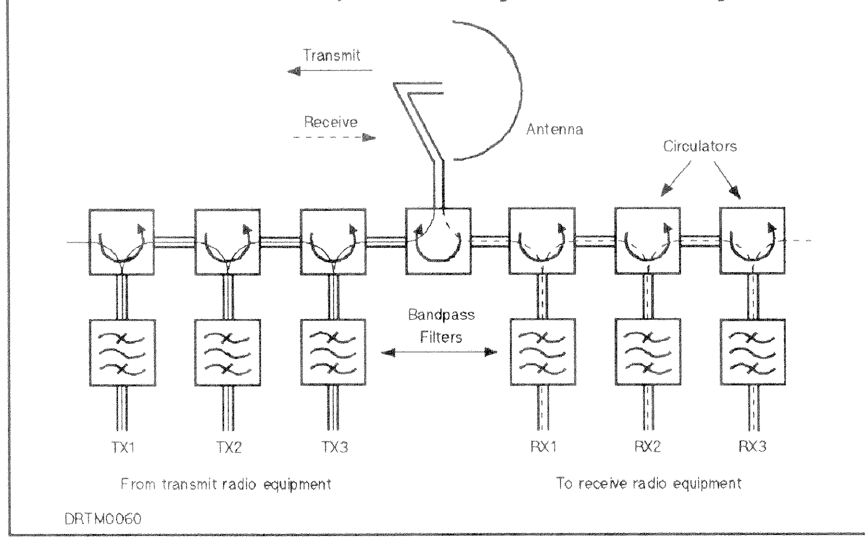
**Exchange Carriers Standards Association TI Committee of the American National Standards Institute.*



A Multi-Hop, One Way Microwave Link

A practical radio relay system often consists of several hops as the maximum distance between transmit and receive antennas or "hop length" is normally 30 - 60 km (20-40 miles) in a line-of-sight system. The intermediate stations are called repeater stations and the traffic data stream may not necessarily be brought down to the CCITT interface at these points, but simply regenerated at the binary level. Some radios use a direct IF repeater without regeneration. This saves cost, but some of the benefits of digital transmission are lost because of the build up of noise and distortion in a similar way to analog radio systems.

The microwave frequency bands and the radio channel spacing in these bands have all been standardized by CCIR (Internaltional Radio Consulative Committee) and FCC in North America. Some typical frequency bands are 2 GHz (used for lower capacity), 4, 6, 7, 8, 11 and 14 GHz. Above 11 GHz rain attenuation becomes a greater problem necessitating a shorter hop length for a given system availability. There is a new generation of radios becoming available, operating in the range 15 -50 GHz which provides low and high capacity short-haul links in cities for interconnecting business centers with main transmission centers. The small physical size of antennas at these frequencies makes this type of link very easy to install.

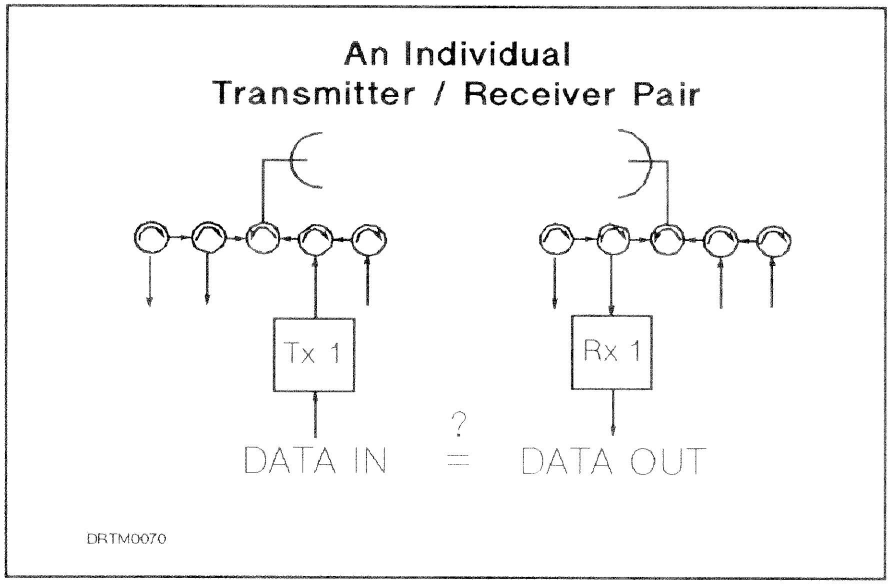


A Multi-Channel, Two Way Antenna System

Several radio channels operate simultaneously in the same microwave band and through the same antenna. The combination and separation of these radio channels are carried out by waveguide filters and circulators. The filters must be carefully designed to avoid interference between adjacent channels. In addition, adjacent channels may be placed alternately on horizontal and vertical polarizations of the antenna to futher improve the isolation.* There is also increasing interest in "frequency reuse", whereby two independent radio channels operate simultaneously on the same frequency but on opposite antenna polarizations.

Sometimes one channel in a multi-channel system is assigned as a protection channel. If the error-rate on a particular traffic channel exceeds a certain threshold, the protection switch will automatically switch the traffic to the protection channel (called frequency diversity). The protection channel can also be used for scheduled out-of-service maintenance on a traffic channel.

**Lightly loaded multi-channel systems may use one polarization for all receivers and the other polarization for all transmitters (for improved isolation, Tx-Rx). More heavily loaded systems will place adjacent channels on alternate polarizations, using separate Tx and Rx antennas for maximum adjacent-channel isolation as well as Tx-Rx isolation.*



In this seminar we are concerned with the individual transmitter/receiver pair. This is the basic building block of the radio network. In a perfectly operating radio the output data stream will be the same as the input data stream. How close the output matches the input is the fundamental measure of the radio link's quality.

Remember, although we only talk about a single radio, that radio is part of a much larger network.

INTRODUCTION

How a Digital Radio Works

Block Diagram

- Coding
- Digital Modulation

Bandwidth Considerations

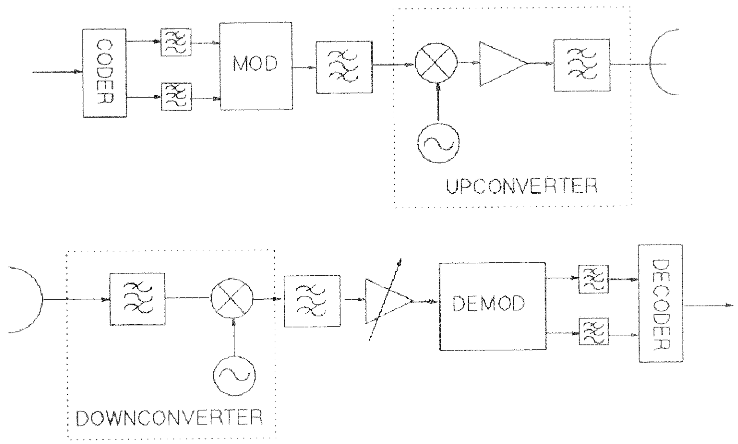
- Spectral Limiting
- Ideal Filtering
- Practical Filtering

NOISE AND DISTORTION

DRTM0080

In this section on "How a Digital Radio Works", we will first look at the similarity between an analog and digital microwave radio and then look more closely at the unique features of a digital radio. We will develop the concept of digital modulation and how we visualize this modulation. Finally, we will look at the issue of bandwidth utilization in digital radio.

Digital Radio Block Diagram



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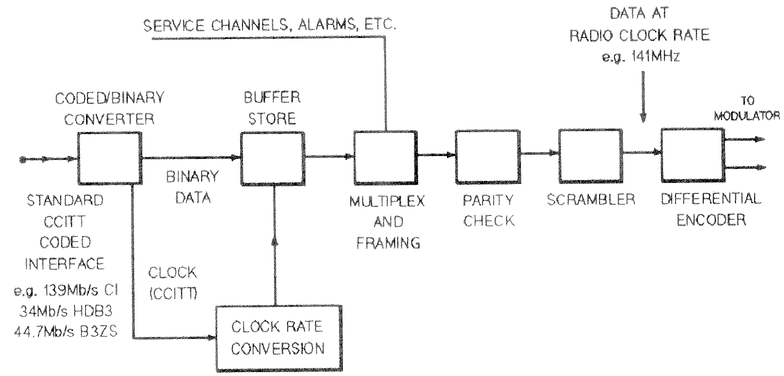
Coding



Typical Digital Radio Coder

DRTM0100

Here is a simplified block diagram of a digital radio transmitter and receiver. Those of you familiar with analog radio will recognize a strong similarity in the block diagram, though the modulator and demodulator sections are very different as we shall see later. This block diagram shows IF modulation and demodulation (at the familiar 70 MHz or 140 MHz IF) with up and down conversion to the microwave transmit frequency. Most high-capacity digital radios use this system but there are quite a number of low-capacity radios with simple modulation schemes which use direct modulation at microwave frequencies. In this case the modulator is connected directly to the power amplifier.

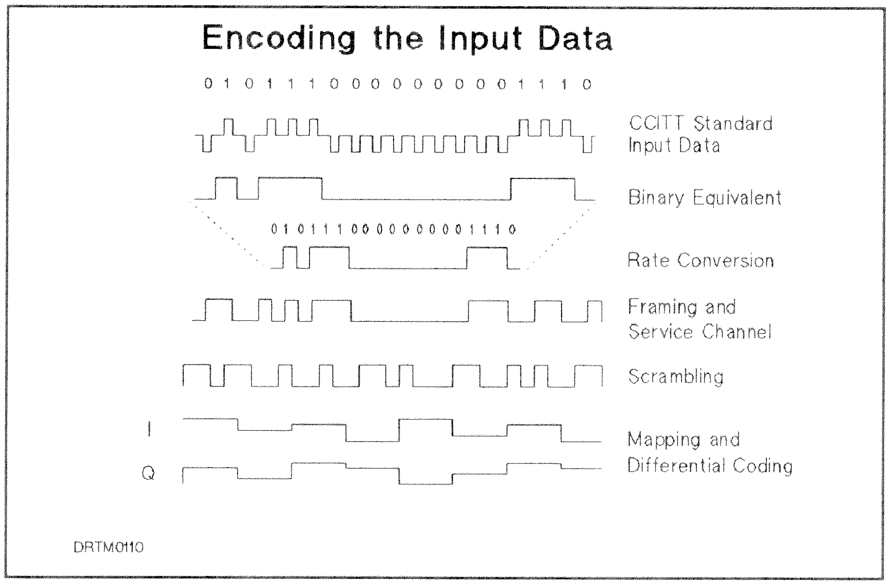
Most radios use the same receiver structure with down-conversion to the IF where the automatic gain controlled amplifier (typically 50 - 60 dB range) maintains a constant level to the demodulator during fading.

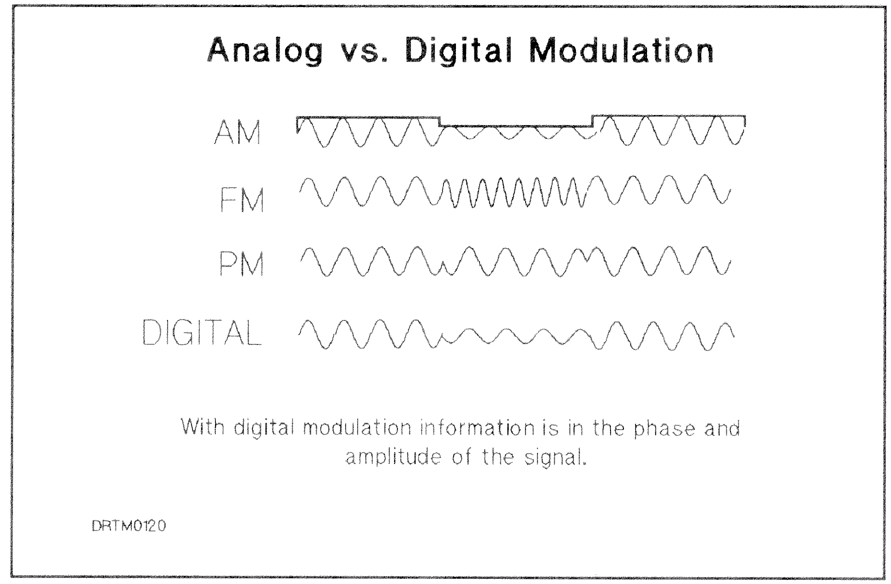
Notice the various filters through the transmitter and receiver. These are very important in the overall design as we shall see later. First we will look at the coder and decoder sections which provide the interface to the outside world.

At first this block diagram looks rather complicated; however, its function is simply to provide the standard CCITT interface to the integrated digital network and then adapt the sequential bit stream to add the additional information used by the radio. The result is that the radio operates at a higher bit-rate than the CCITT interface. The additional information such as digital service channels* and alarms are multiplexed into the data stream along with framing signals to allow the receiver to sort out which bit is which. A parity circuit adds error correction coding to produce an even or odd number of ones in a given block of data. Then the signal is passed through a scrambler to randomize the data being transmitted. The error coding information is used by the receiver to check for and correct errors in transmission and to initiate protection switching. The differential encoder provides the interface to the digital modulator and decides how the binary data will be encoded on the individual phase states.

In practical radios, two or more of these blocks may be combined into a single function or even one integrated circuit! At the receiver the decoder performs a similiar function in reverse. Note at a repeater station where no CCITT interface is required, some of the blocks may not be required. Generally this digital circuitry is highly reliable and does not require testing in installation or maintenance with the exception perhaps of jitter testing at the CCITT interfaces (G823 CEPT Standards, G824 North American Standards and Bell Technical References 43501 and 43806 and ECSA T1X1.3 Committee).

** Service Channel and Alarm capabilities are typically short haul, "part-line" communication channels used for maintenance of the radio system. Some radios do not use digital service channels but instead frequency modulate the audio channel directly onto the carrier signal independently of the digital transmission.*

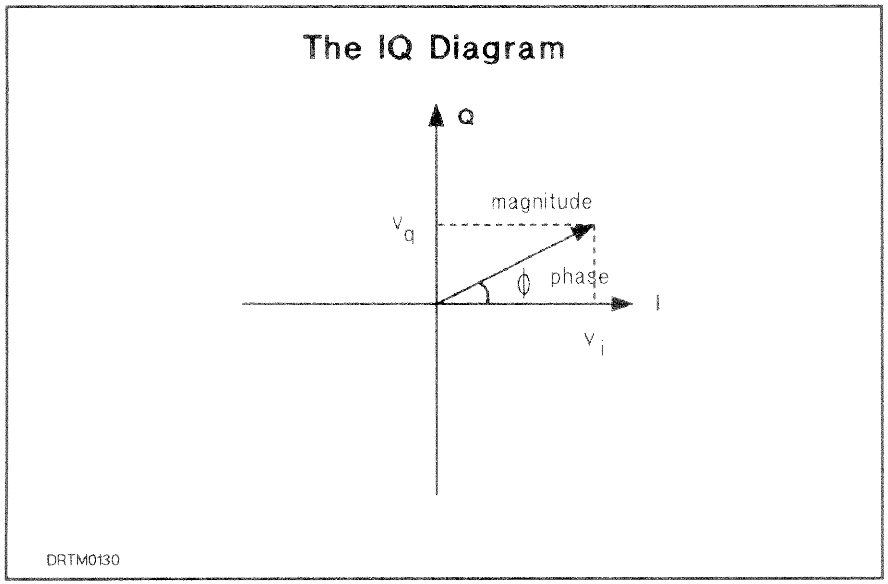




Here is an example of how the coding circuits of a radio might modify an incoming data stream. In our example, the incoming return to zero (RZ) signal is converted to a typical nonreturn to zero (NRZ) format. Depending on the rates the signal may be TTL or ECL. The radio will add additional information to the incoming data. Therefore, to accomodate this additional information the original data is converted to a higher rate. The radio specific information is then added. The original data may contain a long sequence of zeroes. If transmitted this would alter the desired spectrum and confuse the receiver. To avoid this problem, a psuedo random sequence is modulated onto the data stream. This sequence is known by the receiver so that the original signal can be recovered. One of the final steps is to create two signals, I and Q, which are fed to the modulator. These signals determine the resulting digital format of the transmitted signal.

The coder and modulator work together to put the data information onto the carrier. Digital data can be put on a carrier using analog modulation like amplitude modulation (AM), frequency modulation (FM) or phase modulation (PM). Digital modulation is very similar to analog modulation in many respects. In fact, digital or I-Q modulation is a combination of amplitude and phase modulation. However, I-Q modulation transmits data more efficiently than analog modulation and is more immune to noise.

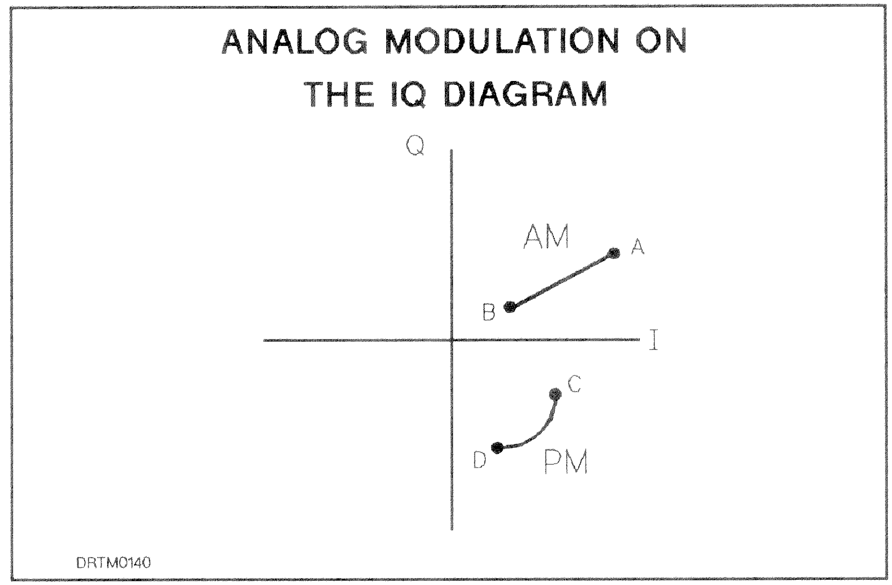
Before we discuss digital modulation further, it is useful to discuss the way that digital modulation can be described. I-Q modulation is easily described using the I-Q or vector diagram.



The sinusoidal microwave carrier can be defined in terms of its magnitude, frequency and phase relative to an arbitrary reference. In most digital radio systems the frequency of the carrier is fixed* so we need to consider only the phase and magnitude (or amplitude). As this slide shows, the phase and magnitude can be represented in polar or vector co-ordinates as a discrete point in the so-called I-Q plane. I stands for in-phase (i.e. phase reference) and Q for quadrature (i.e. 90° out-of-phase). We can then also represent this point by vectorial addition of a certain magnitude of in-phase carrier with a certain magnitude of quadrature carrier. This is the principle of I-Q modulation.

By forcing the carrier to one of several pre-determined positions in the I-Q plane, we can then transmit encoded information — each position or state representing a certain bit pattern, which can be decoded at the receiver.

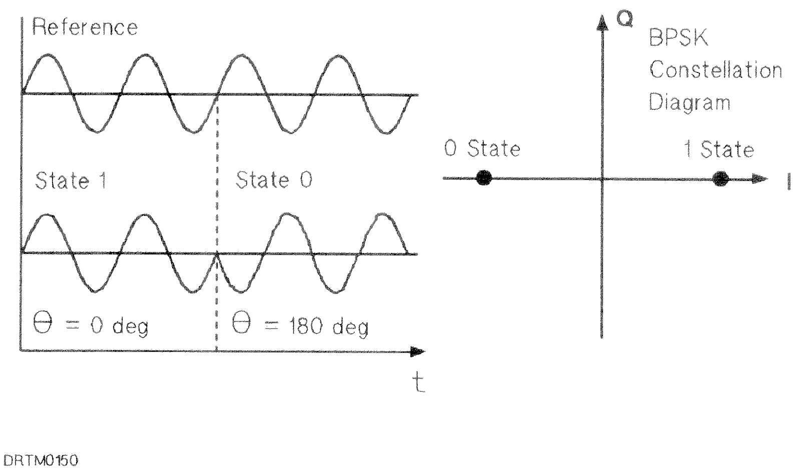
* *Some low-capacity radios and satellites use frequency shift keying (FSK) and minimum shift keying (MSK) but these are not included in the present explanation.*



The IQ diagram is most useful to show the possible phase/magnitude states of a digital modulation format. However, analog modulations can also be described. In AM, the phase of the signal remains constant and the magnitude of the signal (its distance from the center) changes with the data. For example, if the signal has magnitude A then this may be interpreted as a 1 is being transmitted. When the magnitude is changed to B then a 0 is transmitted. In phase modulation the amplitude stays constant but the angle of the signal gives the information. C may mean 1, D may mean 0.

FM is more difficult to describe on the IQ diagram. What would it look like?

BPSK Timing and State Diagram



One of the simplest digital modulation formats is Bi-Phase Shift Keying (BPSK or 2-PSK). Here the carrier magnitude is constant and to transmit either a '0' or '1' the phase is "keyed" or switched between 0° and 180°. The receiver decides whether a '0' or '1' was transmitted and regenerates the original data stream. Notice that in this simple scheme only one bit of information is transmitted with each state or symbol, so the carrier phase is keyed at the data rate.

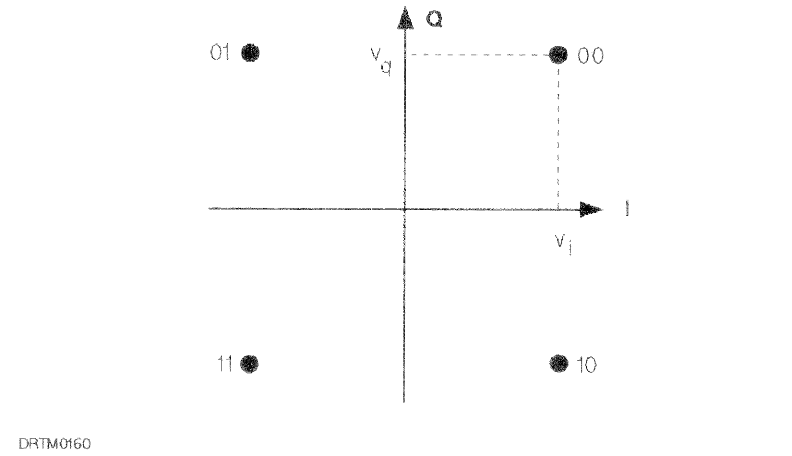
BPSK is simply a special case of PM with two allowed phase values. For noise immunity these two states are placed as far apart as possible (ie: 180°).

BPSK is popular for satellite communication because of its resistance to noise. However, BPSK is the least bandwidth efficient digital modulation.

Notice that the "constellation" contains two points. These represent the position of the signal at the "timing instant". The timing instant is when the receiver interprets the signal. The signal can only be at one position at a time, but the constellation can be thought of as having persistence so that all the possible states appear. Not shown are the transitions between states. The signal takes a finite time to change between states. If these transitions were shown then we would see a series of traces connecting the states.

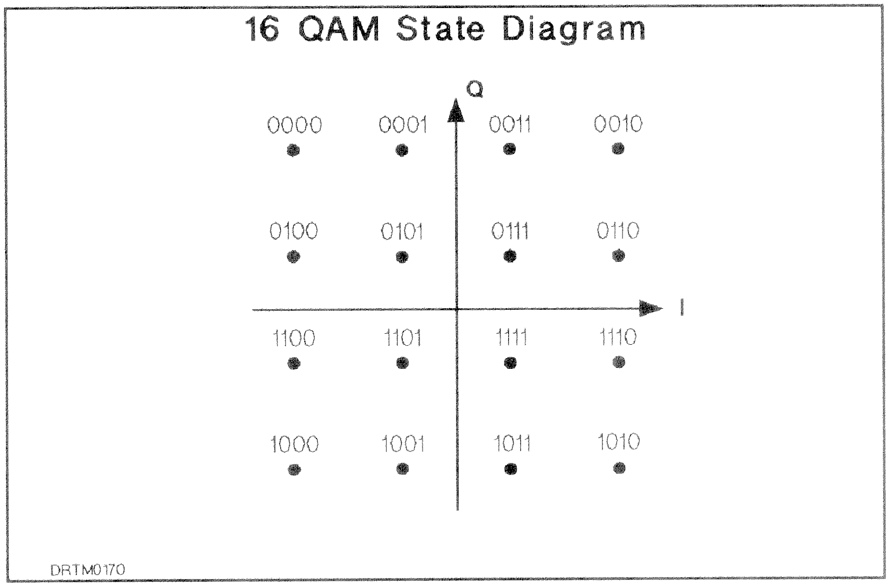
QPSK Modulation

4 Possible States



Quadrature Phase Shift Keying (QPSK or 4-PSK) again uses constant carrier magnitude but now four different phase values (i.e. 45°, 135°, 225° and 315°) are used. The modulation phase-states can be generated by adding together appropriate amplitudes of in-phase and quadrature carrier (V_i and V_q), or alternatively by phase-shifting the microwave carrier directly using an electronically switched phase shifter such as waveguide stubs or delay lines.

Because we have four discrete states or symbols, we can transmit more information per state — in this case, as you can see, 2-bits of binary data are encoded on each of the states, or symbols. Because the serial data is taken 2 bits at a time to form the symbol, the symbol-rate is half the bit-rate. Intuitively you can probably deduce correctly that QPSK would only require half the bandwidth of BPSK for the same bit rate as its symbol-rate is half. This is because the bandwidth required is proportional to the "symbol rate" not the "data rate."



The quest for greater bandwidth efficiency has led to ever more complex modulation schemes. 16 QAM which stands for "Sixteen State Quadrature Amplitude Modulation" takes 4 bits of serial data and encodes them as a single phase state, or symbol, thereby reducing the symbol rate to one quarter of the bit rate. In order to generate this type of modulation the I and Q carriers need to take four different possible levels of amplitude (+3, +1, -1, -3) depending on the code being transmitted.

Perhaps you will have noticed the way the phase states or symbols are assigned with 4-bit words. Adjacent states differ by only 1 bit so that if an error is made in the receiver in determining the transmitted state only 1-bit error will be generated, not 4. (See PN 3708-3 pages 24-26.) This is called Gray Coding.

Symbol Rate:

"The rate at which the carrier moves between points in the constellation"

DRTM0180

Digital radio is similar to analog radio with a special form of modulation. The signal moves among a limited number of discrete phase/amplitude states, or symbols. The more symbols that are used, the lower the required symbol rate for a given bit rate.The symbol rate is important because it tells you the bandwidth required to transmit the signal. The lower the symbol rate the lower will be the required bandwidth for transmission.

Example:

A 16 QAM radio has 4 bits per state (or symbol).

If the radio operates at 16 Mb/s, then the carrier must change states $\frac{16 \text{ Mb/s}}{4 \text{ Bits}}$

or

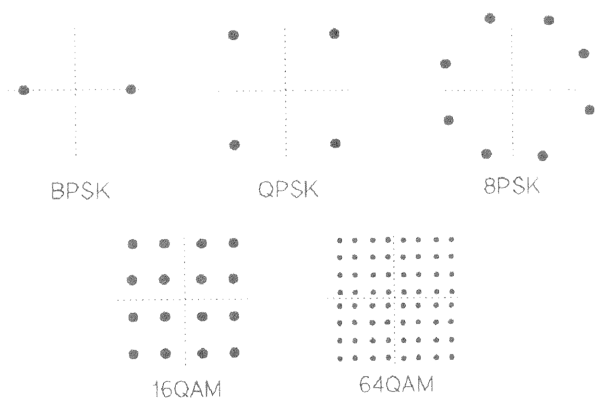
4 million times per second (4 MBaud).

SYMBOL RATE = 4 MHz

DRTM0190

This demonstrates the simple but important concept that bandwidth is related directly to symbol rate.

Some Typical Modulation Formats

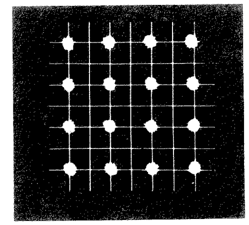


DRTM0200

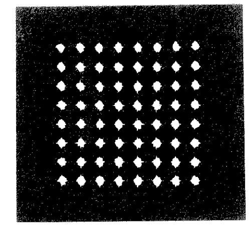
In summary here are some common digital radio modulation schemes from simple BPSK to complex 64 QAM. It is interesting to compare the bandwidth efficiency of these schemes with analog FM radio when transmitting telephony. When carrying 64 kbit PCM, only 64 QAM can match an FDM/FM radio! So why does anyone bother with simple modulation schemes? The answer is that with 64 QAM the states are so close together that the immunity to noise and interference is greatly reduced compared with BPSK and QPSK. In hostile or noisy conditions (e.g. satellite) the simple schemes are favored. In high-capacity line-of-sight systems where signals are strong, bandwidth efficiency is often considered more important. Systems as complex as 256 QAM are now being put into use.

Although they are not shown here, 128 QAM and 32 QAM (also called TCM, Trellis Coded Modulation) are becoming common. These are cross shaped modulation formats. Although these are slightly more complicated than square modulations, they allow 140 Mbit/s radios to transmit at 155 Mbit/s by only changing the modem section. This means that many radio owners can preserve much of their original investment in digital radios and still "upgrade" these radios to allow their use as tributaries in the new synchronous networks.

Practical Constellation Diagrams



16 QAM CONSTELLATION

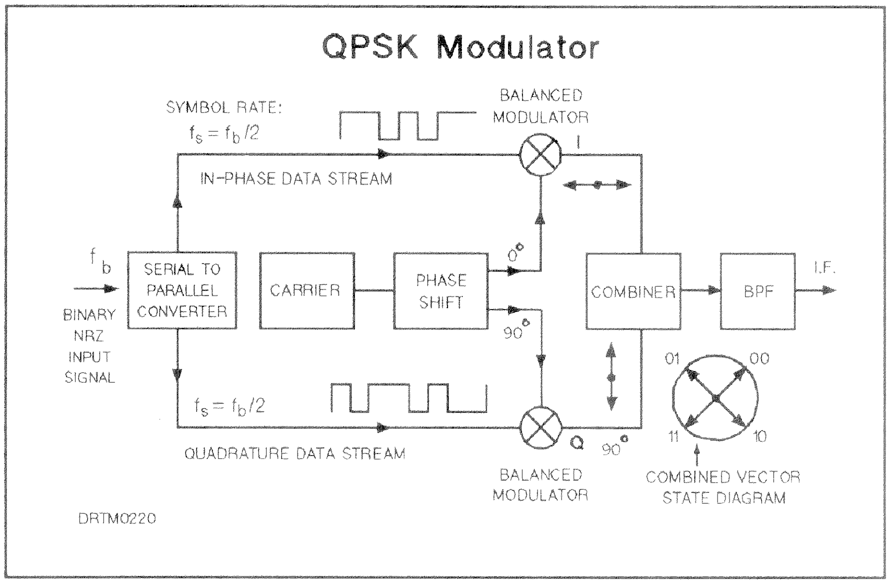


64 QAM CONSTELLATION

DRTM0210

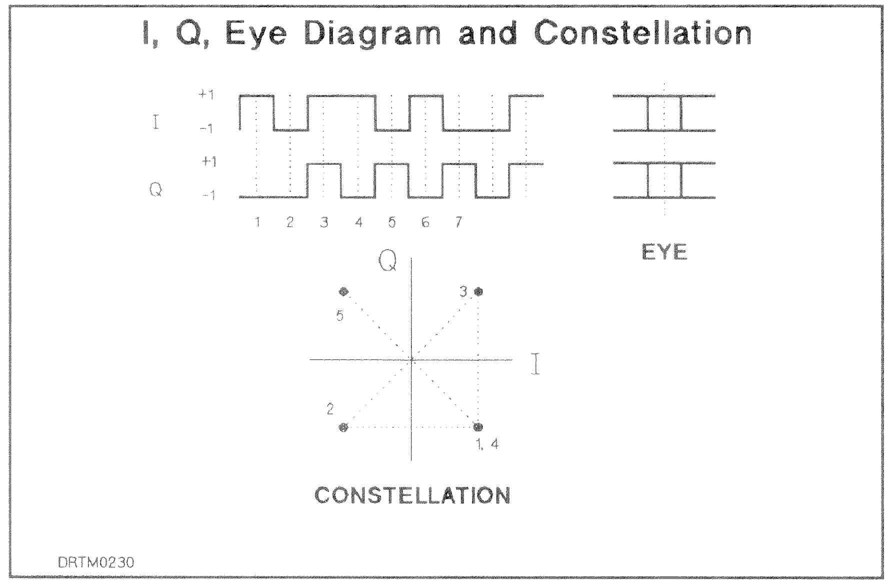
The constellation diagram is so called because the cluster of dots round each phase state looks like star clusters. Theoretically these should be single points, but a practical radio suffers various impairments and noise which cause a spread on these states.

We will spend some time on this topic as an understanding of constellation diagrams and eye diagrams is very valuable in understanding degradations in the radio. The space between the phase states, the eye-opening in the eye diagram, is a measure of quality of the radio and the probability of error.



This slide shows the simplified block diagram of a QPSK (4-PSK) modulator. In QPSK the incoming bit-stream is divided into two parallel streams so that one bit is fed simultaneously to both I and Q balanced modulators to construct the 2 bit symbols. The carrier output from the modulator is controlled by the digital bit-stream and by adding together the I and Q outputs the phase state diagram is generated.

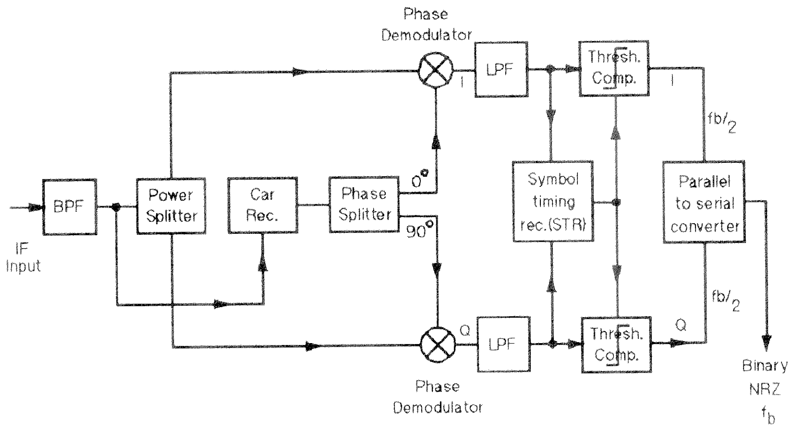
In this case the bandlimiting filter is a bandpass filter at IF, though, provided the modulators are linear, the filtering could have been implemented with LPF filters before the balanced modulators, thereby shaping the spectrum of the incoming pulses. Practically, some band-limiting is required before the modulators, otherwise the very wide *sin x/x* spectrum will fold around dc and overlay the desired central lobe of the spectrum.



Notice in the previous picture that the modulator uses an I and a Q signal. These signals determine the type of modulation created by the modulator. In this picture both the I and Q signals carry one bit of information. This means that each signal has two levels. This tells us that the output will be QPSK. The top two waveforms are I vs. time and Q vs. time. They are marked at equally spaced "timing instants". At these instants the waveform has settled to one of its predefined levels (two possible levels for QPSK). If we plot I vs. Q we see the constellation. I and Q each have two possible states so there are four states in the constellation.

The EYE diagrams are simply I vs. time and Q vs. time as these waveforms appear on an oscilloscope which is triggered at the timing instants.

QPSK Demodulator



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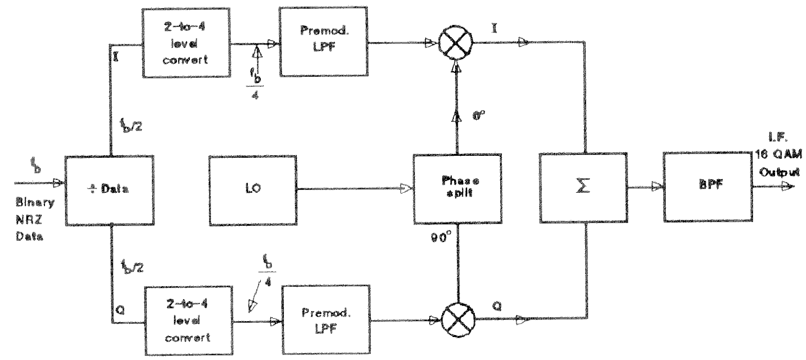
16 QAM Modulator

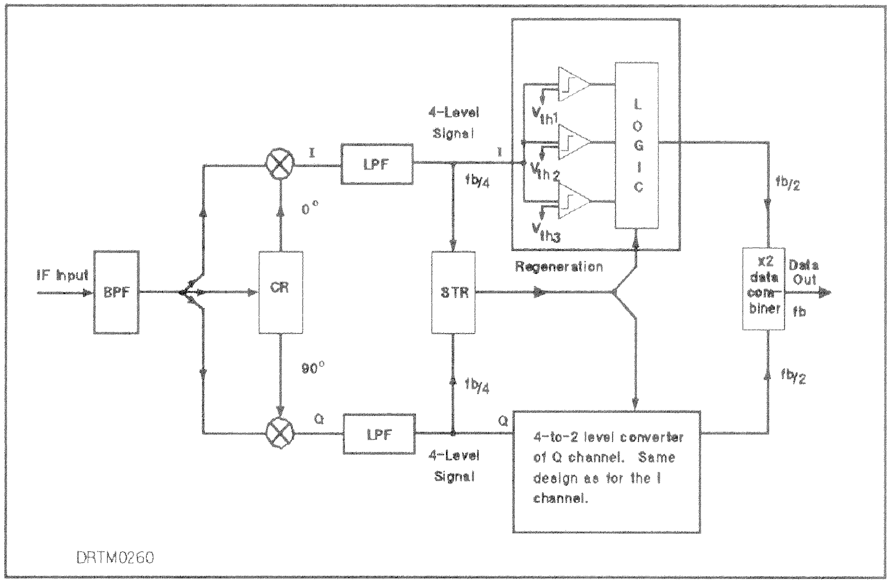


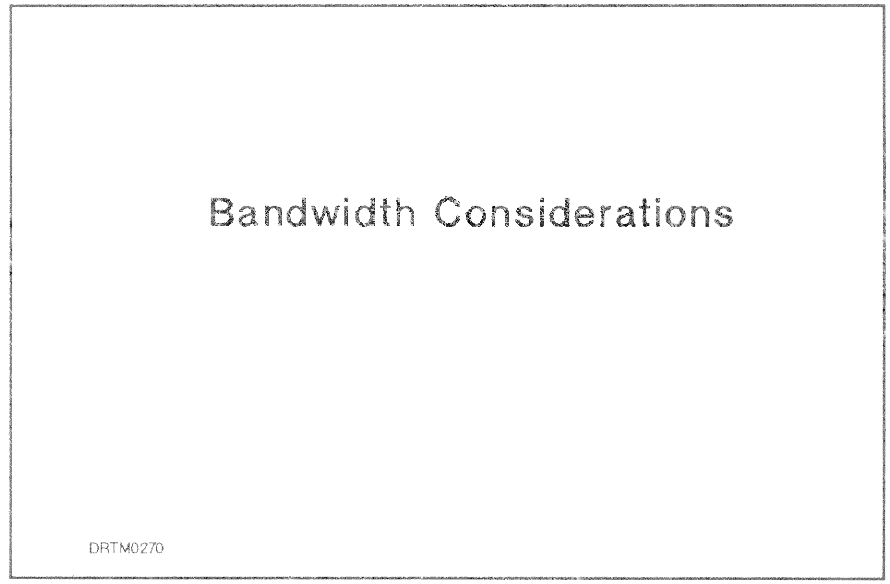
DRTM0250

The QPSK demodulator works in a similar way to the modulator, extracting the I and Q streams by demodulation using in-phase and quadrature carrier signals. The demodulator is more complicated because it must recover a carrier signal and timing signal from the incoming IF. Carrier recovery is usually implemented using a non-linear process such as frequency multiplication followed by a phase-locked loop. Symbol-timing is recovered from the demodulated data stream by a tuned circuit or phase-locked loop filtering out the clock component in the data stream. The scrambler in the transmitter ensures there is always a clock component independent of the data fed to the radio input.

The demodulator I and Q streams are filtered to remove unwanted IF signals and then passed into threshold detectors where a signal is sampled by the symbol-timing clock to determine whether a '1' or '0' is present and to regenerate the data stream. It is during this sampling and regeneration process that errors occur as we shall see later when we consider the effects of noise.

The 16 QAM modulator is similar to the QPSK modulator except that I and Q carriers are now each modulated by 4-level signals. Two serial bits are converted to one of four voltage levels (by a simple DAC) which control the output of the balanced modulators. This shows how the symbol rate becomes $f_b/4$. In 64 QAM 3 bits are taken to generate one of 8 voltage levels on both I and Q streams. For these systems it is necessary to use linear modulators otherwise the phase state diagram will be distorted since the four voltage levels will not translate directly to the correct carrier level.



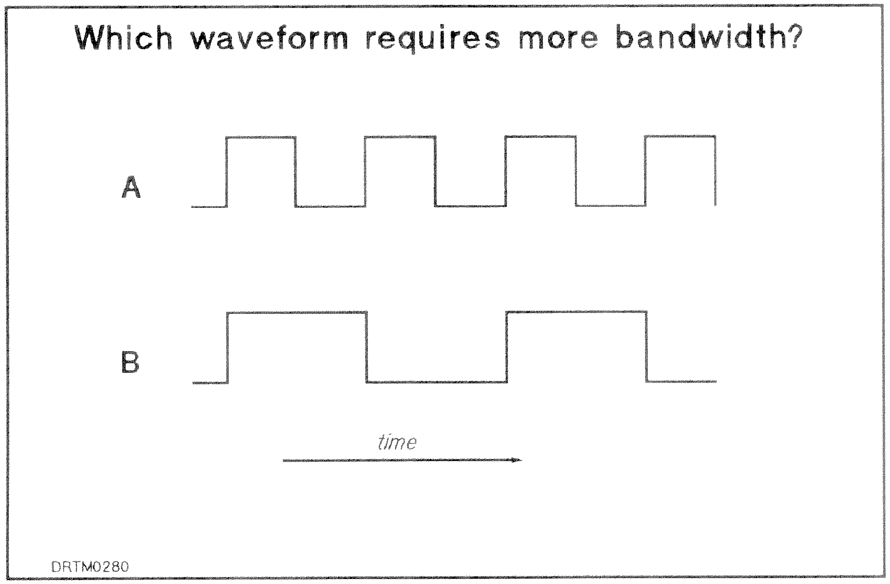


Again the 16 QAM demodulator is similar in outline to the QPSK demodulator except that the threshold detector needs to be more complicated as it must decide which of 4 possible values the signal has. With a knowledge of the encoding scheme used for the 16 phase states, the logic can be designed to regenerate the 4 bit words per transmitted symbol and so recreate the original bit stream.

In 16 QAM systems the stability and accuracy of the modulator and the demodulator are very critical to the overall performance of the radio. Some designs use adaptive techniques to reduce the effect of drifts.

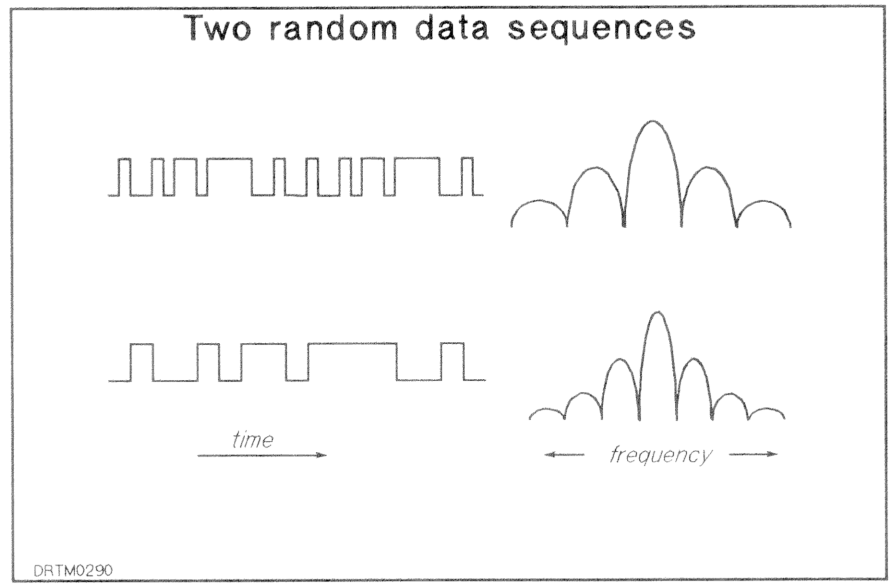
Comment
Some radio and satellite systems use so called Offset Keyed or Staggered modulation. In these systems a delay of half a symbol-time is introduced between the I and Q data streams, so that the modulation envelope is not synchronized on both I and Q carriers. This has the advantage of slightly reducing the peak-power handled by the transmitter. Systems in use include Offset QPSK (OKQPSK) and Offset or Staggered QAM.

Having reviewed the principles of digital modulation, we will now look at the bandwidth required for transmission of these signals.

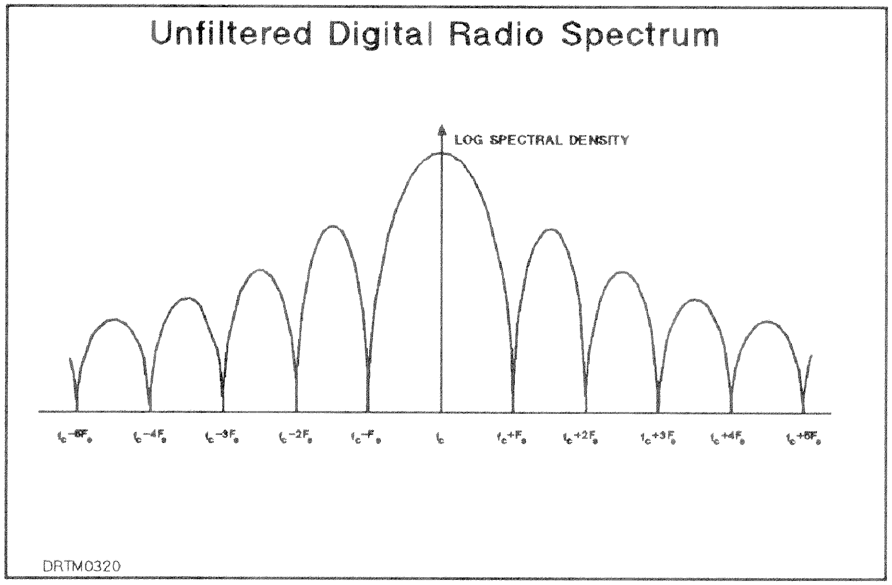


Earlier, we said that the bandwidth occupied by the digital radio transmission is proportional to the symbol rate. This may be a little ambiguous, however. Consider these two waveforms. Which occupies more bandwidth?

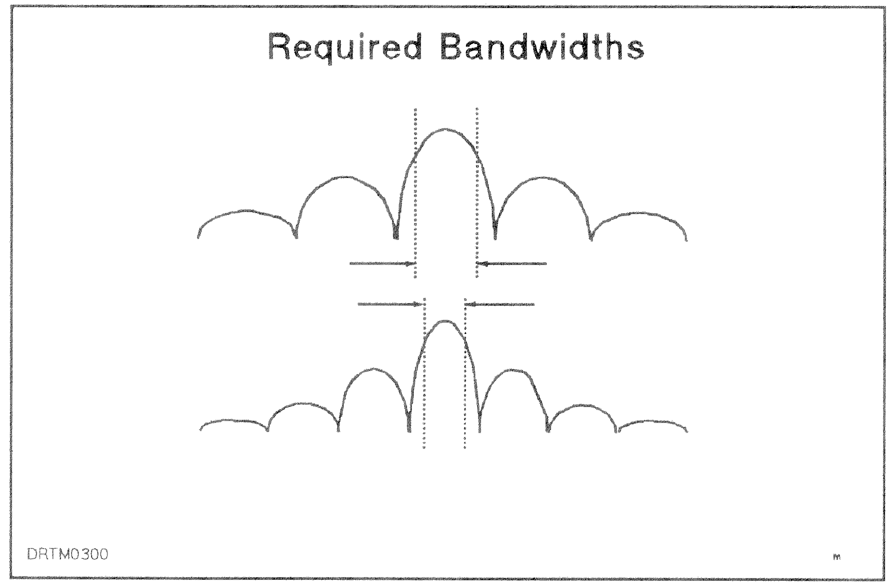
It's a trick question because, if you assume each has instantaneous transitions, then each requires infinite bandwidth (their harmonics continue infinitely). Of course, this much bandwidth is not required to convey the information in the signal. If we filter all but the fundamental component of each signal, B requires less bandwidth than A. This idea extends to digital modulation.



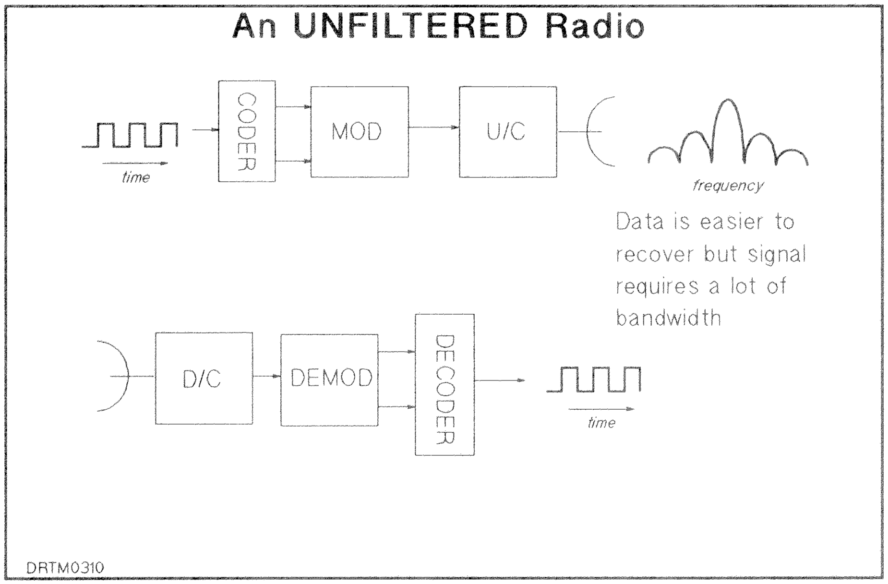
On the left are modulating waveforms for a BPSK radio. On the right are their associated spectrums. Because the upper waveform has a lower symbol rate, each lobe of its spectrum is wider (requires more spectrum).



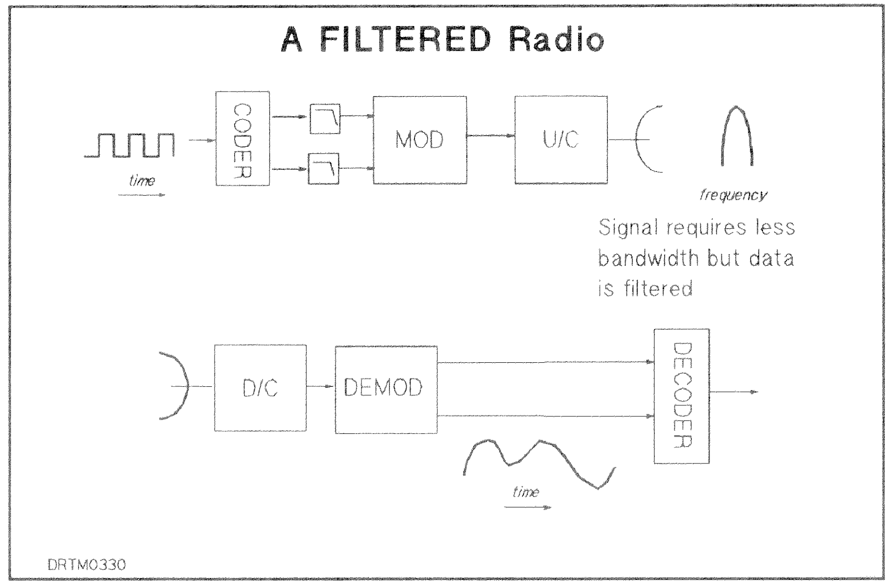
The unfiltered output of the digital radio modulator occupies a very wide bandwidth, theoretically infinite defined by the *sin x/x* characteristic. The digital signal modulating the radio is random, so the spectrum analyzer shows a noise spectrum picture with a spectral density shown in the slide. In fact, the spectrum of the radio should be independent of the data input to the radio - this is the purpose of the scrambler. The nulls in the spectrum occur at multiples of the symbol rate of the radio. The absence of the scrambler could cause a line spectrum to appear with some repetitive incoming data streams.



As we shall shortly see, the spectrum actually used by a digital radio is a percentage of its main lobe. Therefore, if this lobe is wider, more spectrum is used in transmission. Filters are used throughout the radio to limit the spectrum and the minimum tolerable bandwidth is determined by the symbol rate.

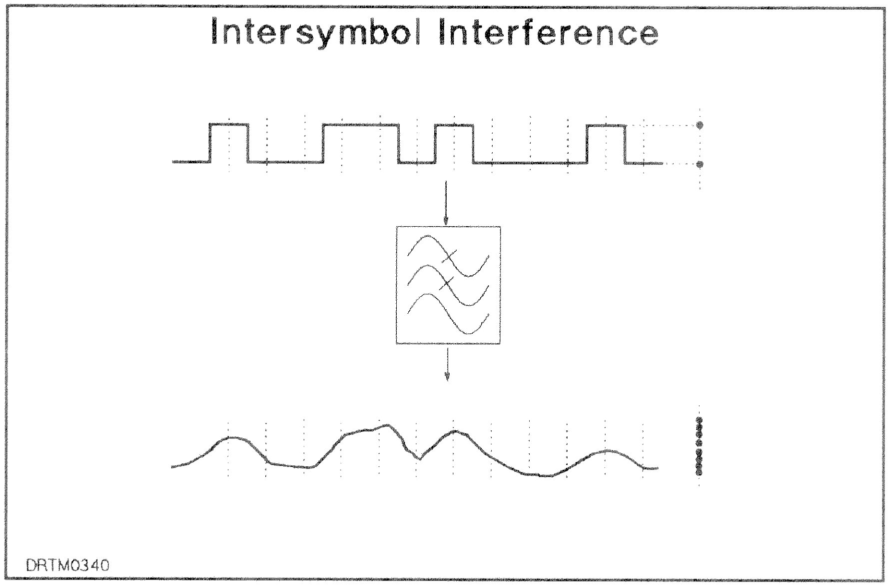


But why limit the spectrum? In an ideal world we could use a radio with no filtering. The radio would transmit the nice square pulses of our data stream. We could easily recover the data at the receive end. The problem is that this radio would take up a lot of frequency spectrum with its transmission. If anyone else tried to transmit a signal close to ours, we would interfere.

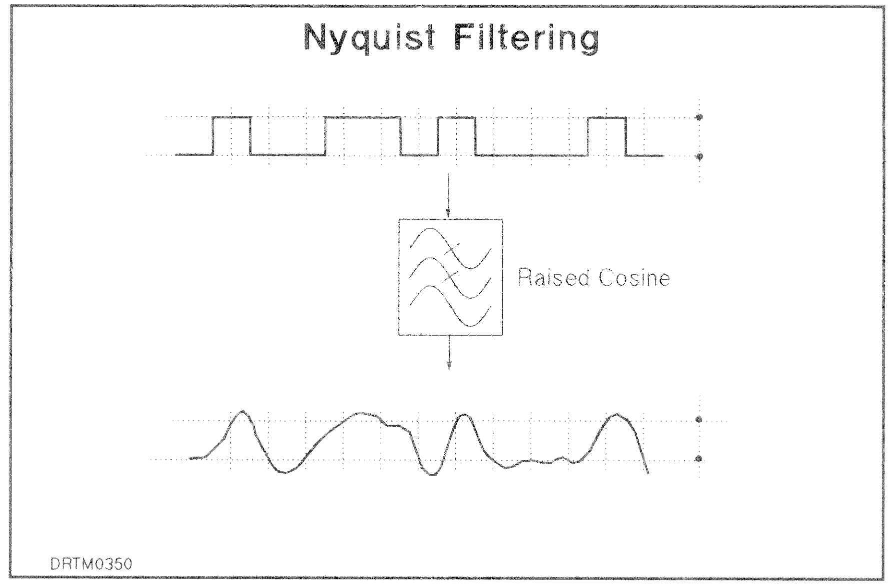


For practical application the radio spectrum must be restricted to avoid interference with adjacent channels. The radio filters are designed to do this while, at the same time, not degrading the data transmission.

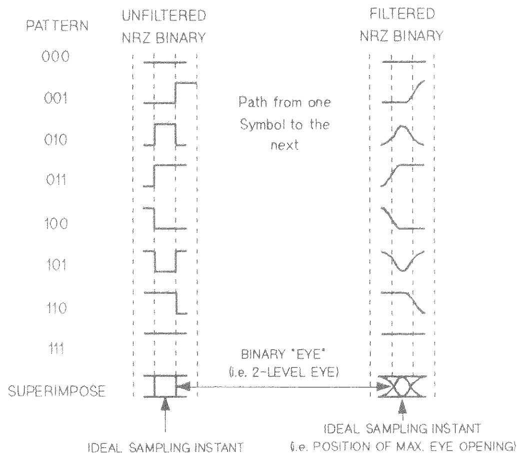
Our signal is filtered so that it is completely contained in a relatively small bandwidth. In this way, other radios can transmit at frequencies close to our transmit frequency. However, filtering our signal will make it difficult to decode. In fact, without careful attention to the pulse shaping effects of filters, the error rate can increase dramatically.



We wish to send a signal which has only a specific number of possible values at the timing instants. If we poorly filter our data stream the result will be many possible levels on the output. In fact, the output level resulting from a '1' being transmitted can change depending on the data which preceded it. This problem is called intersymbol interference.



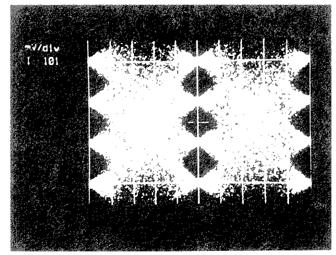
There are certain types of filters which don't cause intersymbol interference (ISI). These filters limit the spectrum to provide high spectral efficiency. In addition, these filters resonate in such a way that, although the path between timing instants varies depending on the data sequence, the number of possible states at the timing instant remains unchanged. The result is that the output signal can be decoded once the timing instants are determined by the receiver.



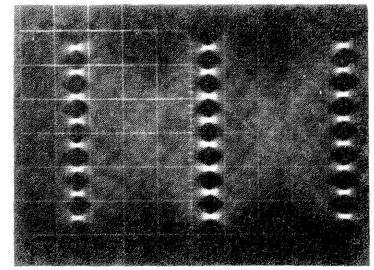
The effect of filtering is seen in the received I and Q signals. For an unfiltered system the transitions are instantaneous so the eye is square. In a practical filtered system the transitions are smoothed and we get the familiar eye-diagram shape. The optimum clock or sampling instant is at the point of maximum eye opening where there is the highest probability of correctly interpreting the state.

In a real signal, there will be many different paths for the signal to take between sampling instants. Therefore, between the sampling instants, the eye diagram will appear noise-like but will converge at the sampling instant to a discrete number of levels.

Practical Eye Diagrams

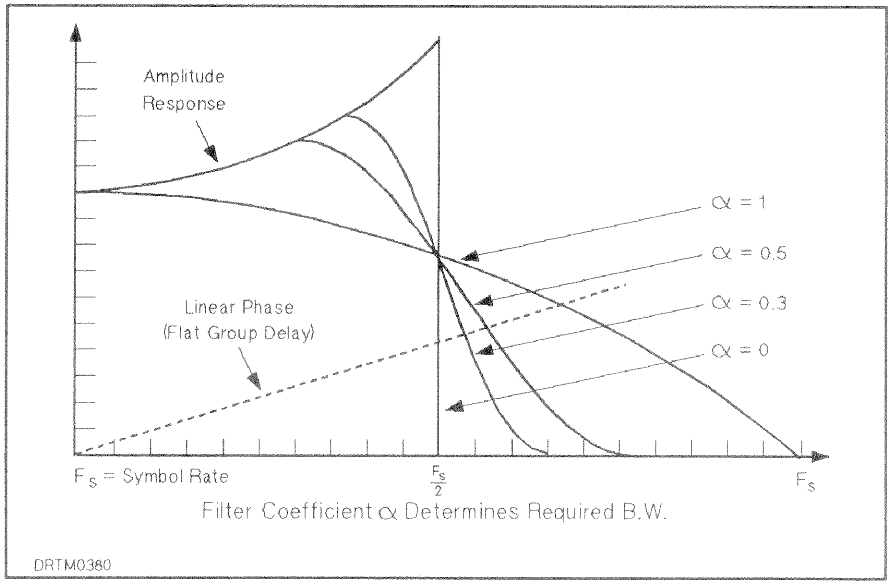


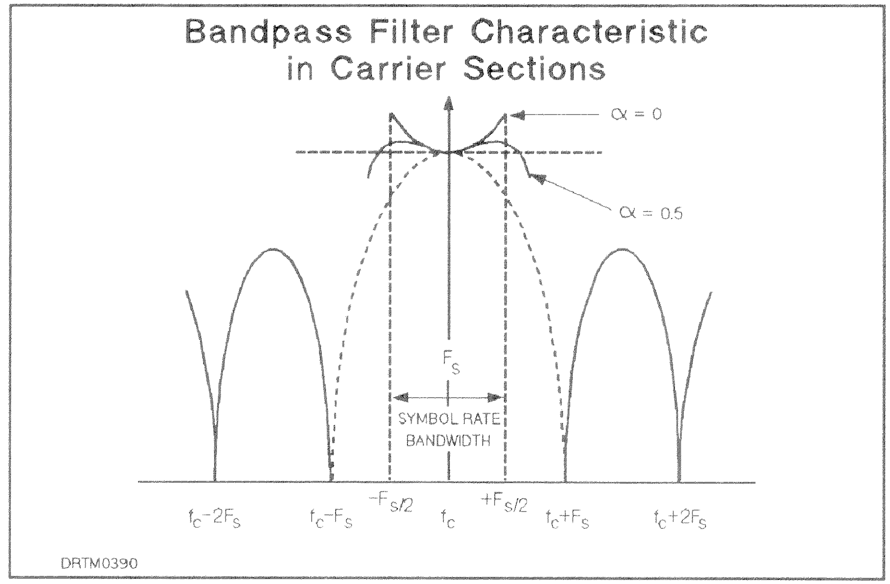
16 QAM EYE PATTERN



64 QAM EYE PATTERN

In digital radios the recontructed data streams often exhibit multi-level eye patterns as, for example, in 16 QAM (4 levels) and 64 QAM (8 levels). A QPSK system has a two level or binary eye. You can see that with more complex modulation schemes the state values are closer together which means they have less tolerance to noise and interference as well as misalignment. You may also notice that the eye-width is narrower on 64 QAM than 16 QAM. This means that the system is less tolerant to errors or jitter in the symbol timing instant.





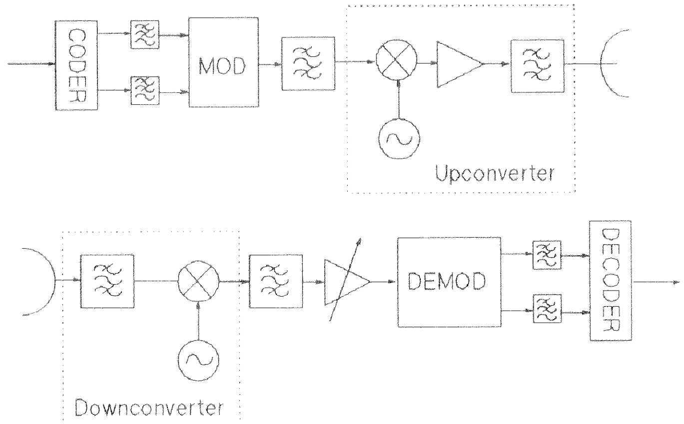
Shown here is a family of filters which work very well for digital radios. They are "raised cosine" filters with a sin x/x correction included. The shape of these filters is described by the alpha factor. Alpha is also called the roll-off or the excess bandwidth factor. The higher the alpha the more bandwidth which is used in excess of the theoretical minimum.

Modulation theory tells us that the minimum bandwidth needed to transmit a signal is equal to half of the symbol rate. However, to realize this system would require a perfect brick-wall filter. This is equivalent to an alpha of 0. This would give us the best possible spectral efficiency. Unfortunately this filter is unrealizable. In practice, radios typically use a filter alpha of about 0.3. This means that they take up 30% more bandwidth than the theoretical minimum.

The filters we discussed in the previous slide are all low-pass filters at baseband. Exactly the same criteria apply for bandpass filters at IF or RF with the filter characteristic mirrored about the carrier frequency. As we are now dealing with a double-sideband signal (due to modulating the I & Q signals on to the IF or RF carrier) we need twice the bandwidth, **so the minimum bandwidth required in the carrier section is equal to the symbol-rate or the symbol-rate bandwidth.**

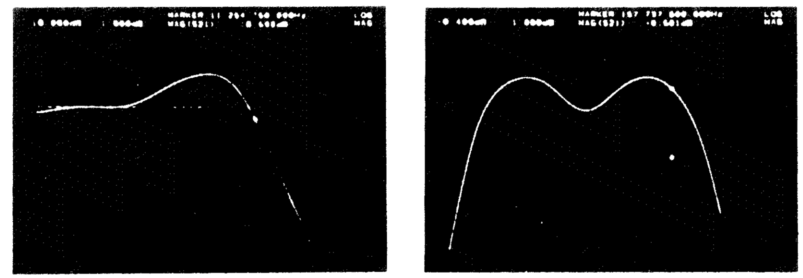
The actual bandwidth is equal to: symbol rate x $(1 + \alpha)$

The Filtering is Distributed in the Radio



DRTM0400

Practical Digital Radio Filters



(a) BB FILTER

(b) IF FILTER

DRTM0410

The overall filtering function we have been considering is the effect of cascading all the filters in the transmitter and receiver from the output of the coder in the transmitter to the input of the regenerator in the receiver. The overall response must have flat group-delay. The main bandshaping is usually shared between transmitter and receiver, for example a square-root raised cosine filter characteristic in each.

This shaping is often done by the IF filters and BB low-pass filters with RF sections being flat. Individual filters will not necessarily have the raised cosine response we have discussed and of course, will not always have a flat amplitude response familiar in analog radio.

Comment:

Practical radio filters may not have exactly the theoretical response described in this section. Modern computer optimization techniques enable a variety of amplitude and group delay characteristics to be synthesized which approximate to the zero ISI requirement.

Another variant in filter design is the so-called partial response system (PRS) or correlative system. In this design the channel bandwidth is deliberately restricted to less than the Nyquist bandwidth so that controlled ISI produces a multi-level signal. An adaptive filter or correlative detector is used in the receiver. Examples of these systems are 9 QPR (filtered QPSK) and 49 QPR (filtered 16 QAM). In common with other complex modulation schemes, greater bandwidth efficiency is achieved at the expense of noise immunity.

This slide shows some practical filter characteristics measured on the HP 3577A Network Analyzer. These are examples of raised cosine filtering at baseband (LPF) and IF (BPF). Over the passband the group delay is effectively flat. The markers have been positioned at the Nyquist frequency ($F_s/2$).

(a) Baseband filter for a 90 Mb/s 16 QAM radio with a symbol-rate of 22.5 Mbaud, $F_s/2 = 11.25$ MHz.
(b) I.F. bandpass filter (140 MHz) for a 140 Mb/s 16 QAM radio with a symbol-rate of 35 Mbaud $F_s/2 = 17.5$ MHz.

Check Your Knowledge

A designer is considering the radio channel bandwidth for a new radio with the following details:

Bit Rate :	140 Mb/s
Modulation :	16 QAM
Raised Cosine Filter :	$\alpha = 0.3$

What is the bandwidth required at RF?

DRTM0420

Solution :

16 QAM has 16 states with 4 bits / state
if the bit rate = 140 Mb/s,
then the symbol rate = 140/4 or 35 MBaud.

Thus the bandwidth, assuming a perfect filter, would be 35 MHz.

However, in practice, if the raised-cosine filter has a factor of 0.3, then the system would have an extra 30% bandwidth making it 45.5 MHz.

DRTM0430

This little calculation uses the ideas we have reviewed so far. If you can work it out you have a good understanding of digital radio principles.

By now you will realize that digital radio design is significantly different from analog radio, particularly in the area of modulation and filtering.

Spectral Efficiency

16 QAM
45.5 MHz Bandwidth
140 Mbit/sec

$$\text{Efficiency} = \frac{140 \text{ Mbit/sec}}{45.5 \text{ MHz}} = 3.1 \text{ bit/sec/Hz}$$

DRTM0440

The radio in this example packs 2.7 bits/sec of information into every Hz of bandwidth. How good is this?

Spectral Efficiency

Theoretical Limit

BPSK	1 bit/sec/Hz
QPSK	2 bit/sec/Hz
16 QAM	4 bit/sec/Hz
64 QAM	6 bit/sec/Hz
256 QAM	8 bit/sec/Hz

DRTM0450

AM radio is not a very efficient way to send digital information. The 16 QAM radio in the previous example doesn't use all of its potential efficiency. However, wasting a little capacity could make the design easier to implement and more robust.

SUMMARY

As the modulation complexity increases, the radio becomes more spectrally efficient. However, it also becomes more susceptible to errors caused by noise and distortions.

DRTM0460

The technology behind digital microwave radio is very complex. However, an understanding of the concepts discussed in the last few pages is sufficient to allow you to begin making successful use of and tests on a digital radio.

INTRODUCTION
HOW A DIGITAL RADIO WORKS

Noise and Distortion

Noise

- –Theory
- –Theoretical Waterfall Curve
- –Practical Waterfall Curve
- –Relating Impairments to C/N

Distortion

- –ISI and Closure
- –Effect on BER

DRTM0470

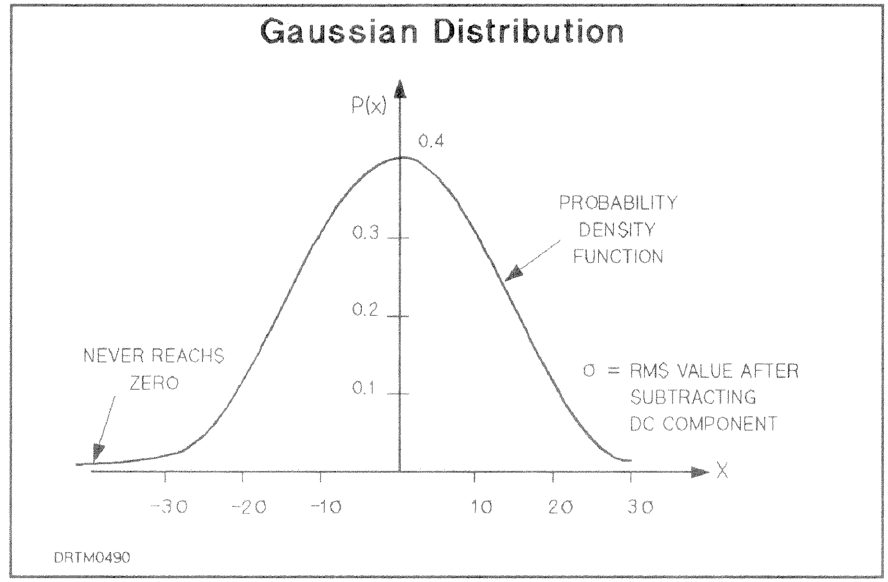
Up until now we have discussed the ideal radio. In practice, the radio must tolerate noise and distortions. Noise is added to the signal by every component in the sytem and during propagation. Distortions are caused by, among other things, misaligned filters and propagation anomalies, such as multipath fading.

We will first discuss how noise affects the radio and then how distortion affects the radio performance.

Effects of Noise

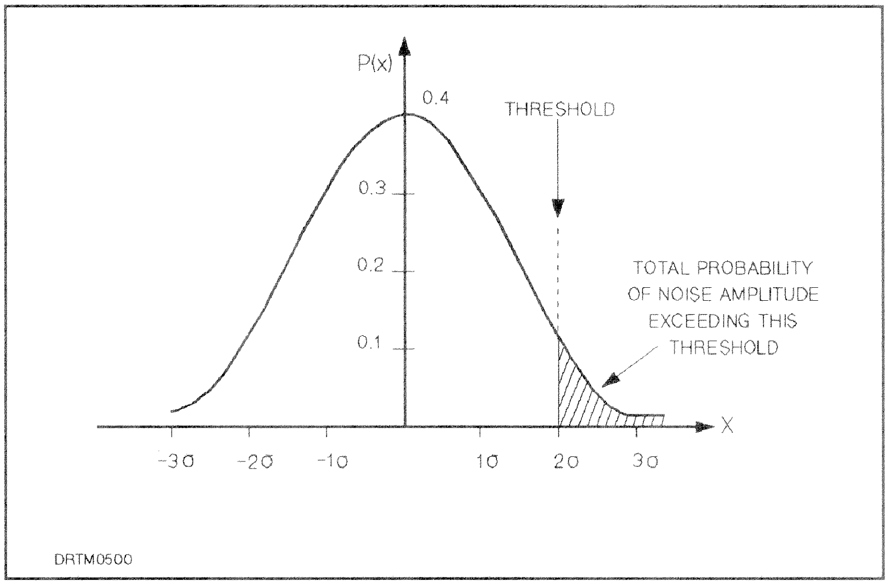
DRTM0480

In this section on Digital Radio Theory we will look at the effects of noise in digital transmission and the specific definitions used in digital radio.

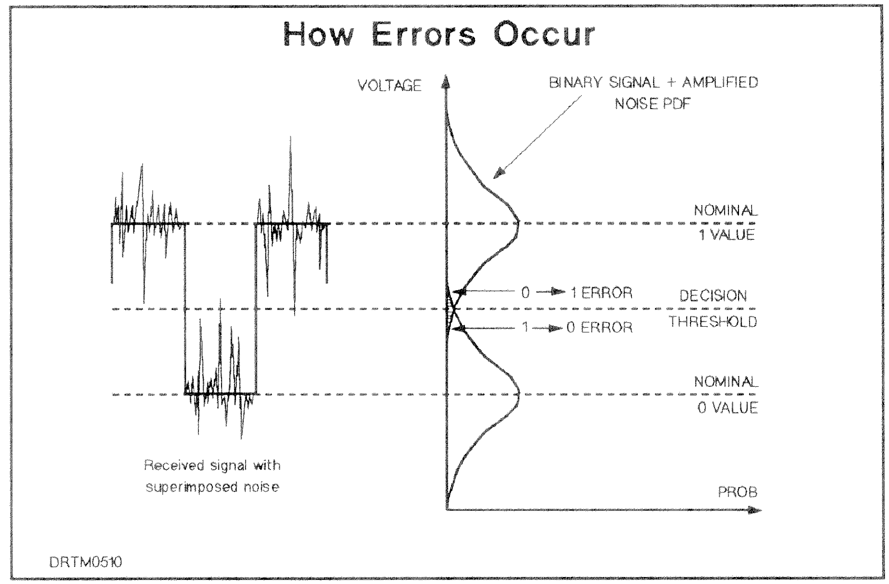


In order to understand the effects of noise in digital radio we need to consider the statistical properties of random noise. One of the most important statistical properties of a random variable is the probability of having a specified value indicated by the probability density function (PDF). The thermal noise generated in the front-end of the receiver can be represented by the Gaussian Distribution shown in this slide. The familiar bell-shaped curve shows the probability (vertical axis) of certain peak amplitude, x (horizontal axis) being reached. Notice the horizontal axis is calibrated in multiples of r (sigma), the standard deviation or RMS value of the noise. In other words this is a normalized curve, the absolute values depending on the RMS value or power level of a particular noise generator.

What this curve tells us is that there is a finite, though small, probability that the signal will have a very large peak at any given instant in time.

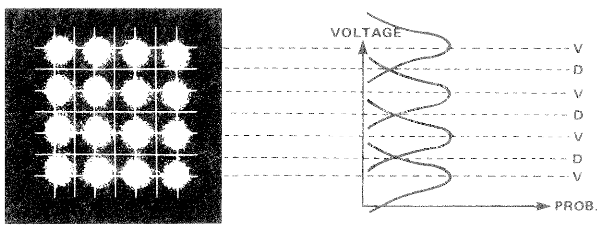


The probability of noise amplitude lying in a given range is the integral of the area under that portion of the curve. Obviously the area under the total curve (–infinity to + infinity) must equal unity (i.e. the signal must always exist somewhere within that range). Of particular interest in digital systems is the total probability of the noise amplitude exceeding a threshold value. This is called the **complementary cumulative probability distribution function** (Complementary CPDF), and is the area under the curve from the threshold value to infinity.



This slide shows how the superposition of noise on a digital signal generates errors. In the simple binary case shown here, a decision threshold will determine whether the received symbol (at a sampling instant) is detected as a '1' or '0'. When noise is superimposed on the '1' or '0' values the PDF's shown in the slide indicate there will be a probability of a '1' being interpreted as a '0' and vice versa. This probability is the area under the curve on the wrong side of the decision threshold, which is given by the complementary CPDF as we saw in the previous slide.

Error Generation in a Practical System

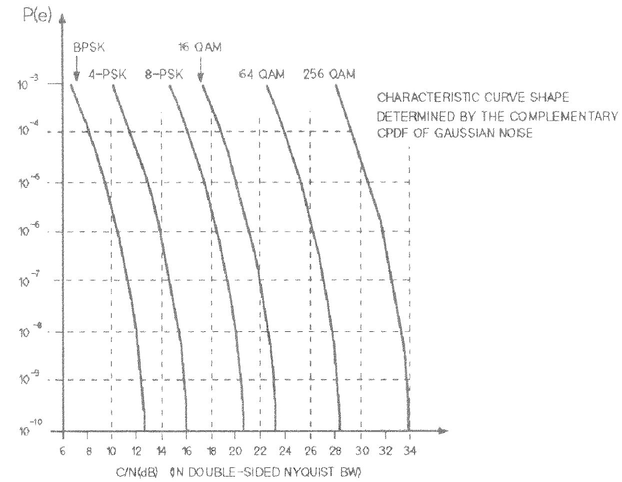


DRTM0520

A particular radio may have a more complex arrangement as, for example, in the 4-level 16 QAM system where there are three decision thresholds. Exactly the same arguments and mathematical concepts apply. The only difference is one of scaling — as the phase-states or levels are closer together a lower noise power will generate the same error probability.

In fact, if we take the ratio between the carrier (or signal power) and the noise power in a digital radio we can plot a set of universal curves independent of absolute levels.

Theoretical C/N vs P(e) Curves



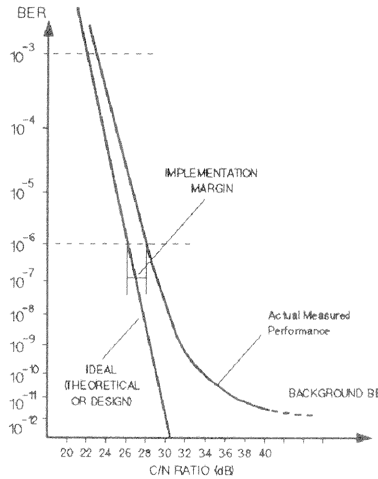
DRTM0530

The curves on this slide show the theoretical relationship between the error probability (or symbol error rate SER) and the carrier to noise ratio C/N. The curves have the same shape determined by the complementary CPDF for Gaussian Noise but are shifted horizontally depending on the complexity of the modulation scheme. A 64 QAM radio requires a much better C/N ratio than 4 PSK for a given SER.

You can also see that, in common with other digital systems, digital radio exhibits a pronounced threshold, being effectively error-free down to quite low C/N ratios and then degrading rapidly to an unusable condition in 4 - 5 dB change in C/N. The steepness of these curves means that high accuracy is required in setting the C/N value when making measurements.

These theoretical curves assume perfect modulation and demodulation with no inter-symbol interference. The noise power is also defined in the **Double-sided Nyquist Bandwidth or Symbol-rate Bandwidth**. This is the theoretical minimum transmission bandwidth.

Practical C/N vs BER Curves



DRTM0540

When we look at the performance of an actual radio, the results depart from the theoretical values in the way shown in this slide*. The difference between theory and practice is sometimes called the implementation margin and results from all the imperfections that can occur in practical radio.

The poorer the performance, the greater the required C/N for a given bit error ratio (BER). At high C/N ratio the digital radio performance becomes asymptotic to the low-level background (or dribble) BER.

** The practical results shown, are for a 64-QAM radio, and are plotted on "error- function" paper which has a vertical scale such that the theoretical curve plots as a straight line. Deviations from this line for practical systems are then clearly seen.*

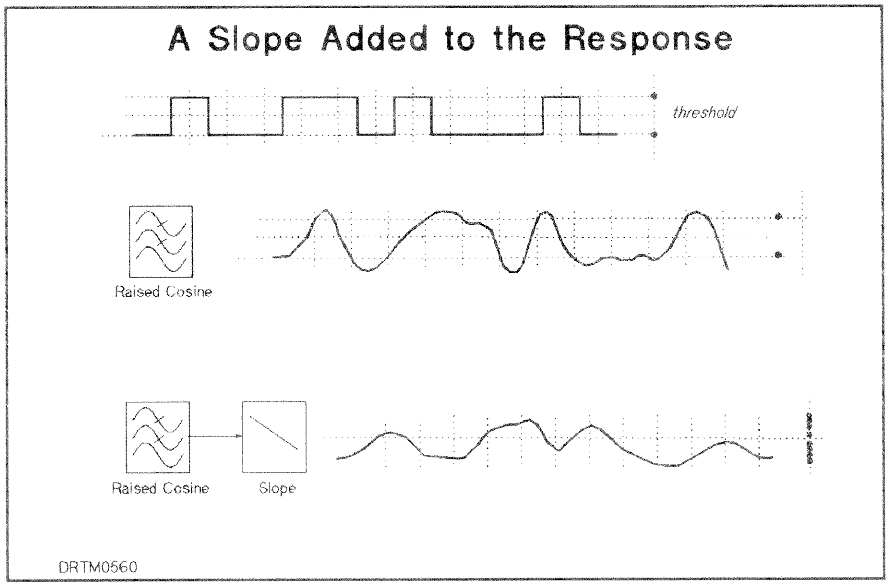
Comment

Normally a radio will be worse than the theoretical curve, i.e. it will require a higher C/N râtio for a given BER. The exception is for systems using forward error correction (FEC) when the practical system can have an overall performance better than theoretical, in which case, bandwidth is being exchanged for better BER.

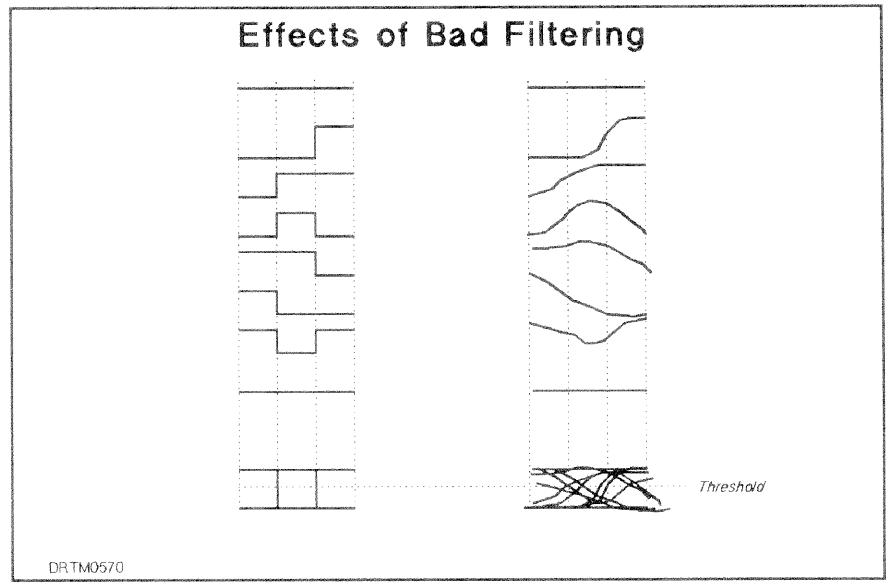
Effects of Distortion

DRTM0550

Noise is not the only source of bit errors in a digital radio. Anything which changes the filter response of the radio will affect the radio's performance. Here we will show how impairments can be represented on the C/N vs. BER curve.

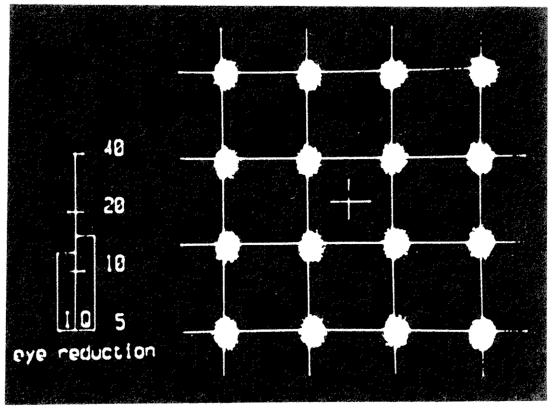


We saw in a previous section that a nyquist filter will band limit a signal without adding any error causing intersymbol interference. However, if this filter shape is disturbed, ISI will result. For example, if additional spectral shaping occurs in the transmission of the signal, degradation and bit errors will occur. By the time the ISI is as bad as shown here, the radio will probably have lost lock. However, for lesser amounts of distortion, there will be an increased BER.



Distortions will cause the eye to close. Each level will get closer to the threshold. Therefore, less noise would be required to cause a given BER.

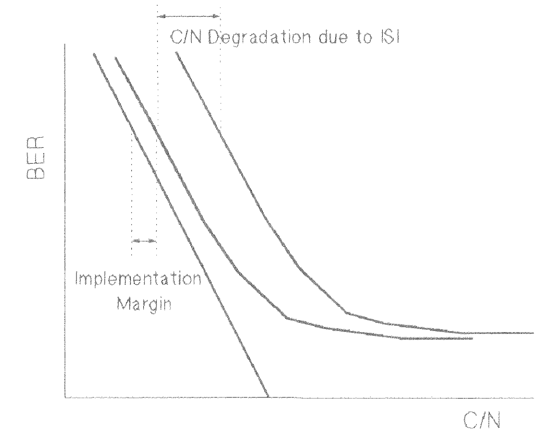
Effect of Amplitude Non-Flatness



DRTM0580

This slide shows the carrier to noise degradation resulting from amplitude slopes and parabolic amplitude in the radio passband. Notice that the clusters are closer to the decision threshold.Therefore, less susperimposed noise is required to cause errors.

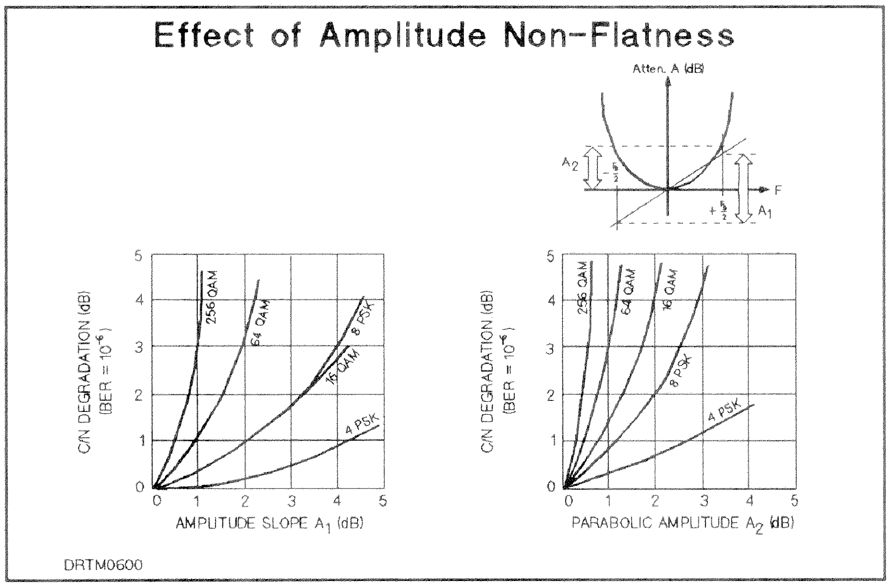
ISI Causes C/N Degradation

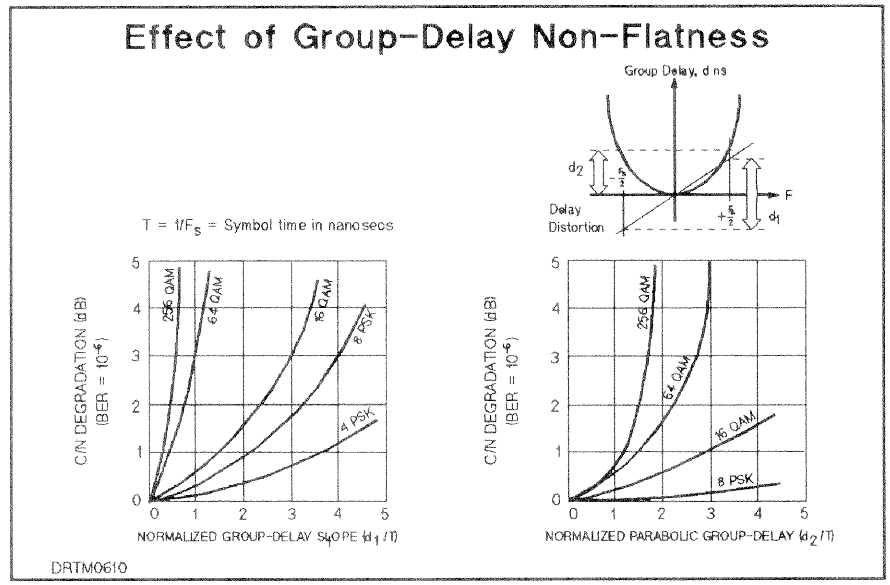


DRTM0590

In the constellation, ISI looks a lot like noise. However, its effect on the BER is different. ISI does not have the same probability distribution function as noise. It does, however, bring the states in the constellation closer together making it easier for noise to create errors.

It is common to express the effects of ISI as a degradation of the C/N curve. ISI will shift the curve some amount to the right. With ISI, a higher C/N is required for a given BER.





These next two pictures relate amplitude and phase distortion to a shifting to the right "or degradation" of the C/N vs. BER curve. The amplitude response is measured across the symbol rate bandwidth and the C/N degradation interpreted from the curves depends on the modulation scheme. Notice how much more sensitive the higher modulation schemes are -- if you are working with 64 QAM, amplitude response must be better than 0.5 dB across the band.

These curves also show why the higher modulation schemes are so sensitive to multipath fading.

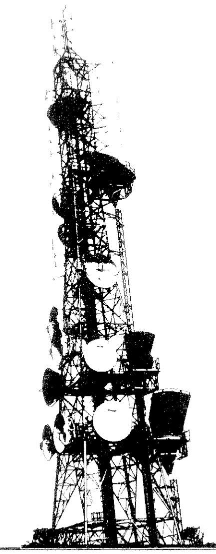
This slide show a similar set of curves for group-delay non-flatness. We measure the group delay in nanoseconds over the symbol rate bandwidth and normalize the result by dividing by the symbol time T (=1/Fs). We can then read off the C/N degradation depending on the modulation scheme.

Summary

Digital Radio is very similar to analog radio and requires many of the same measurements. However, it does have some unique properties which require a few special tests like BER, C/N vs. BER and multipath signatures.

DRTM0615

Along with the traditional measurements made on any radio: power, frequency ... It is important to measure the response of a digital microwave radio to noise and multipath distortion.



DRTM0620

In this first part, we looked at how a digital radio works and reviewed some theory about conditions which effect its performance. In the next part, we will discuss actual measurements made on digital radios.

PART 2

Practical Problems
and
Measurement Solutions

Part 2
Practical Problems and Measurement Solutions

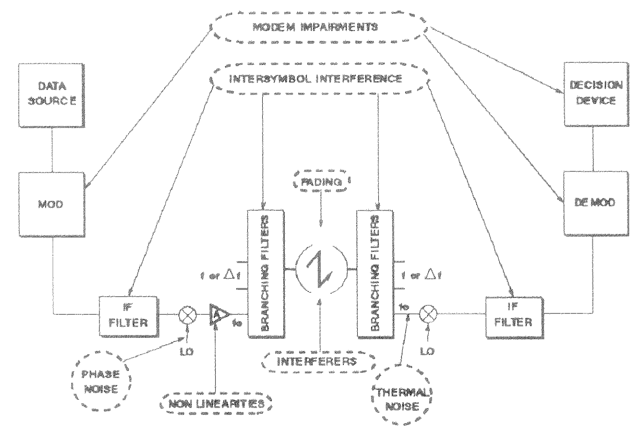
- Introduction
- Error Performance
- Stress Testing
- In-service Testing
- Diagnostic Testing
- Summary

DRTM0630

Digital radio has many advantages over analog radio. Digital radios are in many ways, however, very similar to their analog predecessors. The major differences lie in the modem and baseband sections. The two types of radio, therefore, share many common test requirements. In addition, digital radio requires a number of critical measurements not made on analog radios. In this part of the seminar we will discuss a number of important tests. Some apply equally well to all types of radios, but the emphasis is on digital radios and their particular test requirements.

The first subject discussed is error performance. This is the bottom line measurement of a radio's quality. Stress testing is used to predict the error performance of a radio when it is subjected to propagation impairments. In-service and diagnostic tests are then covered and refer to tests made during routine maintenance, monitoring and troubleshooting.

Block Diagram of a Radio Link with Impairments



DRTM0640

A practical digital radio can suffer from a number of impairments which give rise to error generation in the system. The most common causes of degradation are illustrated on this slide.*

As you can see, some of these impairments are due to propagation and interference effects and are external to the radio equipment, while others are due to imperfections in the digital radio itself.

First we will look at how we characterize the performance of a radio. After this we will stress the radio to predict its ability to cope with transmission impairments, and finally we will measure individual impairments.

**"Comparison of High-Level Modulation Schemes for High-Capacity Digital Radio Systems" by Michel Borgne. IEEE Transactions on Communication, Vol. Comm-333 No. 5 May 1985. pp 442-449.*

INTRODUCTION

Error Performance

- BER
- Jitter

STRESS TESTING

IN-SERVICE

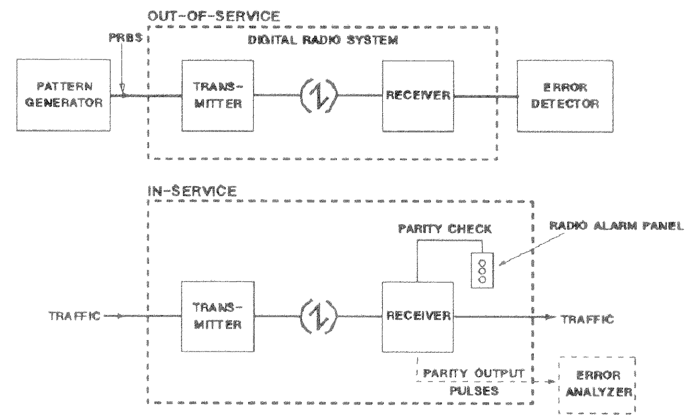
DIAGNOSTIC TESTING

SUMMARY

DRTM0650

The basic measure of digital radio performance is Bit Error Ration (BER). In this section we will look at how it is measured and some terms and conventions used to describe BER.

Error Performance Testing

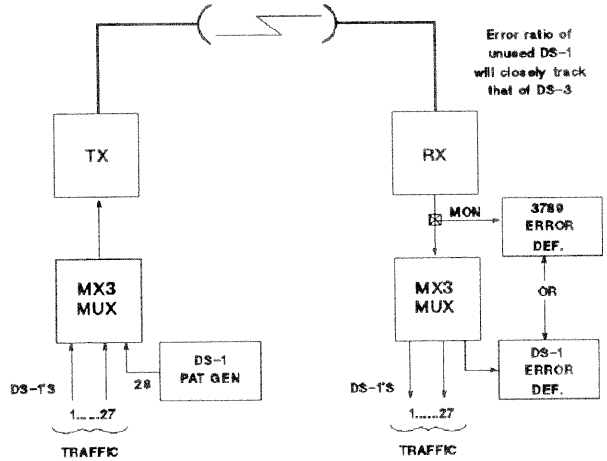


DRTM0660

Error performance measurements can be made in two ways:
(a) Out-of-service, where the traffic is removed and a pseudo-random binary sequence (PRBS) is applied to the transmit terminal, and the received data stream checked bit by bit for errors. Sequence lengths of 2^{15}-1 and 2^{23}-1 are specified by CCITT. This is the preferred method for assessing the performance of the radio particularly during commissioning since every bit is checked for errors. Normally the pattern-generator and error-detector are connected at the coded CCITT interface on the terminal. Alternatively, the connection may be made at a binary data and clock interface depending on the terminal design.

(b) In-service, where the radio operates normally carrying revenue-earning traffic and the error performance is measured internally by parity checking on data blocks. This works quite well at moderate or low error ratios, but becomes inaccurate during bursts of errors, for example during multipath fading, when there is a possibility of parity error cancellation in the data block. The result of this simple test is usually displayed on the radio control panel. Alternatively the parity error detection may be available as an electrical pulse which can be connected to the “external error input” of the error analyzer. 'Through-data' options of the HP 3764A and HP 3784A offer through-data jitter modulation. This allows the user to make measurements of jitter tolerance on equipment which needs framing bits sto be present in the test signal eg. demultiplexers.

Partial Out-of-Service Testing



DRTM0670

A compromise between full in-service or out-of-service testing is partial out-of-service testing. Here most of the radio's capacity bears live traffic. Only a single lower rate stream is taken out.

Propagation Problems Require Statistical Error Analysis

CCIR Recommendation 594 for 2500 km link
(64 kb/s unidirectional channel)

- BER worse than 1×10^{-6} for less than 0.4% of any month.
- BER worse than 1×10^{-3} for less than 0.054% of any month.
- Residual BER should not exceed 5×10^{-9} (15 minute integration).

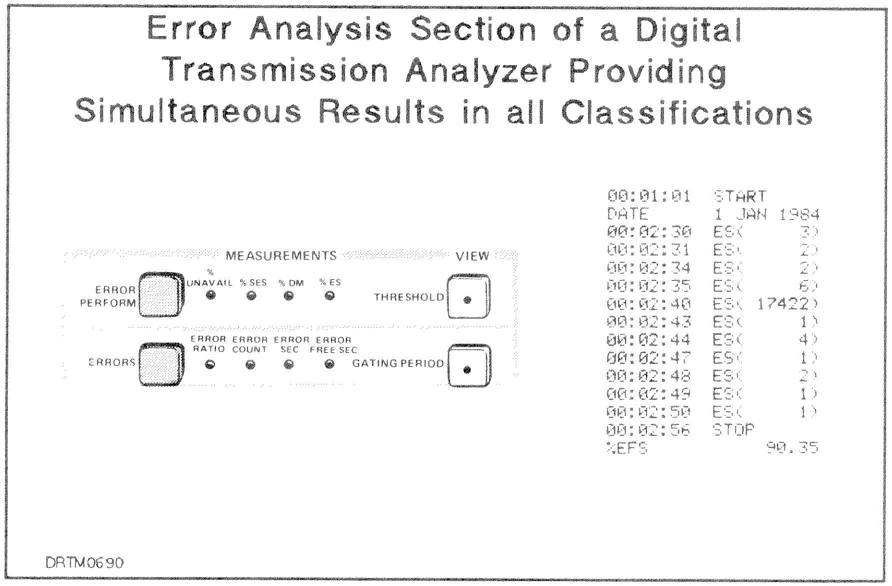
DRTM0680

Why does error performance measurement matter in digital radio sytem testing?

Because digital radio systems have to provide high quality transmission.

Due to the nature of digital radio systems links, error performance changes with time, and because of this, the measurements must be classified statistically for the % time that the error performance is worse than certain thresholds. The latest CCIR Recommendation 594 is shown on this slide and relates to a unidirectional 64 kb/s channel over a hypothetical reference circuit of 2500 km. For shorter length systems the % time and residual BER value would be scaled in proportion to the length (L/2500).

The recommended measurement period is one month and usually this is taken to be the worst propagation month for a particular route depending on whether it is dominated by multipath propagation or rain attenuation. These revised recommendations are compatible with a high-grade circuit in the CCITT Recommendation G.821 for the error performance requirements of the ISDN. The addition of the errored-second objective also recognizes the importance of burst errors in microwave radio systems, caused by multi-path propagation.



In order to classify the performance according to the CCIR/CCITT recommendation, simultaneous analysis of all the error-performance critieria is necessary during the measurement period of up to one month. This slide shows the 8 simultaneous measurements available on the HP 3764A Digital Transmission Analyzer. The error performance categories are those defined in CCITT Recommendation G821.

% Unavailability – 10 sec period at worse that 10^{-3}

% Severely Errored Seconds (%SES) – available second periods worse than 10^{-3}

% Degraded Minutes (%DM) – available periods worse than 10^{-6}

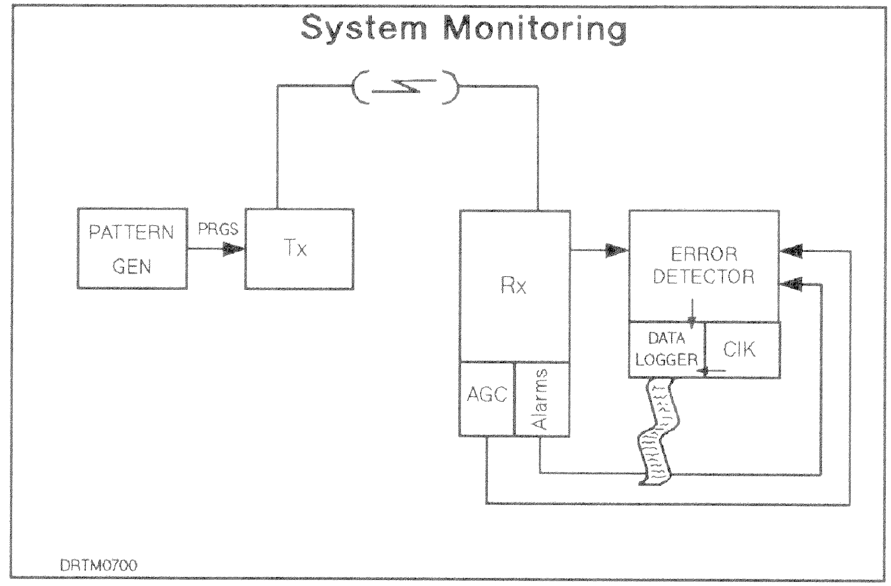
% Errored Seconds (%ES) – available seconds with one or more errors

Comment

These relate closely to the CCIR Recommendation shown in the previous slide, and in both case the performance relates to a single 64 kb/s channel. Normally, digital radio measurements are made at high multiplexed rates and the question arises as to how these results relate to the 64 kb/s criteria. It is usually accepted that taken over a sufficiently long period, the BER criteria transfer directly to the high-speed measurement.

For the error-second criteria it is necessary to know the number of errors that occur in an errored second on the high-speed system. From that an estimate of %ES at 64kb/s can be made. An example of error-second error count is shown in the printout on this slide.

For more information see AN-387 "High Productivity Measurements in Digital Transmission," Lit. No. 5959-7898.

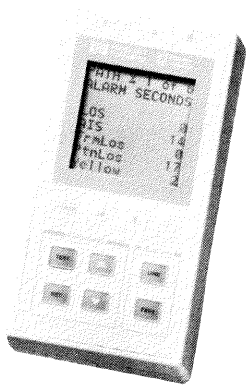


Often when monitoring the error-performance of a radio system, it is useful to correlate error occurrance with other events such as radio alarms and a.g.c. voltage (as an indication of fade depth). On some error detectors, these signals can be checked and recorded with time along with the error measurements.

This has a substantial benefit in reducing the amount of equipment required for a complete test of the radio, avoiding the need for data acquisition equipment and system software to correlate the measurements.

Hewlett-Packard manufactures a wide range of pattern-generators and error-detectors suitable for North American or European hierachies. The latest products incorporate comprehensive error-performance analysis and data-logging.

The HP 37741A DS1 Tester



DRTM0711

The HP37741A is a handheld DS1 tester. It has full DS1 capability (both transmit and receive) and can generate every T1 frame format, line code and test patter. Loop up and loop down codes can also be generated, test tones can be inserted into any DS0 channel.

On the measurement side, the HP 37741A monitors T1 alarms, as well as frame, CRC-6, logic and code errors, Signalling bits can be monitored and the signal level, frequency and simplex current are also measured.

Automatic result storage eliminates the need to bring along an external printer, and the HP 37741A is fully remote programmable (EIA-232) and accessible by a PC either locally or over modems, enabling unattended monitoring.

HP 37741A FEATURES

- Full DS1 test capability
- Handheld
- Easy to use
- Battery operation

DRTM0712

Small enough to fit in the palm of your hand, the HP 37741A weighs only 0.9 kg (2 lbs) and even has a carrying pouch which straps to your belt. This means that the HP 37741A can be taken anywhere you need it.

The HP 37741A incorporates several ease-of-use features to ensure that you get the measurement "right the first time":

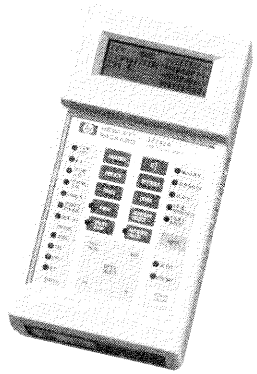
- All measurements are made simultaneously, so there is no risk of not selecting the required measurement.

- The tester can automatically configure to any frame format.

- The clear display is easy to read in any lighting conditions, and the large keys can be used with a gloved hand.

- The HP 37741A gives a full days operation with the tester's rechargable batteries.

HP 37742A 2M Test Set



DRTM0713

The HP37742A is HP's handheld solution to 2Mbit/s testing. It provides full in and out-of-service testing in the palm of your hand.

HP 37742A Features

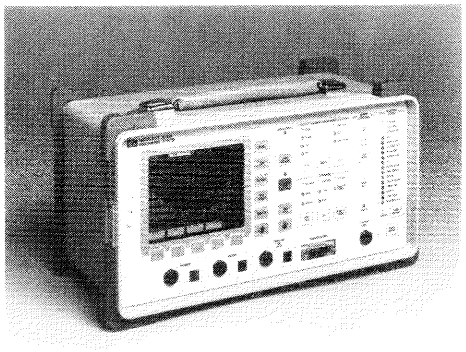
- 2 Mbit/s and n x 64 kbit/s
- Handheld
- Timeslot map
- Regenerator
- RS-232 remote control

DRTM0714

Standard, CR4 and/or CAS 2 Mbit/s framing are provided for testing at 2 Mbit/s and n x 64 kbit/s. A full timeslot map displays if channels are busy or idle and what they are carrying.

Regenerator substitution allows for regenerator maintenance, and RS-232 remote control allows for unattended testing.

HP 37701A T1 Tester



DRTM0730

The HP 37701A is HP's test for T1 (1,544 Mb/s) installation and maintenance. It is portable (lunch-box size), weighs under 10 lbs and is rugged enough to be flung in a truck. There is a battery-powered version for testing where AC power is not available.

The HP 37701A is for use by telephone companies, interexchange carriers and telecom end-users.

HP 37701A FEATURES

- Connects at any T1 access point
- Graphic results presentation and Trouble scan
- Fractional T1 testing
- Pulse shape measurement
- Channel access
- Result storage for up to 99 days
- High-resolution clock slips measurement
- Upgradability

DRTM0740

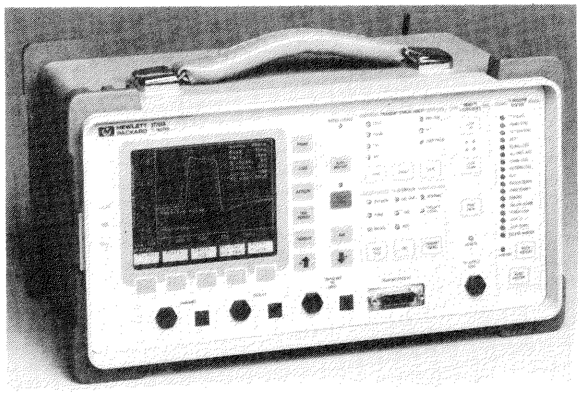
Connection at any T1 access point means only one box is needed for all T1 testing requirements in the field or central office. Graphic result presentation gives at-a-glance interpretation of long-term tests and no need to hook up a printer. Trouble scan which shows all significant error types simultaneoulsy, saves running several tests or stepping through results to find out what was wrong.

Fractional T1 testing provids testing of n x 64 kbit/s and n x 56 kbit/s circuits. T1 pulse shape measurement (with screen display) gives rapid distinction of marginal failures from gross failures, and simple detection of badly set operational equipment. Channel-access means individual channels can be checked easily and idle channels can be identified quickly. Automatic result storage means there is no need to carry a printer to record test results.

High resolution (1/8th UI) clock slips measurement gives faster and more positive identification of timing problesm on T1 networks.

Upgradability (for example to datacom measurements) protects your investment in test equipment.

HP 37702A Digital Data Tester



DRTM0741

The HP 37702A is HP's solution for testing at T1, fractional T1, DDS and datacom in a single instrument.

HP 37702A Features

- T1, fractional T1 and DDS
- n x 64 kbit/s drop and insert
- Pulse shape measurement
- Graphical results presentation
- Results storage
- High resolution clock slips measurement
- Upgradability

DRTM0742

T1, fractional T1, DDS and datacom testing in a single test set means only one instrument to buy, learn, carry and store.

Fractional T1 testing provides testing of n x 64 kbit/s and n x 56 kbit/s circuits.

N x 64 kbit/s drop and insert allows external analysis (eg. protocol) of up to six channels.

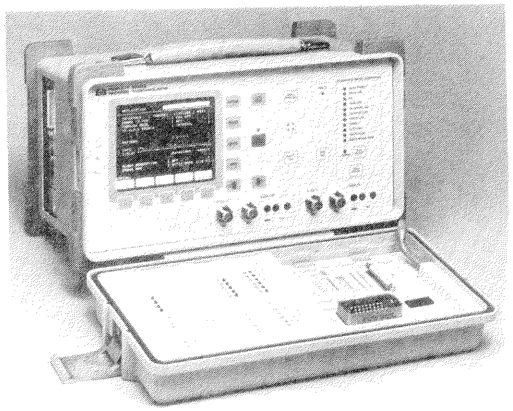
Graphics result presentation, with up to 99 days of results storage, gives at-a-glance interpretation of long term tests without the need for a printer.

T1 pulse shape measurement (with screen display) gives rapid identification of marginal failures and easy detection of badly aligned equipment.

High resolution clock-slips measurement (1/8th IU) gives faster and more positive identification of timing problems on T1 networks.

Upgradability (for example to datacom measurements) protects your investment in test equipment.

HP 37722A Digital Telecom Analyzer



DRTM0743

The HP 37722A is HP's field-portable test set for installation and maintenance of 2 Mbit/s, n x 64 kbit/s and 64 kbit/s circuits and services. Options provide testing at 704 kbit/s, 8 Mbit/s and sub-rates, as well as drop and insert capability. It is portable, rugged and has optional battery operation.

HP 37722A Features

- Full 2 Mbits and n x 64 kbit/s
- Extra optional interfaces
- Graphical results presentation
- Sub-rates - X.50 and X.58
- n x 64 kbit/s drop and insert
- 80 days results storage
- Easy-to-use
- Upgradability

DRTM0744

Full 2 Mbit/s and n x 64 kbit/s testing provides for standard and CRC4 framing and/or channel associated signaling. Extra rates and sub-rate testing to CCITT Recs. X.50 and X.58 are available as options.

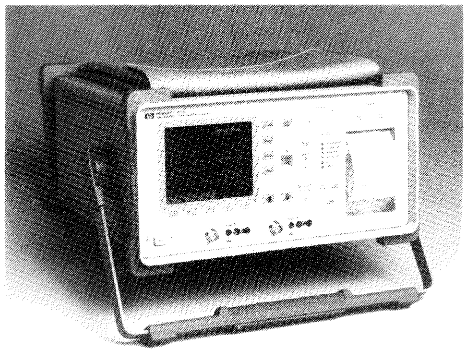
N x 64 kbit/s drop and insert allows external analysis (eg. protocol) of up to six channels.

Graphics result presentation, with up to 80 days of results storage, gives at-a-glance interpretation of long term tests without the need for a printer.

Application-driven software and a large, clear screen with simple menus makes the HP 37722A easy-to-use.

Upgradability (for example to datacom measurements) protects your investment in test equipment.

HP 37721A
Digital Transmission Analyzer



DRTM0750

The HP 37721A Digital Transmission Analyzer is a rugged lightweight tester for in and out-of-service measurements at standard CEPT rates of 704 kb/s, 2, 8, 34 and 140 Mb/s. It is powerful and at the same time easy-to-use, with test capability suitable for digital radio testing.

- 704 kb/s, 2, 8, 34, 140 Mb/s (in and out-of-service)
- Bit, frame and CRC error measurements
- G.821 error performance analysis
- Frequency and frequency offset measurement
- Binary interfaces
- Internal printer

HP 37721A FEATURES

- Installation
- Commissioning
- Maintenance

DRTM0760

Transmission equipment can be installed by the network operator, but in many applications is installed by the equipment manufacturer. The HP 37721A can be used to carry out a quick functional check before handing the equipment over to the network operator commissioning people. The test results can be printed out in a clear, easy-to-understand format to be used as proof of performance.

Before new equipment is used to transmit live traffic, it can be checked out using the HP 37721A over a longer period to ensure the error performance complies with CCITT recommendations.

The HP 37721A can be set up quickly with standard test parameters and left unattended to monitor error performance. The measurement results are clearly presented and relate error performance to time.

For in-service testing, the HP 37721A provides analysis of the framing bits at 704 kb/s to 140 Mb/s and the CRC bits at 2 Mb/s.

Network maintenance is performed by maintenance technicians, who must track down faults and bring circuits back into service as quickly as possible. Test equipment must be easy to use and reliable. When a fault is located, the faulty card is replaced and the performance of the circuit is then measured over a longer period before switching over to live traffic again.

HP 37721A KEY CONTRIBUTIONS

- Field portable – rugged and lightweight
- Easy-to-use – autosetup, large, clear display, graphics
- All rates in one unit
- In-service testing at all rates
- Frequency and frequency offset measurement
- Internal printer

DRTM0770

The HP 37721A can be easily carried to a remote site, and you know you can depend on it functioning correctly, even after the roughest journey.

The HP 37721A is very easy to use with a large screen and graphics for straight-forward results interpretation. The auto-setup function in particular contribues to faster test times, with the receiver automatically recognizing and configuring itself to the incoming test pattern. The opertor can then run the measurement, confident that the instrument is set up correctly.

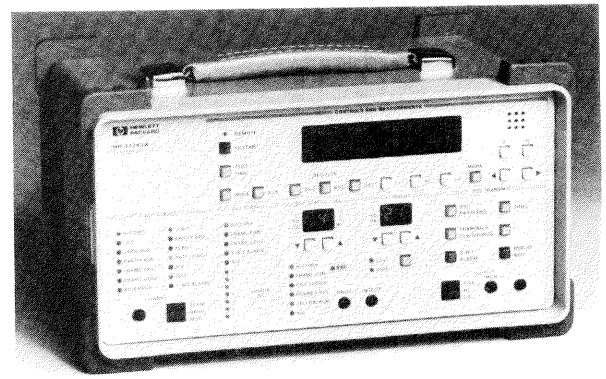
With all rates in the one unit, you don't require multiple test sets for testisng at different points in the network.

In-service testing maximizes network uptime.

And with frequency and frequency-offset measurement combined in the same unit, you can also track down timing problems in the network and immediately tell whether or not the clock rate is withing CCITT spec without calculation.

The internal printer provides a time-stamped record of error results.

The HP 37743A DS3 Test Set



DRTM0771

The HP 37743A DS3 Test Set packs full DS3 test capability into a small and extremely easy to use instrument. At 4 kg (9lbs), it's portable enough to carry around any test location.

It's full DS3 capabilities include both transmit and receive. Any DS3 signal can be simulated either framed (M13 or C-bit) or unframed, as well as DSX-3, DS3-HI and DS3-LO levels.

In-service error monitoring can be performed on the frame word of the embed-ded DS2 signals and the dropped DS1 signals.

The DS3/DS1 drop and insert enables the test set to be used as a substitute multiplexer/demultiplexer. Any of the 28 DS1 digroups can be dropped out to the output connector on the front panel. The HP 37743A performs frame and CRC measurements on this DS1 and detects any alarm conditions.

A DS1 signal from an external source can be inserted into any of the 28 DS1 digroups and multiplexed up to the DS3 signal.

HP 37743A FEATURES

- Portable
- Easy to use
- DS3 transmit and receive
- In-service DS2 and DS1 measurements
- DS3/DS1 drop and insert

DRTM0772

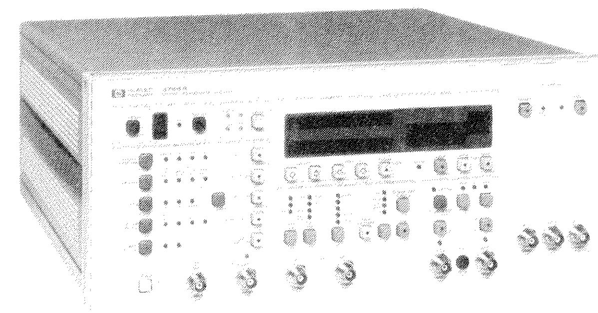
Many features contribute to the HP 37743A's ease-of-use:

Autosetup - This saves test and training time as the test set automatically configures to the frame format of the incoming signal.

Front Panel Layout - All set-up and results are logically grouped together by rate, with no hidden screens or results.

Status LED's - A full range of status and alarm LED's clearly indicate system performance at a glance.

HP 3764A Digital Transmission Analyzer (for CEPT rates 2, 8, 34 and 39 Mbit/s)



DRTM0780

The HP 3764A Digital Transmission Analyzer is used for error and jitter tsting at 140 Mb/s and bit error measurements at rates up to 170 Mb/s.

The HP 3764A covers network and manufacturing applications where BER and jitter testing at 140 Mb/s is required and applications where non-standard rate BER is required.

HP 3764A Versions

- 002 – BER and jitter at 140 Mb/s
- 006 – Multirate BER with synthesizer to 170 Mb/s
- 007 – BER and jitter at 140 Mb/s with synthesizer to 170 Mb/s and through-data jitter

DRTM0790

There are several versions of the HP 3764A to cover different applications:

with Option 002
BER and jitter test capability at 140 Mb/s

with Option 006:
BER at fixed telecom rates and internal clock synthesizer for bit error measurements at binary TTL/ECL level interfaces at rates 1 kB/s up to 170 Mb/s.

with Option 007:
BER and jitter at 140 Mb/s, with clock synthesizer for bit error measurements at binary TTL/ECL level interfaces at rates 1 kb/s up to 170 Mb/s. Jitter can be added to a framed signal passing through the instrument to allow testing of demultiplexers.

What the HP 3764A offers Network Operators

- BER and jitter together in one instrument
- Stored setups for ease of use
- Robust single cabinet
- Internal printer

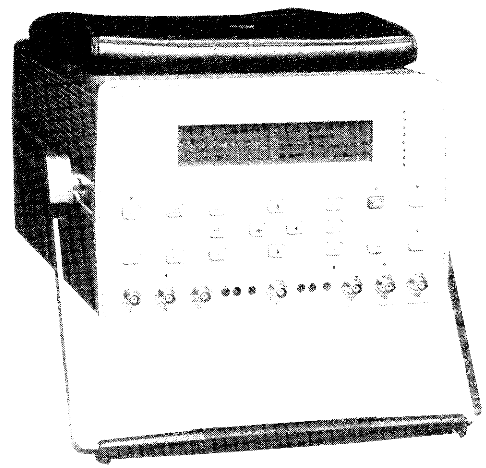
DRTM0800

The HP 3764A combines BER test capability and jitter generation and measurement in one portable cabinet. The network operator can stress parts of the network with a jittered test signal and look for transmission errors, or measure the jitter on a signal output from a particular network element.

Measurement setups can be stored internally and recalled whenever you want to set up a test quickly. You know that the HP 3764A is set up correctly every time.

With a printer incorporated in the same unit, you can leave the HP 3764A unattended and return to a full set of measurement results.

HP 3784A Digital Transmission Analyzer



DRTM0830

This is the HP 3784A Digital Transmission Analyzer. It is packed with features to take the hard work out of error and jitter testing at bit rates from 1 kb/s to 50 Mb/s. It is rugged and portable and is equally at home on the factory floor or out in the field. It can be used in both manufacturing and network applications wherer error and jitter test capability is required.

WHAT THE HP 3784A OFFERS

- Bit and code error measurements at 704 kb/s, 2, 8 and 34 Mb/s
- Manual and automatic jitter measurements at 2, 8 and 34 Mb/s
- Bit error measurements from 1 kb/s to 50 Mb/s
- Code error measurements at 64 kb/s codirectional interfaces
- Stored setups and receiver autosetup
- Error performance analysis to CCITT G.821

DRTM0840

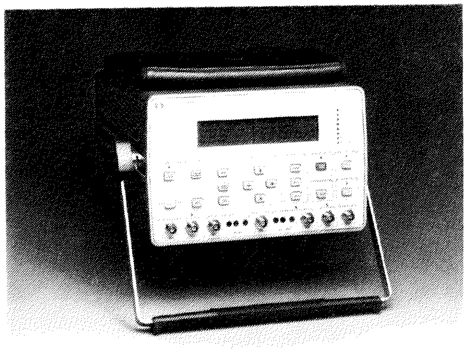
The HP 3784A does error testing at standard telecom interfaces up to 34 Mb/s. It can also work at monitor points sto allow in service monitoring of live traffic based on code errors.

The optional jitter teting allows interfaces of multiplex and transmission equipment to be checked out during manufacture and installation.

The instrument has ease-of-use features which are particularly useful in network applications. The stored set-up feature allows commonly used test set-ups to be stored and recalled when required. This feature makes the writing of test procedures easy. Auto set-up makes the receiver automatically set itself up on the incoming test signal and reduces the chance of mistakes when setting up end-to-end tests.

The HP 3784A can analyze error performance based on CCITT standard G.82 with powerful logging capability to an external 80-column printer.

HP 3784A Option H13
Digital Transmission Analyzer



DRTM0720

A special version of the HP 3784A Digital Transmission Analyzer offers error and jitter measurements at North American and binary interfaces using unframed data. It provides DS1 (1.544 Mb/s,) DS1C (3.152 Mb/s, DS2 (6.312 Mb/s and DS3 (44.736 Mb/s).

With automatic and manual jitter measurements, the HP 3784A offers a fast accurate means of characterzing digital transmission equipment.

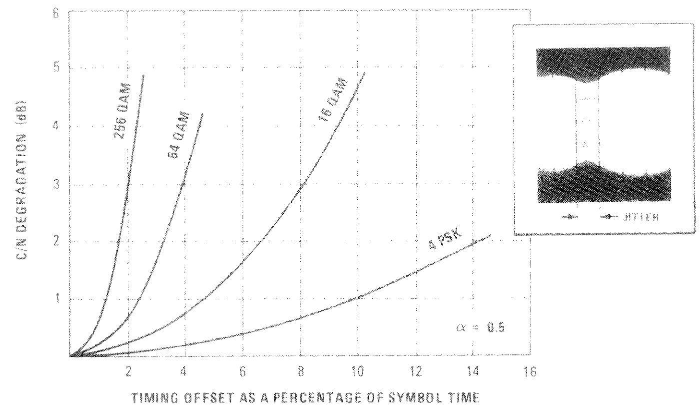
How Jitter Degrades Radio Performance

DRTM0950

Timing jitter causes problems in two areas: internal to the radio in the symbol-timing clock recovery in the regenerator, and externally at the interfaces of the radio to the digital network.

The next couple of slides look at the effects of jitter in degrading digital radio performance.

Jitter Measurements in the Digital Network

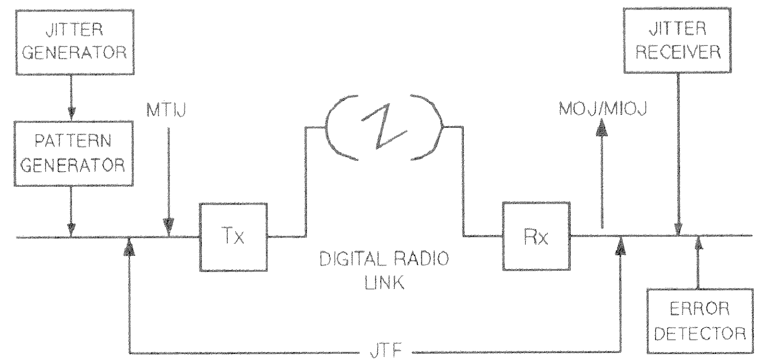


DRTM0960

Jitter on the symbol timing clock which is used to sample the demodulator I and Q signals is also a source of errors in digital radio. If the demodulator signal is not sampled at the correct point, the effect of eye closure (discussed later) leads to loss in performance.

The higher order modulation schemes (16 and 64 QAM) are progressively more sensitive to the effects of timing errors and jitter, with increasing deterioratioin in radio performance.

Jitter Measurements in the Digital Network



MTIJ = Maximum Tolerable Input Jitter
MOJ = Maximum Output Jitter
MIOJ = Maximum Intrinsic Output Jitter
JTF = Jitter Transfer Function

DRTM0970

Perhaps the most common jitter measurements are made at the standard CCITT interface on the radio which connects with the digital network. A number of jitter specifications have been laid down by CCITT (REc. G.823 and G.824) for the CCITT standard hierarchy rates. The idea is that if a piece of equipment meets the specifications at its input and output, then it can be connected freely within the digital network without degrading jitter performance and causing errors.

There are three classes of measurements:

- Maximum Tolerable Input Jitter--which is tested by applying increasing jitter to an imput data stream and determining the onset of bit errors.
- Maximum Output Jitter (and Intrinsic Output Jitter)--which is the level of output jitter with a jittered (or jitter-free) input signal.
- Jitter Transfer Function--which is a measure of how the jitter is attenuated by passing throught the system, a necessary specification to prevent jitter accumulation in the network.

Although jitter measurements are mostly made within the factory where equipment should be fully checked to the appropriate specification, they are sometimes made in the field, particularly with large networks where there may be a chance of jitter accumulation.

The jitter options of the HP 3764A and HP 3784A (already discussed in the is section) perform these measurements to the CCITT standards, so are well suited to performing these jitter measurements.

INTRODUCTION

ERROR PERFORMANCE

Stress Testing

- Flat Fading
- Multipath Fading

IN-SERVICE TESTING

DIAGNOSTIC TESTING

SUMMARY

DRTM1000

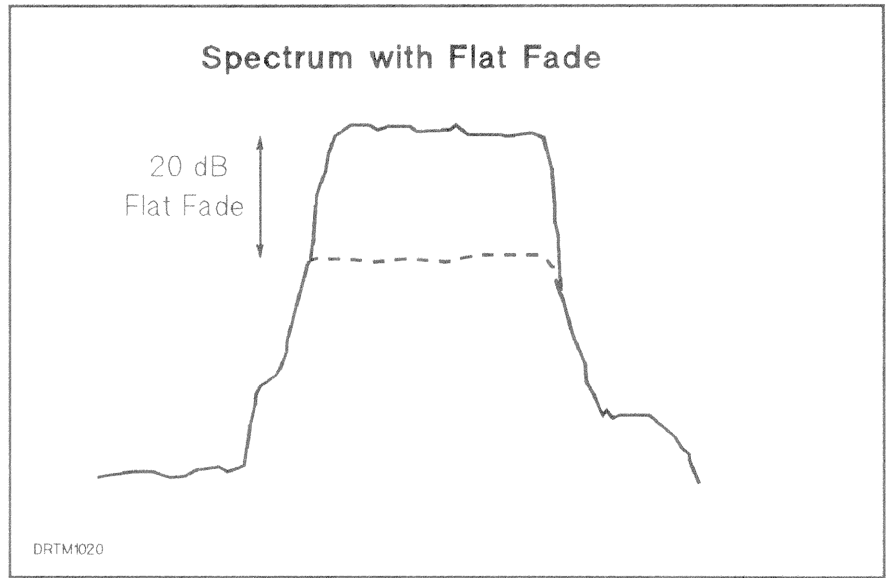
Bit errors often occur when impairments occur on the transmitted signal. It is useful to be able to predict how well the radio will tolerate transmission problems. The radio is subjected to calibrated levels of impairments while the BER is monitored. This process highlights failures withing critical subsystems within the radio in addition to the overall quality of the radio design.

This section examines the radio's response to flat fading and multipath fading--the two main ways of stressing a digital radio system.

Flat Fading

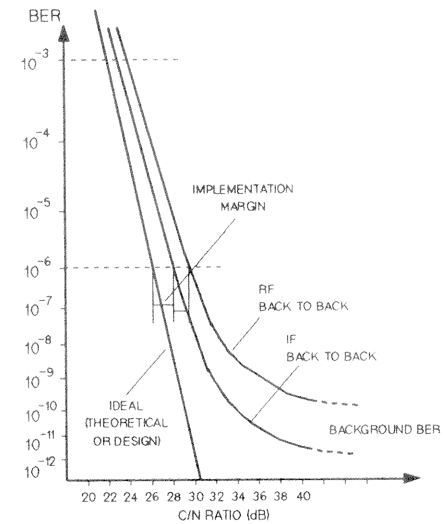
DRTM1010

Flat-fading as its name implies is a non-frequency dependent attenuation of the input signal and typically occurs during period of heavy rain--particularly at higher microwave frequencies. When the signal level is low, the C/N ratio is degraded and errors occur in the transmitted data. The better the design and alignment of the radio (the greater the eye-opening), then the greater the fade margin. The fade margin is defined as the amount of signal attenuation (eg. 50 dB) from normal received level that is possible for a given Bit Error Ratio (BER) such as 10^{-3}.



During flat fading the signal strength decreases. However, the noise added by the environment and from components within the radio doesn't decrease, therefore, the C/N ratio decreases. The next slide illustrates the C/N ratio curves and implementation margin.

Practical C/N vs BER Curves



DRTM1030

When we look at the performanceof a practical radio, the results depart from the theoretical values in the way shown in this slide. The difference between theory and practice is sometimes called the **implementation margin** and results from all the imperfections that occur in a practical radio.

The poorer the performance, the greater the required C/N for a given bit error ration (BER). At high C/N ratio the digital radio performance becomes asymptotic to the low-level background (or dribble) BER.

We can quantify the loss of the C/N margin for each of the individual impairments in the IF and R.F. sections as shown in the example in the next slide.

(Note: The practical results shown, are for a 64-QAM radio, and are plotted on "error-function" paper which has a vertical scale such that the theoretial curve plots as a straight line. Deviations from this line for practical systems are then clearly seen.)

Comment

Normally a radio will be worse than the theoretical curve, i.e. it will require a highter C/N ratio for a given BER. The exception is for systems using forward error correction (FEC) when the practical system can have an overall performance better than theoretical, in which case, bandwidth is being exchanged for better BER. Some line-of-sight radios use this technique, and it is quite common in satellite systems.

System Degradation Budget in a Typical High-Speed (90 Mb/s) Radio System

DEGRADATION CAUSED BY	DEGRADATION (dB)
1. MODEM IMPERFECTIONS - IF BACK-TO-BACK:	
1.1 Phase and amplitude errors of the modulator	0.1
1.2 Intersymbol interference caused by the filters in a back-to-back modem	1.0
1.3 Carrier recovery phase noise	0.1
1.4 Differential encoding / decoding	0.3
1.5 Jitter (imperfect sampling instants)	0.1
1.6 Excess noise bandwidth of receiver (demodulator)	0.5
1.7 Other hardware impairments (temperature variations, aging, etc.)	0.4
Modem total:	2.5 dB
2. RF CHANNEL IMPERFECTIONS:	
2.1 AM/PM conversion of the quasi-linear output stage	1.5
2.2 Band-limitation and channel group delay	0.3
2.3 Adjacent RF channel interference	1.0
2.4 Feeder and echo distortion	0.2
Channel total:	3.0 dB
Total modem and channel degradation:	5.5 dB

DRTM1040

This table shows a typical budget for the C/N penalty due to individual impairments. This indicates that the required C/N ratio will need to be 5.5 dB higher than theoretical for a given BER. this means that higher transmit power or lower receiver noise figure will be required for a given fade margin or system gain. Every extra dB of transmit power is very expensive particularly when linearity is important as in QAM systems.

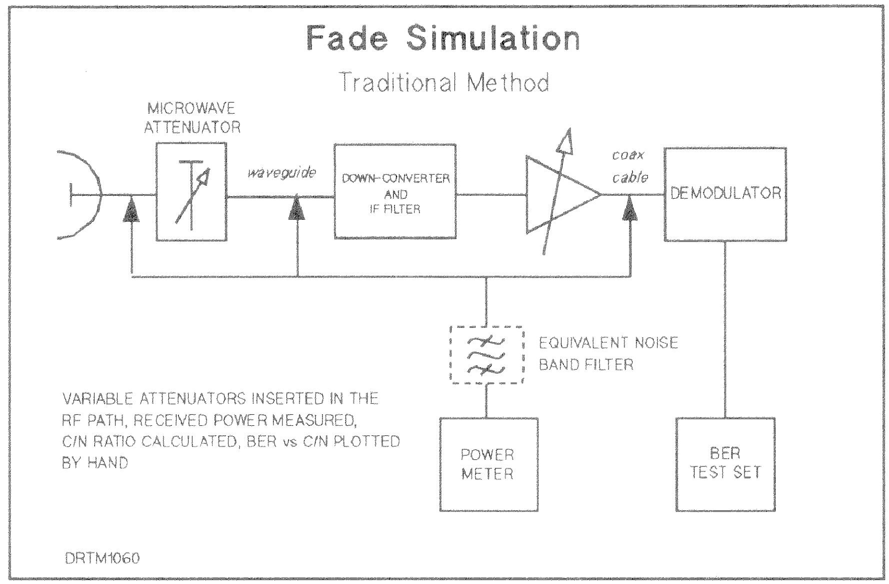
The C/N penalty or implementation margin is the most important measure of performance for the design and alignment of a digital radio, and later as we look at individual impairments. We relate these to equivalent C/N degradation. First, we consider how we can accurately measure the implementation margin and the practical C/N verses BER curve.

Two Methods of Making C/N versus BER Measurements

- The traditional fade method using an attenuator at the receiver input (varying C)
- The additive noise method using a noise generator (varying N)

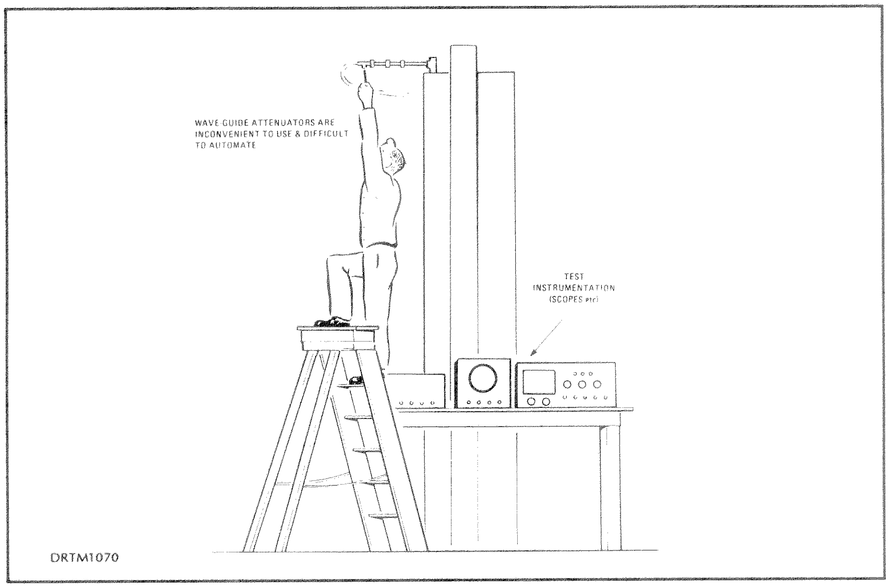
DRTM1050

We will now consider two methods of making this measurement. First, the tradional method of fade simulation and second, the additive noise method using the HP 3708A and how it can overcome the problems experienced with the traditional method.



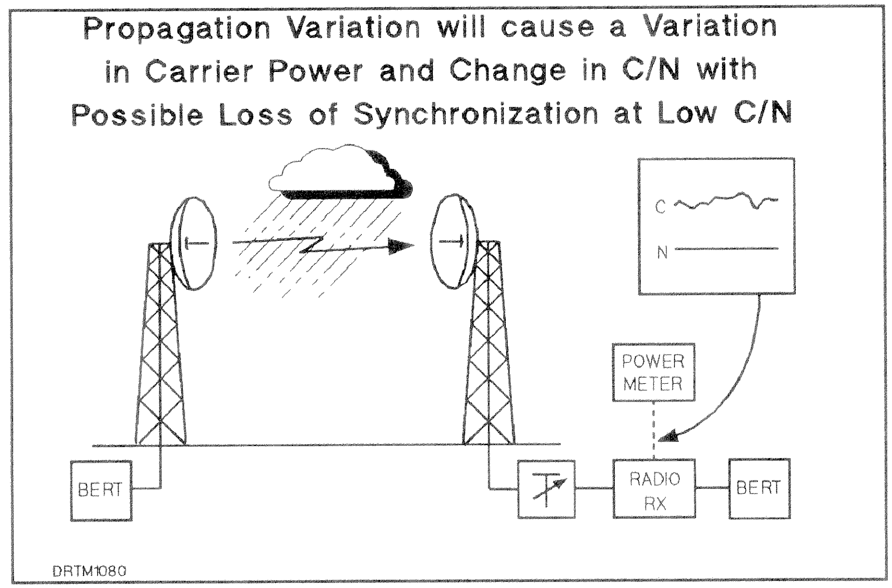
In this method an attenuator is connected at the microwave input of the receiver so that the incoming signal can be attenuated into the receiver noise. A power meter is used to check the effective C/N ratio in the IF section* or to measure the received signal level (RSL) if that is the parameter being used to plot the BER curve. In the latter case, the levels are very low so it is normal to measure the signal entering the receiver and then to rely on the attenuator accuracy to set the RSL, assuming the incoming signal level has not changed! When the noise level is measured at some point in the IF, the measured level will probably be higher than the noise level at the regenerator following the demodulator. This is because additional filtering may exist after the measurement point. this can be accounted for by making the measurement via an equivalent noise band filter at IF.

**Measuring the effective C/N requires a measurement of (C+N) and then N. In order to do this, it is necessary to switch the A.G.C. amplifier to "manual" and switch the transmitter off (to remove C), requiring communication and co-operation with the transmit-end multiple measurements.*

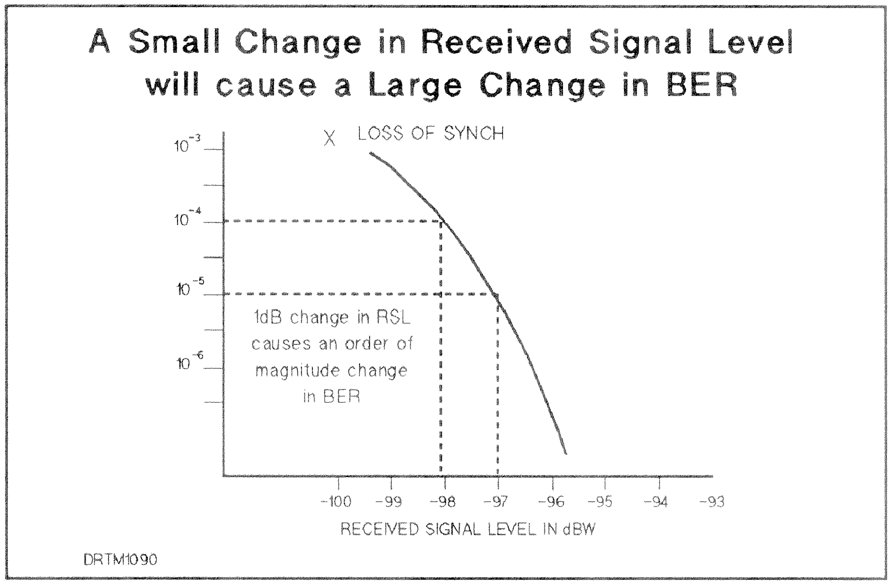


Sometimes the inaccessibility of the waveguide attenuator makes the measurement slow and it is difficult to automate. Matching problems and inherent attenuator inaccuracy at microwave frequencies reduces the reliability and repeatability of the measurements and increase the probability of operator error.

Furthermore, in the field-maintenance environment, it is undesirable to interfere with the microwave sections of the radio because of the danger of misalignment.



There is an additional problem in field measurements due to propagation effects which will cause a variation in carrier power. The noise level is fixed by the receiver front-end noise figure which to a first approximaion is constant, so the C/N varies, typically 1-2 dB even on a good day. This will lead to measurement errors and unstable BER readings. This is particularly true at low BER values where long gating times are required for statistically stable measurements.



The effect of the varying received level (or C/N ratio) can easily be seen on this slide where a 1 dB level change (quite normal) could result in an order of magnitude change in BER.

Furthermore, as the receiver is working close to its minimum receivable level, any further reduction in carrier level, for example, a fade of 2-3 dB could cause loss of synchronization in the radio and the results would then be completely invalid.

Some Typical Problems Experienced in C/N Testing using the Traditional Method

- Conflicts between factory and field/end user measurements because of inaccuracy/repeatability.
- Unstable measurements in the field due to varying carrier levels and possible loss of synchronization.
- Difficult to resolve small changes in C/N margin due to inherent inaccuracy/repeatability.
- Time consuming and prone to operator error because many adjustments required to plot a complete C/N curve (difficult to automate)
- Uncertainty in relating theory and measurements and determining C/N penalty because of unknown noise parameters and bandwidths.

DRTM1100

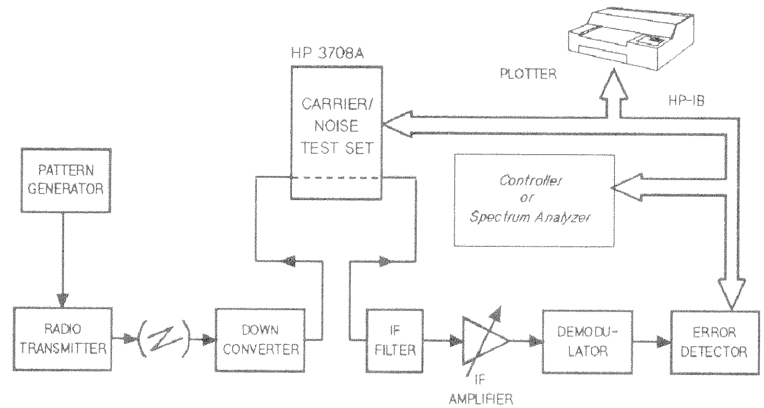
If you have tested digital radios using the traditonal fading method, you probably have experienced one or more of these problems. Most of them relate back to the uncertainty and variation in the received signal level and the inaccuracy of microwave attenuators. In other words, there are too many uncontrolled variables for repeatable measurements.

How does additive noise and interference testing using the HP 3708A overcome these problems?

DRTM1110

We will now consider how the HP 3708A Noise and Interference Test Set can overcome these problems. First, we will describe how the additive noise test is made.

Additive Noise and Interference Testing using the HP 3708A

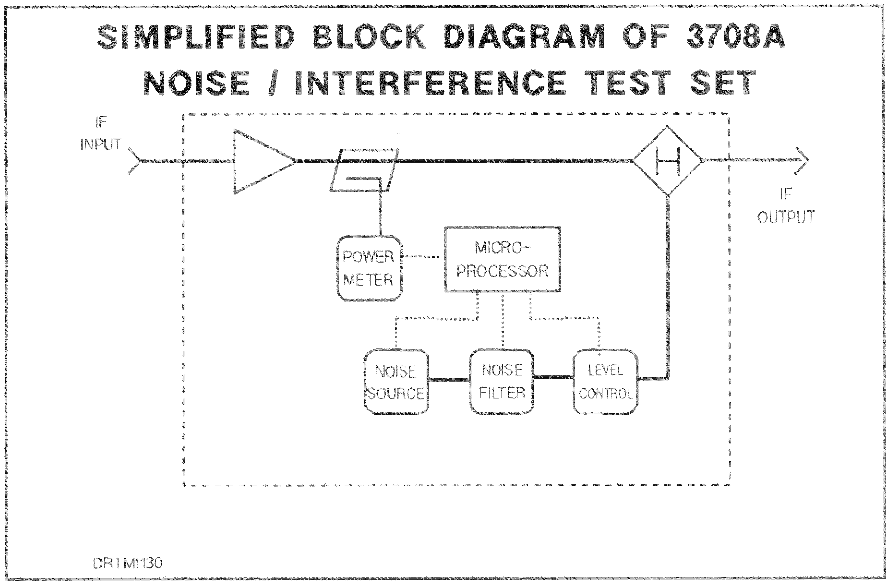


DRTM1120

In additive noise testing, the digital radio receiver operates at normal unattenuated levels so that the effect of receiver nosie figure is negligible and possible loss of syncronization is minimized. The IF signal in the receiver path is connected through the HP 3708A, set 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 BE is checked using the pattern generator and error detector.

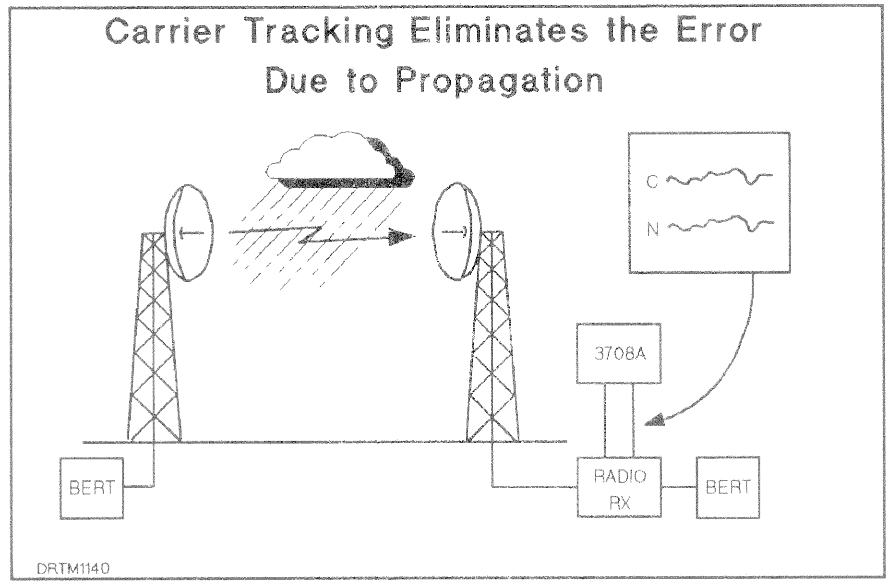
The configuration shown here performs automatic measurements with HP-IB controllable BER testers under the control of a computer or HP 8590 series spectrum analyzer. The measurements can also be made manually with a wide range of non-programmable BER testers.

**Comment*
To obtain accurate measurements at low BER values it is necessay for the noise crest factor to be >15 dB. Typically the HP 3708A crest factor is 20 dB permitting accurate measurements down to 10^{-12} BER.



In this simplified block diagram of the HP 3708A, you can see that the radio signal is passed through the noise injection assembly via the IF input and output ports.

The injection assembly has 0 dB loss to the radio signal and is specified to have negligible transmission impairments for signal levels up to +5 dBm. The signal level is measured using the high-accuracy power meter and the microprocessor then automatically control the noise source level to establish the desisred C/N ratio at the IF output. The power meter is also designed for fast response (< 10 msec) so that the microprocessor can control the noise source to automatically tack any variations in the received carrier level and maintain a constant C/N ratio.



This slide demonstrates the carrier-tracking capability where the noise level tracks the varying carrier level to keep a constant C/N ratio over the measurement period.

HP 3708A Carrier to Noise Ratios

1. CARRIER POWER TO NOISE POWER C/N dB
2. CARRIER POWER TO NOISE DENSITY C/No db Hz
3. ENERGY PER BIT TO NOISE DENSITY E_b/No dB

$$No = \frac{N}{B_e} \qquad E_b = \frac{C}{f_b}$$

$$C/No\ dB\ Hz = (C/N)\ dB + 10 \log_{10}(B_e)$$

$$E_b/No = (C/N)\ dB - 10 \log_{10}\left(\frac{f_b}{B_e}\right)$$

B_e = RECEIVER NOISE BANDWIDTH IN Hz

f_b = BIT-RATE IN Hz OR BITS/SEC

DRTM1150

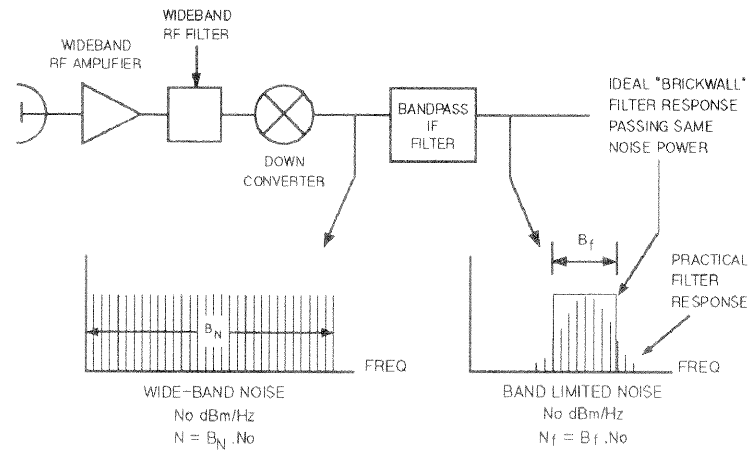
There are three units comonly used in carrier to noise testing available on HP 3708A: carrier to noise (C/N), carrier to noise-density (C/N9) and energy-per-bit to noise-density (3_b/No). C/N9 and 3_b/No are independent of bandwidth and particulary useful in R&D work for comparing the efficiency of different systems. Thes measurements require the test set to have an accurately known noise-density for injection into the radio IF.

C/N needs to be related to specified system bandwidth of practical receiver filters or to the theoretical minimum Nyquist bandwidth (or symbol-rate bandwidth) (see theory section).

The HP 3708A is designed with accurate noise bandwidth filters so that noise-density is calibrated. The HP 3708A can also measure the nosie bandwidth of external IF filters.

See Product Note 3708-1 (literature no. 5953-5487) for more details on the theory.

Noise Bandwidth



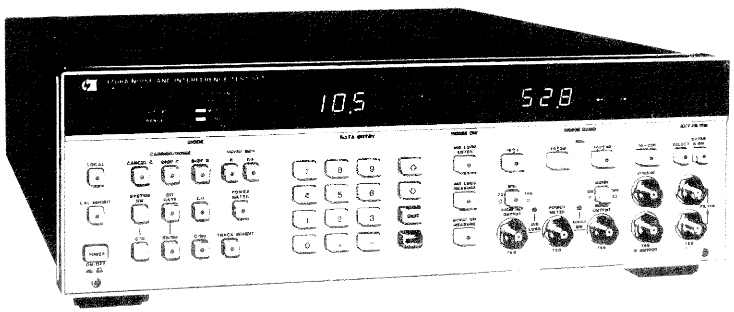
DRTM1160

Specifying the correct nosie bandwidth is essential for accurate measurements.

Consider the simplified diagram of a digital radio receiver. At the IF filter input, some amount of carrier power, C, and noise power, N, will be present. This noise power will be spread over a large frequency range and will have a given bandwidth (B_n) and noise density (No) - i.e. noise level expressed as power in 1 Hz bandwidth. At the the I.F. filter output -- asssuming zero insertion loss -- the unmodulated carrier power will still be C. The noise-density will also remain unaffected, but the total noise power will be reduced by the filter. The filter's nosie bandwidth (B_t) is defined as the bandwidth of the equivalent "brick-wall" filter which would deliver the same noise power.

Clearly the C/N ratio measured at these two points would be different and if the bandwidths are undefined the results become confusing and meaningless. The noise power cana be defined in the theoretical symbol-rate bandwidth or in the practical bandwidth of the radio.

HP 3708A Noise & Interference Test Set



DRTM1170

This slide shows the front panel of the HP 3708A Noise and Interference Test Set. On the left-hand side you can see the keys that control the modes of operation and the measurement units. You will notice a key in this area labelled SYSTEM BANDWIDTH which allows the entry of a user defined bandwidth for referring the C/N ratio value (for example, the symbol-rate bandwidth or receiver bandwidth).

On the right-hand side, you can see the main IF input and output connectors and the selection of internal filter bandwidths. The bandwidth quoted above each key is the flat bandwidth. Normally the band of noise chosen should be wider than the radio IF, the bandwidth being subsequently defined by the radio filtering. The HP 3708A can test radio systems using 70 MHz and 140 MHz IFs.

The standard instrument has 75 Ω interfaces, 50 Ω version available as Option 001.

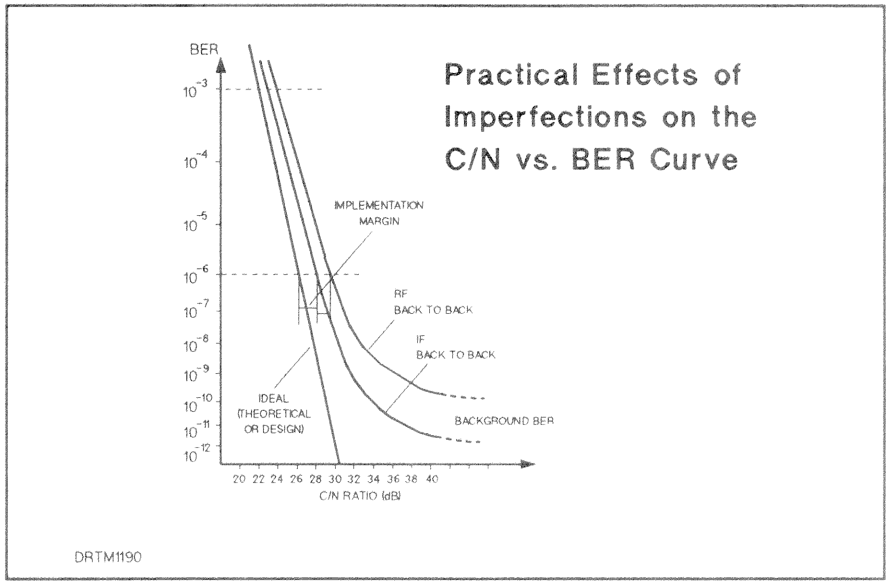
See Product Note 3708-2 (literature no. 5953-5489) for more details on using the HP 3708A.
Product Note 3708-5, "Testing Satellite Systems with the HP 3708A," (literature no. 5954-9555) tells how to get the best from satellite systems with the instrument. It also includes a hints and tips section.

The HP 3708A Overcomes the Problems Described Earlier by the Following Advantages:

- Accuracy and repeatability better than 0.1 dB typically.
- Accuracy independent of varying carrier level in field applications
- Simple operation and automation saves time and reduces operator error.
- Accurate noise density and system bandwidth definition

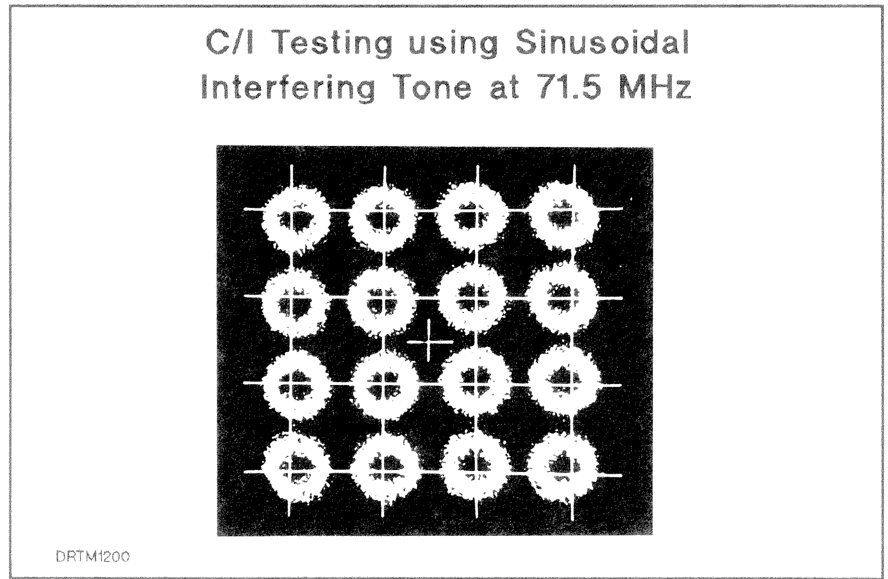
DRTM1180

The accuracy and repeatabilty of the HP 3708A test method means that measurements can be made on individual radios at different times and results used for reliable comparison of degradation in performance.



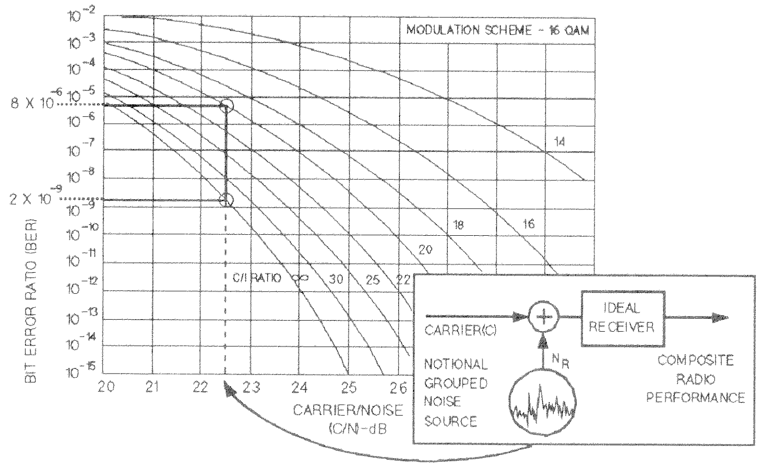
So the practical BER versus C/N curves, shown here, can be accurately and quickly plotted using the HP 3708A. The only remaining problem is the long gating time (maybe several days) required in the BER test in order to measure the very low background BER at high C/N values. It is important to know the background BER as when many radios are cascaded, the overall error performance may become unacceptable. This is particularly relevant now that the latest version of CCIR Rec. 594 includes the RBER (Resdidual BER) specification. An overall value of 5×10^{-9} for 2500 km requires a single hop specification of 10^{-10} to 10^{-11}. 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 a sinusoidal 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 effect is shown in the next slide.



This constelllation display of a 16-QAM digital radio with an interfering tone added shows clearly the reduction in space between the individual phase-states which cause the increased BER value. Estimation of the true background error ration is made using the graphs illustrated in the next slide.

Graphical Method of Estimating Residual BER



DRTM1210

The principle of this technique depends on representing all the imperfections in the radio as equivalent to a notional grouped noise source which is summed into an ideal receiver. A level of C/I is chosen (in this 16 QAM example C/I = 20 dB) which gives a reasonable BER with the radio under test (e.g. 10^{-3} to 10^{-6}). From the BER value and C/I value we can then find the equivalent C/N ratio for the notional internal grouped noise source (in this example 22.5 dB). If we assume this has a gaussian distribution, then we can extimate the residual BER from the intersection with the C/I - infinity curves shown in this slide. The curves are calculated theoretically for an ideal radio with varying amounts of sinusosidal interference. These allow the estimation of the equivalent notational noise source and from that the C/I - infinity curve, we can estimate the effective bacdground BER, 2 x 10-9 in this case.

Comment

There are a number of assumptions in this technique which are described more fully in these two HP publications:
Product Note 3708-3 Determination of Residual Bit Error Ratio in Digital Microwave Systems (literature no. 5953-5490)
"Methods for Estimating Residual BER in Digital Radio" by Ian Kennedy Compston (literature no. 5954-7942).

Determination of Radio Residual BER

Major Advantages of HP 3708A C/I Test Method

- Reduced measurement time
  Example : 100 Mbit/s Digital Radio
  Residual BER (approx) 10^{-12}
  Traditional method test time : 3 days (approx for 30 errors)
  HP 3708A method test time : 2-3 mins (approx)
- Measurement accuracy
  In field measurements, the propagation conditions are unlikely to remain stable over a 3 day measurement period.

DRTM1220

This simple calculation demonstrates the time-saving made by using the C/I test. Estimation of residual BER becomes feasible in field installations without the excessively long measurement time required by the normal method. Test time is also saved in production, allowing repeated tests for evaluation of adjustments.

In high-density modulation schemes such as 16 and 64 QAM, excessive background BER can be a significant problem.

HP 3708A Software

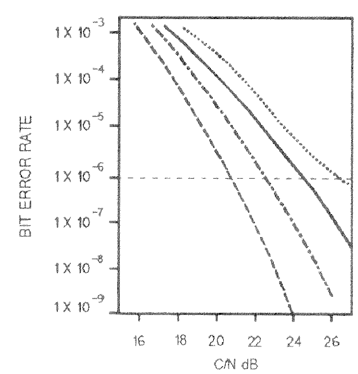
- Fully automatic plotting of C/N and C/I curves including sequencing
- Storage of measurement curves for comparison
- Flexible plotting format including use of graph paper
- Storage of measurement configuration and parameters for easy measurement execution

DRTM1230

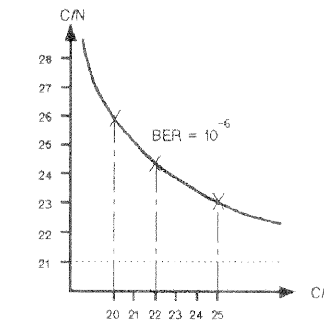
The demonstration software for the HP 3708A shows the power of a fully automated system incorporating HP 3708A, HP 3764A or HP 3789A/B, HP 300 Series Controller and Plotter. Once the software is loaded, measurements can be initiated and results plotted and stored with a few key-strokes. Automatic measurements can be left running unattended, or the sequency repeated several times to detect varitions in radio performance.

For more details see:
Product Note 3708-4 "HP 3708A Demonstration Guide" (literature no. 5954-9551).

Testing Radio Receiver Susceptibility to Interference



TYPICAL 8-PSK CO-CHANNEL INTERFERENCE PLOT



The same results plotted on a C/N vs. C/I plot for a given BER of 10^{-6}

DRTM1240

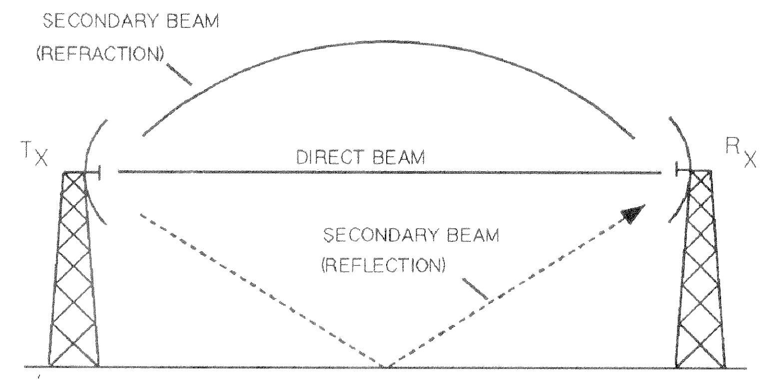
It is sometimes necessary to specify the performance of the receiver with varying levels of adjacent channel or co-channel interfence by plotting a family of C/N versus BER curves for varying levels of interence as shown here. For a given BER (e.g. 10^{-6}) the effective loss of receiver sensitivity (or C/N penalty) can be measured as a function of C/I so that it is then possible to plot a C/N versus C/I curve as shown here.

Multipath Fading

DRTM2000

We just looked at stressing a radio by changing the noise level. In this section we will stress the radio by subjecting the receiver to multipath fading.

Multipath Propagation



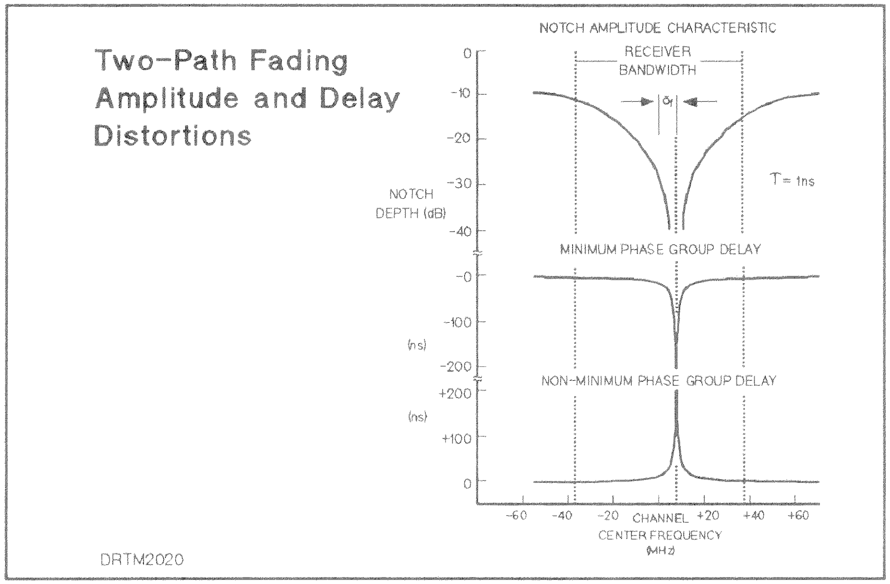
DRTM2010

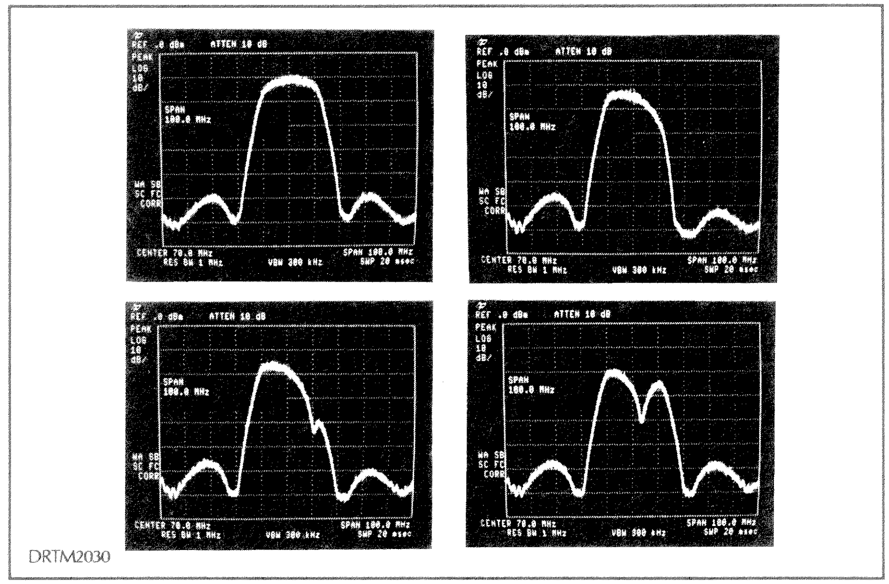
All terrestrial microwave radio systems can suffer from multipath propagation where the receiver antenna receives not only the direct signal but also a secondary signal which is slightly delayed relative to the direct beam.
The secondary beam* bends due to the varying refractive index of the air. The phenomena is particularly prevalent in hot summer weather and when the radio path is across water. The result is frequency-selective fading.
The degree of multipath fading is heavily dependent on the “hop” length — the longest hops requiring very careful attention in the system design. For this reason radio links operating at microwave bands below 15 GHz with relatively long hops tend to suffer predominantly from multipath propagation whereas higher-frequency systems with shorter hops are affected mostly by flat fading from attenuation due to rain.

** Secondary beam can also result from reflections off buildings etc.*

For more information on multipath fading see:

**Multipath Fading Channel Models for Microwave Digital Radio” by Rummler, Coutts and Liniger. IEEE Communications Magazine, Nov. 1986, Vol. 24, No. 2, pp 30-41.*





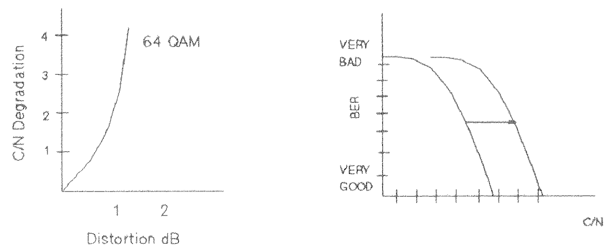
Frequency-selective fading gives rise to notches or slopes in the amplitude response across the radio channel. The group-delay is similarly affected, and as shown in the slide, the shape will invert if the fade becomes non-minimum phase, i.e. when the secondary beam amplitude is greater than the direct beam. The depth and frequency of the notch vary continuously during multipath fading and create very serious inter-symbol interference in a digital radio.

The presence of multipath activity can be identified in-service by monitoring the received digital radio spectrum on a **spectrum analyzer**. The normally stable and symmetrical spectrum will be distorted as the multipath fade passes through the band. Multipath can also be identified in-service on the **HP 3709B Constellation Display**.

The result is short periods of very high error ratio which can cause loss of synchronization in the radio itself or in associated multiplex equipment.

The notch created by multipath fading is not permanent or predictable, and when there is a notch present it may sweep in frequency and depth. Fortunately, in the typical radio hop the radio is unaffected by multipath for most of the time. During this time the signal spectrum is shaped solely by the transmitter. However, when multipath fading creates a notch in or around the spectrum, it will distort the spectral shape. As demonstrated earlier, this will cause ISI and can increase the BER.

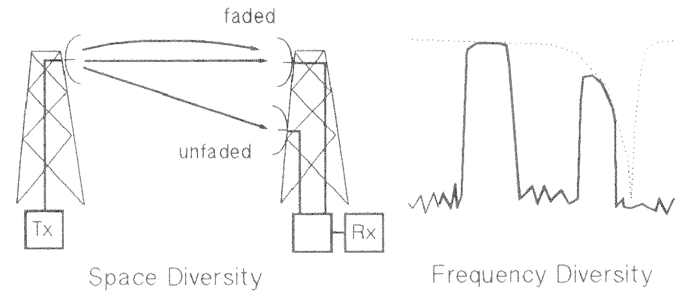
Amplitude and Phase distortions affect BER



It only takes a little distortion to ruin a transmission.
Multipath can cause a lot of distortion.

DRTM2040

What is done to assure quality?



Diversity techniques are common.
Diversity attempts to provide MP-free transmission.

DRTM2050

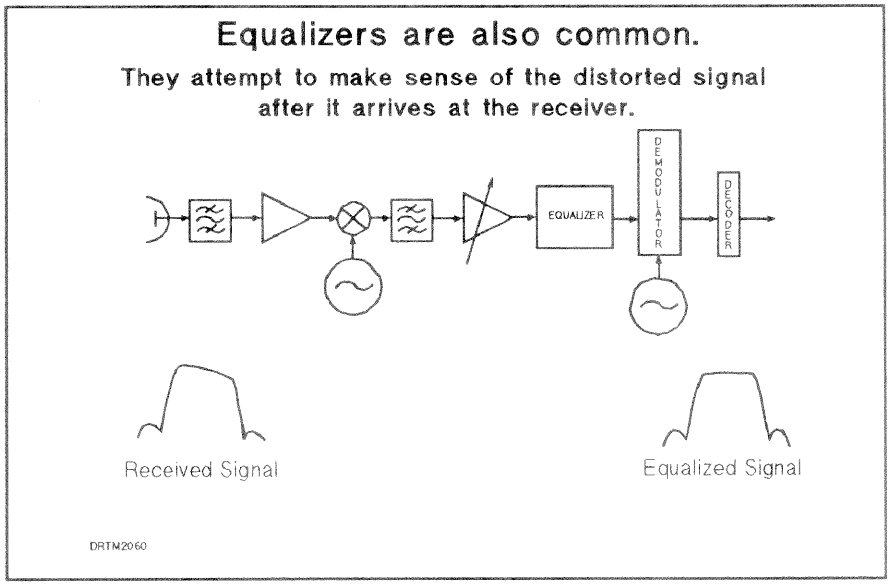
Much care is taken to remove any amplitude and phase unflatness from a digital radio. Even a small amount of distortion will greatly degrade performance. The above picture shows the effect of parabolic distortion on the amplitude transfer function of a 64 QAM radio. At a little more than 1 dB distortion, the degradation increases quickly.

Multipath, although not strictly parabolic, can cause distortions much greater than 1 dB. This would seem to indicate that even a little multipath fading will make a digital radio unuseable. Digital microwave radio works quite well, however, and we will see how even a complex radio like 64 QAM can tolerate as much as a 20 dB notch and continue to operate virtually error free.

The techniques used to provide acceptable transmission quality include two general catagories. There are techniques which attempt to provide a distortion free transmission path and techniques which attempt to correct for distortions encountered in transmission. The two techniques are often used together.

The picture demonstrates two types of diversity which attempt to provide distortion free transmission. These techniques use redundancy and are termed diversity. In the first example, two antennas receive the same transmission. However, because of the nature of multipath fading, only one antenna at a time will undergo fading. Usually, at least one of the antennas will receive a relatively clear signal. This technique is called space diversity. The receiver chooses the better of the two signals or combines the two to create a usable signal.

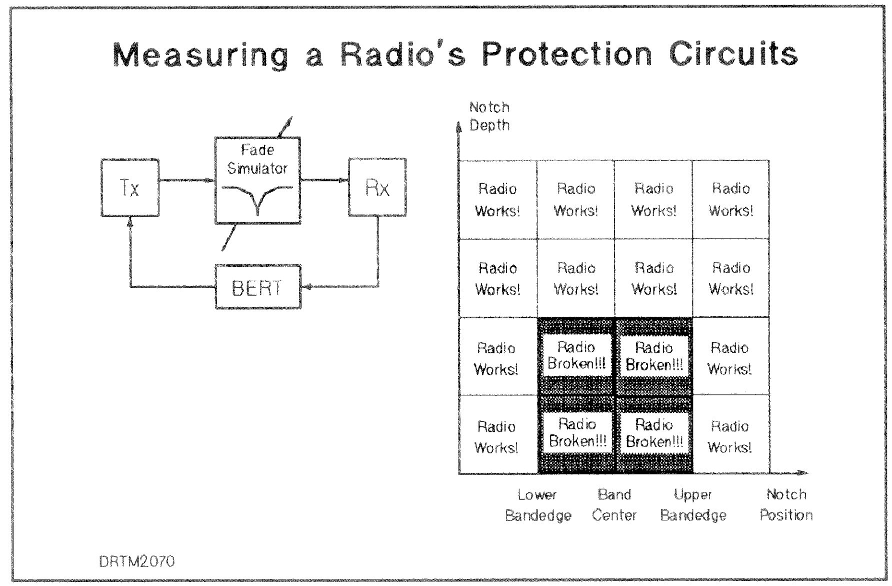
The second example is frequency diversity. The same information is available on two different frequencies. Because of the unique nature of multipath, at least one of these frequencies will be free from mutipath. The receiver chooses the frequency with the better signal. This example demonstrates 1 + 1 diversity where one backup channel protects one live channel. For greater efficiency, one standby channel may protect a number of live channels, for example, 11 + 1 frequency diversity.



Another increasingly common technique to combat multipath fading is the use of equalizers. Equalizers are devices in the IF and/or baseband sections of the receiver which "take out" the notch from the received spectrum. Equalizers are complex devices. However, the basic idea behind them is simple. They act as frequency selective AGC. They peak up the spectrum where it is notched out. Because the fading may change extremely quickly (the notch may change position at up to 100 MHz/s and depth at 100 dB/s), equalizers must be able to adjust the spectrum based on the instantaneous fading conditions.

Originally, equalizers were analog circuits residing in the IF of the receiver. This is still common, but more and more, equalizers are becoming digital signal processors operating on the digitized signal in the baseband following demodulation. Depending on their design and location in the radio, equalizers go by many names:

Adaptive Time Domain Equalizer (ATDE)
Transverse Equalizer
Slope Equalizer
Tapped Delay-Line Equalizer . . .

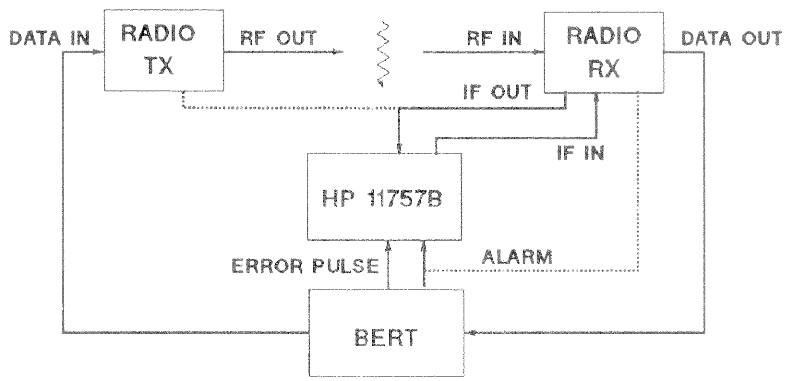


Equalizers are somewhat unique devices in a radio. In a properly operating radio on a well designed and optimized route an equalizer, most of the time, does nothing. It is only during random fading events when it must react to maintain the link. An equalizer is designed to not interfere with proper operation during periods of normal propagation. However, if the equalizer fails or is out of adjustment it may cause spurious errors or "hits". A bad equalizer may also appear just fine during normal operation yet fail to correct for even slight multipath fades. Either case will lead to poor link performance, the cause of which is hard to diagnose.

This is why a special test is necessary for equalizers. The only way to test equalizers is to create a calibrated amount of fading and monitor the ability of the equalizer to compensate.

One simple way to test the equalizer would be to create a notch at each of a number of different depths and positions. At each of these conditions we would record whether or not the radio is working (has an acceptable BER) or is not working. This is a simple example of the most common multipath measurement — the M-Curve.

How do you measure M-Curves

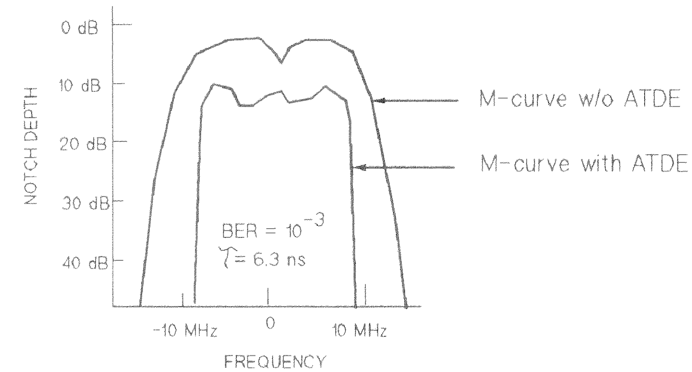


DRTM2080

Although multipath fading actually occurs at RF frequencies, it is difficult, costly and unreliable to simulate fading at these frequencies. It is better to simulate the fading at IF. The HP 11757B Multipath Fading Simulator is inserted in the IF of the Digital Radio receiver before any equalizer to be tested. If possible it should also be inserted before the AGC.

The HP 11757B monitors the error output from a BERT, or an alarm output from the radio, to help generate M-Curves.

The M-curve tells us the fading conditions under which the radio will operate properly



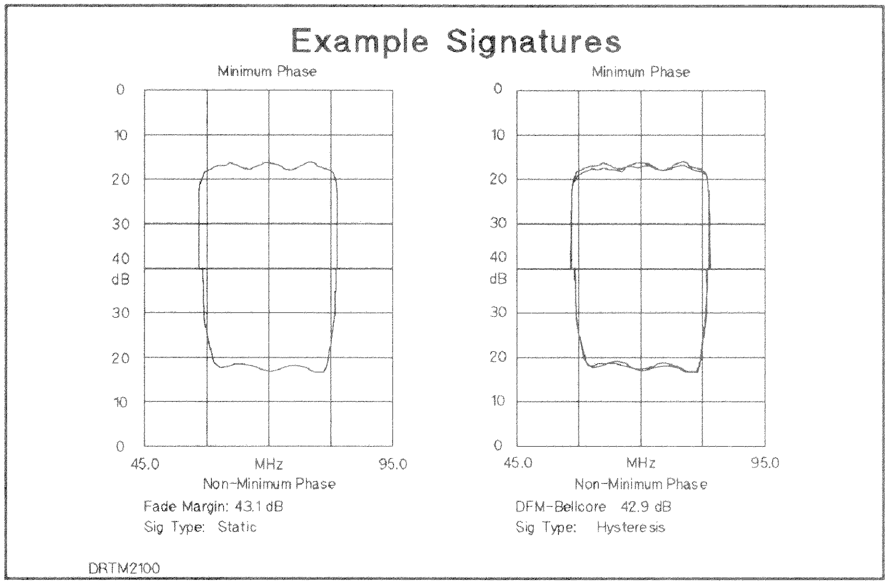
DRTM2090

The M-Curve, also called the W-Curve or signature, is the most common test of equalizer performance. It is performed by moving a notch to each of a number of positions. At each position the notch is made deeper and deeper until the radio reaches a certain threshold BER. This threshold is often 10^{-3} or 10^{-6}.

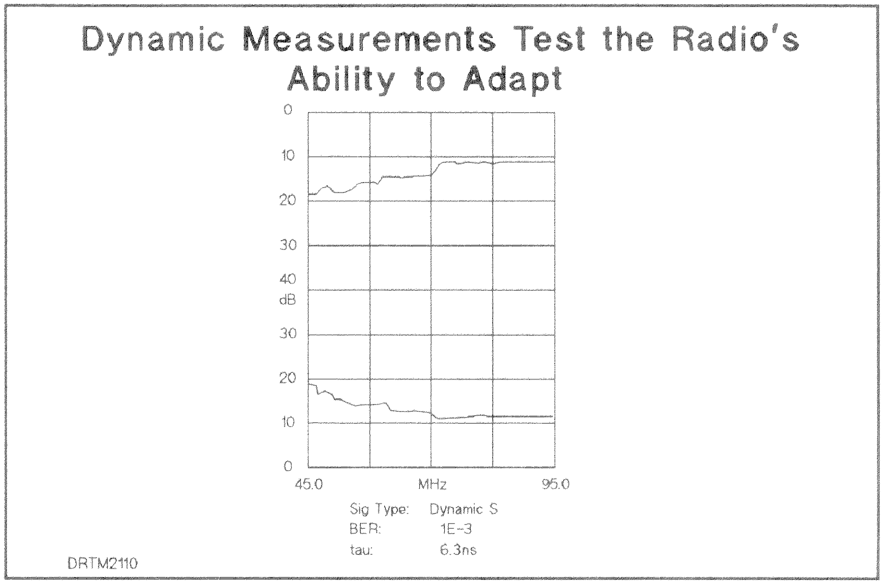
The M-Curve is useful for a number of reasons:

1) It can be used to compare different model of radios. The smaller the M-Curve, the better the radio can cope with multipath.
2) It can be used to troubleshoot. An M-Curve can be measured at commissioning or read from the radio's spec sheet. If radio problems occur which put the equalizer under suspicion, another M-Curve can be measured and compared to the original.
3) Route planners can use the M-Curve to estimate the multipath caused downtime of a radio.

Note that an M-Curve must always include the threshold BER value and the delay.

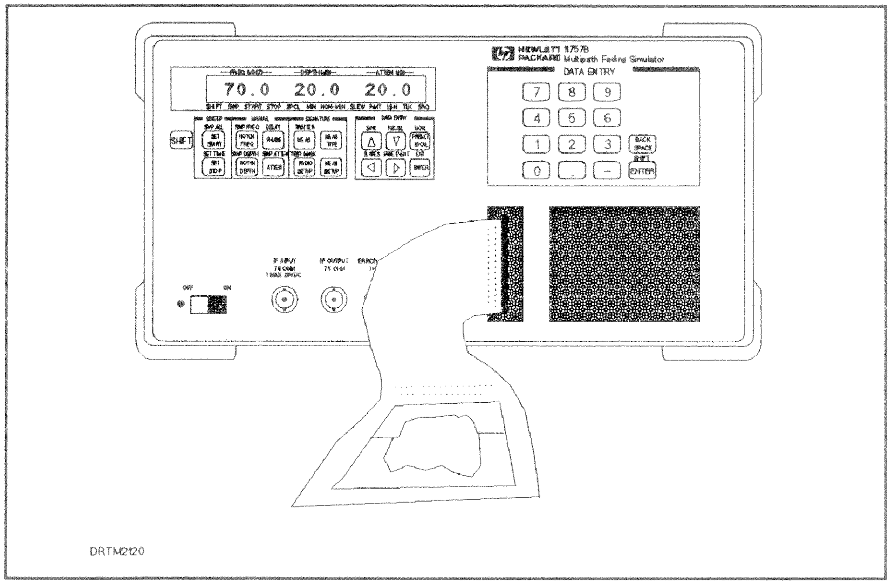


Here are some example curves. The curves on the left are Static M-Curves. They show the equalizers' ability to handle a notch that is increasing in depth. The curves on the right are Hysteresis M-Curves. They show the equalizers performance when presented with a notch increasing in depth and its performance when presented with a notch decreasing in depth.



Dynamic tests are becoming more common. Recognizing that multipath is a very dynamic phenomenon, tests like this are important. One popular test is shown here. It shows the radio performance at various notch depths and velocities. It is called the dynamic S-Curve. Note that tau and BER are shown.

Another common dynamic test is the Dynamic M-Curve. In this test, the HP 11757B varies the notch frequency sinusiodally as the notch increases in depth.



The M-Curve measurement as well as other measures of multipath susceptibility are relatively simple measurements to perform using the HP 11757B.

The HP 11757B makes it easy to do complete characterization or perform go/nogo testing in the field.

If an HP 8590 Series spectrum analyzer is available then, using a special DLP, the measurement results can even be displayed on the analyzer's CRT.

At times it is useful to make a quick simple test which will give an indication if the equalizer is working properly or not. The HP 11757B Multipath Fading Simulator and the HP 11758V Digital Radio Test System are capable of a variety of field GO/NOGO tests. One of the simplest tests is to put a notch of a predetermined depth in the middle of the signal. This depth can be determined by experimenting with known good radios or by looking at the M-Curve specification. If the radio's equalizers are operational then the notch won't cause many errors. Another quick test is to sweep a notch in frequency with a fixed depth. This tests the equalizers' ability to adapt. A more informative test which is only slightly more involved is to measure a single point on the dynamic signature.

More comprehensive tests are possible using the fade event memory in the fading simulator. This allows you to preload a table of fade characteristics. You can then play these back to test a radio. As an example, this fade event might represent worst case multipath fading. Your HP Sales Engineer can help you design the right test for your system.

INTRODUCTION

ERROR PERFORMANCE

STRESS TESTING

In-Service Testing Using Constellation Analysis

DIAGNOSTIC TESTING

SUMMARY

DRTM2140

In-service testing is highly desirable for digital radio operators because they need to maintain service at all times, and need to reduce the risk of faulty components causing breakdown.

A very powerful way of providing this in-service preventive maintenance is by using constellation analysis. We discuss this powerful technique in this section.

In-service testing allows you to keep revenue-earning radios running while still assuring the signal quality. Trends or gradual degradation on performance can be monitored and the radio only taken out of service when corrective maintenance is required.

Modulator / Demodulator Imperfections

- Amplitude errors
- Quadrature angle errors
- Phase-lock angle errors
- Incorrect demodulation decision thresholds

DRTM2150

How can constellation analysis help us in digital radio testing?

A variety of imperfections can exist in a digital radio system, and the more complex the modulation scheme is, the greater the potential problems.

In the modulator and demodulator:

Amplitude Errors might consist of non-equal amplitude values in the four states of QPSK or unequal I and Q levels or non-linear modulation of I and Q carriers.

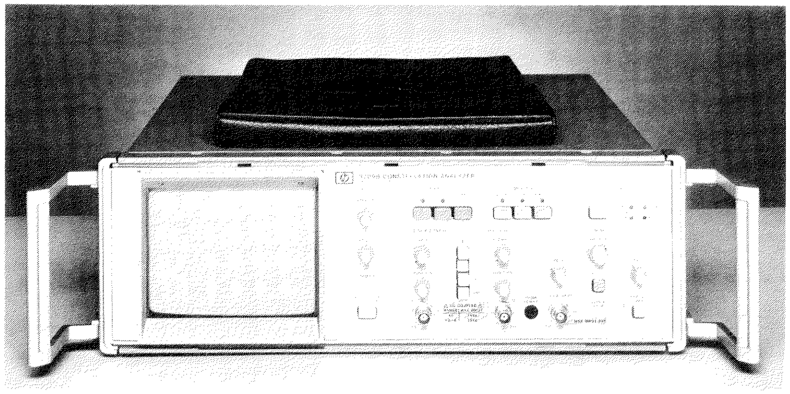
Quadrature Errors are effects due to the I and Q carriers not being at exactly 90°. The result is a modulation diagram which is trapezoidal or rhombic in shape.

Phase Lock Errors occur when the recovered carrier in the demodulator is not correctly phased with the incoming signal, resulting in a rotated constellation diagram.

Incorrect Demodulation Decision Thresholds are similar in effect to the amplitude errors in the modulator. The result is a reduced margin between the state value and the decision threshold.

The HP 3709B Constellation Analyzer quantifies these effects and, as we will see, can also do a lot more to measure digital radio performance.

HP 3709B Constellation Analyzer



In-Service analysis of digital radio performance

DRTM2160

The HP 3709B Constellation Analyzer is a special purpose high-performance dual-channel sampling oscilloscope designed for digital radio measurements (for 4 PSK, 9 QPR, 16 QAM, 256 QPR, 49 QPR, 64 QAM, 81 QPR and 256 QAM). It can display the radio constellation or either I or Q eye-diagrams at the push of a button. The analog circuitry is designed to handle the random digital radio signal with the minimum of distortion (ISI) and very low drift, and the autoranging timebase automatically displays 2 periods of eye-pattern for symbol rates between 1 and 80 Mbaud.

In addition to visual interpretation, the HP 3709B can make estimates of the average rms closure for all displayed phase states, lock and quadrature angle, and non-linear distortion either on a repetitive basis or in a single shot mode for higher accuracy and repeatability.

Measurements and constellation display can be dumped directly to the HP 2225A Thinkjet Printer via HP-IB.

For more information on HP 3709B measurements see HP 3709B Training Manual (literature no. 5954-9544).

Analyze performance IN-SERVICE

DRTM2170

Isolate problems instantly — Identify impairments and pinpoint causes with just a brief examination of the constellation pattern.

Evaluate the impact of impairments — Realize an in-service alternative to C/N and BER measurements.

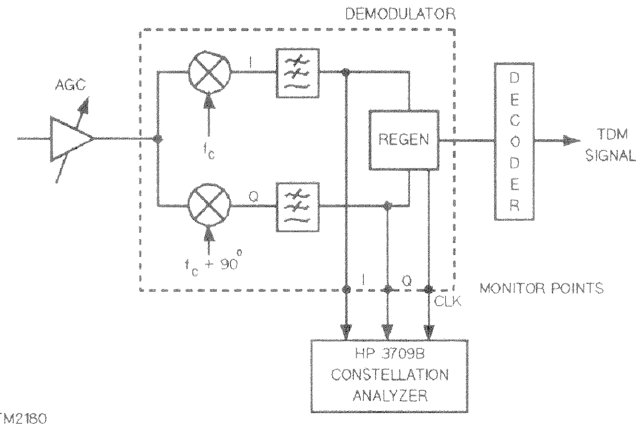
Characterize the TWT — Quantify the non-linear AM-AM and AM-PM distortion caused by an improperly matched TWT and pre-distorter pair.

Remove the distortions — Follow adjustments on the constellation pattern then use the measurements to accurately align the radio.

Optimize performance — Detect residual degradation not visible to the naked eye and perform fine-tuning to eliminate the problems.

Don't wait until the alarm bells ring — Stop degradations in-service and tackle them before they become serious enough to cause outage during a fade.

Making the In-Service Constellation Measurement



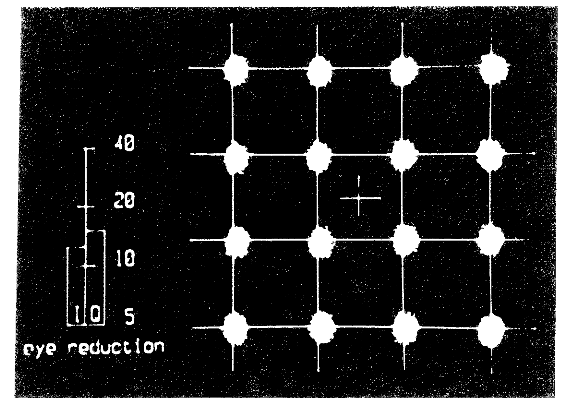
DRTM2180

This is how the HP 3709B connects to the digital radio system.

To make in-service constellation measurements, the radio must be equipped with suitable monitor points in the demodulator providing the post demodulation I stream, Q stream and symbol timing clock.

These connections are available on most digital radio systems.

HP 3709B Bar-Chart Display

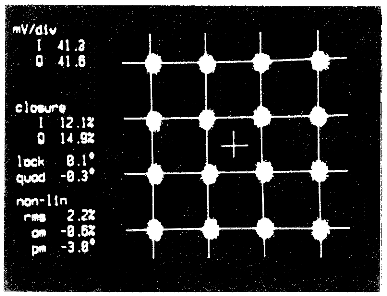


DRTM2190

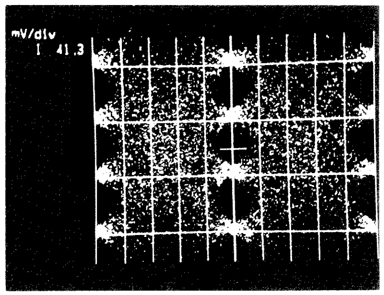
The HP 3709B has a selection of displays, showing the data in different ways.

This shows a 16 QAM constellation with a 'bar graph' showing the 'eye reduction' of the signal. This is a composite measurement including all the effects of individual impairments, similar to the measurement of overall C/N margin. The bar chart has a fast update rate for making adjustments.

16 QAM Radio Normal Operation



Constellation



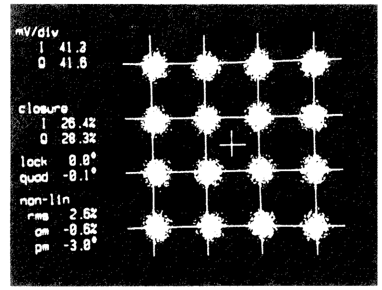
Eye

DRTM2200

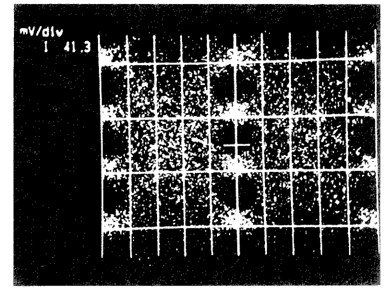
This is the picture you would like to see!

The 16 states are correctly placed on the rectangular grid and the cluster size is small indicating low thermal noise, interference and ISI. The constellation measurements can be seen on the left-hand side of the display and indicate an eye closure of 12% - 14% and negligible angular displacements.

16 QAM Radio Degraded C/N



C/N = 15 dB

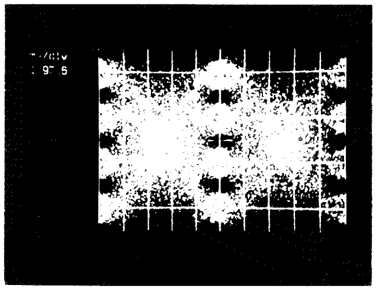


C/N = 15 dB

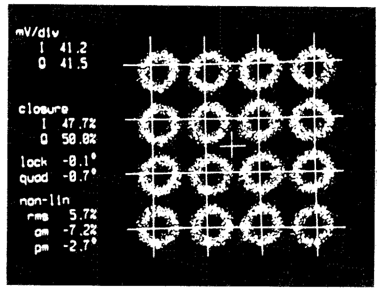
DRTM2210

This slide shows the effect of a poor C/N ratio (15 dB) in the radio. As expected, the constellation states are enlarged creating eye closure and a higher BER. In this slide the rms eye closure is around 27%. Note that in this and the last slide, the same information is available from the eye-diagram since there are no geometric distortions present in the constellation.

16 QAM Radio with Sinusoidal Interference



C/I = 15 dB

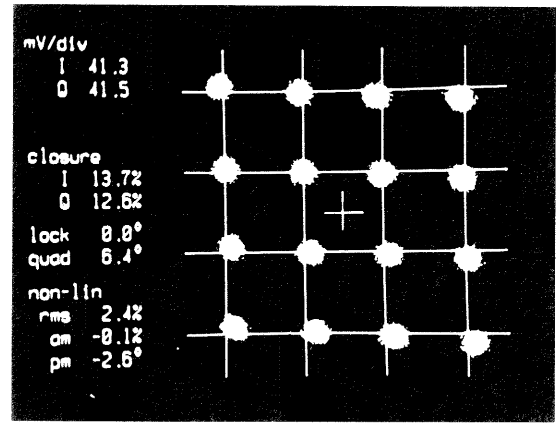


C/I = 15 dB

DRTM2220

In this case the radio is being affected by a sinusoidal interfering tone as might be the case when interference is being received from the strong carrier component of an FM radio. The sinusoidal interferer generates a "doughnut" shape due to the rotating vector of the interference signal which is frequency offset from the digital radio carrier.

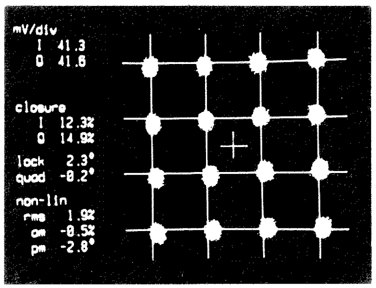
16 QAM Radio : Quad without Lock



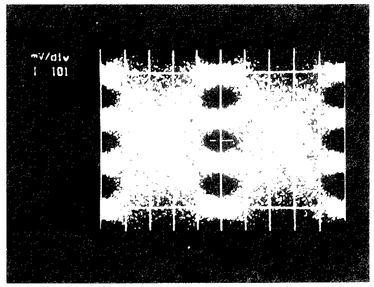
DRTM2230

The next two slides show some modulator/demodulator impairments. This is the kind of picture you would see if the I and Q carriers were not exactly 90° to each other and indicates that either the modulator or demodulator needs a quadrature adjustment. Such a fault would produce eye-closure on one eye-diagram but not on the other, provided no other fault were present. Often, however, this situation may be combined with a phase lock error shown in the next slide.

16 QAM Radio with Carrier Lock Error



2.3° Carrier Lock Error



2.3° Carrier Lock Error

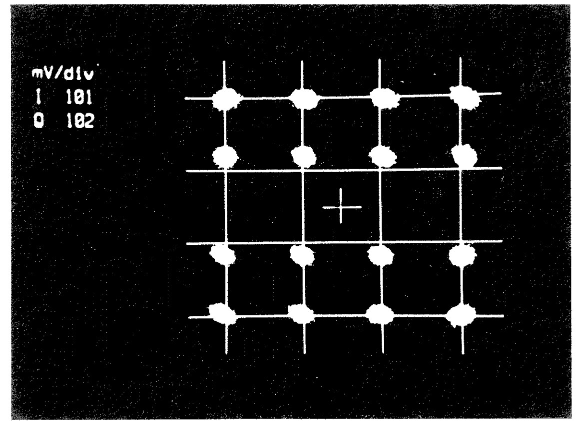
DRTM2240

The rotation in this picture is due to a phase-lock error in the demodulator carrier-recovery loop.

The carrier lock error effectively closes the eye pattern and leads to increased bit errors. But by looking at the eye diagram alone, it is impossible to distinguish lock error from added noise.

The constellation measurement indicates a rotation or lock error of $2.3°$, a serious impairment for a 16 QAM digital radio system.

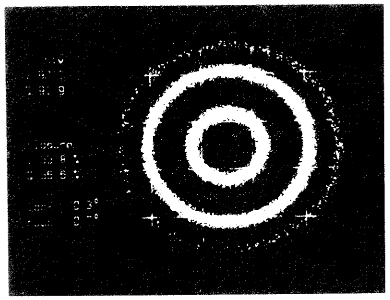
16 QAM Radio : Amplitude Imbalance



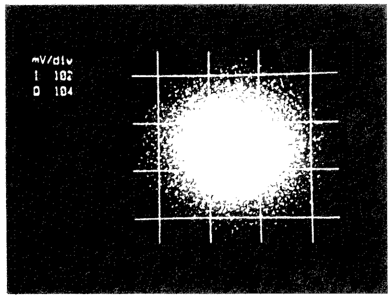
DRTM2250

This constellation shows an example of another impairment which can occur in the modulator and demodulator. In this case the amplitude levels on the quadrature carrier are not correctly set. This might be due to a non-linear modulator or inaccurate D to A converter.

16 QAM Radio: Carrier Recovery Loop Out-of-Lock



16 QAM Radio: No Signal



DRTM2260

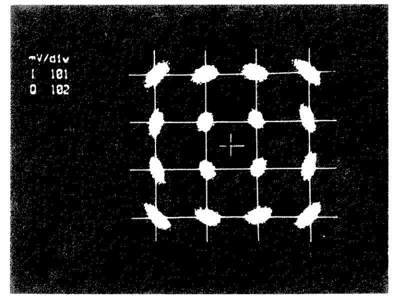
These two constellation pictures illustrate complete failure.

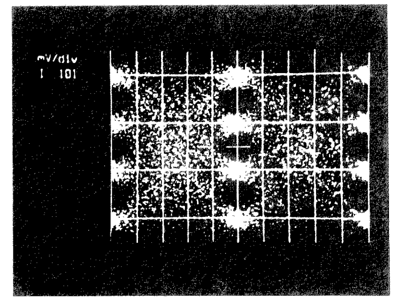
(1) When the radio demodulator is out-of-lock, the lack of phase coherence creates circles on the display.

(2) The lack of any input signal produces a large cluster of random points.

(Note that the eye diagram would show both of these as complete eye closure.)

16 QAM Radio : Phase Jitter

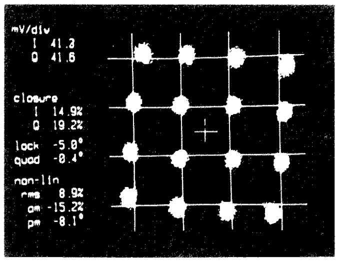




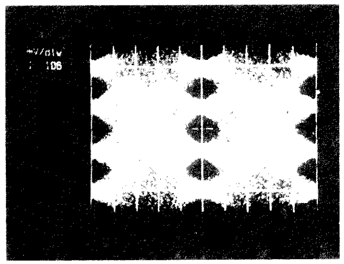
DRTM2270

Phase jitter on a carrier supply (local oscillator) or recovered carrier will cause a spreading of the constellation points in a circular fashion as shown in this slide. The eye diagram does not reveal this fault.

Constellation and Eye Diagram for 3 dB Overdrive of TWT



Constellation



Eye

DRTM2280

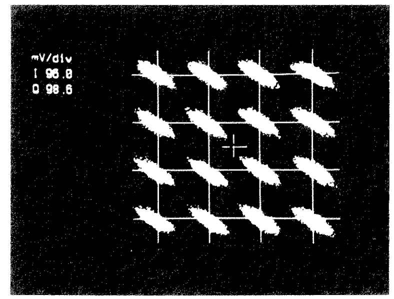
Looking now at transmitter power amplifier non-linearities, here we can see the effect of a 3 dB rise in output power. Notice how the constellation is twisted and rotated (AM/PM) and compressed at the corners where there is maximum power (AM/AM).

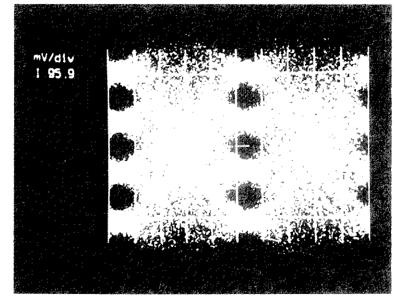
The constellation is a very powerful method of analyzing non-linearity, and optimizing performance either using the internal "non-linearity" measurement or with increased precision through an external computer.

Comment

Constellation measurements are probably the best way of analyzing non-linearity effects for two reasons. Firstly, the test signal is the true digital radio modulation so the non-linearity is exercised exactly as it would be in normal operation. For example, sinusoidal test signals do not have the same dynamic behaviour. Secondly, as this slide shows, both amplitude distortion (AM/AM) and phase distortion (AM/PM) effects can be measured. These effects are quantified in the HP 3709B non-linearity measurement.

Constellation and Eye Diagram for Amplitude Slope across the Channel





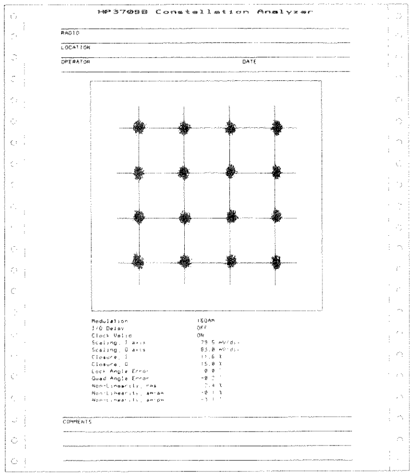
DRTM2290

Lastly, this slide shows the effect of an amplitude slope as might occur during a multipath fade. The 45° oval shape of the clusters shows that there is crosstalk between the I and Q signal which is the dominant effect of assymetrical distortion such as amplitude slope. You may notice that the point of maximum eye-opening on the eye-diagram is shifted from the nominal position at the center of the screen (i.e. the sampling position for normal operation). In order to obtain the constellation pictures the I and Q timing controls need to be slightly adjusted to explore the correlation between I and Q channels.

The characteristic eliptical and diamond shaped clusters can also be seen with time-varying multipath activity. The variable nature of the phenomena would be distinguishable from static transmission impairments in filters, antennas, etc.

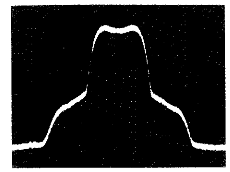
This series of slides shows the diagnostic power of the constellation measurement for in-service test.

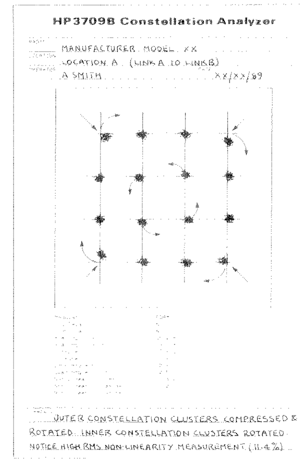
HP 3709B Constellation Analyzer



DRTM2300

This shows a typical printout on the HP 2225A Thinkjet Printer connected to the HP 3709B. This provides a simple way of documenting radio performance and generating a catalog of impairments to help in troubleshooting a particular radio system. A similar printout can be obtained from the HP 8980A Vector Analyzer and the HP 8981A Vector Modulation Analyzer.

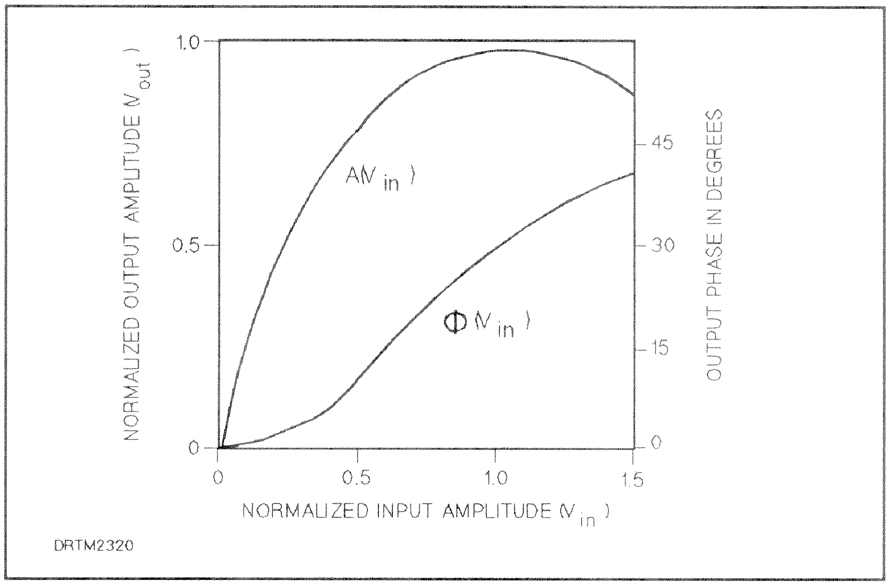




DRTM2310

This shows a new technique using the HP 3709B to align the pre-distorter and RF amplifier in a digital radio system.

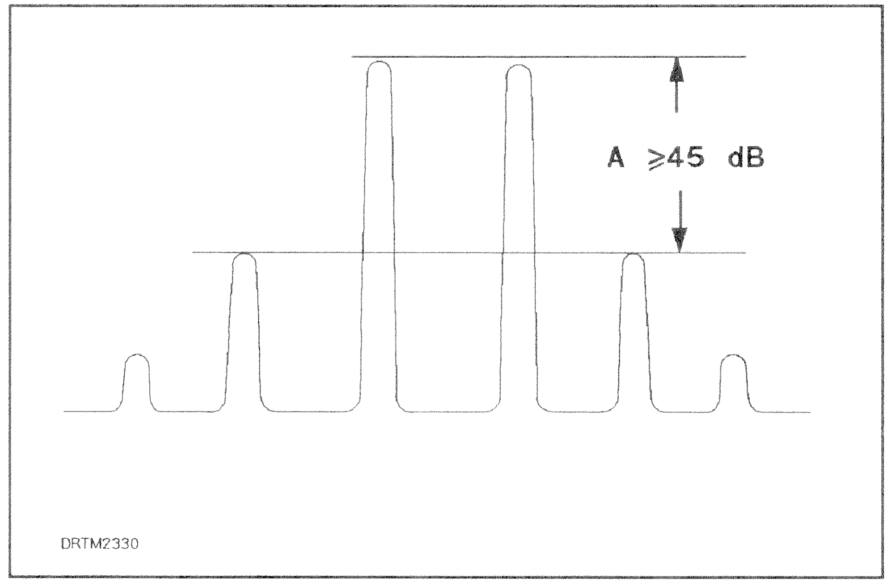
This is normally done by utilizing the three-tone or signal methods using a spectrum analyzer. As we will see, the HP 3709B method offers a number of advantages.



We will start with a quick look at the non-linear characteristics of the RF amplifier and the need for the pre-distorter.

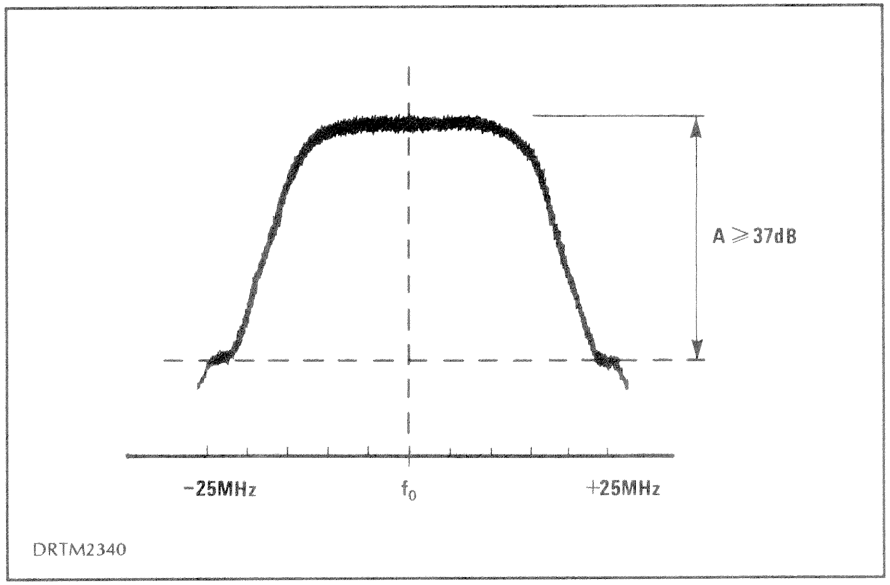
The above plot characterizes the gain and phase response of the TWT amplifier. To compensate for this non-linearity, the amplifier needs a pre-distorter which has a complementary gain and phase response to compensate for it.

Accurate alignment of this pre-distorter to the amplifier is essential to ensure performance without non-linear distortion.



This is the first of two methods to set up the pre-distorter using the spectrum analyzer.

The above figure describes the two-tone method. This injects two signals, one above and one below the IF frequency at equal amplitude. This substitute signal passes through the pre-distorter, upconverter, and RF amplifier. The spectrum analyzer displays the signal spectrum. For optimum setup conditions, the harmonics (shown in the shape of the filter skirt) must be a certain number of dB down from the main signal, 45 dB in this example. This method only tests the upconverter and pre-distorter/RF amplifier combination of the transmitter. Other components such as the modulator and any receiver components are not tested.



The signal method uses a PRBS stimulus to the modulator. This signal passes through the pre-distorter then is upconverted to RF and passes through the RF amplifier.

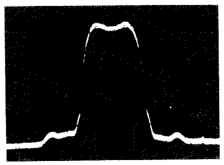
The spectrum analyzer monitors the signal spectrum at the RF amplifier output. This waveform should be a characteristic shape and follow a pre-determined mask. This method only tests the transmitter components. Any interaction between transmitter and receiver is not considered.

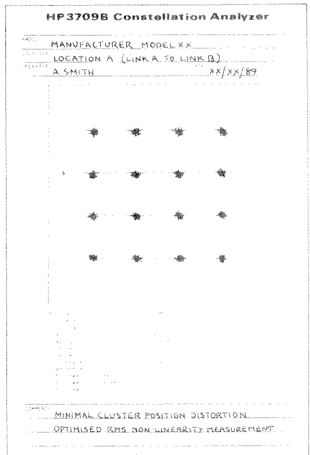
Using the HP 3709B to Optimize the Pre-Distorter/RF Amplifier

DRTM2350

The HP 3709B connects to the receiver baseband I,Q and clock in the usual way.

To optimize the pre-distorter/RF amplifier, the HP 3709B is used in two operating modes. Firstly, the HP 3709B is used in the "repeat" measurement mode. Here, the instrument continually updates the rms measurements as the pre-distorter is adjusted to come close to the optimum setting. When the adjustments are close to optimum, the rms measurement approaches a minimum value. From here, further adjustments are made using the "single" measurement mode. This makes rms non-linear distortion, AM-AM and AM-PM measurements with a greater number of samples (5000) to improve acccuracy. The objective is to reduce all these measurements to a minimum level so the constellation is as close to "ideal" as possible.





DRTM2360

This shows the optimum settings for the predistorter with minimum levels of non-linear distortion.

Benefits in Using the HP 3709B for Setting up the TWT/Pre-Distorter:

- Quantitative measurements
- Aligns most of the radio
- Uses normal traffic, not a simulated signal
- Hardcopy results
- Portable and versatile

DRTM2370

Quantitative measurements provide diagnostic information, making it easy to determine when to adjust the predistorter.

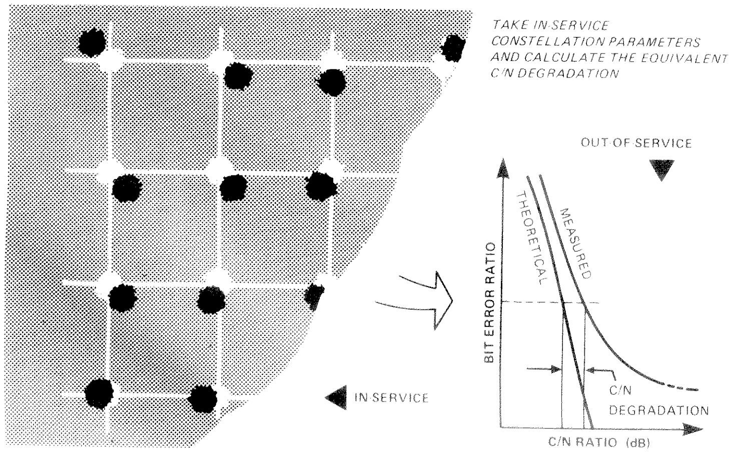
Aligns more of the radio than both the two-tone and signal methods.

Optimizes radio performance using normal traffic rather than a PRBS.

Instant results hardcopy provides permanent record for analysis and storage.

The HP 3709B is portable and versatile. It can be carried to radio sites and is versatile to perform other fault-finding tasks.

Interpreting Constellation Measurements



DRTM2380

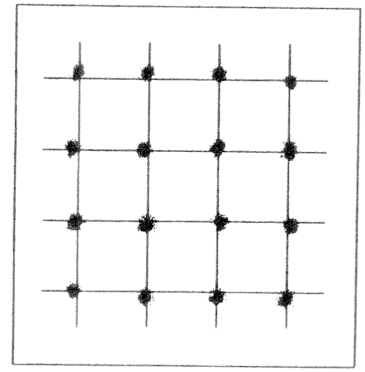
We now look at one of the most beneficial applications of the HP 3709B — linking the constellation measurements to equivalent out-of-service C/N performance:

By taking the statistical constellation parameters for position, cluster shape and size, it is possible to calculate the equivalent C/N degradation and residual BER of the digital radio system.

The next few slides show models for interpreting linear and non-linear distortion and linking them to C/N degradation. The benefit of using this technique is that in-service measurements provide test results that would normally require the radio to be taken out-of-service.

16QAM Constellation Showing Measurements

16QAM constellation showing measurements



Modulation	16QAM
Scaling, I axis	19.1 mV/div
Scaling, Q axis	19.0 mV/div
I/Q Delay	OFF
Closure, I	7.5 %
Closure, Q	7.6 %
Lock Angle Error	-0.1 °
Quad Angle Error	1.4 °

DRTM2390

We will now look at how we model linear impairments and relate them to equivalent C/N ratio.

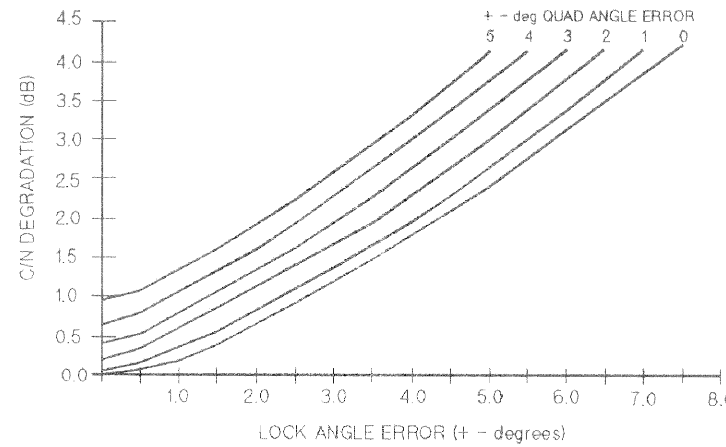
CONSTELLATION CLOSURE TO C/N RATIO (16QAM)

% Closure

Q \ I	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	30.0	29.5	29.1	28.6	28.1	27.6	27.1	26.6	26.1	25.7	25.2										
6		29.1	28.7	28.2	27.8	27.3	26.8	26.4	25.9	25.5	25.1	24.7									
7			28.3	27.9	27.4	27.0	26.6	26.1	25.7	25.3	24.9	24.5	24.1								
8				27.5	27.1	26.7	26.3	25.9	25.5	25.1	24.7	24.3	23.9	23.6							
9					26.7	26.4	26.0	25.6	25.2	24.9	24.5	24.1	23.8	23.4	23.1						
10						26.0	25.7	25.3	25.0	24.6	24.3	23.9	23.6	23.2	22.9	22.6					
11							25.3	25.0	24.7	24.4	24.0	23.7	23.4	23.1	22.7	22.4	22.1				
12								24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.6	22.3	22.0	21.7			
13									24.1	23.8	23.5	23.2	22.9	22.7	22.4	22.1	21.8	21.5	21.3		
14										23.5	23.3	23.0	22.7	22.4	22.2	21.9	21.6	21.4	21.1	20.9	
15											23.0	22.7	22.5	22.2	22.0	21.7	21.5	21.2	20.9	20.7	20.5
16												22.5	22.3	22.0	21.8	21.5	21.3	21.0	20.8	20.5	20.3
17													22.0	21.8	21.5	21.3	21.1	20.8	20.6	20.4	20.2
18														21.6	21.3	21.1	20.9	20.7	20.4	20.2	20.0
19															21.1	20.9	20.7	20.5	20.3	20.1	19.8
20																20.7	20.5	20.3	20.1	19.9	19.7
21																	20.3	20.1	19.9	19.7	19.5
22																		19.9	19.7	19.5	19.4
23																			19.6	19.4	19.2
24																				19.2	19.0
25																					18.9

DRTM2400

C/N DEGRADATION DUE TO LOCK AND QUAD ERRORS (16QAM)



DRTM2410

This slide shows a table linking constellation closure to equivalent C/N ratio for a 16 QAM modulation scheme. The table derives an equivalent C/N ratio from the noise present in the digital radio system measured by the I and Q constellation closure measurements.

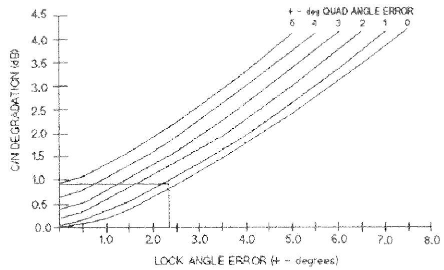
The table axes are I and Q % constellation closure, and the figures in the table center show the equivalent C/N ratio measurements. These measurements are derived from the constellation closure measurements taken from the HP 3709B. The nearest whole percentage closure is used to predict the equivalent C/N ratio of the radio noise. This doesn't take into account any geometric cluster movement due to additional impairments.

The above slide shows the additional C/N degradation resulting from geometric impairments of the constellation clusters. The model links lock and quad angle error to C/N degradation for a 16 QAM modulation scheme. If the HP 3709B indicates no lock or quad angle error, then the overall C/N ratio of the digital radio system is as predicted from the table. If there is lock and/or quad angle error, then the C/N degradation is subtracted from the initial C/N ratio to yield the final equivalent C/N ratio.

This is shown on the next slide.

Using the Linear Model to Determine Equivalent C/N Ratio

Q \ I	11	12	13
14	24.4	24.1	23.8
15	24.0	23.8	23.5
16	23.7	23.5	23.2



DRTM2420

Using the 16 QAM look-up table, closure of 15% and 12% correspond to a C/N ratio of 23.8 dB. Having found the "operating point" for the radio system, the degradation due to lock and quad angle error can be read from the 16 QAM graph. Lock angle error of 2.3° and quad angle error of 0.2° corresponds to a degradation of 0.85 dB.

If the degradation figure (0.85 dB) is now subtracted from the "operating point" (23.8 dB) then the overall C/N ratio can be calculated ie:

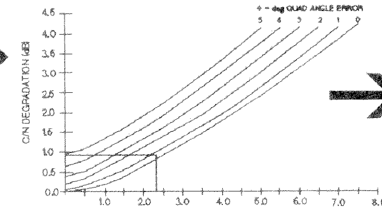
23.8 - 0.85 = 22.95 dB

This value of C/N ratio may then be linked to an equivalent value of BER to estimate residual BER of the radio system.

% CLOSURE

TABLE 1 CLOSURE vs C/N RATIO (16QAM)

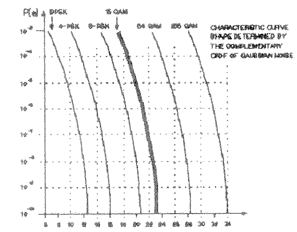
Q \ I	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5	30.0	29.5	29.1	28.6	28.1	27.6	27.1	26.6	26.1	25.7	25.2					
6		29.1	28.7	28.2	27.8	27.3	26.8	26.4	25.9	25.5	25.1	24.7				
7			28.3	27.9	27.4	27.0	26.6	26.1	25.7	25.3	24.9	24.5	24.1			
8				27.5	27.1	26.7	26.3	25.9	25.5	25.1	24.7	24.3	23.9	23.6		
9					26.7	26.4	26.0	25.6	25.2	24.9	24.5	24.1	23.8	23.4	23.1	
10						26.0	25.7	25.3	25.0	24.6	24.3	23.9	23.6	23.2	22.9	22.6
11							25.3	25.0	24.7	24.4	24.0	23.7	23.4	23.1	22.7	22.4
12								24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.6	22.3
13									24.1	23.8	23.6	23.2	22.9	22.7	22.4	22.1
14										23.5	23.3	23.0	22.7	22.4	22.2	21.9
15											23.0	22.7	22.5	22.2	22.0	21.7
16												22.5	22.3	22.0	21.8	21.5
17													22.0	21.8	21.5	21.3
18														21.6	21.3	21.1
19															21.1	20.9
20																20.7



LOCK ANGLE ERROR (+ - degrees)

CURVE A

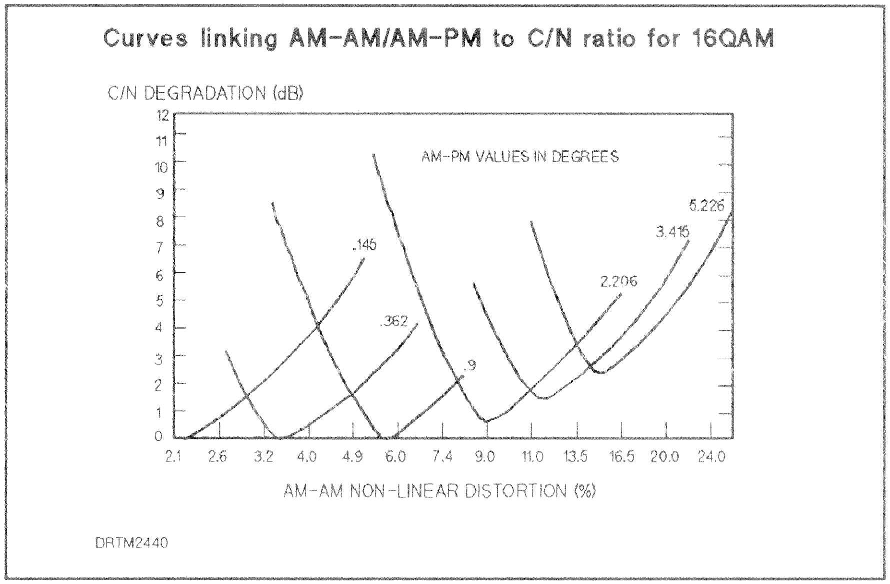
LOCK/QUAD vs C/N DEGRADATION (16QAM)



CURVE B: C/N vs BER

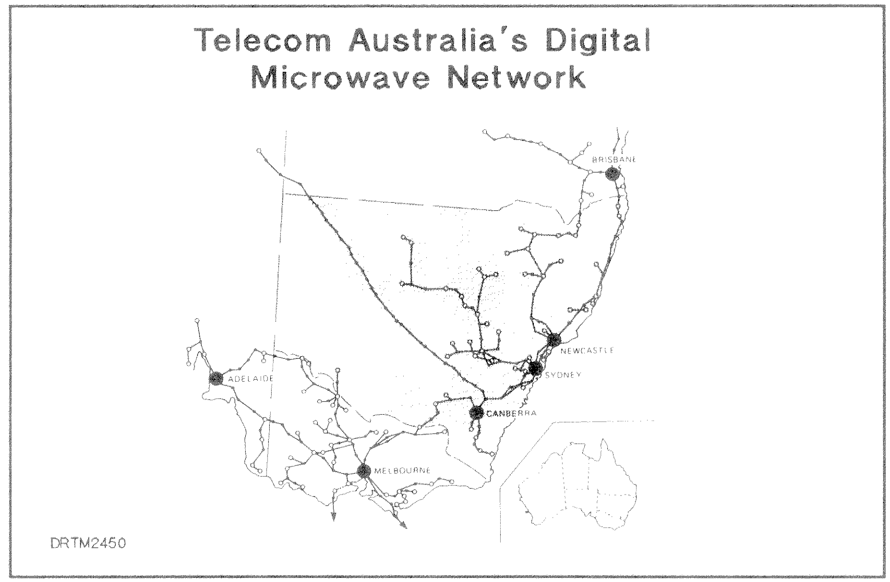
DRTM2430

This slide summarizes the procedure for estimating equivalent C/N ratio and residual BER for a 16 QAM modulation scheme.



These curves show the equivalent C/N degradation for different levels of AM-AM and AM-PM distortion. It is substituted for the lock and quad angle error curves shown in the last section.

These curves are more useful than the lock and quad angle error curves because most of the misalignment is due to non-linear components (RF amplifier & pre-distorter).



Telecom Australia is the PTT who supplies voice and data communication links across most of Australia. The backbone of this complex network is a long-haul digital microwave system which covers most of the country. The picture shows the most active area - New South Wales.

The cost of system downtime to them is $A1300 per minute, so they cannot afford the risk of their system going down. They require measurement tools which will give them accurate, repeatable information, so they choose the HP 3709B to help them in their task. The HP 3709B provides them with the following benefits:

- Identifies faults quickly and easily
- Provides fault diagnosis through display and measurements, or from a printout
- Reduces fault-finding time
- Portable instrument - easy transportation.

For more information, refer to: Application Note 364-1 'Quality Gains in Telecom Australia's Digital Microwave Network' (literature no. 5954-9572).

British Telecom

Modulation Scheme	RF Frequency				
2-State Phase-Shift Keying					29 GHz
Reduced Bandwidth QPSK (RBQPSK)		4 GHz	L6 GHz		
QPSK	2 GHz	4 GHz		11 GHz	19 GHz
16 QAM			U6 GHz	11 GHz	
64 QAM			L6 GHz		

Key : L6 GHz - Lower 6 GHz frequency band
U6 GHz - Upper 6 GHz frequency band

DRTM2460

British Telecom is the UK's main operator which supplies voice and data communications across the UK by both digital microwave radio and fiber optic cable. The BT core digital radio network mainly consists of QPSK and 16 QAM digital radio systems, at various transmission frequencies.

They use the HP 3709B for the following:

- For acceptance testing. They take a printout for all newly installed equipment and this forms part of a logbook for the radio.
- For preventive maintenance. They perform regular checks and record performance over time.
- For corrective maintenance. They use the HP 3709B to identify the fault location in the link, quickly and accurately. We have documented several examples of faulty component identification.
- Linking the HP 3709B measurements to equivalent BER, they use the linear models extensively for determining the overall performance of their digital radio network.

Constellation analysis has now become such an important part of BT's testing philosophy that new radio equipment manufacturer specifications must include I,Q and clock monitor points for connection of the HP 3709B.

For more information, see Application Note 364-2 Digital Radio Testing with British Telecommunications.

INTRODUCTION
ERROR PERFORMANCE
STRESS TESTING
IN-SERVICE TESTING

Diagnostic Testing

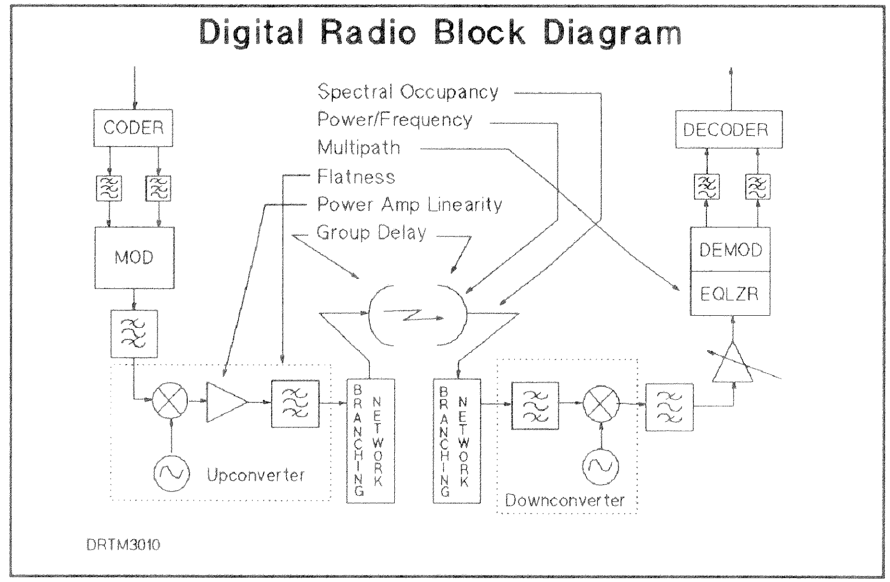
- Spectral Occupancy
- Output Power and Frequency
- Group Delay
- Equalizer Testing
- Amplitude Flatness
- Power Amplifier Non-Linearity

SUMMARY

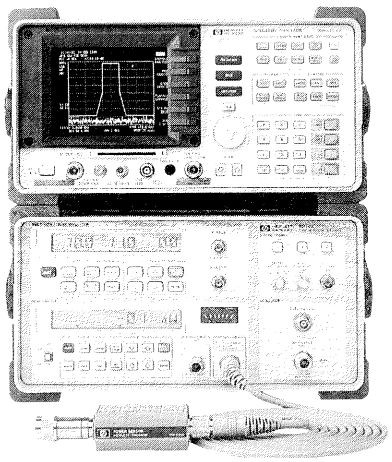
DRTM3000

This part of the seminar deals with measurements used to verify specifications of the digital radio and to troubleshoot the cause of problems.

Although the exact set of tests required to commision a radio varies between manufacturers, the tests described here are the most commonly made of every radio. These tests are certainly necessary at commisioning and also prove exceedingly useful during routine maintenance or troubleshooting.



A digital radio can suffer from a number of impairments. Many tests are made on a digital microwave radio during installation, maintenance and repair to measure and correct for these impairments. Shown here are a few of the more common tests. Some measurements like spectral occupancy, frequency and power level are measured routinely on every radio. Others measurements are done at the time of installation as part of an extensive alignment and setup procedure. Depending on the maintanence philosophy of the radio user, some of these measurements designed for troubleshooting might be made in the field or at a central repair depot.



DRTM3020

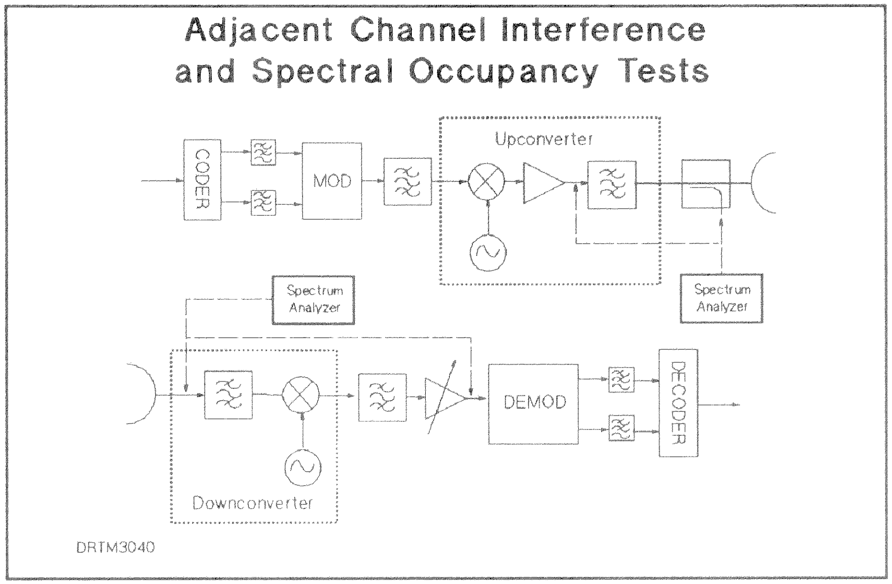
All the tests described in this section are made using the HP 11758V Digital Radio Test System (DRTS). Its capabilities include a spectrum analyzer, power meter, frequency counter, flatness analyzer, intermodulation test source, multipath fading simulator and RF and IF sources and group delay.

Spectral Occupancy

- Adjacent channel interference from transmitter (spectral occupancy)
- Check levels of interference at receiver input

DRTM3030

The first two impairments relate to the generation of interference by the transmitter and the effects of interference at the receiver.

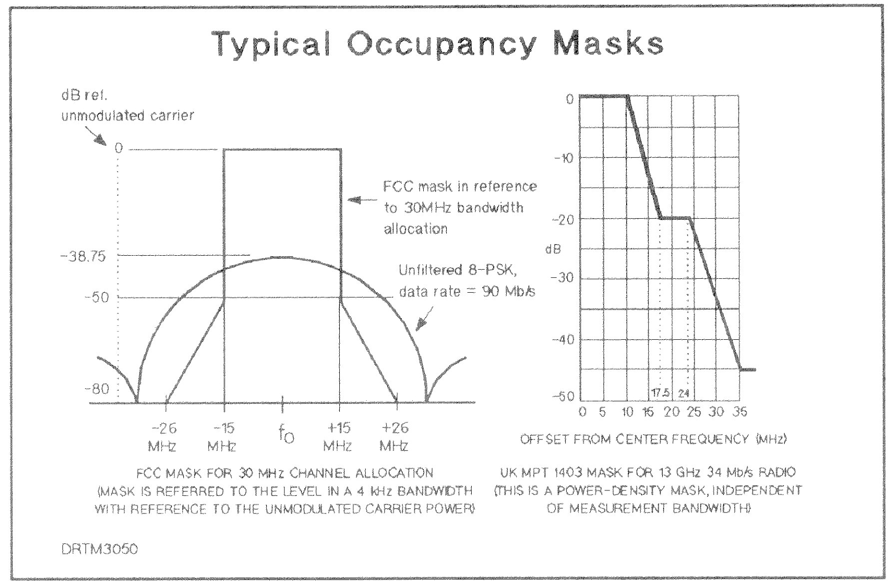


These two tests are generally made with a spectrum analyzer. The Spectral Occupancy test is a measure of how well unwanted sidebands and spurious signals have been suppressed by the successive filters in the transmitter. To minimize interference to adjacent radio channels it is very important that the radio complies with the occupancy mask laid down by the local regulating authority (e.g. the FCC in the USA or a PTT in a European country etc.).

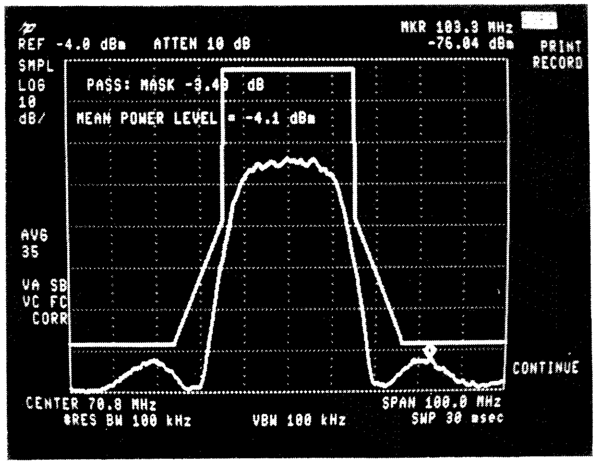
The levels of interference present at the receiver can also be checked using a spectrum analyzer with the associated transmitter switched off. Sources of interference include:

- Adjacent Channel – due to poor out-of-band suppression from adjacent transmitters.
- Co-channel – from another radio on the same frequency possibly using an opposite polarization.
- External Sources – such as radar systems.

Interference causes eye-closure in the demodulator and results in a C/N penalty or loss of receiver sensitivity.



This slide shows two typical occupancy masks in use in the industry. The out-of-band response is measured relative to either the unmodulated carrier (or total mean power level of the spectrum) or the mid-band power density (dBm/Hz). An example of the first case is the FCC mask and for this test it is necessary to take account of the noise bandwidth of the spectrum analyzer filters. The relative power-density type of mask (e.g. UK MPT 1403) is independent of the filter bandwidth provided a sensible filter is chosen (i.e. less than 10% of symbol-rate bandwidth).



DRTM3060

The spectrum analyzer in DRTS automatically compares the spectrum to a user-defined spectral occupancy mask.

This slide shows the measurement of a 64-QAM radio against the FCC 30 MHz mask.

For more information on the many uses of spectrum analyzers see: "Practical Applications of Spectrum Analyzers for Digital Radio Measurements" by Jim Kaylor and Hugh Walker (literature no. 5954-7944).

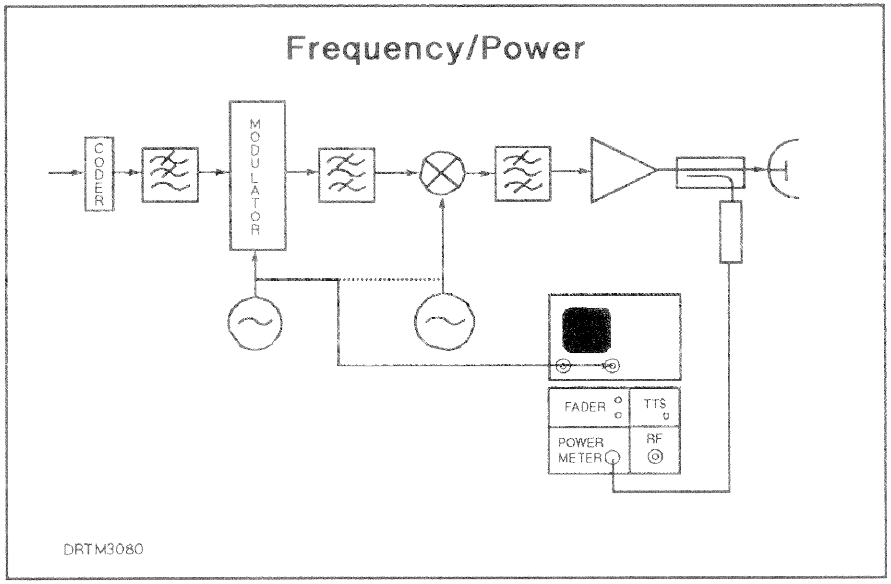
Frequency and Power

Output Power

LO Frequencies

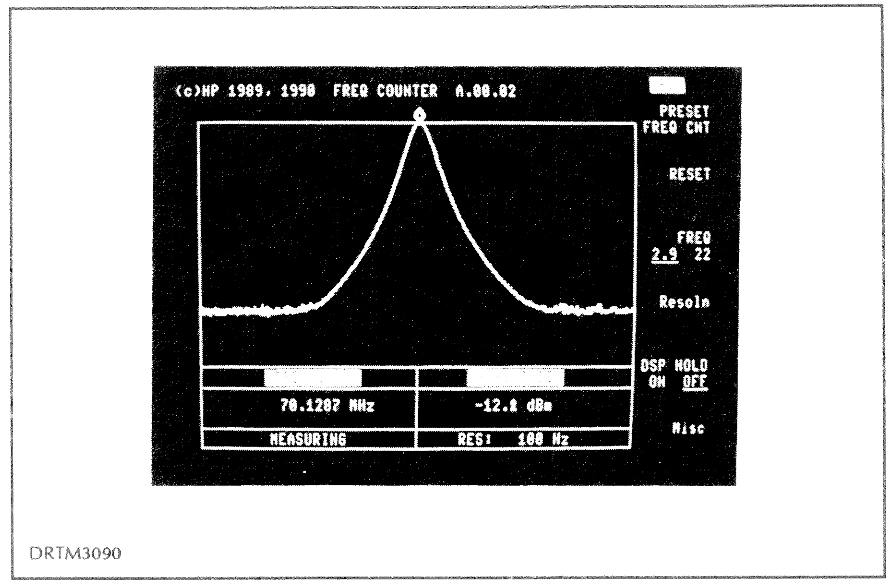
DRTM3070

Two of the most basic measurements made on any microwave system are frequency and power. Frequency and power measurements are made on many parts of a digital radio, but we will just discuss the output power level and the local oscillator frequencies.



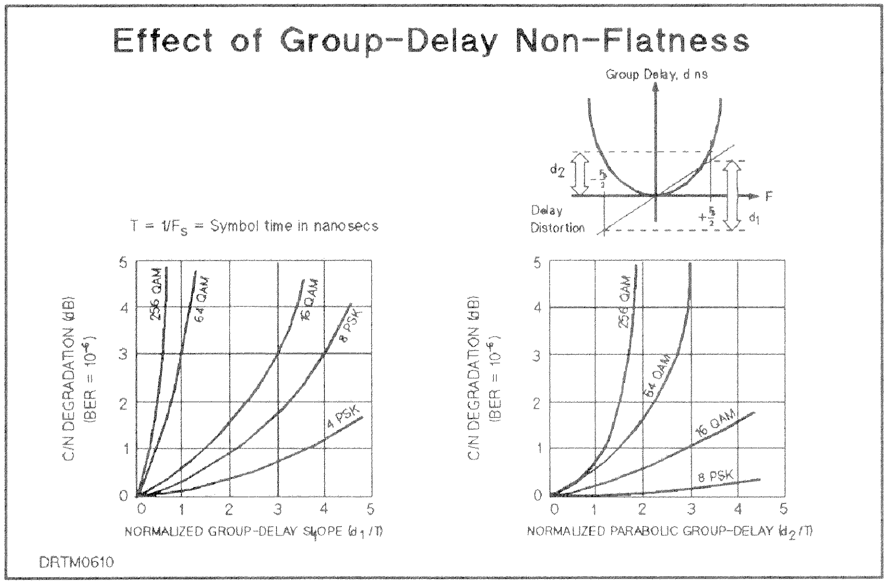
A power meter and frequency counter are probably the two most commonly used pieces of test equipment used on a digital microwave radio. Initial alignment procedures include adjusting LO frequencies. Therefore, monitor points are readily available. Transmitted LO and IF power and frequency are logged on a routine basis for virtually every radio.

Radio transmitters carry high power levels often in excess of 30 dBm. Therefore, use the appropriate attenuators to avoid destroying test equipment. In general, the IF section of the radio will have 75 Ω terminations while the RF section will have 50 Ω. Use a 50 to 75 Ω adapter where appropriate to assure accurate power measurements.



This picture shows the frequency counter display on the HP 11758V Digital Radio Test System (DRTS).

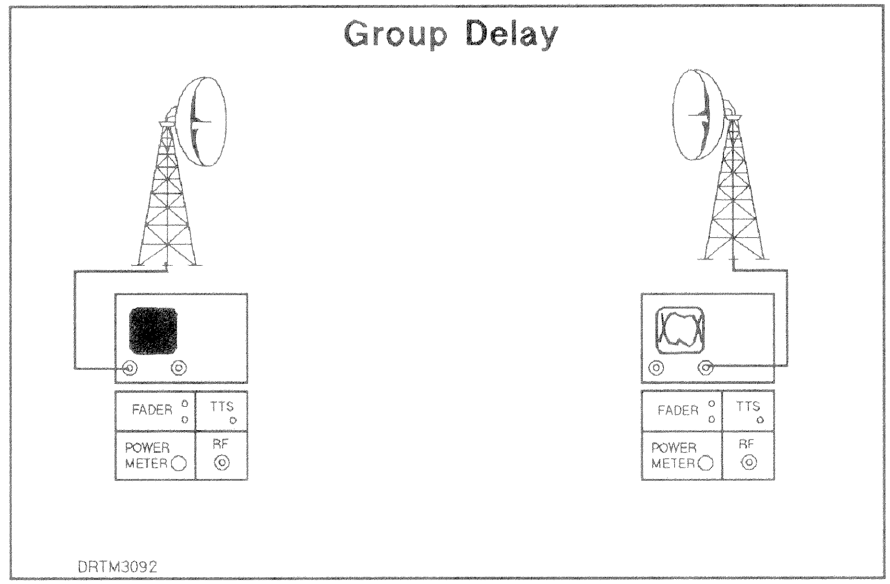
The HP 11758V displays the frequency and a rough indication of power. For high accuracy power measurements, the HP 11758V includes a standard power meter.



Narrow band radios and those using simpler modulation schemes tend to be most affected by C/N degradation caused by "flat fading." These flat fading effects tend to outweigh any mulitpath distortion or other frequency selective distortions in the channel.

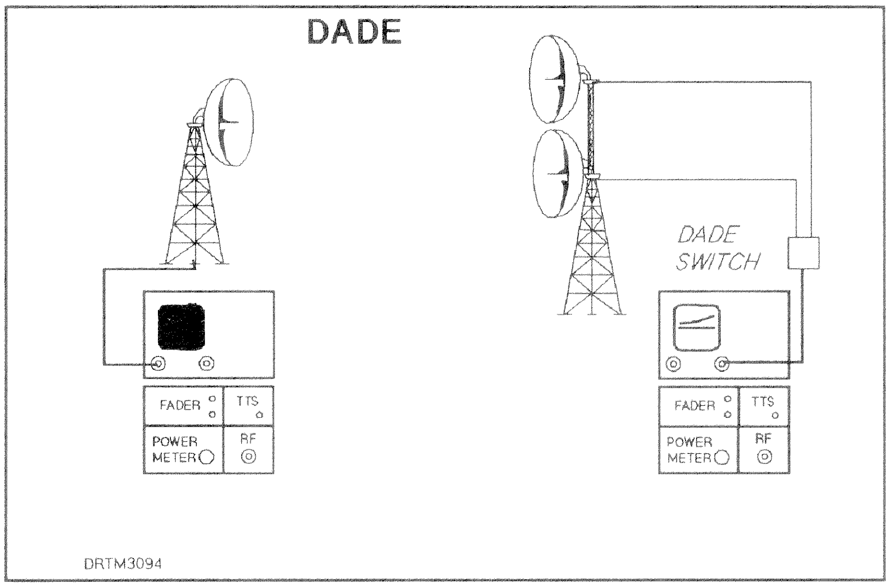
However, for complex-modulation high-capacity radios, the effects of frequency selective distortions are greatly magnified. As this picture shows, 64 QAM radios are exceedingly sensitive to even small amounts of group delay distortion.

For this reason, it is important to adjust out most of the distortions present in a newly installed radio.



End-to-end group delay is measured during the installation and commissioning of a radio. The measurement is made between the IF input of the transmitter and the IF output of the receiver. This tests for any distortions present in the transmitter, receiver, antenna feed and path. Any "residual" distortions are generally corrected out by adjusting the link (or hop) equalizer in the receiver.

Two HP 11758V systems equipped with the group delay option will make this measurement. One unit acts as the measurement transmitter. At the receiver a second HP 11758V detects and sychronizes to the signal and displays the group delay and amplitude response of the channel.



To improve the performance of a link, space diversity is often used. Two (or more) receive antennas are used. This technique is very effective if the electrical length from each receive antenna is matched. To match these paths, a Diversity Antenna Delay Equalization (DADE) measurement can be made.

The measurement is similar to an end-to-end test, but a DADE switch (HP 11766A) is used to compare the diversity paths. Differences in length are corrected by adding sections of cable into the shorter path.

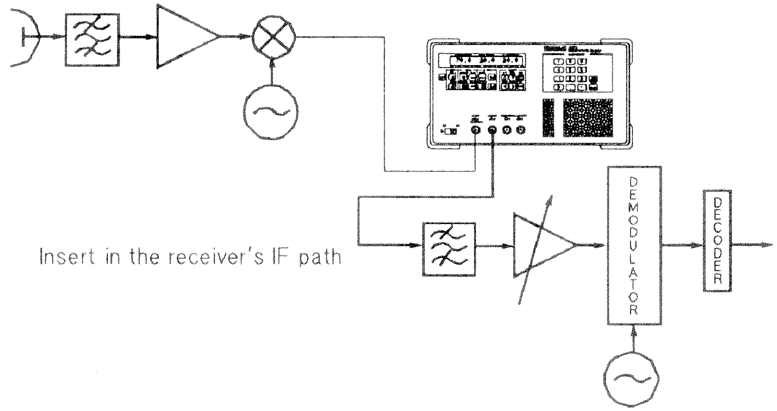
Equalizer Testing

DRTM3100

Equalizers play a dual role in the radio. Not only do they correct for the distortions caused by random multipath fading, they also correct for any residual unflatness in the radio itself. Without equalizers, the flatness of radios with complex formats like 64 QAM would have to be adjusted to a high accuracy. However, because the equalizer can correct for many distortions, the flatness measurement is less critical.

This takes the difficulty away from flatness measurements, but makes it all the more important to test the performance of the equalizer.

Using the 11757B Multipath Fading Simulator



DRTM3110

Until 1989, multipath fade simulation was not a traditional field test. This is because there was not a convenient simulator available. The HP 11757B Multipath Fading Simulator is integrated into the HP 11758V Digital Radio Test System. Both of these instruments bring convenient multipath testing to the field.

The HP 11758V will even display multipath measurements on the spectum analyzer CRT.

Amplitude Flatness

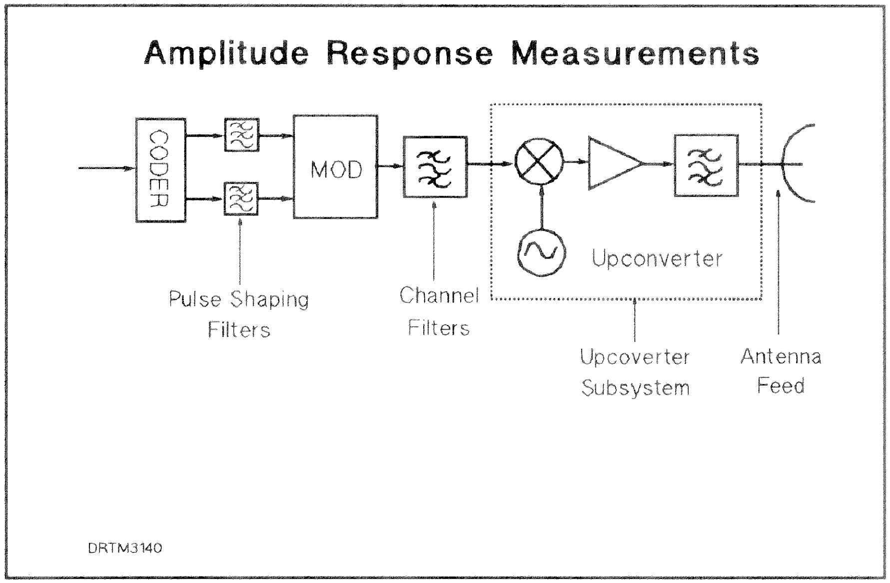
Upconverter Flatness

Return Loss

DRTM3130

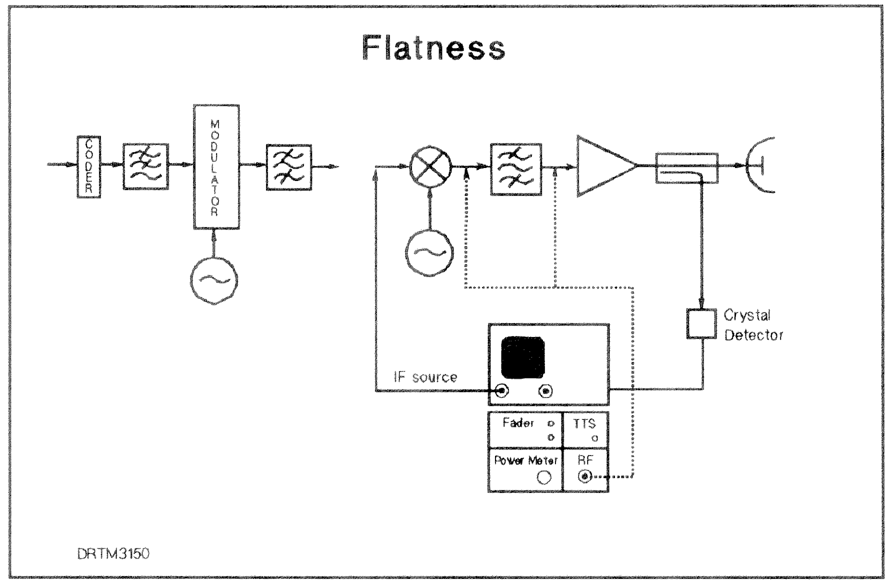
The equalizers in the receiver of a digital microwave radio will correct for many of the amplitude and phase distortions created in the propagation of the signal or by slight misalignment of the radio itself. However, the equalizers cannot correct for gross misalignments in the radio or for some distortions which cause very closely spaced ripples in the passband.

To ensure that these extreme distortions are not present, it may be necessary to make amplitude flatness measurements on sections of the radio such as the upconverter subsystem or the antenna feed.

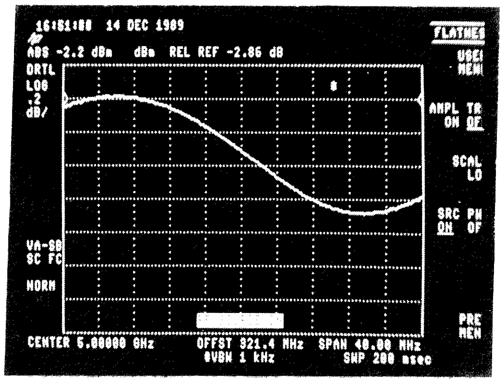


Amplitude flatness measurements are usually made by vector or scalar network analyzers. In our examples we will again use the HP 11758V Digital Radio Test Set. Among its other functions it contains both an IF and an RF source and a flatness detector.

While the pulse shaping can be done anywhere in the radio, the upconverter section is generally kept flat in band. This simplifies its design and allows for interchangeability of modules. It is important, therefore, to verify and possibly adjust the flatness of the upconverter.



DRTS acts as a scalar analyzer to measure the response of a radio. Because it uses a broadband crystal detector, DRTS can measure across frequency translations. For example, here the upconverter flatness is being measured. The tracking generator supplies the IF frequency swept signal and the response is measured at RF by the crystal detector and displayed on the DRTS CRT. The RF source can also be used to make RF-RF measurements. In this way, individual components, groups of components or entire subsystems can be analyzed and adjusted.

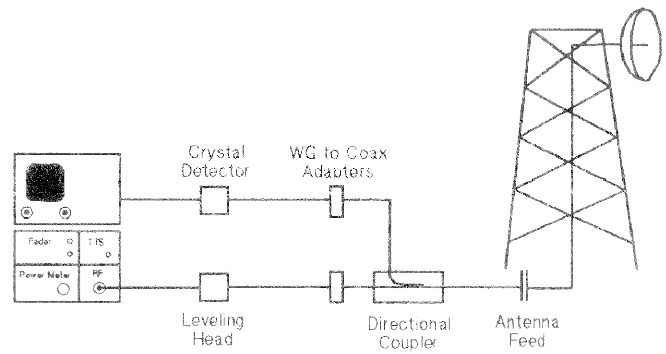


DRTM3160

Here we see a flatness measurement as it appears on the DRTS. Once the peak-to-peak unflatness is measured, the resulting C/N degradation can be calculated from a table such as shown at the end of the theory section of this seminar.

However, the usual practice is to adjust the flatness until it is within its specified limit, such as ±0.2 dB. The equalizers then take over from there.

Antenna Return Loss

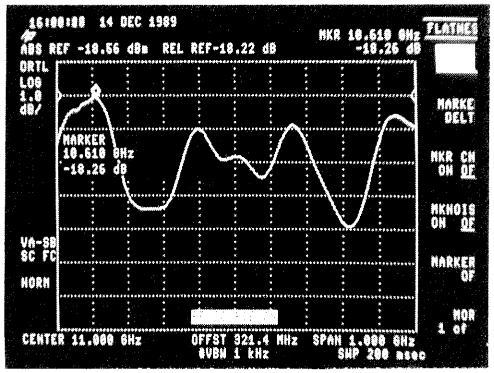


Locate damage
Prevent dispersion

DRTM3170

Even a perfectly adjusted radio may not operate properly if attached to a damaged or poorly installed antenna system. Multiple reflections within the antenna feeder system can recombine and cause dispersive fading (a non-flat transfer function). Return loss is a common measure of the health of an antenna feeder network. A minimum acceptable return loss is often specified in the radio manual. For example, 64 QAM radios often require that the antenna have a return loss of 25 dB or better.

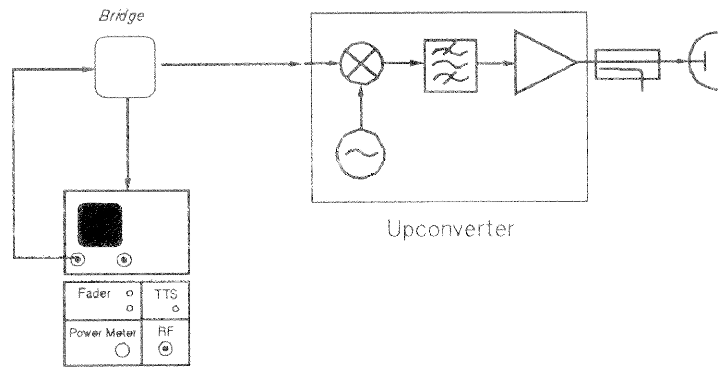
DRTS is ideal to measure return loss. For a description of the measurement see AN 379-2 "Measuring Microwave Radio Antenna Return Loss using the HP 11758T Digital Radio Test System".



DRTM3180

Here is the return loss of an antenna feed measured on DRTS. If the return loss indicates a problem, further measures can be taken to locate the reflection.

IF Return Loss



DRTM3185

Some test procedures call for a measurement of the return loss at the IF input of the transmitter. This measurement is made using the HP 11758V tracking generator and the HP 11769A Return Loss Bridge.

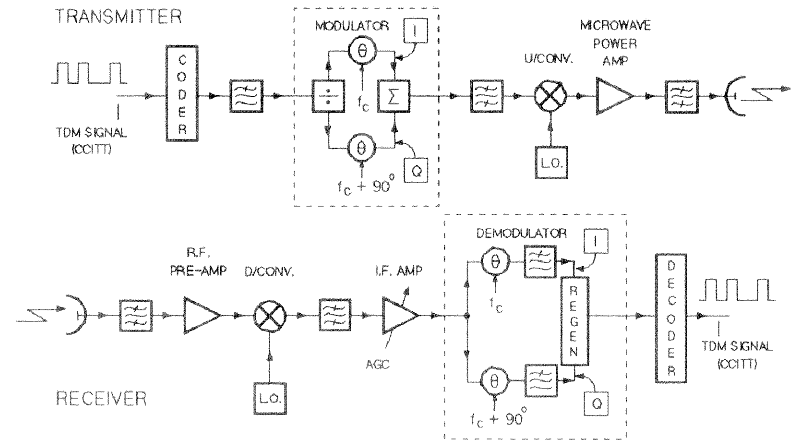
Power Amplifier Non-Linearity

DRTM4000

The next impairment we will consider is the effect of the non-linear distortion on the digital radio signal. This is a serious problem particularly in more complex modulation schemes such as 64 QAM and 256 QAM.

The HP 11758V has a multitone intermodulation test source that is used to measure and adjust the radio's power amplifier and upconvertor non-linearity.

Digital Radio Block Diagram



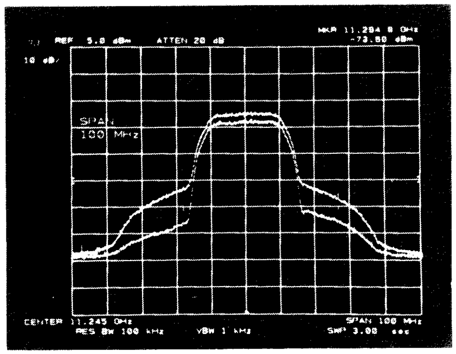
DRTM4010

Almost all digital radio modulated signals exhibit amplitude modulation (AM) either intentionally as in QAM or as a result of spectrum truncation as in filtered 4-PSK. When these signals pass through a non-linear amplifier they are compressed and distorted and inter-symbol interference (ISI) and phase-state displacement result with a loss of C/N margin.

These effects can take place at any point in the carrier section of the radio where there is a non-linear device, but predominantly in the transmit amplifier because of the high-power operation. In complex modulation systems such as 64 QAM and 256 QAM it may also be necessary to check non-linearity in other sections such as up and down converter and AGC amplifier.

Spectrum Re-Growth for a 16 QAM Radio due to 3 dB TWT Overdrive

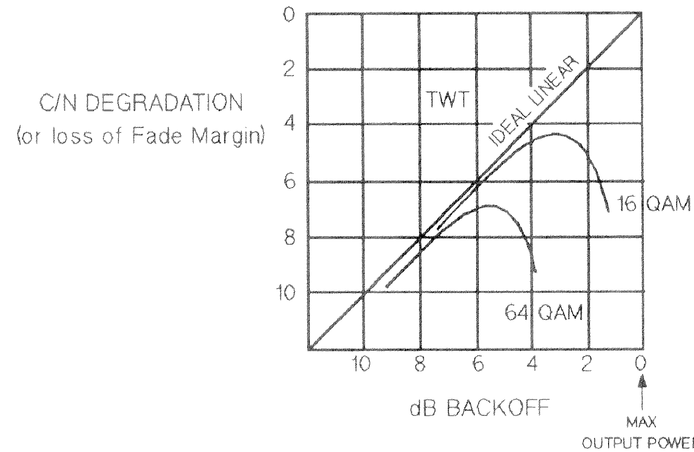
(Measured before Main Transmit Filter)



DRTM4020

One consequence of intermodulation and amplifier nonlinearity is spectrum regrowth. Intermodulation products rise and may cause the radio to exceed its specified spectral occupancy limits.

Effect on C/N Degradation

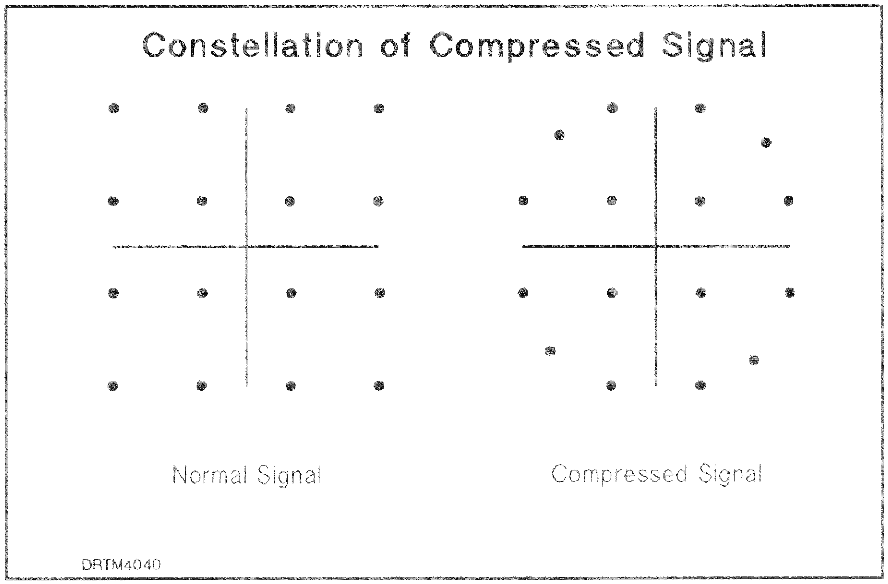


DRTM4030

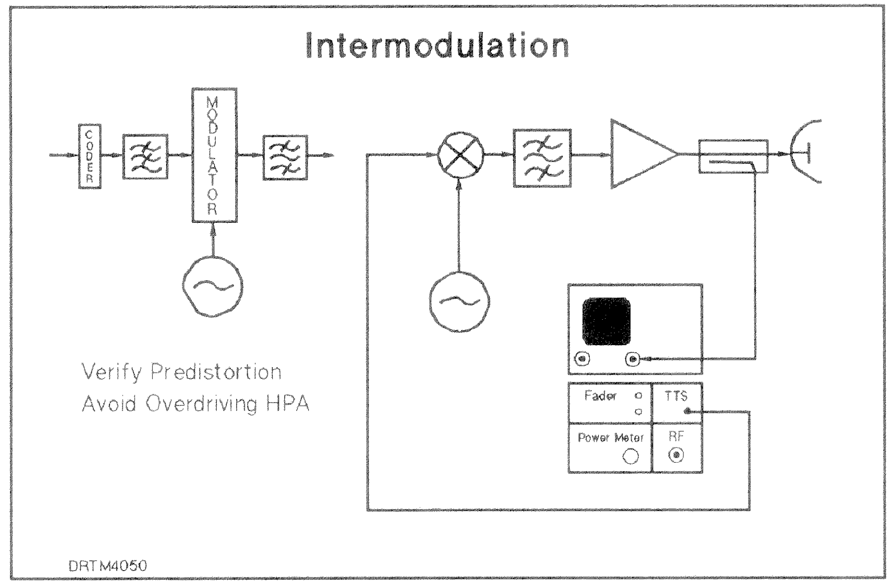
This slide shows the typical effect on the C/N margin or fade-margin of the radio when the power amplifier is working in a non-linear region. If the amplifier were perfectly linear, the more output power transmitted, the greater the fade margin of the radio (Ideal Linear Line). Because of the non-linearities in the practical amplifier, the increasing distortion at higher power levels causes more ISI so we enter a region of "diminishing returns". Eventually the curve turns over as the distortion becomes very severe and further increase in transmit power actually results in a lower fade margin! (Analog radio engineers may recognize a similarity to the familiar white noise V-curve test.)

You will notice the horizontal axis is calibrated in dB of "backoff" which is the amount the output power is reduced below the maximum available from the TWT. Typical "backoffs" of 10 dB or more are used in complex modulation. Normally the power amplifier is preceded by a **predistorter** (usually at IF) which tries to produce the reverse AM/AM and AM/PM characteristic and cancel the non-linearity. The adjustment of these devices is quite critical in 16-QAM and 64-QAM systems.

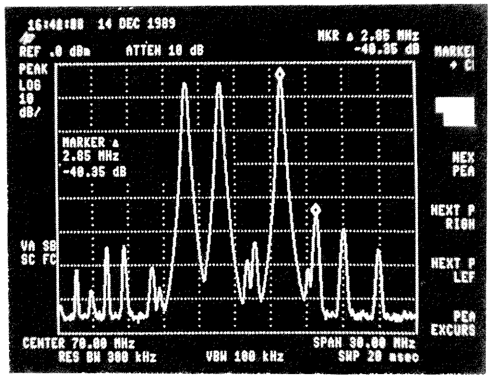
The effects in 4-PSK are far less serious, which is another reason for its popularity in satellite systems where very high transmit powers are required.



The outer states represent a higher signal level than the inner states. As the amplifier is driven at a higher and higher level, the outer states of the constellation are compressed. This causes the states to be closer together and so more vulnerable to noise.



The multiple IF tones are input to the upconvertor stage. At the radio output, the original signal and any intermodulation products are viewed on the spectrum analyzer. If necessary, adjustment can be made to the predistorted to cancel out the intermodulation products.



DRTM4060

	HP 37721A	HP 3784A/3764A	HP 3708A	HP 11757B	HP3709B	HP8981A	HP11758V	HP 5347A/48A	HP 8593E	HP 8970	HP 3048A
Bit Error Rate	●										
Errored seconds	●										
Unavailability	●										
Jitter Testing		●									
Maximum tolerable		●									
Transfer function		●									
Noise Testing			●								
C/N vs. BER			●								
Residual BER			●								
Multipath Testing				●			●				
Go/No Go testing				●			●				
M-curves				●			●				
In-Service Diagnostics					●	●					
Non-linearities					●						
Mod/demod inpairments					●	●					
Noise/interference					●	●					
Jitter					●	●					

DRTM4065

Here we see the intermodulation products created by the output amplifier of a digital radio. Notice that the highest intermodulation products are only 40 dB below the level of the input tones.

	HP 37721A	HP 3784A/3764A	HP 3708A	HP 11757B	HP 3709B	HP 8981A	HP 11758V	HP 5347A/48A	HP 8593E	HP 8970	HP 3048A
Diagnostic Testing							●				
Spectral Occupancy							●		●		
Power							●	●			
Frequency							●	●			
Group Delay							●		●		
Multipath				●			●				
Flatness							●				
Return Loss							●				
Intermodulation							●				
Phase Noise											●
Noise Figure									●	●	

DRTM4070

Key to Model Numbers

HP 37721A Digital Transmission Analyzer
HP 3784A/3764A Jitter Generator and Receiver
HP 3708A Noise and Interference Test Set
HP 11757B Multipath Fading Simulator
HP 3709B Constellation Analyzer
HP 8981A Vector Modulation Analyzer
HP 11758V Digital Radio Test System
HP 5347A/48A Counter/Power Meter
HP 8593A Spectrum Analyzer
HP 8970 Noise Figure Measurement System
HP 3048A Phase Noise Measurement System

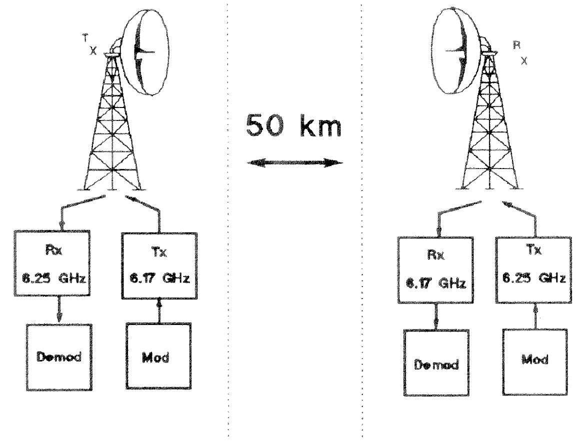
DRTM4080

Summary

A systematic approach to commissioning, monitoring and maintenance

DRTM4100

The link to be established



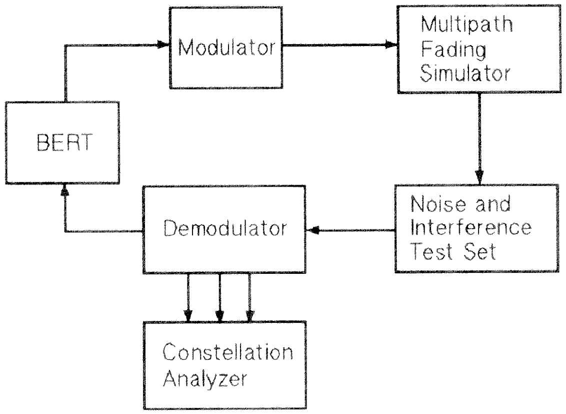
DRTM4120

Up to this point we have talked about individual tests and instruments. In this final section we will bring together everything we have discussed and suggest an approach to radio installation and maintenance. Here we will show a procedure to systematically install a radio so that each part can be adjusted as necessary and if there is a fault we will discover the problem quickly. We will then describe a way to monitor in-service the radio performance and identify faults as they develop and possibly before they degrade the link performance.

Throughout this procedure, we will be using the HP 11758V Digital Radio Test System, the HP 3708A Noise and Interference Test Set, the HP 3709B Constellation Analyzer and the appropriate Hewlett-Packard Bit Error Rate Tester

Here is a representative of our link to be commissioned. There are two obvious problems for us here. First, the transmitter and receiver are many kilometres apart. Second, locally the transmitters and receivers are at different frequencies so that local RF loopback is impossible.

Step 1: Test the Modem

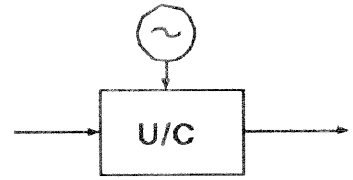


DRTM4130

The first step of this procedure is to verify that we have the basic capability to modulate information onto a carrier and recover it from a carrier without any errors. In short, we will test our modem by locally looping back the IF. Test that the power level out of the modulator is correct and check that the IF oscillators are adjusted to the correct frequency. Insert in the IF the HP 3708A Noise and Interference Test Set and the Multipath Fading Simulator portion of the HP 11758V Digital Radio Test System. Attach, to the demodulator, the HP 3709B Constellation Analyzer. Monitor the BER through the modem using the appropriate Bit Error Rate Tester.

Take a measurement on the HP 3709B. Check that the closure is low and that there is little non-linear distortion, quadrature error or phase offset. Make a printout of the display for your records. Next, measure the M-Curve and C/N vs. BER curve. All these measurements should indicate near ideal performance.

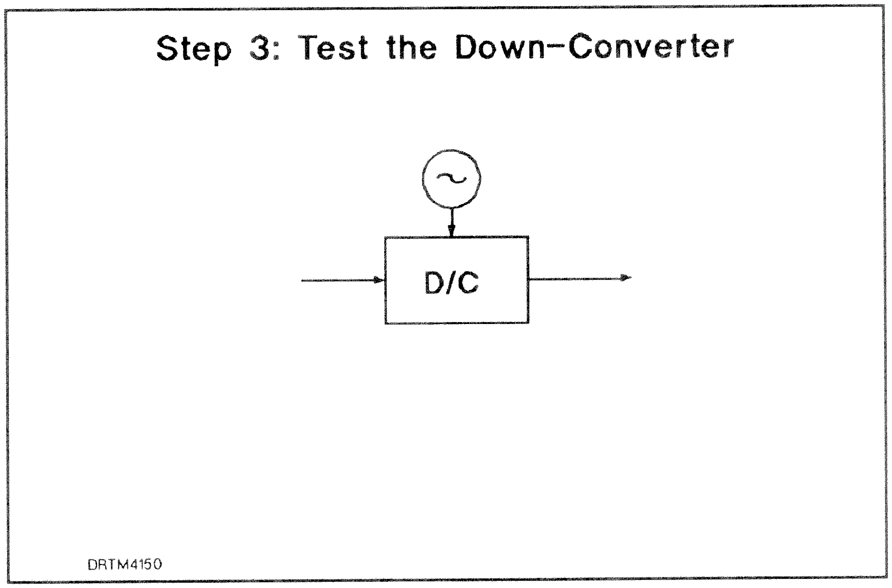
Step 2: Test the Up-Converter



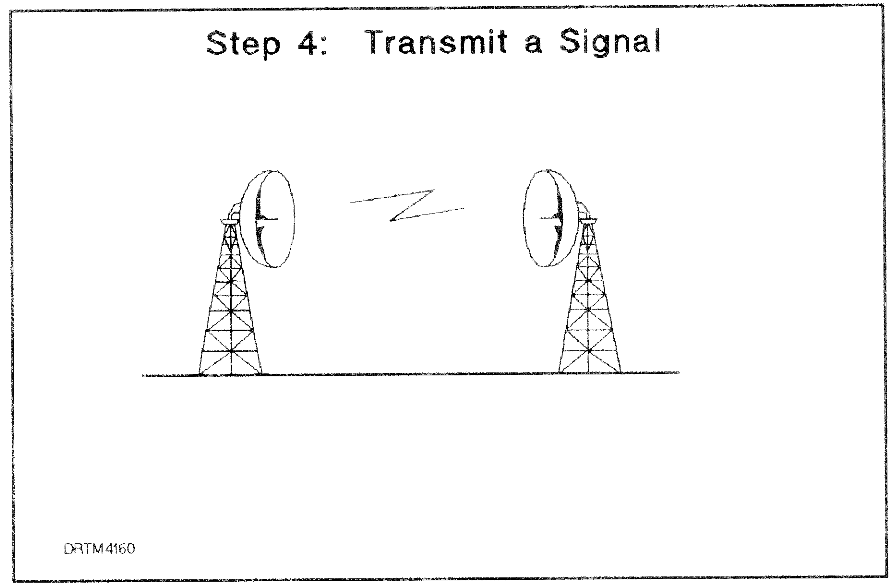
DRTM4140

The next step is to test the upconverter. The upconverter should do nothing more than translate the IF to RF and amplify the signal. Measure and adjust the oscillator frequency, the input return loss, the antenna feed return loss, the power out with the modulator attached, the gain and flatness and the intermodulation distortion. Also, measure the radio's output spectrum against the required spectral occupancy mask.

Once this is done, you are able to send a known good signal to the receiving site. Of course, the same procedure is followed at the other site so you must now prepare to receive a signal.



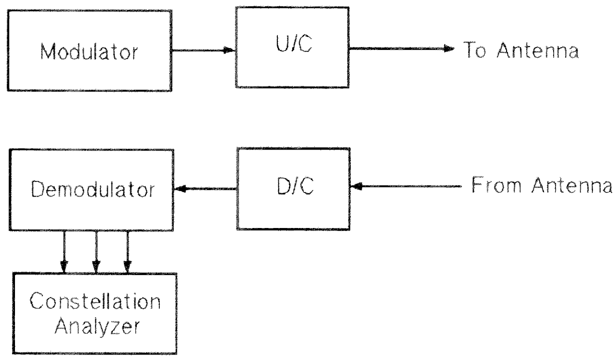
Test and adjust the downconverter. Check the input return loss, gain and flatness, frequency of the oscillator, and power out over a range of input powers. This will verify AGC performance.



Next measure the IF-IF group delay and amplitude response of the link. This measurement takes into account the transmitter, the transmitter feed and antenna, the transmission path itself, the receive antenna and feed and the receiver. If necessary, adjust out any slope or distortion to within the required performance for the radio.

Transmit the modulated signal. Again check with the HP 3709B Constellation Analyzer.

Step 5: Routine Monitoring



DRTM4170

The constellation analyzer can routinely be connected to the receiver while it remains in-service. Reference to earlier printouts will allow you to spot gradual degradations throughout the radio as well as estimate BER. If necessary, the radio can be scheduled out-of-service for repair if problems are indicated.

Step 6: Troubleshooting

Repeat Steps 1 through 4

DRTM4180

To isolate the source of errors, procedures such as used in commissioning can be used.

The solution for maintaining

Digital Microwave Radios

DRTM4190

The HP 11758V Digital Radio Test System, the HP 3708A Noise and Interference Test Set, the HP 3709B Constellation Analyzer and the appropriate Hewlett-Packard Bit Error Rate Tester provide the necessary tools to maintain a reliable digital radio network.

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(fax) (080)769 0900
Latin America:
(tel) (305) 269 7500
Taiwan:
(tel) 0800 047 866
(fax) 0800 286 331
Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 6755 0042
Email: tm_ap@agilent.com
Contacts revised: 05/05/05

The complete list is available at:
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