Dynamic Testing of Frequency Agile Radios

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RF & Microwave Measurement Symposium and Exhibition

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TESTING FREQUENCY AGILE RADIOS

With the technology in communications advancing every day, more complex communications systems have emerged. These newer communications systems have been developed for several reasons. They allow a means to more efficiently send information, to resist interference from the surrounding environments, to secure the information being sent from outside parties, to resist being jammed intentionally from a third party, etc. One of the methods used by radio manufacturers that give a user additional performance capability is to use spread spectrum techniques. Basically, the idea behind using spread spectrum is to take the normal bandwidth of the information being sent and either spread it out (that is to add additional signal to the transmitted information so that its effective bandwidth is increased considerably) or to take the normal R.F. occupancy and spread it over a large number of frequencies (being several octaves or even decades apart) or a combination of the two. In both cases, the information is being transmitted in a much wider bandwidth than if no spreading was used. This increased bandwidth makes the spread spectrum system more jam or interference resistant. It also helps avoid signal fading common in fixed frequency systems due to multi-path signal cancellations. Military tactical radios are a prime example of these techniques in use. The need for secure, jam resistant, reliable communications is extremely important in field use. Radio manufacturers like ITT, Magnavox, Racal, Thompson, B.E.L., Harris, Marconi, etc., are or have developed radios that change frequency from a few times a second, to thousands of times a second. While production of these radios has increased immensely in recent times, very little, if any commercial test equipment has been developed for testing these radios. Manufacturers have had to design custom test fixtures adapted from their own radio hardware that are expensive and limited in capability. These test fixtures allowed manufacturers to develop and manufacture hopping radios. However, now that there are larger productions lines and end users who want to evaluate the performance of these radios, as they have in the past with conventional radios, the need for commercial test equipment that will accurately dynamically test radios has arisen.

This paper addresses these issues and gives insight on how testing of frequency agile radios can be performed using newly developed test instruments from Hewlett-Packard.

Agenda

Review of Conventional Transceiver Testing
Frequency Agile Transceiver Testing
Required Equipment for Frequency Agile Testing
Sychronization of the HP 8645A
Interfacing to the Rockwell/Collins MP-83
Applications
Summary

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Slide 2

A Frequency agile radio can operate on a single channel or over a number of channels

f_c $f_1 f_2 f_3 f_4 f_5 f_6$

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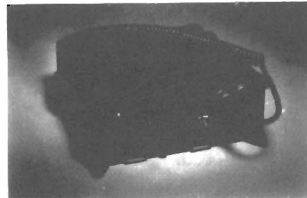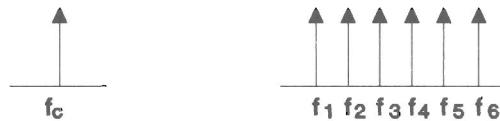
Slide 3

Nearly all frequency hopping radios currently being manufactured have a conventional single channel operation mode built-in as well. One of the primary reasons that frequency agile radios have single channel capability is so that they can communicate with older existing radios. This is very important to military organizations since they have thousands of conventional tactical radios currently in use that need to be able to communicate with the newer radios. Although at sometime in the future, the majority of tactical radios will probably have frequency agile capability, upgrading of all these radios will take a considerable amount of time.

Block Diagram of Conventional Transceiver
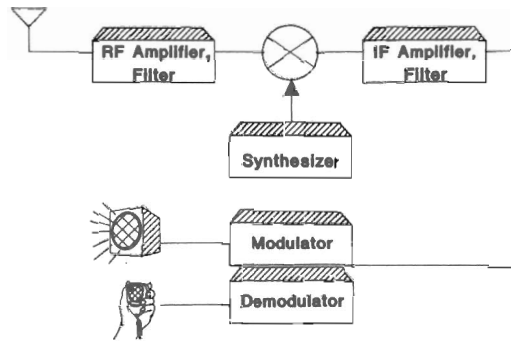
Slide 4

This is a block diagram of a conventional radio lets quickly go through the various blocks of the receiver and transmitter and discuss what the function of each is.

The RF signal arrives at the receiver, is filtered, amplified, and then down converted to an intermediate frequency. At the I.F. level the signal is again filtered and amplified. The signal is then sent into a discriminator or envelope detector (depending on whether the radio is a angle modulated or amplitude modulated) from which the audio is then recovered.

On the other end a voice is input into a microphone and either amplitude modulates, or angle modulates the carrier, and then is amplified. As you can see, there are several blocks that make up a transceiver. Although many of the portions can be tested alone, (board level or modules) tests on the entire receiver or transmitter are desired. Tests that enable the manufacturer to characterize the performance of his radio. Not only under normal operating conditions but determining limits of the radio by simulating various field conditions. This not only tells how his radio will operate in adverse conditions, but enables him to improve the radio design so that optimum performance can be obtained from the design being used.

TESTS DONE ON CONVENTIONAL TRANSCEIVERS

RECEIVER TESTS

	IMPORTANCE
Sensitivity	Determines range of radio
Adjacent channel selectivity	Determines radio's ability to reject signals in adjacent channels
Spurious response attenuation	Determines how well radio rejects unwanted spurious signals
Audio tests	Determines quality of recovered audio

TRANSMITTER TESTS

Frequency Error	Determines accuracy of transmitted carrier
Carrier power	Determines output power level
Adjacent channel power	Determines power output in adjacent channels
Modulation limiting	Determines modulation limiting capability
Audio tests	Determines quality of transmitted audio

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Let's look at a few of the tests that evaluate the performance of these radios, who is interested in the performance, and why.
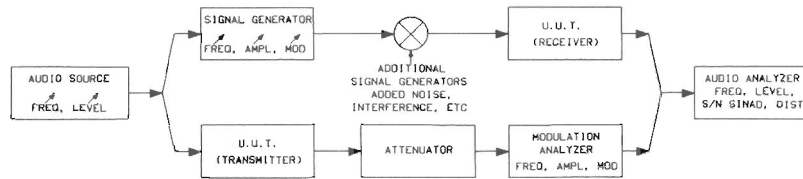
There are basically three groups of people who are interested in having tests like these run on radios, 1) regulatory commissions 2) users and 3) manufacturers

Regulatory commissions (FCC, EIA, CEPT, CCIRR, etc.) are performing these tests to determine if a manufacturer's radio is operating within the standards they establish. With the RF spectrum being utilized nearer to its capacity, stricter regulations are being placed on users. It is their job to see that all radios being sold are within these regulations.

Users are interested in doing these tests as it allows them to verify the specifications that a manufacturer guarantees for a given radio. This also gives the user a standard by which he can evaluate the performance of radios built by various manufacturers. Finally, it allows a user to quickly verify that his radios are fully operational or require repair after they have been in use.

The manufacturers are interested in performing these tests as it helps them to precisely characterize their radios as well as use the results to improve their radio design. In addition, it gives them a high confidence level that the radios they are shipping will work. And, of course, the manufacturer's do these tests as the users and regulatory commissions demand it.

Block diagram of equipment for performing conventional radio tests.

```
                    SIGNAL GENERATOR          ⊗           U.U.T.
                    FREQ. AMPL. MOD                    (RECEIVER)
AUDIO SOURCE                              ADDITIONAL                        AUDIO ANALYZER
                                      SIGNAL GENERATORS                      FREQ. LEVEL.
FREQ. LEVEL                              ADDED NOISE.                        S/N SINAD. DIST.
                                     INTERFERENCE. ETC
                     U.U.T.                                   MODULATION
                   (TRANSMITTER)      ATTENUATOR              ANALYZER
                                                          FREQ. AMPL. MOD
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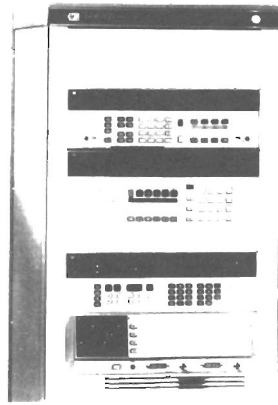**MCG/Spokane Division**
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Slide 6

Let's look at the block diagram of equipment that will allow us to perform all the tests that I previously listed as well as many additional tests.

Note the methodology that is used for testing the transmitter and receiver. The idea here is to substitute calibrated test equipment for all parts of the communication system except for, of course, the unit under test. By using calibrated test equipment the following advantages are gained:

1) The equipment has guaranteed specifications for its performance that are traceable to standards labs like NBS, therefore allowing the user to very accurately measure and record specifications for his radio.

2) It allows operating parameters to be varied so that the results of these variations can be seen on the unit under test.

3) Eliminates discrepancy in the results obtained by two different labs performing the same tests.

4) It provides a standard to be measured against when more than one source manufacturers the same radio.

5) It insures that the performance measured is that of the unit under test and not due to the uncertainty of non-specified or uncalibrated test equipment.

HP 8955A Transceiver Test System

Slide 7

Here is HP's solution for filling in the blocks of the block diagram and performing a comprehensive set of tests on conventional radios. The HP 8903B is a calibrated audio source and audio analyzer. It can generate audio signals as well as analyze the demodulated audio for frequency, level, distortion, signal-to-noise, as well as Sinad.

The HP 8656B is a RF signal generator that simulates a transmitter. It allows the user to vary the amount of deviation, depth of modulation, output amplitude, and frequency of the carrier in a very precise and calibrated manner.

The HP 8901B is a modulation analyzer that measures RF power & RF frequency as well as characterizes the modulation and audio of the transmitted carrier.

The HP 8956A is an interface box that allows each of the above test instruments to be switched in and out of the test system according to the test that is to be performed .

Additional test instruments could be added to this setup to give even greater testing capability. For instance, another signal generator could be added so that out of channel tests could be done, or a spectrum analyzer could be used to look at the transmitted signal's spectrum usage.

This equipment, coupled with a computer and transceiver test software (HP 11805A), makes an entirely automated transceiver test system. This test system was put together for manufacturers/users of radios so that radios could be fully tested in a minimum amount of time. In addition, by using a computer and software, results for each radio can be printed out and sent with that radio. And, as you can see, after running a radio through this test system and it passing all the tests, you can be assured that it is working properly.

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Block Diagram of Frequency Agile Radio

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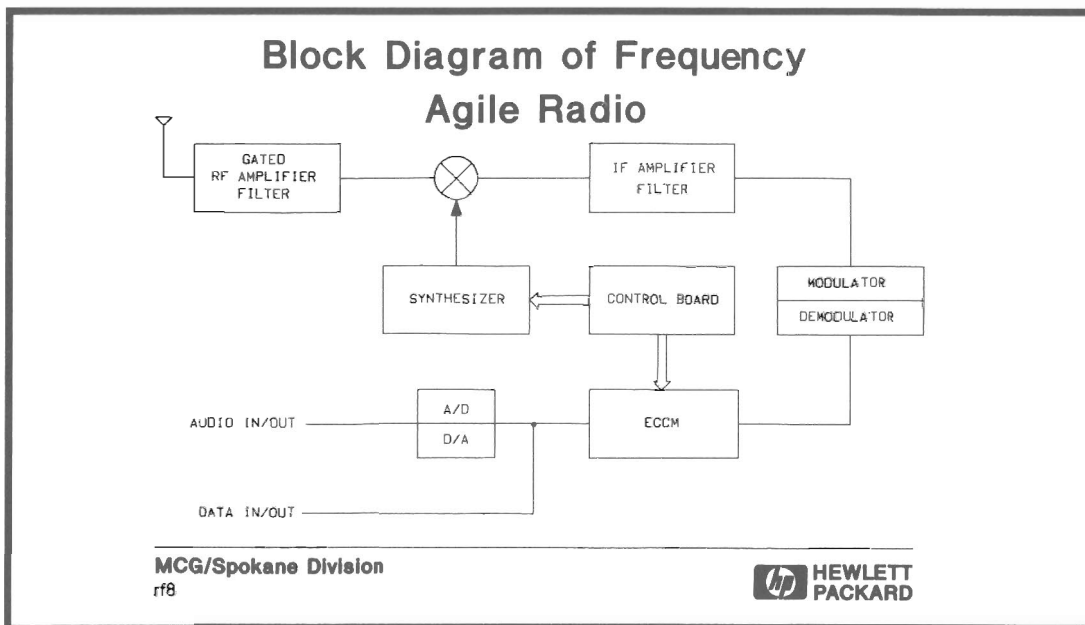
Slide 9

Let's now look at the block diagram of a frequency agile radio. The lighter color areas represent components that we saw in the conventional radio. Basically, this radio is similar to the conventional radio block diagram that we saw earlier. However, there are some key differences:

1) The synthesizer is constantly changing frequencies many times per second. At a rate anywhere from a few times per second to ten's of thousands of times per second. In addition, the frequency that the synthesizer changes to is determined by a pseudo-random algorithm. This pseudo-random sequence of frequencies (or TRANSEC) is one of the things that make frequency agile radios secure since the sequence is kept secure. This pseudo-random sequence is generated in the control board of the radio. Implemented in VLSI and/or firmware along with a microprocessor, a pseudo-random digital word is generated. This digital word is then sent to the synthesizer and translated into a carrier frequency. Since this algorithm is usually classified or kept secure, some means of externally controlling the test equipment is necessary.

2) Audio is digitized or data may be directly transmitted by the radio. Although there are a few radios that take the analog signal and just hop carriers, most radios digitize the voice input. In addition to just digitizing the audio, synchronization bits (framing) are added to allow the receiving radio to lock up with the transmitting radio. Furthermore, many radios also have encoding and or encryption schemes (COMSEC) that add even more bits of information. These schemes enhance bit error rates as well as add another level of security to the transmitted information. This is done in the A/D and through additional hardware and firmware located in the ECCM module.

3) As the transmitter hops from frequency to frequency the radios usually gate off the power during the period of transition so that spectral splatter is minimized. That is, as the radio is changing from one frequency to another the actual frequency output could be any frequency depending on how the radio is designed. While the synthesizer unlocks the PLL's used for the previous frequency and locks other PLL's to get the next frequency, frequencies within the radios band as well as others could be output. This would result in a degradation in system performance as these unwanted frequencies essentially act like jamming signals to radios operating in other nets. Output power gating is done in the output amplifier section.

It is obvious that the test equipment requirements for testing agile radios is different from that used on previous radios. First of all, a signal generator needs to be able to hop over the same secure pseudo-random frequency sequence as the radio being tested while simulating the necessary modulation.

Secondly, a receiver needs to be able to demodulate the frequency hopping carrier. That is, the local oscillator used by the receiver needs to be hopping with the radio at some offset frequency so that the baseband data can be recovered. Finally, there is still the problem of how to deal with the framing, encoding and encryption that is put on the baseband data in the transmitter and stripped off again in the receiver.

New Consideration for F.A. Radios

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f$_1$ f$_1$ f$_2$ f$_3$

τ
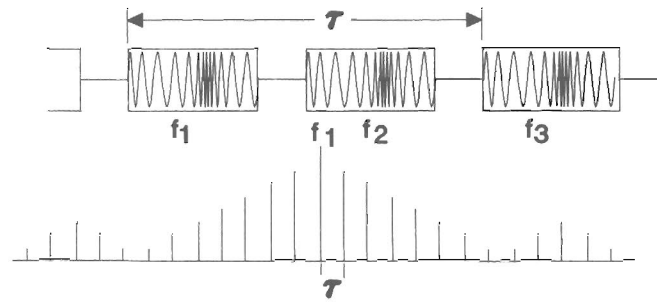
1 Spurious, Phase Noise
2 Sensitivity
3 Frequency accuracy, setting times
4 Aquistion, Synchronization

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Slide 10

Associated with frequency agile radios are a new set of challenges. Challenges that weren't necessarily addressed with conventional transceivers.

Challenges like minimizing the phase noise and spurious of a frequency hopping gated signal. Phase noise and spurious performance can be well characterized at individual frequencies. However, these measurements are being made when the radio is in static or non-hopped mode. This performance could change while the radio is hopping over many frequencies per second. For instance, loop bandwidth settling times could affect the phase noise performance of the radio at different frequencies thereby degrading its performance. Another phenomenon associated with gating the output signal on and off is the apparent spurs (actually sidebands related to the rate at which that specific frequency is hopped to) that show up with each frequency transmitted at intervals equal to the rate at which this frequency is visited. If the transmitted signal is thought of as a 100% square wave amplitude modulated signal, the source of these spurs can be seen. With very fast rising and falling edges (essentially square) on the gated output, apparent spurs unrealistically as large as 6 dB down from the carrier (if the same frequency is hopped to over and over and the RF power is turned on and off with switching speed approaching zero) will show up at offsets equal to the rate at which the frequency is visted and multiples of this rate. The way to minimize this spurious output is to shape the amplitude as the power is gated on and off. The ideal shape for the rising and falling edges of this gated output is a raised co-sine waveform. It turns out that by using the raised co-sine shape on the rising and falling edges results in the least spectral splatter or spurious output. So by slowing ramping, the power as it is gated on and off decreases the level of these spurs considerably. The trade off is, of course, that less information can be transmitted at each frequency used since time must be allowed for this shaping process.

Getting a frequency agile radio to have good sensitivity. The output power is gated on and off in a frequency agile radio which tends to decrease its average output power. In addition, all the switching that is going on in the radio due to this gating tends to increase the noise floor or background noise of the radio thereby decreasing its sensitivity.

Attaining good frequency accuracy and settling time. Since the synthesizer is changing frequencies many times per second, the synthesizer must get to its final frequency quickly and accurately at each channel so that the information can be transmitted and the next frequency hopped to.

Obtaining short acquisition times and synchronization time. Getting the radio to acquire the transmitted signal and synchronize with it in as little time as possible is important since it reduces the delay of information or loss of data transmitted. Tied in with this is developing highly accurate timing in each radio so that each radio can be synchronized with all other radios. If the two radios are off by only a few seconds, it could mean a difference of thousands of frequencies between radios.

All properties associated with sending digital information versus analog. Traditionally, analog information was sent. Now digital data is being sent that requires different modulation and filtering. In addition, complex and precise encoding and timing schemes are required.

Testing frequency agile radios using the golden radio

Atten.

Golden Radio

U.U.T.

B.E.R.T.

Audio Analyzer

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rf9

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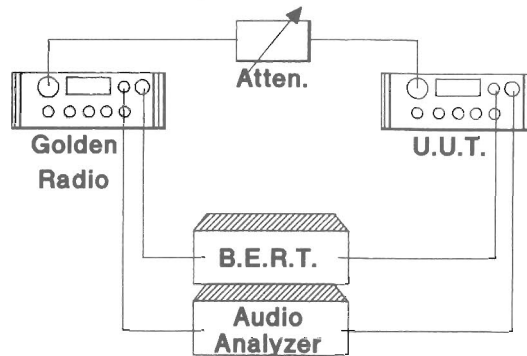
Slide 10A

With this in mind, let's look how current tests are being performed on frequency hopping radios. Current methodology employs using a so called "Golden Radio" to see if other radios operate properly.

First, board level tests are done on each board/section of the radio. These tests involve testing all of the digital circuitry as well as the components to see that they are operating correctly. In addition, as much testing as possible is done on modules of the radio before it is assembled. Once assembled, conventional radio tests are performed on the radio in static mode (single channel) using calibrated and specified test equipment as previously described.

When testing the radio dynamically (frequency hopping) a second radio is employed to be used as the "calibrated transmitter or receiver" and tests are done using it in the test system. This "Golden Radio" is a unit that has proven through experience to meet functional specifications.

By using a "Golden Radio" the problem of having a signal generator and calibrated receiver that hops along with the radio in a pseudo-random sequence is solved. Moreover, any special framing, encoding, and encryption that is done to the information signal is added in the "Golden Transmitter" and taken off in the "Golden Receiver". Using additional equipment, bit error rate tests, audio tests, sensitivity on the receiver, etc., can be performed on the radio while hopping to verify that it is working. Of course, since a radio is being used instead of a calibrated signal generator or calibrated receiver, the flexibility in the tests that can be performed on the U.U.T. is limited. Moreover, it is difficult to determine if the test results are due only to the U.U.T. or perhaps affected by the "Golden Radio". Nonetheless, this type of testing does in fact verify that the radio being tested communicates with the "Golden Radio" and therefore should communicate with other radios tested against this same standard.

The method of back-to-back testing is well suited to quick operational testing such as on location "over the air" testing. However, because this test method does not generally yield measured performance data on the key system parameters, operation at or near system limits is not certain. The back-to-back test method also does not uncover interoperability problems of radios from different manufactuers on a common net. Here again, it is important to independently verify performance for key system parameters to guarantee worst case interoperability.

Back-to-back testing leaves some uncertainty in the results obtained. Since a radio of similar performance and specifications is being used, it is difficult to determine if the results obtained are really the U.U.T, the "Golden Radio", or a combination of the two radios. Finally, using a "Golden Radio" only ensures that the radio tested can communicate with it and not with other radios that have been tested against it.

ADVANTAGES OF USING CALIBRATED, PROGRAMMABLE TEST EQUIPMENT

- Radios are Tested to a Separate, Unrelated Reference
  - Complimentary problems can be detected
  - Serves as a mediator for multi-sourced radios
  - Troubleshooting can be simplified
- Verifies True Performance of the Radio
  - Quantitative results obtained
  - Adjustable operating parameters
- Specifications Traceable to Standards Labs
- Commercially Available

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RF9A

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Slide 10B

There are many advantages to testing frequency agile radios using calibrated and specified, programmable test equipment. It provides an unrelated reference which the radios can be tested against. This enables complementary problems in radios to be identified. With multiple sources producing the same radio it provides a mediator to determine which radios are performing properly. It verifies that all radios will function with each other. It gives the ability to adjust operating parameters so that a thorough characterization of the radio can be performed. For instance, being able to vary things like deviation, frequency, amplitude, dwell time, hop rate, pulse shape, etc., allows the true performance of the radio to be measured. This gives quantitative measurement results which can be compared over time to determine any trends that may be occurring in radio's operation. Finally, the specifications given for the test equipment are traceable to standards labs thereby guaranteeing its performance.

TESTS OF IMPORTANCE FOR A
FREQUENCY AGILE RECEIVER

RECEIVER TESTS

Sensitivity Measurements
B.E.R. vs R.F. level
B.E.R. vs C/N or C/I ratio
B.E.R. vs co-channel interference
B.E.R. vs R.F. frequency offset
B.E.R. vs modulation accuracy
B.E.R. vs premodulation filter B.W.
B.E.R. vs RF amplitude shaping
B.E.R. vs induced data, systematic timing
jitter timing errors
Initial acquisition time
Hop synchronization time
Adjacent channel selectivity
Spurious response
Blocking rejection
Jamming tests
Audio measurements
Residual B.E.R.

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Slide 11

Let's look at a fairly complete list of tests that fully characterizes a receiver. Sensitivity determines how well the receiver can recover the transmitted signal under worst case signal strength conditions. And since these radios transmit digital data a way to measure sensitivity of the receiver is to make a bit error rate measurements vs received power level. The first and probably most important sensitivity measurement is B.E.R. vs the RF level. This measurement determines the level that the received signal needs so that the data sent can be recovered with some accepted minimum bit error rate. Or in simpler words, at what distance can two radios communicate effectively. Other tests that give further insight as to the radios performance by making bit error measurements would be:

B.E.R. vs C/I and vs C/N; add impulse and random noise at baseband, RF or IF levels. Tests demodulation circuits, error decode circuits, and deframe circuits.

B.E.R. vs co-channel interference; interference due to a second source transmitting on the same channel. Tests demodulation circuits, and error decode, deframe circuits.

B.E.R. vs RF offset frequency; adjust the transmitted RF center frequency to some offset. Tests frequency accuracy of receiver hopped L.O., settling time of receiver hopped L.O., tuned RF filters in receiver, error decode, and deframe circuits.

B.E.R. vs modulation accuracy; vary the amount of deviation, % depth of modulation, additive AM, FM, or phase modulation. Tests RF and IF frequency response of receiver, demodulation circuits, error decode, and deframe circuits.

B.E.R. vs pre-modulation filter bandwidth; vary the pre-modulation filtering of the transmitter and determine its effect on the transmitted signal. Tests RF and IF frequency response of receiver, demodulation circuits, error decode, and deframe circuits.

B.E.R. vs RF amplitude shaping: vary the manner in which the level of the RF amplitude comes up and shuts off. Tests acquisition characteristics of demodulator, error decoder, and deframe circuits.

B.E.R. vs induced data, systematic timing, jitter timing errors; induce data, encoding, framing and timing errors in transmitter information. Tests demodulation circuits, error decode, and deframe circuits.

Initial acquisition time and hop synchronization time measures firstly, how fast the receiver reacts to a transmitter signal and then how long after that does it take to get the receiver to synchronize with the transmitting radio. It also tests synchronization range of radio.

Adjacent channel selectivity is very important to these radios since they are using many frequencies within a given range over time. And, with multiple radios being used in different operating nets, it is important to be sure that your radio rejects these "stray" signals when they are in adjacent channels. In addition to this, the receiver must be able to reject spurious as well as inter-modulation related spurious as these are both generated by either the transmitting radio or other radios in different nets in the area.

Blocking rejection. This would be a test of the radios ability to communicate effectively with selected frequencies being dropped out. That is, how well the receiver performs when certain frequencies are filtered out or are at a lower level than all other frequencies transmitted. This test could tell what level of channels could be taken out without losing synchronization and would still allow for communication between the transmitter and receiver.

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Slide 11 (contd.)

Jamming tests could be approached many ways. One method would be to employ additional signal generator(s) that transmit bogus information or noise at various amplitude levels on some portions of the transmitting radio's sequence. This could be used to test the receivers immunity or susceptibility to jamming and the effectiveness of its decoding scheme. Other methods of jamming could include transmitting a C.W. at some of the frequencies employed by the radio simultaneously. Follow jamming, where the jam signal only occurs at some final portion of the dwell. Broadband jamming, where a large amount of RF power is spread over all or part of the frequencies being used. These jamming tests would allow the performance of the receiver to be evaluated with nearly all field conditions simulated and without complex or one-of-a-kind test equipment. In addition, complete audio tests could be done on the radio like frequency response, distortion, signal-to-noise, Sinad, etc., as is done on conventional radios. Residual bit error rate or a test on the receiver's demodulation, synchronization, deframing, decoding, decryption circuits while frequency hopping. The importance of these tests are that they evaluate the performance of the radio by pushing its limits as well as operational parameters.

But what would we need to be able to do these tests?

Block diagram for testing
frequency agile Receivers

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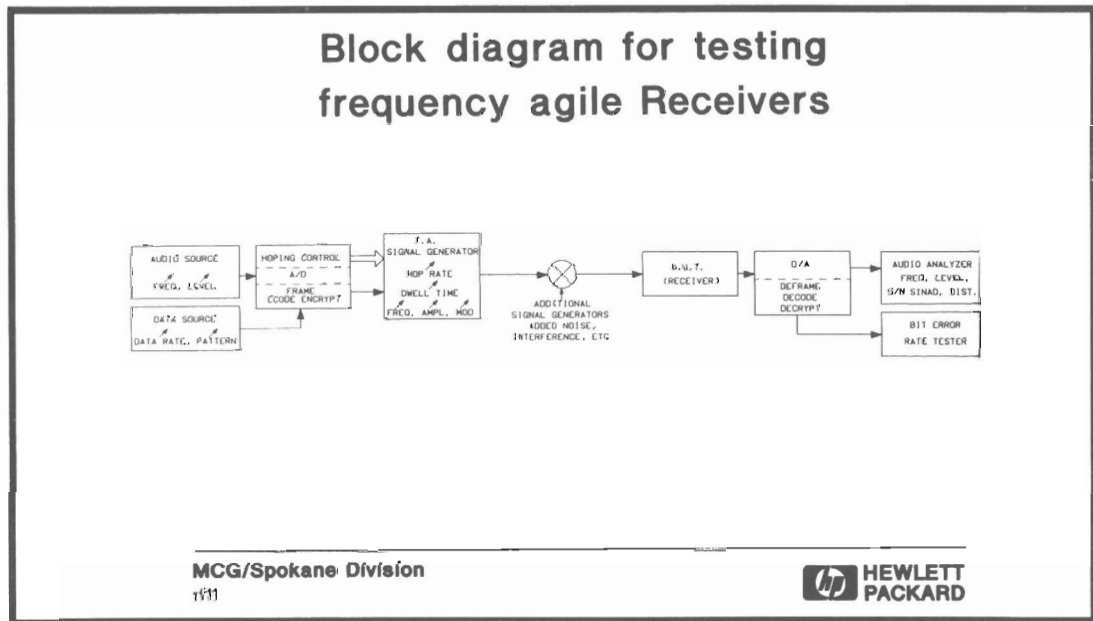
Slide 12.

Let's not worry about the problem of getting the signal generator to hop with the receiver. Now we can approach testing frequency agile radios dynamically just as testing conventional radios is done. The block diagram of a setup for doing receiver tests would look like the following.

As you can see, this type of test setup would allow much flexibility in testing a receiver. With this set up the receiver can be more fully characterized. Virtually every part of a transmitter has been replaced with calibrated test equipment. This insures that the results obtained are those of the receiver and not from other parts of the test set. Also, with test equipment substituted everywhere around the receiver, any one parameter can be varied to see the affect it has on the receiver.

TESTS OF IMPORTANCE FOR A
FREQUENCY AGILE TRANSMITTER

TRANSMITTER TESTS

Average carrier power in channel
Dynamic carrier power in channel
Dynamic frequency accuracy
Channel occupancy
Channel usage
Instantaneous, average, peak deviation
Adjacent channel power
Occupied bandwidth
Spurious power
Audio measurements
Residual B.E.R.

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Slide 13

Again we see from this list that there are some additional tests that could be done on a frequency agile transmitter.

Average carrier power in-channel is basically a measure of the transmitter over several hops of the radio. This can determine how the power level of the radio varies for blocks of frequencies.

The dynamic carrier power in-channel test would enable the instantaneous power to be measured in any one channel. This would determine if the radio is transmitting the same amount of power at all frequencies.

Dynamic frequency accuracy test would allow one to measure the frequency of the carrier at any one hop. Thus determining its accuracy as well as any variations or drift that may occur while dwelling on that channel.

Channel occupancy test would ensure that all channels or frequencies are used by the radio while it is hopping.

Channel usage is one of the key parameters for frequency agile radios. To have a purely pseudo-random frequency hopping pattern over all channels ensures one level of the radio's security. So, naturally, verifying that the transmitter is using all channels equally over a given time is a very important test.

Being able to verify and measure the FM deviation or depth of AM modulation of a radio while hopping is important in characterizing the modulator of the transmitter as well.

Adjacent channel power, occupied bandwidth, and spurious power tests determine the amount of RF power that the transmitter emits outside the desired channel. This is important to know since these unwanted signal emissions could interfere other hopping radios in different operating nets.

And, of course, audio measurements like microphone sensitivity, audio frequency response, distortion, etc., and residual bit error rate test that evaluate the radio's baseband circuitry.

Again, from this list of tests one can see the advantages of making these measurements and others on a frequency agile radio.

Block diagram for testing frequency agile transmitters.
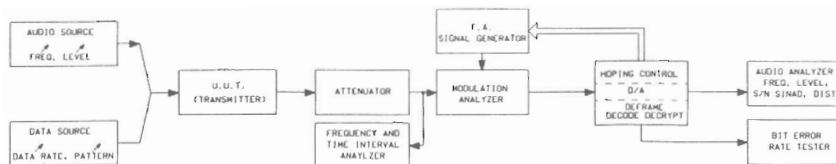
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rf13

hp HEWLETT PACKARD

Slide 14

Similarly, if we do not worry about test equipment and its ability to demodulate an F.A. source, a block diagram of a transmitter test system can be drawn up. Again, the versatility of such a set can be seen. A thorough characterization of the transmitter can be performed. Simulation of many different field conditions can be done to see how the transmitter responds thus enabling the manufacturer/user to know the limitations and benefits of his radio.

Frequency Agile Signal Generator
HP8645A
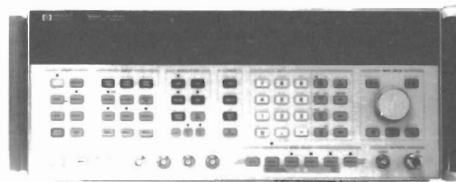
Frequency range 252kHz – 2060MHz
Amplitude +16dBm to –127dBm +/–1dB accuracy
Full modulation capability AM, FM, ϕM, Pulse
Phase noise <–124dBc, spurs≤–100dBc >20kHz offset
<15μ sec switching speed capability
Performance for both static and dynamic testing

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Slide 16

This is the HP 8645A frequency agile signal generator which can be used to test these radios. It has frequency coverage for testing virtually every frequency agile radio currently available. Unlike fast switching sources that only change carrier frequencies many times a second, it has amplitude control as well as modulation capability. The HP 8645A allows you to precisely control hop, dwell time, frequency, amplitude, and modulation of your frequency agile signal. This, in essence, allows you to use the HP 8645A to simulate a frequency agile transmitter accurately and eliminates the necessity of using a "Golden Transmitter" to test frequency agile receivers.

1) The switching speed of the HP 8645A is less than 15 microseconds while switching in the 128 to 2060 MHz frequency range. The switching speed increases to less than 85 microseconds for frequencies down to 8 MHz and < 500 microseconds down to 252 kHz.

2) Amplitude is decreased by >60 dB while switching between frequencies so as to minimize spectral splatter and amplitude shaping is possible by using the DCAM input.

3) Minimum RF dwell time at a given frequency is 6.4 microseconds with the maximum being 99 milliseconds using the internal timer. Using an external trigger input (into the fast hop bus) allows longer dwell times and variable dwell times from frequency to frequency .

4) Frequency accuracy is ±2 ppm of the carrier frequency typically ± 1 ppm while hopping.

5) Fixed hopping rates from 8 Hz to 50 kHz are available using the internal timer. Using an external trigger input (into the fast hop bus) allows slower and variable hop rates.

6) The HP 8645 allows simultaneous internal/external AM/FM modulation while hopping.

7) The HP 8645A is a very versatile frequency agile signal generator with good specifications but it can also be used as a conventional signal generator. When used in this mode it has the same frequency accuracy as other high performance signal generators and has slightly improved phase noise performance over its frequency agile operation.

CHANNEL AND SEQUENCE TABLE
IN HP 8645A

CHANNEL TABLE

Channel #	Channel Frequency	Channel Amplitude
0	30.000 MHz	−100 dBm
1	30.025 MHz	−100 dBm
2	30.050 MHz	−120 dBm
3	30.075 MHz	−100 dBm
4	30.100 MHz	−100 dBm
5	30.125 MHz	−100 dBm
6	30.150 MHz	−100 dBm
7	30.175 MHz	−120 dBm
⋮	⋮	
2399	90.000 MHz	−100 dBm

SEQUENCE TABLE

Sequence Step #	Channel #
0	2319
1	2318
2	2317
3	2316
4	2315
5	2314
6	2313
⋮	
3999	129

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RF16

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Slide 18

You are probably wondering how does it know what frequency to hop to. Well, the HP 8645A has two tables built into it. These two tables determine what frequencies to hop to and in what order. The first table is called the channel table. It contains every frequency that you want the HP 8645A to use while it is hopping. The other table is the sequence table. It contains the order in which each frequency or channel is visited. The values entered into these tables can be entered either through the front panel or via the HP-IB bus. Channel table entries do not contain the order in which the frequencies are to be output from the instrument. The sequence table contains the order in which the channel frequencies are selected. Hence, the inputs to the sequence table are channel table entry numbers, not frequency information. The use of these two tables minimizes the input work required by the user: all that is required is to enter the frequency information for each hop frequency into the channel table. The maximum number of different frequencies that can be entered into the channel table is 2400. Thus the maximum number of frequencies that the HP 8645A can hop over is 2400. However, the sequence table may be as long as 4000. That is, although you are limited to 2400 different frequencies, you can sequence them in such a way that some frequencies may be used more than once in any given sequence.

One other important feature of the channel table is that it allows an amplitude to be entered with each frequency entered. The amplitudes entered can be set to different levels as well. The maximum variation of all the amplitudes entered in the channel table is 20 dB to be within given operating specifications.

The HP 8645A uses FLL's while it is hopping so that faster switching times can be attained. Due to this method of using FLL's a "learn cycle" must occur before the HP 8645A can actually begin hopping over the frequencies entered into its tables.

In order for the frequency locked loop to be set to the desired output frequency and amplitude, the instrument is first phase locked to the desired frequency, and then several internal parameters are measured for the frequency and amplitude level. This information is then stored into memory "learned" which is recalled later when the generator is hopping. The result of this is that the HP 8645A needs to be phased locked at each frequency stored in its channel table. This technique requires a setup time after entering in the channel and sequence tables and before actual frequency hopping takes place. This setup time is called "learn time" and can be as short as 10 seconds to as long as 2 minutes (if all 2400 channel table entries are used.)

FAST HOP CONTROL OF HP 8645

- Internally Repetitive
- Internally Single
- Internally Stepped
- Externally Repetitive
- Externally Single
- Externally Stepped Using Internal Control of Dwell
- Externally Stepped Using External Control of Dwell
- Fast Hop Bus Using Internal Control of Dwell
- Fast Hop Bus Using External Control of Dwell

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RF17

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Slide 18a

There are various ways to control the hopping of the HP 8645A. This can be done either through the internal hardware of the HP 8645A or by using the external fast hop control bus.

Let's look at the different methods that can be used to control the hopping of the HP 8645A. The first method is to use the internally triggered mode. This basically allows for the entries in the sequence table to be output in a repetitive cycle, a single cycle, or allows the user to step through the frequencies one by one.

The next method is to use the externally triggered mode. This mode lets you to start and stop the sequence of frequencies by using a control line. Again, a repetitive cycle, single cycle, or stepped cycle can be used. The stepped cycle also allows for either internal control of the RF dwell time or lets the user provide a TTL signal that determines the RF dwell time.

Finally, there is the Fast Hop Bus. This control bus is what gives the user the most flexibility in controlling the HP 8645A and makes hopping over pseudo-random frequency sequences possible. It is a 25-pin connector that uses TTL level signals to directly control the HP 8645A's hopping sequence. The details of this bus and how to use it will be discussed later.

Frequency and time interval analyzer
HP 5371A
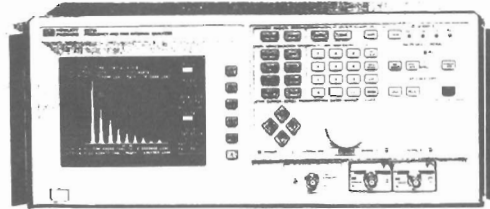
Continous frequency and time interval measurements
up to 10M samples/sec.
DC to 500MHz frequency range
Sample intervals from 100ns to 8sec
Flexible arming/triggering capabilities
Built in analysis capability
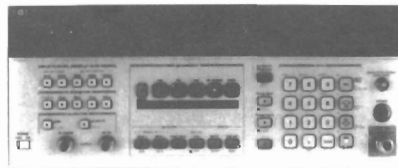
MCG/Spokane Division
rf18

HEWLETT PACKARD

Slide 19

The HP 5371A is a continuous frequency and time interval analyzer. It has all the features normally associated with traditional counters and a whole lot more. Unlike traditional counters, the HP 5371A allows continuous frequency measurements to be made on a carrier.

The advantage of this can be readily seen for testing frequency agile radios. First of all, it now gives the ability to analyze the carrier as it hops from frequency to frequency. Measurements like hop rate and dead time between carriers can be made. In addition, by making block measurements over time on a transmitter and storing the data you can determine which frequencies are being used, how often they are being used, and show the results in a histogram form on the screen of the analyzer.

The HP 5371A can be used to measure deviation on a hopping carrier as well as allow you to look at the modulation on the carrier. In addition, by using the external arm/trigger capabilities individual channels can be analyzed in detail for frequency accuracy and settling characteristics.

Frequency agile receiver
HP 8901 H45

Demodulates frequency agile carrier with hopping
External L.O.
  Frequencies 10MHz to 1300MHz
  AM,FM
Conventional Measurements
  RF Power
  RF Frequency
  Modulation Characterization
 Audio Characterization

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rf19

HEWLETT PACKARD

Slide 20

This is the HP 8901B modulation analyzer. As you probably know, it has been used quite extensively in conventional transmitter testing. The H45 option adds frequency agile operation to this already versatile instrument. Additional circuitry has been installed to an HP 8901B option 030 that enables it to demodulate a frequency agile carrier by using a hopping local oscillator.

The HP 8645A is set up as a L.O. for the HP 8901B H45, with all of the frequencies entered into its channel table being offset by 1.5 MHz of the transmitter's frequencies. By internally mixing the transmitted agile carrier with the agile L.O., an intermediate frequency is produced that allows the HP 8901B H45 to demodulate the carrier, thus allowing the baseband signal to be recovered.

Bit Error Rate Tester HP 1645A
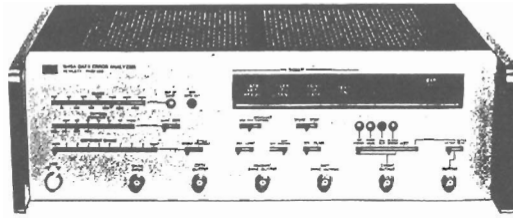
Can Measure Bit Error Rates >10%
Variable Data Rates up to 5MHz
Variable Data Interval Lengths
Selectable Test Pattern Lengths

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rf20

HEWLETT
PACKARD

Slide 21

Currently the only bit error rate tester available from Hewlett-Packard that can be used for testing these radios is the HP 1645A. This instrument can handle relatively large bit error rates (>10%) that can be experienced while testing frequency agile radios. By using an external clock variable data rates can be produced up to a maximum of 5 MHz. It also allows the user to select the number of bits to be cycled through for a given test. One drawback of the HP 1645A is that it is not HP-IB controllable.

Agenda

Review of Conventional Transceiver Testing
Frequency Agile Transceiver Testing
Required Equipment for Frequency Agile Testing
Sychronization of the HP 8645A
Interfacing to the Rockwell/Collins MP-83
Applications
Summary

MCG/Spokane Division
rf 23A

HEWLETT
PACKARD

Rockwell/Collins MP 83
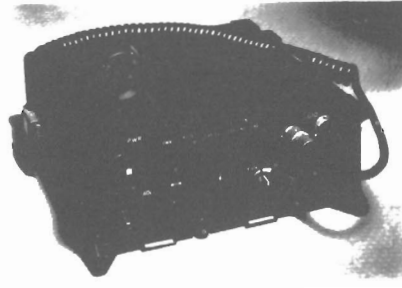
30-88 MHz
25 kHz channel spacing
Transmits 16kbit/sec data or digitized voice
FSK with 7kHz peak deviation
16kbit bursted to 20kbit for transmission

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rf21

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Slide 22

The Rockwell/Collins MP83 is a frequency-agile manpack radio that is very similar to the SINCGARS radio; it hops at 104 hops per second over the 30-88 MHz band with a channel spacing of 25 kHz. Audio is digitized at 16 kbits/second. Digitized audio or externally supplied 16 kbit/sec data is then compressed to 20 kbit/sec and bursted for transmission during the 8 millisecond dwell time of each hop. The peak deviation of the FSK modulation is 7 kHz.
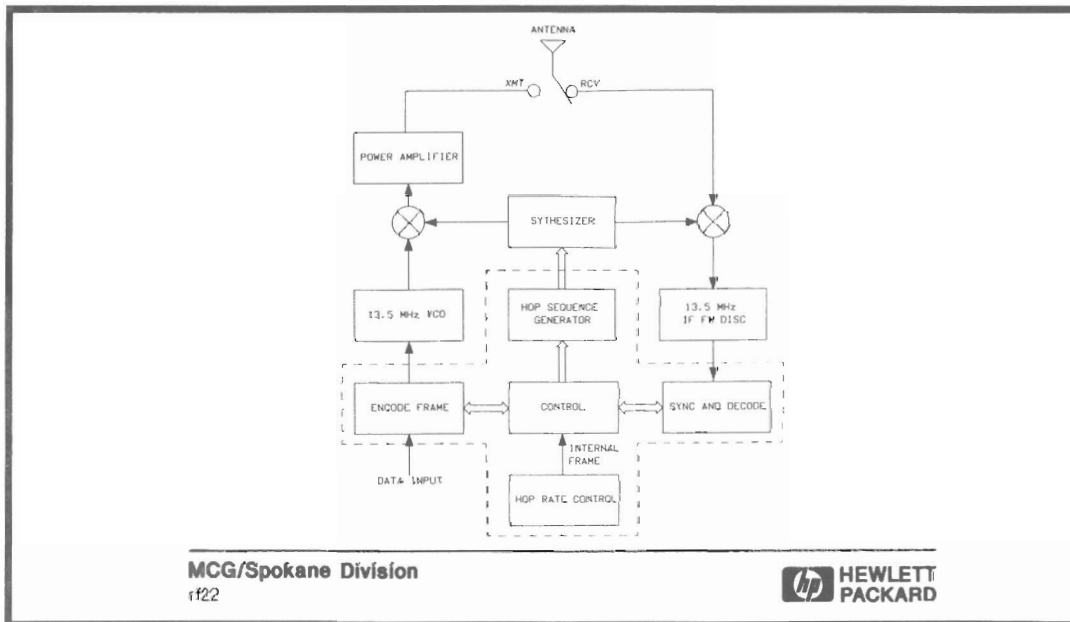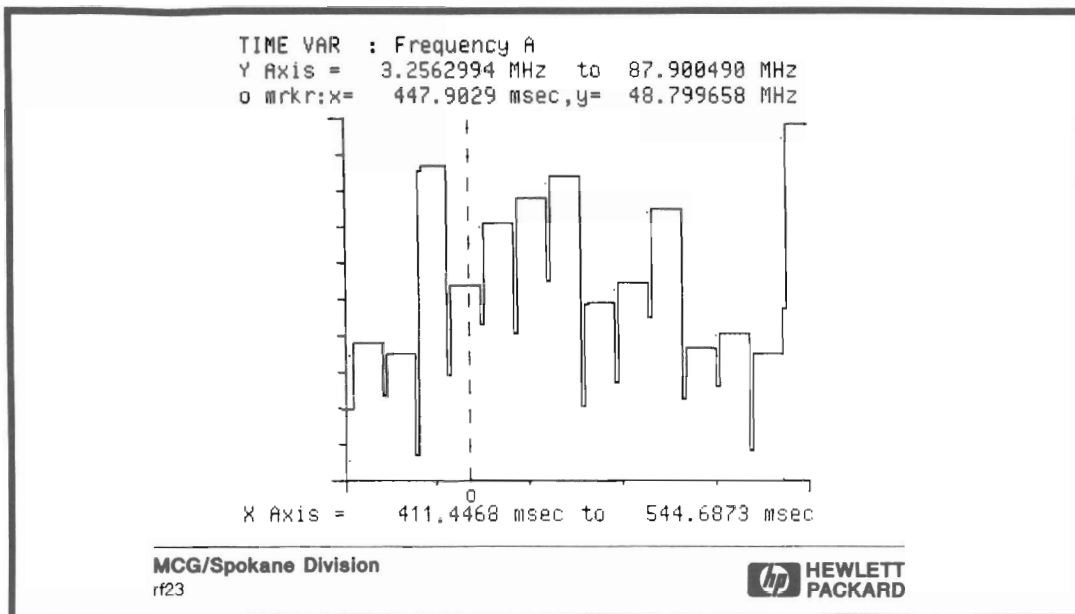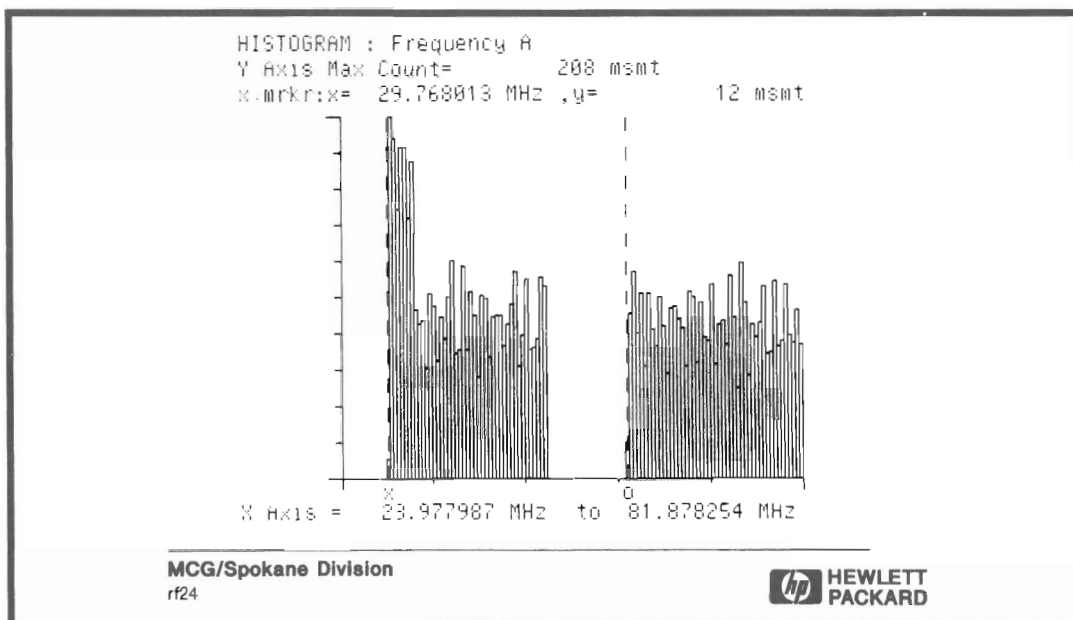

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rf22

HEWLETT
PACKARD

Slide 23

This slide shows a simplified block diagram of the MP83. If the Digital Control and ECCM (Electronic Counter-Counter Measures) boards were removed and replaced by a simple fixed frequency control for the synthesizer, you would have a conventional CW transceiver. The Control and ECCM boards allow for frequency agile operation by varying the synthesizer frequency control according to a pseudorandom sequence.

```
TIME VAR  : Frequency A
Y Axis =   3.2562994 MHz  to  87.900490 MHz
o mrkr:x=   447.9029 msec,y=  48.799658 MHz



                          0
X Axis =    411.4468 msec to   544.6873 msec
```

MCG/Spokane Division
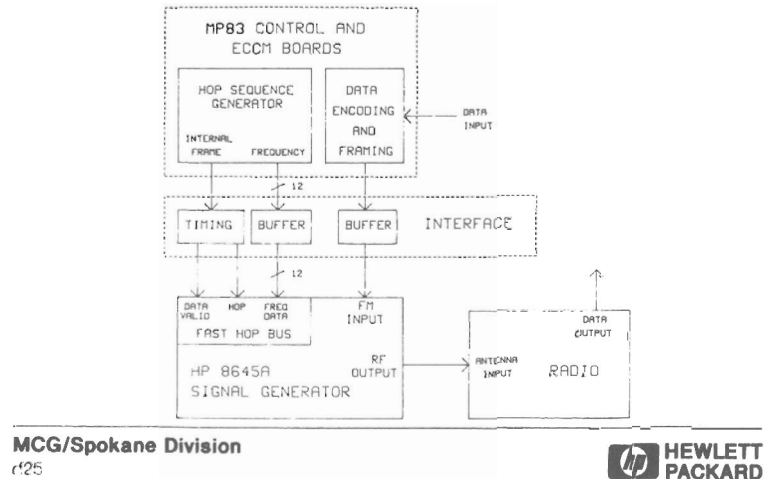rf23

HEWLETT PACKARD

Slide 24

The HP 5371A Time Interval Analyzer can be used to record the hop sequence of the MP83 transmitter as a function of time. Operation of the HP 5371A is simple; the transmitter output is merely attenuated and connected to the RF input of the HP 5371A.


```
HISTOGRAM : Frequency A
Y Axis Max Count=        208 msmt
x.mrkr:x=  29.768013 MHz ,y=      12 msmt



                   x             0
X Axis =    23.977987 MHz  to  81.878254 MHz
```

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rf24

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Slide 25

The effectiveness of the pseudorandom sequence generating algorithm in the radio can be tested by using the HP 5371A Time Interval Analyzer. This slide shows an example of a histogram distribution of spectrum utilization that was measured by the HP 5371A. An ideally pseudorandom sequence would have a uniform distribution so that no channel is visited more often than any other channel; this makes the radio more difficult to jam.

## Controlling the HP 8645A using
MP-83 Control and ECCM Boards

MP83 CONTROL AND ECCM BOARDS

HOP SEQUENCE GENERATOR

INTERNAL FRAME   FREQUENCY

DATA ENCODING AND FRAMING

DATA INPUT

TIMING   BUFFER   BUFFER   INTERFACE

DATA VALID   HOP   FREQ DATA   FM INPUT

FAST HOP BUS

HP 8645A SIGNAL GENERATOR   RF OUTPUT

ANTENNA INPUT   RADIO

DATA OUTPUT

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25

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Slide 26

The HP 8645A Signal Generator can be used to test the receiver of the MP83 by using the Fast Hop Bus on the rear panel. This bus consists of a parallel data bus for frequency data; DATA VALID, which latches the frequency word into the HP 8645A; HOP, which triggers the HP 8645A to hop to the new frequency; and other lines which are not of interest in this application. We will take a closer look at the Fast Hop Bus later.

In order to test a frequency hopping receiver, there must be some means of synchronizing the HP 8645A Signal Generator to the radio. This requires prior knowledge of the hop sequence as well as data framing and encoding algorithms. Using a set of tested and verified digital control and ECCM boards identical to those in the radio under test eliminates any need for explicit knowledge of the pseudorandom hop sequences or data encoding algorithms used. The frequency data that drives the radio's synthesizer supplies the hop sequence, and an internal framing pulse can be used to generate the HOP and DATA VALID lines for the HP 8645A Fast Hop Bus. The input to the radio's FM modulator is the encoded, framed data; this data also includes information necessary for synchronization. Buffering this signal to drive the FM input of the HP 8645A completes the interface; the HP 8645A can now be used as a calibrated transmitter.
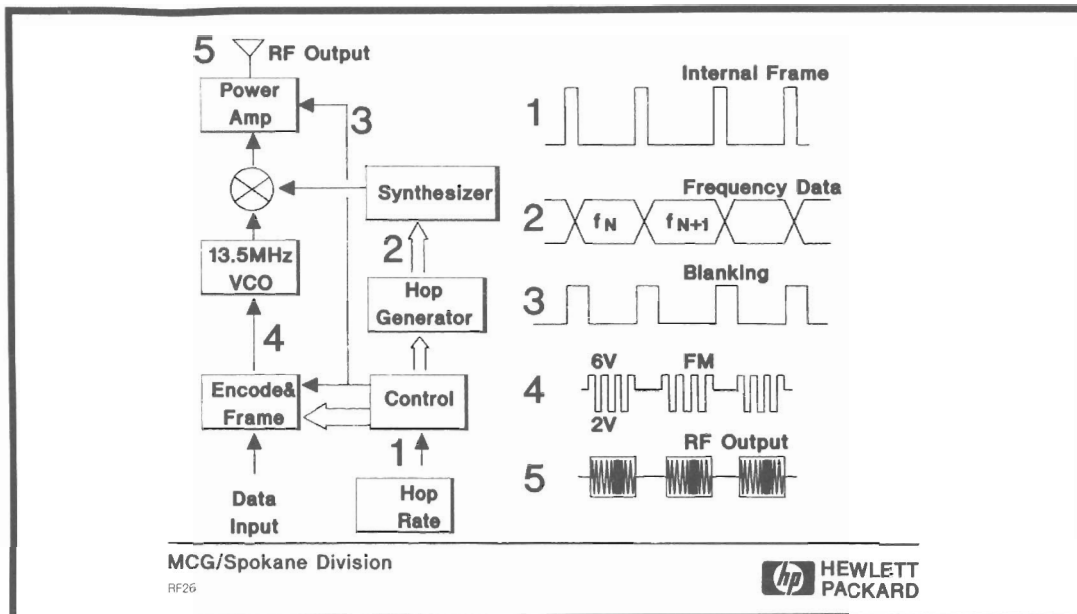
Slide 27

In order to see how to interface the HP 8645A Signal Generator to the Rockwell/Collins MP83, we need to take a closer look at the transmitter side of the MP83. The Internal Frame signal in the MP83 controls the hop rate of the synthesizer. Frequency data appears on a 12 bit parallel bus from the Hop Sequence Generator to the MP83's synthesizer. Blanking turns off the RF output for 1.6 milliseconds while the synthesizer is settling; it also provides a reference for framing the modulation.

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RF27

HEWLETT
PACKARD
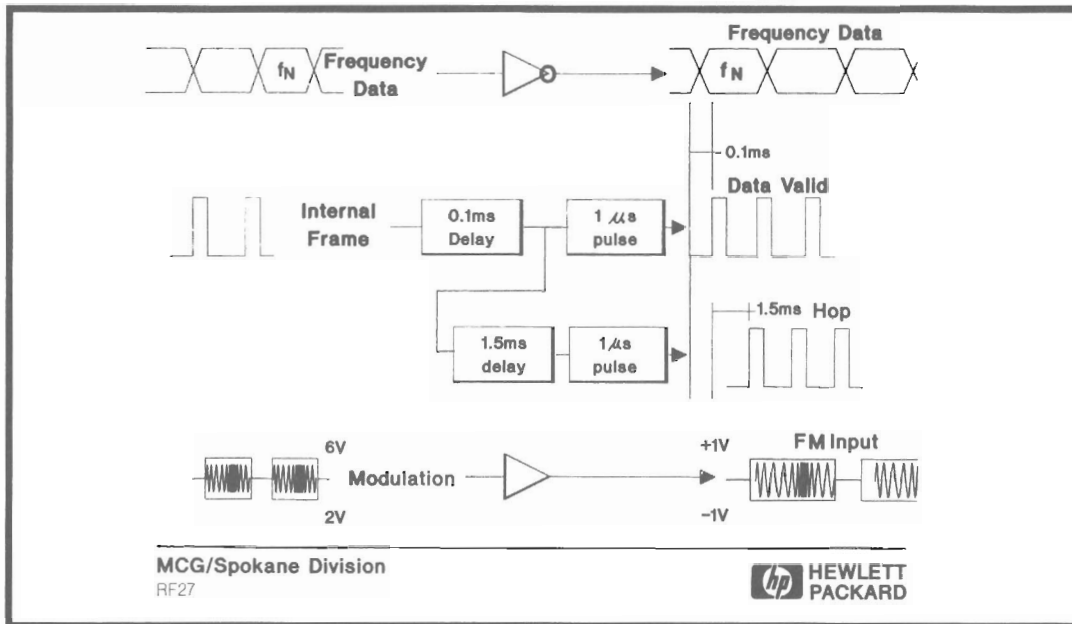
Slide 28

The interfacing required to link the HP 8645A Signal Generator to the MP83 Digital Control and ECCM boards is straightforward. Frequency data is sent to the MP83's synthesizer over a 12-bit parallel bus; this bus is simply buffered to drive the Fast Hop Bus on the HP 8645A.

The timing of the MP83's frequency hops is controlled by an internal frame pulse. HOP and DATA VALID can be derived from this pulse using minimal external circuitry.

The encoded, framed modulation is converted to ± 1 Volt peak and buffered to drive the FM input of the HP 8645A using a simple op amp circuit.

MCG/Spokane Division
RF28

HEWLETT
PACKARD
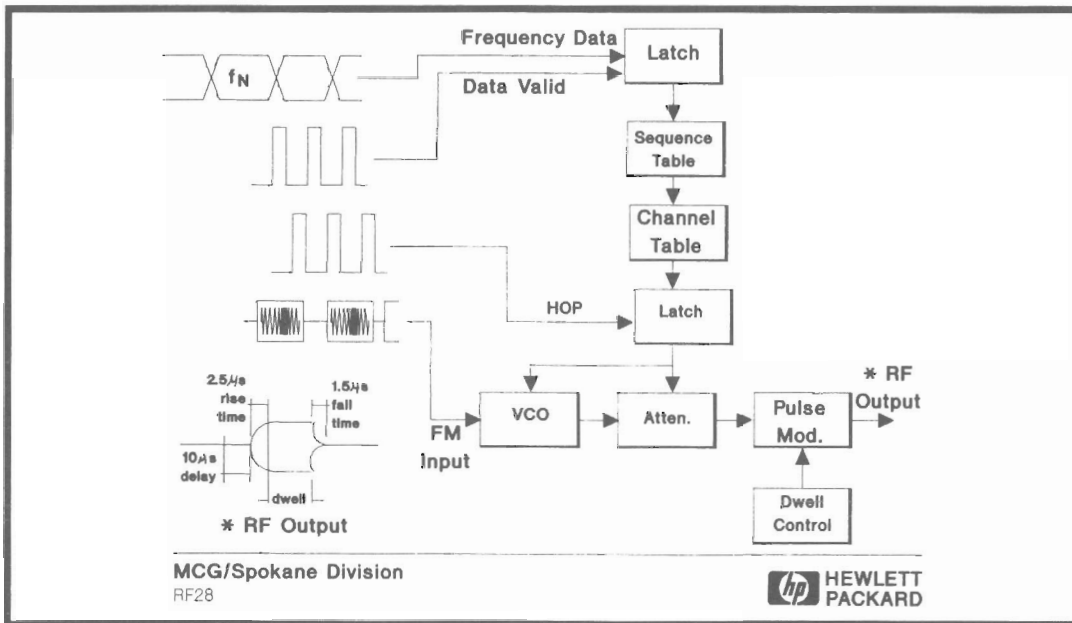
Slide 29

There are nine modes of frequency hopping in the HP 8645A Signal Generator. The mode used for the MP83 interface is Mode 8. Fast Hop Bus, Internal Timer Control of Dwell. This slide shows a simplified block diagram of how the HP 8645A Fast Hop Bus operates in this mode.

In Mode 8, the sequence of frequencies over which the HP 8645A hops is controlled externally using the Fast Hop Bus on the rear panel; A 12- bit word corresponding to the next frequency in the hop sequence is loaded into the HP 8645A over the parallel data bus and latched into the instrument when DATA VALID goes high.

The Sequence and Channel Tables set up the HP 8645A for the frequency and amplitude corresponding to the data word that was just latched in.

The HOP pulse determines when the HP 8645A hops to the next frequency. The dwell time is determined by a programmable timer in the HP 8645A.

Channel and Sequence Table in Fast Hop Mode
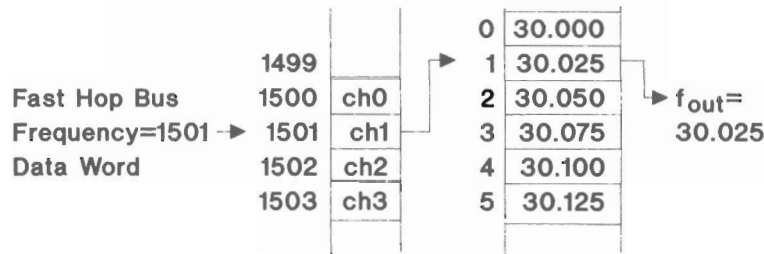
Channel table contains all channel frequencies
Sequence table assigns a 12-bit word to each channel

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rf29

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Slide 30

When Fast Hop Modes 1-7 are used, the Sequence Table contains Channel Table addresses in the order of the desired hop sequence. Sequence 0 contains the first channel in the sequence, Sequence 1 contains the second channel, and so on. A given channel can be repeated many times in the sequence.

However, when the Fast Hop Bus is used for external control of frequency hopping (Modes 8 and 9), the Sequence Table performs a different function. The order that the channel numbers are stored in the Sequence Table is not the order of the frequencies in the hop sequence; in Modes 8 and 9, the Sequence Table is used as a decoder. The frequency data word on the Fast Hop Bus addresses a location in the Sequence Table, which then points to a Channel Table location. The Sequence Table determines what data word from the Fast Hop Bus corresponds to each frequency in the Channel Table. In other words, the Sequence Table essentially assigns an address to each frequency; this assignment can be changed by reconfiguring the Sequence Table.

The Channel Table is loaded with all frequencies over which the HP 8645A will hop, but the highest valid address in the Channel Table is 2399. Since the Sequence Table has a maximum address of 3999, frequency data words from the Fast Hop Bus in the range 0-3999 can be translated to valid Channel Table addresses in the range 0-2399.

For example, many radios operate in the 30 to 88 MHz band with 25 kHz channel spacing. This is a total of 2320 channels, so these frequencies could be stored in channels 0 through 2319 in the Channel Table. If the data words corresponding to each of these frequencies ranged from 1500 to 3819, then Sequence 1500 would point to Channel 0, Sequence 1501 would point to Channel 1, and on up to Sequence 3819, which would point to Channel 2319. Loading the number 1500 on the Fast Hop Bus would cause the HP 8645A Signal Generator to hop to 30.000 MHz, and 3819 would produce 87.975 MHz.

28
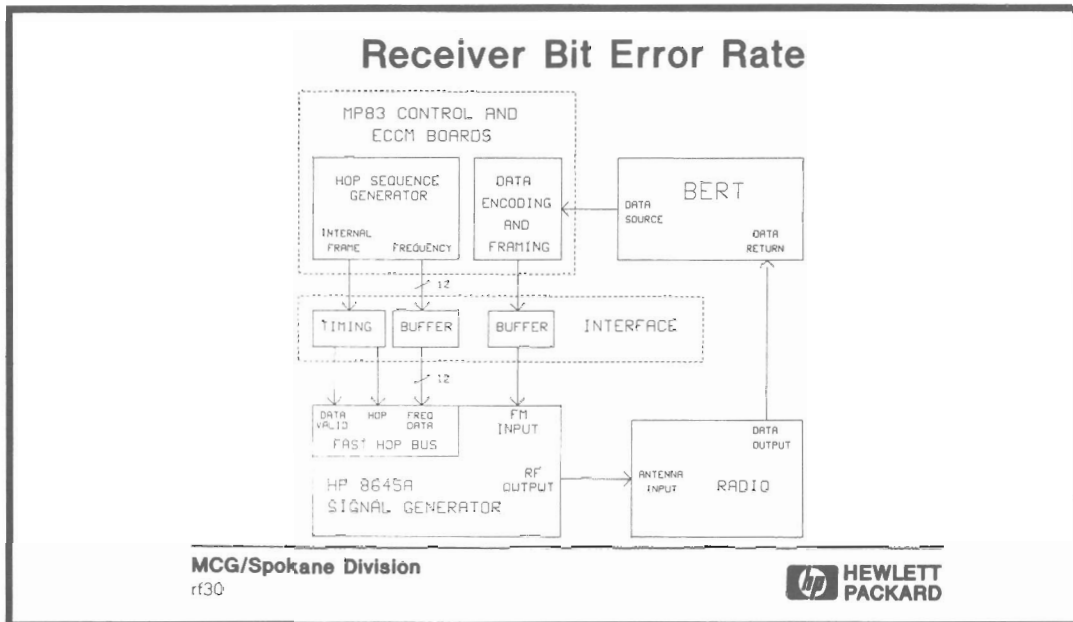
Slide 31

Bit Error Rate testing on the receiver can be done by adding a Bit Error Rate Tester to the block diagram shown earlier. This test checks the functionality of all parts of the receiver except for the audio circuits; substituting the HP 8903B Audio Analyzer will allow testing of the audio portion of the radio.
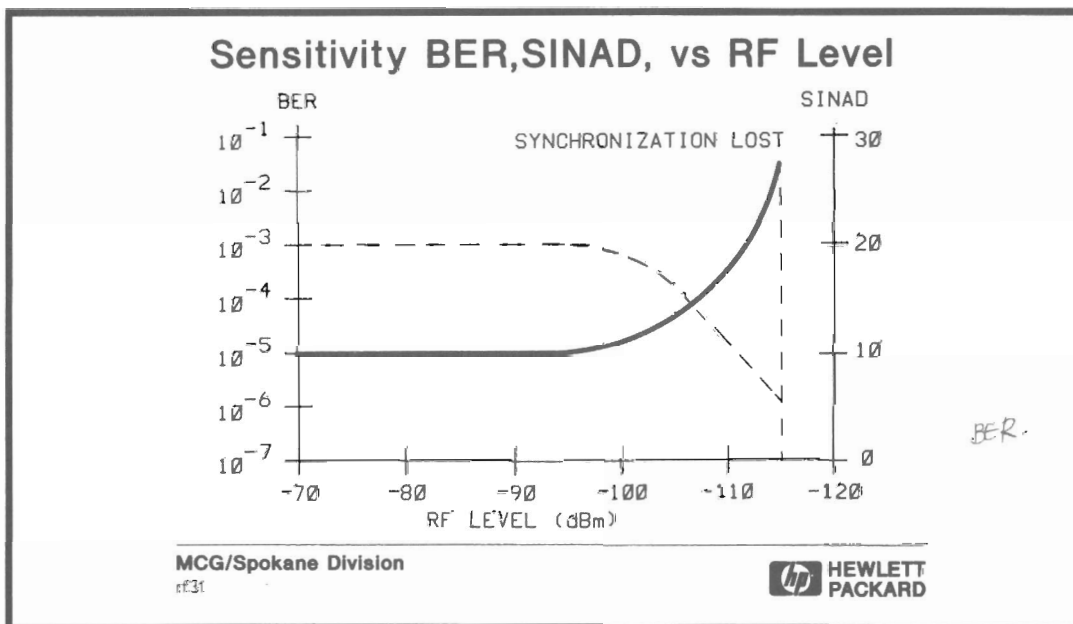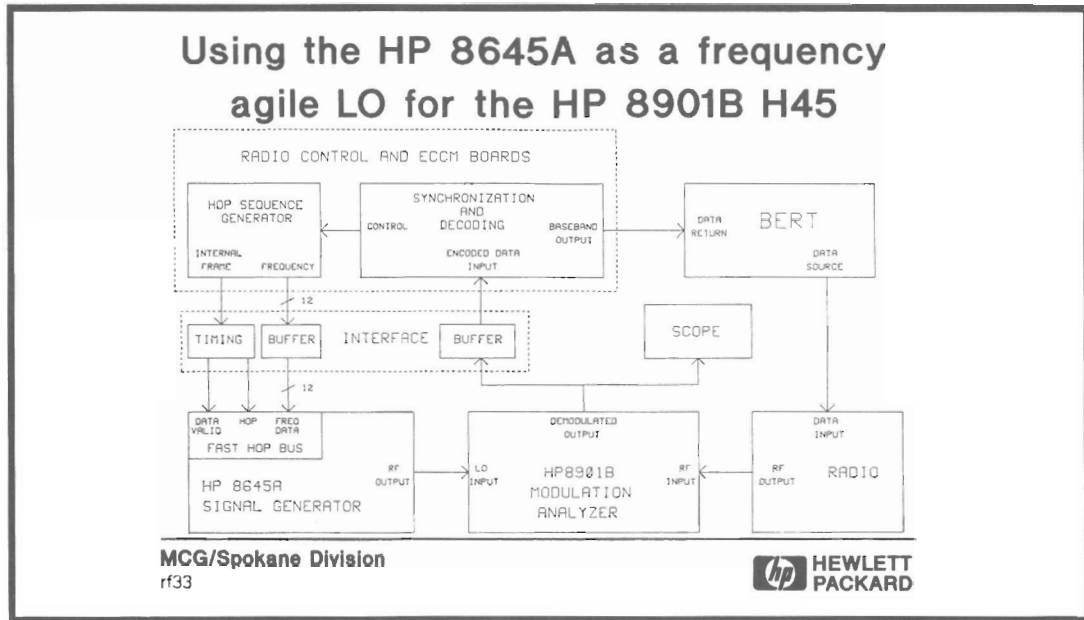

Slide 32

Since most frequency agile radios are digitally modulated, one of the most important tests is BER (bit error rate) while hopping. This slide shows the MP83's BER and SINAD vs. RF level. The BER reaches a level of 0.1 at a level of −113 dBm, and loses synchronization at lower RF levels. Bit error rate measures the performance of all parts of the radio except for the audio circuits; SINAD measurements test the audio portion of the radio.

Measuring the sensitivity of a receiver using both BER and SINAD is redundant, but the SINAD measurement can provide information about how the audio quality degrades as BER increases. This test provides accurate and repeatable information about the useful range of the radio.
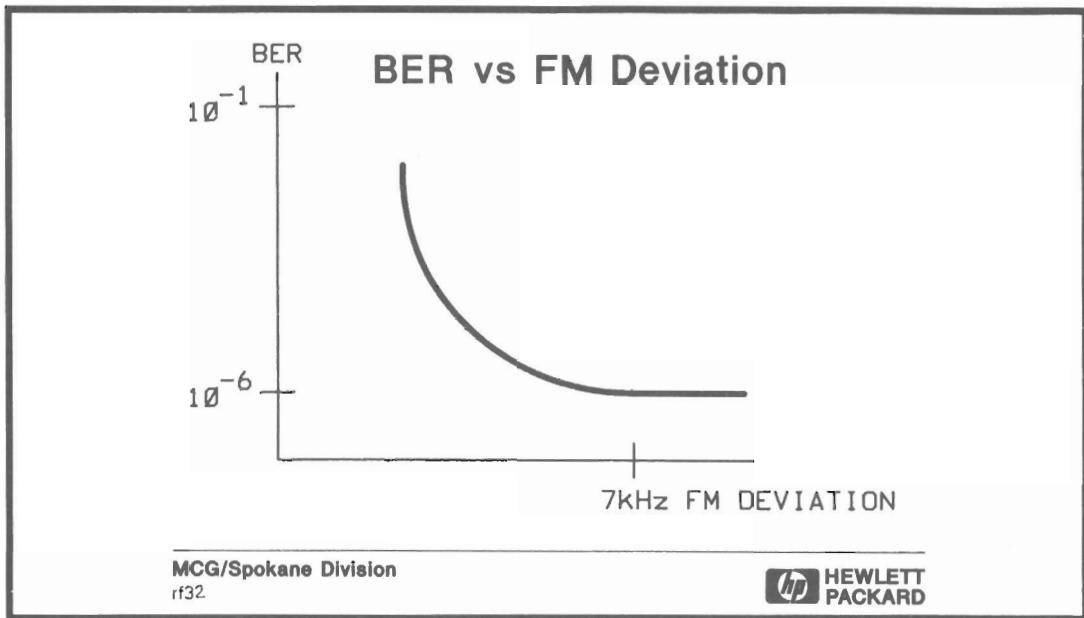
BER vs FM Deviation

Slide 33

By varying the FM deviation in the HP 8645A Signal Generator, the performance of the IF strip in the receiver can be characterized. This slide shows Bit Error Rate vs. FM deviation; as the deviation is dropped below 7 kHz, BER degrades until the receiver loses synchronization.

Using the HP 8645A as a frequency agile LO for the HP 8901B H45
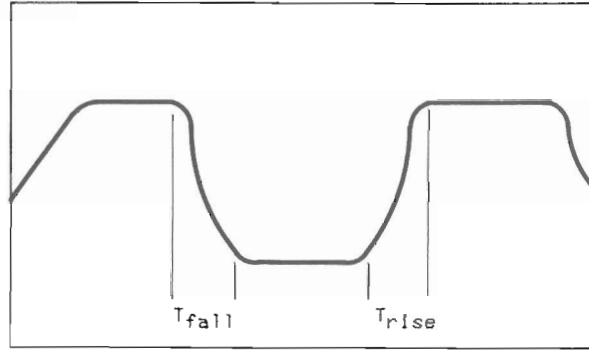
Slide 34

To test a frequency agile transmitter, the HP 8645A Signal Generator can be used as a frequency agile local oscillator for the HP 8901B (opt. H45) Modulation Analyzer to demodulate frequency hopping signals. As explained earlier, Option H45 allows use of an external frequency hopping LO.

To accomplish this, the Channel Table of the HP 8645A is loaded with frequencies that are offset from the transmitted frequencies by the IF of the HP 8901B Modulation Analyzer. When synchronized, this will produce a fixed intermediate frequency that can be demodulated by the HP 8901B.

Again, the digital control and ECCM boards are used to drive the Fast Hop Bus on the HP 8645A. The Modulation Output of the HP 8901B is buffered to TTL levels and routed into the radio boards; the synchronization information present in the transmitted data resets the control boards and allows them to synchronize the HP 8645A to the transmitter. Once synchronized, the control boards decode and deframe the transmitted data.

Slide 35

Pre-modulation filtering is often used to limit the bandwidth of the transmitted signal. Also, many FM radios modulate a CW carrier and translate it using a hopping local oscillator. The output of the fixed VCO may have some additional bandpass filtering to further limit the bandwidth. The effectiveness of the filtering in the transmitter on pulse shaping as well as its effect on data integrity can be determined by analyzing the demodulated output of the HP 8901B Modulation Analyzer. This slide shows the first ten bits of data in a given hop captured by the HP 1631D Logic Analyzer; the HP 1631D displays rise and fall times as well as peak amplitude. The instantaneous peak deviation can be deterimined from the peak amplitude of the demodulated output.

GMSK