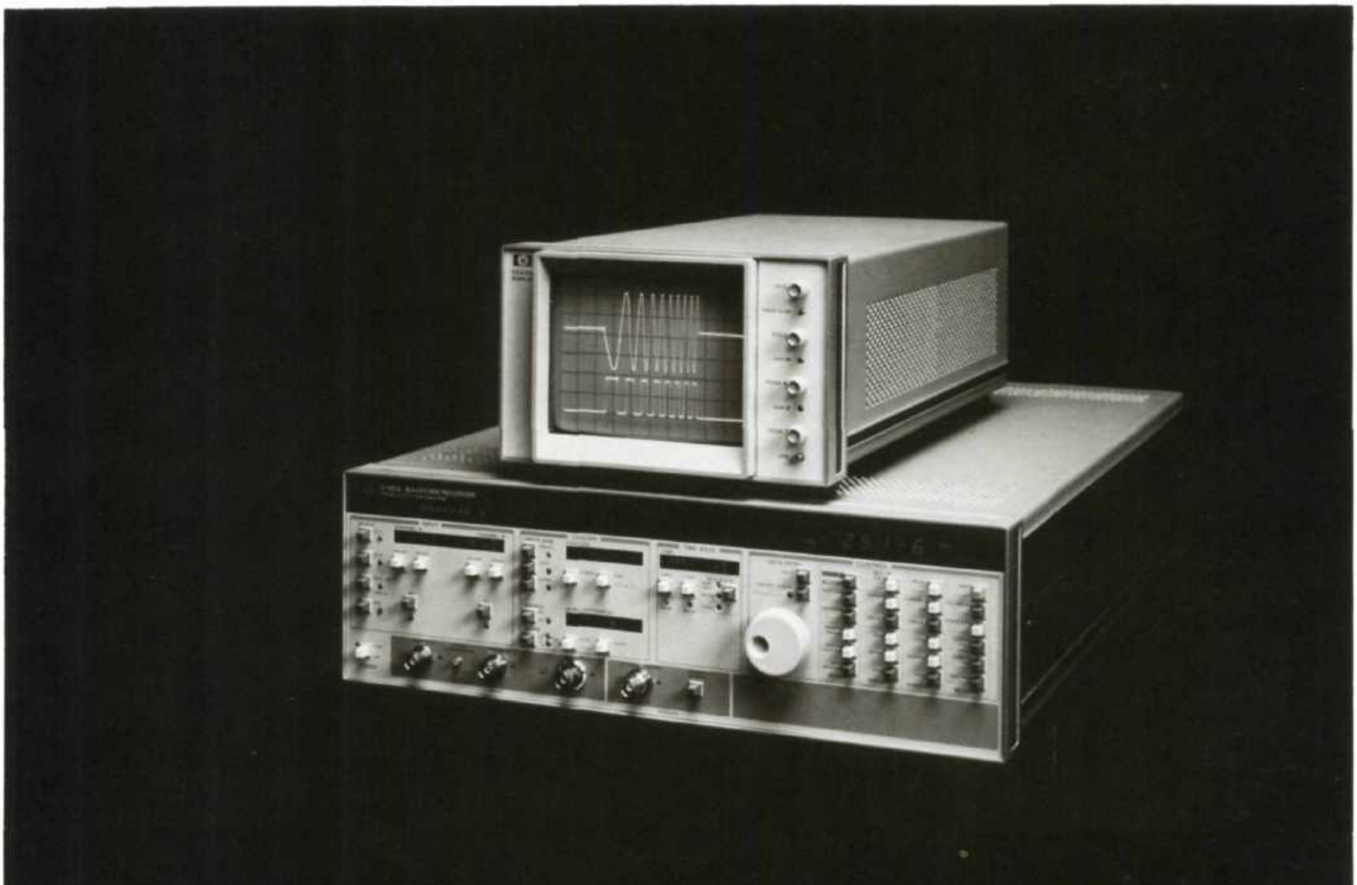
Application Note 313-2

Teaming Up a 5180A Waveform Recorder and a Spectrum Analyzer for New Time-Domain Measurement Capabilities



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Introduction

A powerful measurement capability can be realized by combining a spectrum analyzer and a waveform recorder, such as the HP 5180A. The versatility of the spectrum analyzer in receiving and down-converting incident microwave signals matches ideally with the 5180A Waveform Recorder's capability to digitize and store an input. The waveform recorder-spectrum analyzer applications described in this note use the set-up shown in Figure 1.

Figure 1 shows two possible interconnections between the 5180A Waveform Recorder and the spectrum analyzer: either the detected video or the IF output from the spectrum analyzer is the input to the 5180A. Whichever interconnection is used, the measurement benefit of this instrument combination is that the *time-domain* information from the RF input can be stored in the 5180A and processed, if desired. Since the feature set of the 5180A is oriented toward single-shot data capture, transient or short duration signals can be reliably monitored with this set-up. Because the 5180A has pre-trigger measurement capability, a single RF burst can be completely captured, not just the portion following the trigger.

Applications for the 5180A-spectrum analyzer combination are found in *EW, ECM,* radar, noise measurement, and in the processing of communications signals. Aside from these specific areas, true RMS measurements can be made with this set-up. These applications are detailed in later sections. To test each of these applications, an HP 5180A Waveform Recorder and an HP 8565A Spectrum Analyzer were used.

ABOUT THE 5180A WAVEFORM RECORDER

The 5180A has 10-bit (1 part in 1024) resolution, a maximum conversion rate of 20 MHz, a 16,384 sample data memory, and many unique measurement features. Like a spectrum analyzer, the 5180A Waveform Recorder is a powerful measurement instrument by itself. Detailed information about the 5180A is available in numerous technical publications.

THE SPECTRUM ANALYZER IS USED IN ZERO-SPAN MODE

Instead of using the spectrum analyzer in its most familiar mode of operation, where a filter is repeatedly swept across a selected frequency span (thus displaying time-limited frequency versus amplitude information), the spectrum analyzer is used in "zero span" mode in all of the applications described in this note. As the term implies, in zero-span mode, the filter is not swept. Instead, the filter remains stationary at a selected center frequency, with the filter bandwidth controlled by the selected resolution bandwidth.

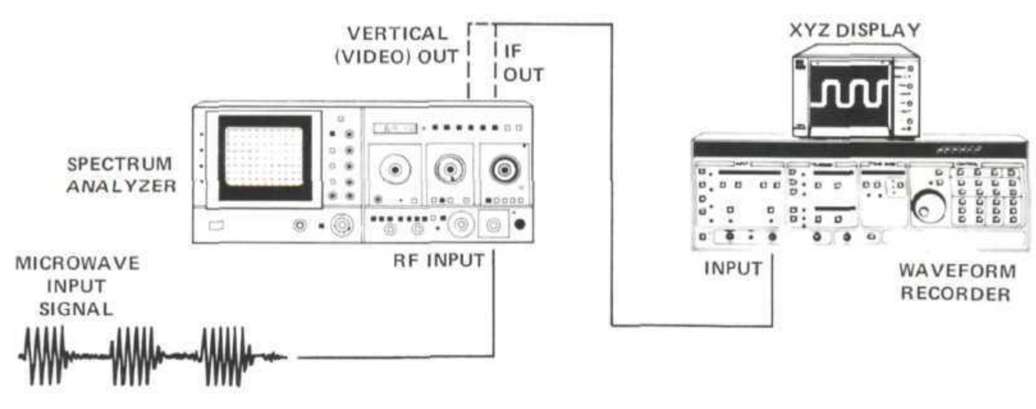


Figure 1. Interconnections for Spectrum Analyzer-Waveform Recorder Combination

Thus, in zero-span mode, the spectrum analyzer becomes a variable bandwidth, superheterodyne tuneable receiver (the output is frequency-limited time versus amplitude information). The video output from the spectrum analyzer in the zero-span mode is the time-domain envelope of the RF input. The IF output from the spectrum analyzer is simply a down-converted version of any input signal falling within the IF passband. For the 8565A (and many other HP spectrum analyzers), the IF center frequency is 21.4 MHz, and the IF bandwidth is controlled by the selected resolution bandwidth. An important property of the IF is that modulation that is present on the microwave input will be preserved in the down-conversion, so that the modulation can be monitored on the IF signal.

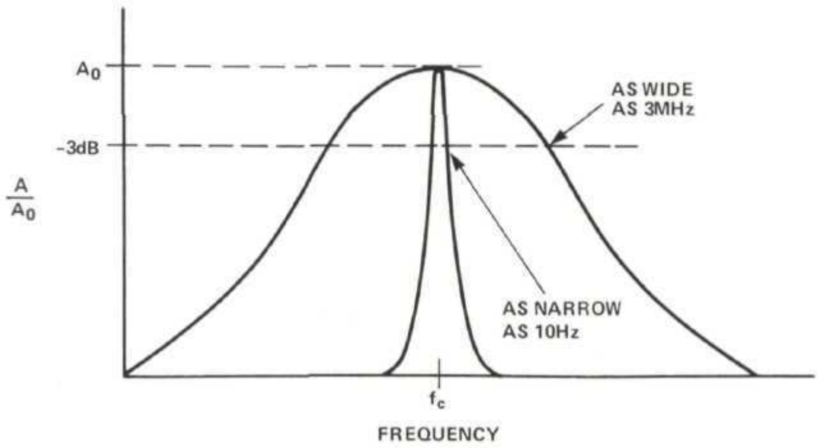


Figure 2. An illustration of zero span mode. f_c is the center frequency. Using the resolution bandwidth control, a wide range of passband filters can be centered about this frequency. The center frequency does not change with time.

Applications (Using the Detected Video Interconnection)

PULSE PATTERN RECOGNITION

There are many applications in communications, radar, and EW where pulsed RF bit streams are generated in a coded pattern. The spectrum analyzer-5180A combination is well suited for testing the code generating sources, or for comparing a received pulse pattern with a reference pattern (or even a library of reference patterns) in order to identify it.

The 8565A Spectrum Analyzer is placed in zero-span mode, the center frequency is tuned to the pulse carrier frequency, and the resolution bandwidth is set as large as possible (to preserve the pulse shape as faithfully as possible). The down-converted RF pulse pattern is envelope (AM) detected and routed to the 5180A Waveform Recorder, where the signal is digitized and stored for processing.

To demonstrate the capability of the 8565A-5180A combination for this application, a 5 MHz PRF (pulse repetition frequency), 10.819 GHz carrier frequency, bit stream was generated using a word generator to drive the PIN diode controlling the RF pulse modulation. A 256-bit pattern was formed according to the following rules:

1. The beginning of the pattern is indicated by four consecutive pulses
2. A pulse is generated in every 9th bit position
3. A pulse is generated in every 10th bit position
4. A pulse is generated in the 6th bit position, 6 + 7th bit position, 6 + 7 + 8th bit position, etc.

So, the beginning of the sequence looks like:

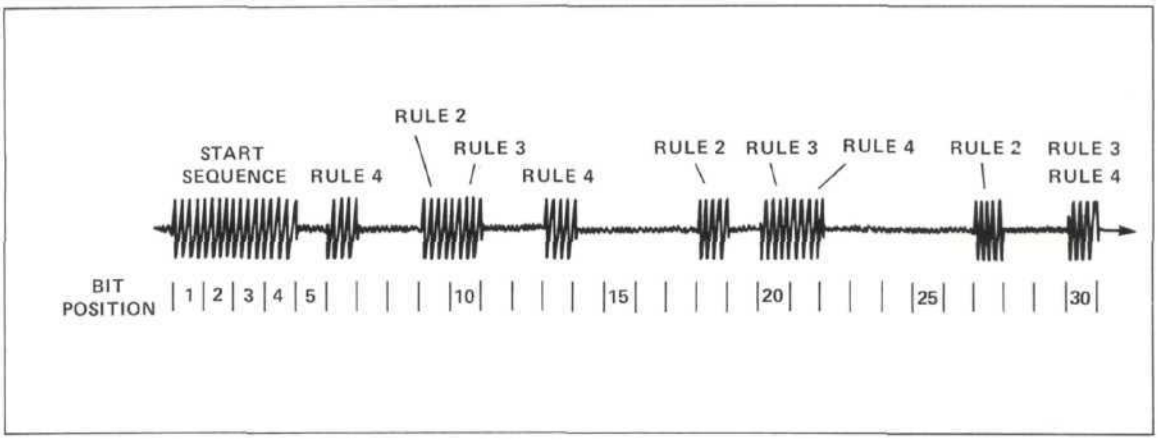


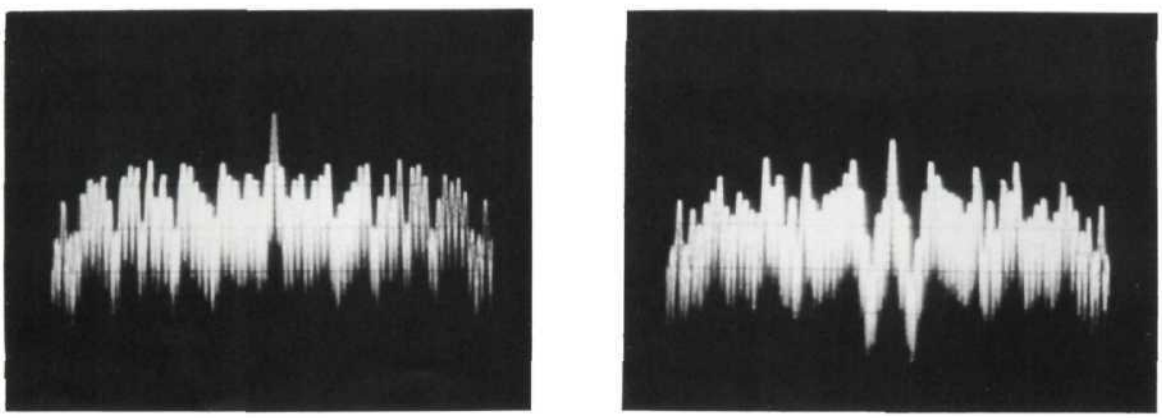
Figure 3. The first 30 bits of the coded microwave pulse pattern.

The challenge here is to determine if a given pulse sequence matches this form. Trying to do the analysis in the frequency domain is unwieldy. Examples of the spectral content of the correct pattern and the pattern without rule 2 (see Figure 4) show that, while it is clear that they are different, it is impossible to quantify *how* they are different.

The time-domain envelope of several pulse patterns was captured in the 5180A. If a synchronizing clock is available, the 5180A can be externally sampled, so that only one sample is taken per bit position. This is the most efficient way to sample the data because only one sample is needed to determine the status of each bit position. Using this method, a sequence of up to 16,384 samples can be stored in a single measurement. A less efficient, but still valid way to collect the data is to use an internally selected sample rate, ensuring that this rate exceeds the bit rate of the pattern. Examples of data collected this way are shown in Figure 5.

By adding a controller to the set-up, the data collected in the 5180A can be compared to the expected or ideal waveform. Figure 6 shows several patterns that were actually captured and compared with the reference waveform.

The program that produced this analysis appears on page 6. It was written for an HP9825 controller. This analysis program shifts the relative phase of the reference and actual waveforms to find the best possible fit. This is necessary since there is no way to ensure that the actual waveform will always be collected starting at the same place in the pattern. With this measurement technique, locating the faulty bit positions is easy since a position by position comparison can be made.



(a) (b)

Figure 4. Photo a shows the spectrum of the ideal reference pattern.
Photo b is the spectrum of the same pattern with rule 2 left out.

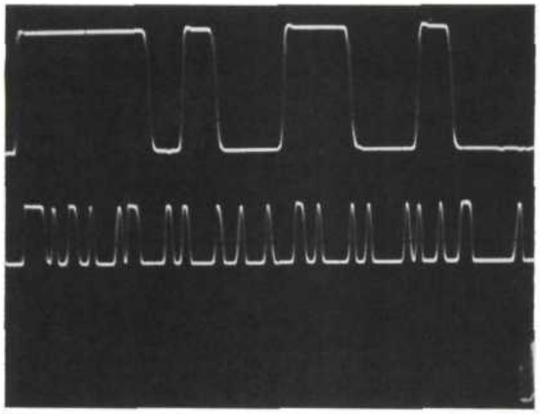


Figure 5. The reference 10.819 GHz pattern captured by the 5180A. The top waveform is a zoomed in version of the lower one. The start sequence is at the left edge.

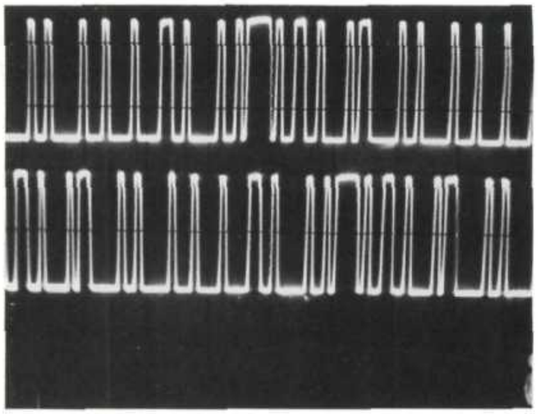


Figure 6a. The reference pattern as captured twice by the 5180A. Notice they are not in phase.

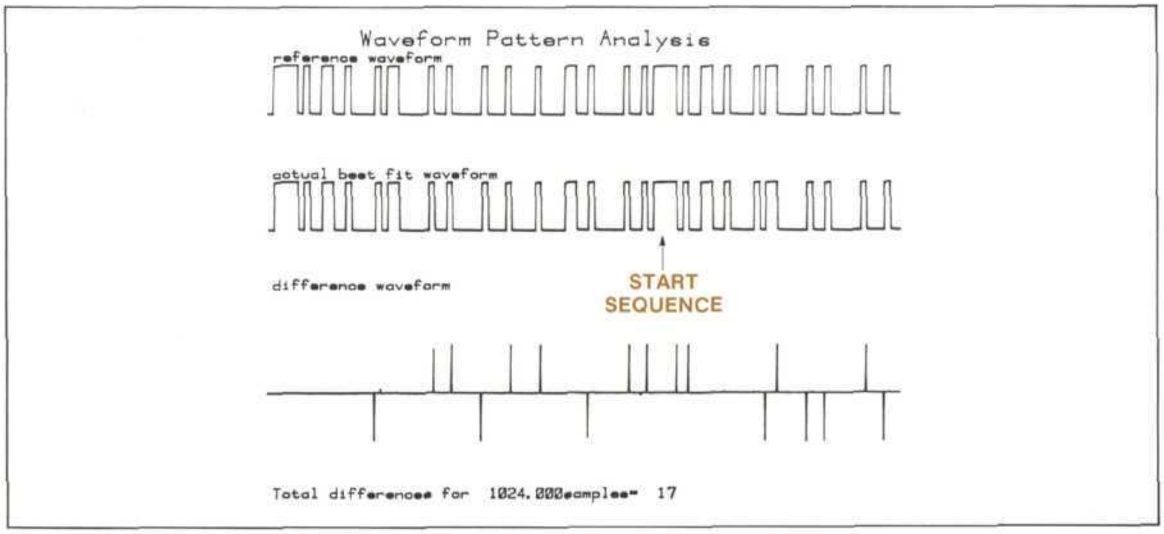


Figure 6b. The two waveforms shown in part a after analysis, using the program listed in Figure 7. The program found the best fit between the two waveforms by shifting the relative phase.

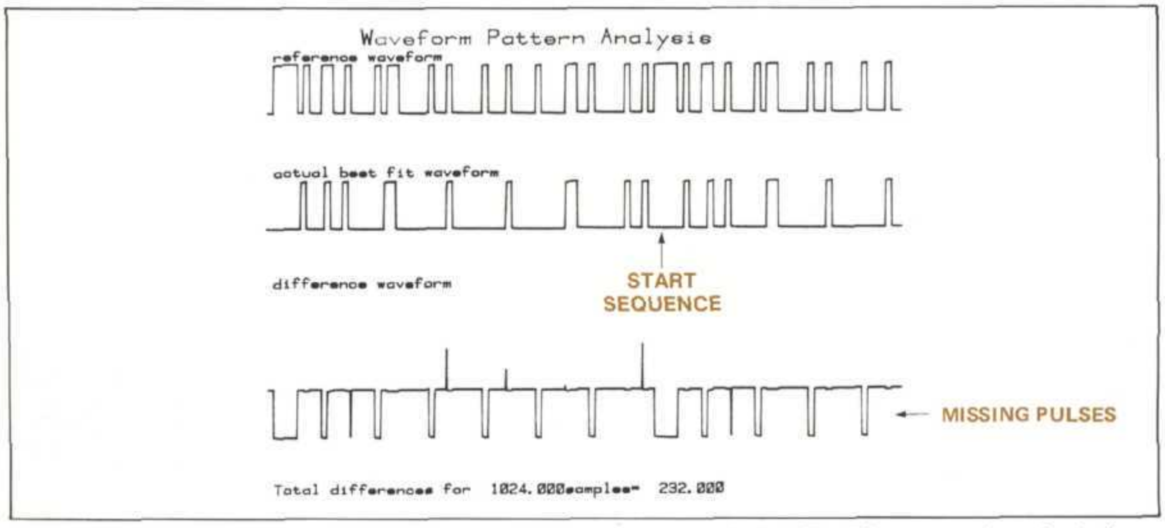


Figure 6c. Another waveform was captured that lacked the start sequence and rule 2. The difference waveform clearly shows what's missing.

```
0: 512→N          N IS THE NUMBER OF SAMPLES IN THE DATA RECORD
1: dim X[0:N-1],Y[0:N-1]
2: ent "file of good pattern",r1    DATA
3: ent "file of test pattern",r2    ENTRY
4: ldf r1,X[*];ldf r2,Y[*]
5: N→D
6: for J=0 to N-1
7: for I=0 to N-1
8: if abs(X[I]-Y[(I+J)modN])>25;C+1→C
9: next I                               THIS SECTION CONTINUALLY ADJUSTS PHASE
10: dsp "SHIFT=",J,"CORR.=",(N-C)/N     OF TWO WAVEFORMS UNTIL BEST FIT IS
11: if C<D;C→D;J→E                      DETERMINED.
12: if C=0;gto 15
13: 0→C
14: next J
15: scl 0,N-1,-1000,3800
16: plt 150,3720,1;csiz 3;lbl "Waveform Pattern Analysis"
17: plt 10,3550,1;csiz 2;lbl "reference waveform"
18: for I=0 to N-1
19: plt I,X[I]+2500
20: next I
21: pen;plt 10,2350,1;lbl "actual best fit waveform"
22: for I=0 to N-1                                          PLOTTING
23: plt I,Y[(I+E)modN]+1300                                 ROUTINES
24: next I
25: pen;plt 10,1200,1;lbl "difference waveform"
26: for I=0 to N-1
27: plt I,Y[(I+E)modN]-X[I]+130
28: next I
29: plt 10,-950,1;lbl "Total differences for ",N,"samples= ",D
30: end
*6712
```

Figure 7. Pattern Analysis Program

AMPLITUDE PROBABILITY DISTRIBUTION MEASUREMENT

The down-converted time-domain envelope data that is captured in the 5180A can easily be processed to produce amplitude versus frequency of occurrence information. Data in this form is much like a probability density of the input signal, the only difference being that instead of probability of occurrence the vertical axis is frequency of occurrence*. Figure 8 shows a simple example of the results of transforming a sinusoidally amplitude modulated microwave signal into an amplitude probability distribution.

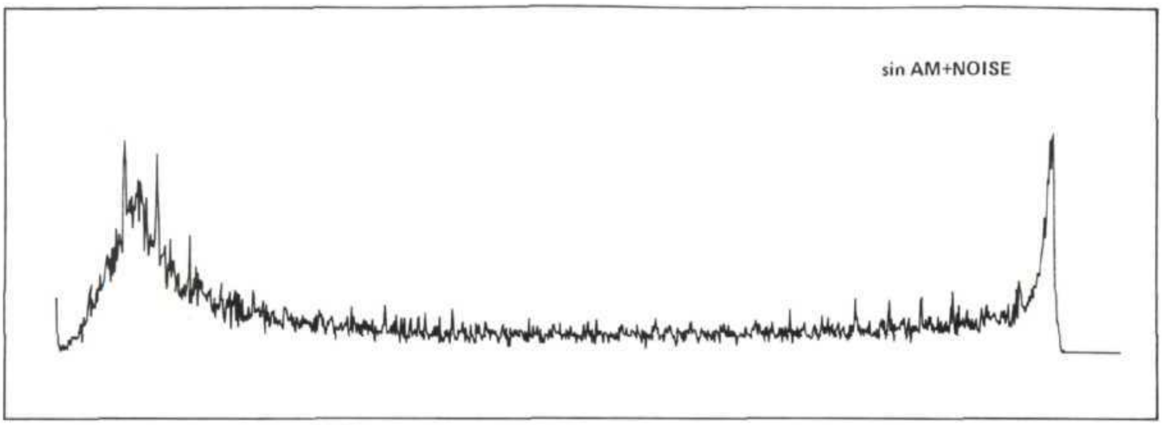


Figure 8. Amplitude probability distribution (APD) of a microwave signal amplitude modulated by a sine wave.

*The relationship between probability and frequency of occurrence is a direct proportionality:

(frequency of occurrence)/ (total samples) = probability of occurrence.

To generate an APD from 5180A data is easy — the following HP 9825 program converts the 5180A data into an APD and rewrites the processed result back into the 5180A.

APD is a useful measurement technique in many applications, a few of which are described below.

```
0: dev "5180A",704
1: dim H[0:1023]
2: wrt "5180A","OB1"
3: for I=1 to 16384
4: red "5180A",A
5: H[A]+1→H[A]
6: next I
7: wrt "5180A","LE1024,JB1"
8: for I=0 to 1023
9: wrt "5180A",H[I]
10: next I
11: end
```

COLLECT DATA. LENGTH OF LOOP DEPENDS ON 5180A RECORD LENGTH. (lines 3–6)

WRITE APD RESULT TO 5180A (lines 7–10)

Figure 9. 9825 program for generating Amplitude Probability distributions in the 5180A.

Using APD in Surveillance

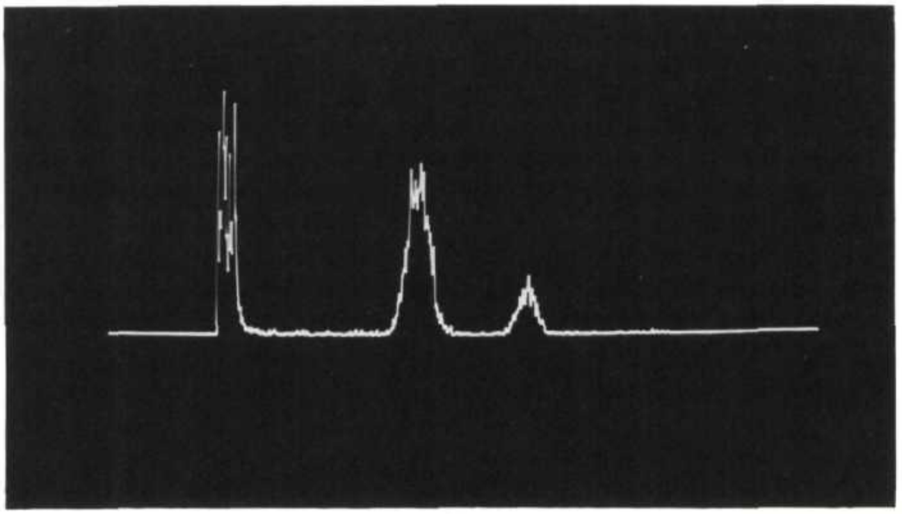
Surveillance is the business of monitoring signals of unknown composition, and is a fundamental capability of most EW and ECM systems. The objective in surveillance is to somehow extract whatever information these signals contain. This information can be in many forms: it may be a characteristic pulse pattern which identifies a certain type of radar, or it may be actual voice traffic that's been modulated onto the carrier. Either way, APD can be used to assist in the identification process.

Suppose that a signal of unknown composition has been detected and is suspected of being a voice transmission. Before the signal can be demodulated it is necessary to know what type of modulation was used in generating the transmission. APD analysis can be used to identify the modulation type, since each modulation type exhibits a characteristic amplitude probability distribution. The technique is especially useful when many signals are present simultaneously because the APD analysis will sort out the various signals, whereas the frequency or time-domain signal may be too complex for determination of the various modulation schemes. Figure 10 shows results of using APD on a multiple signal input.

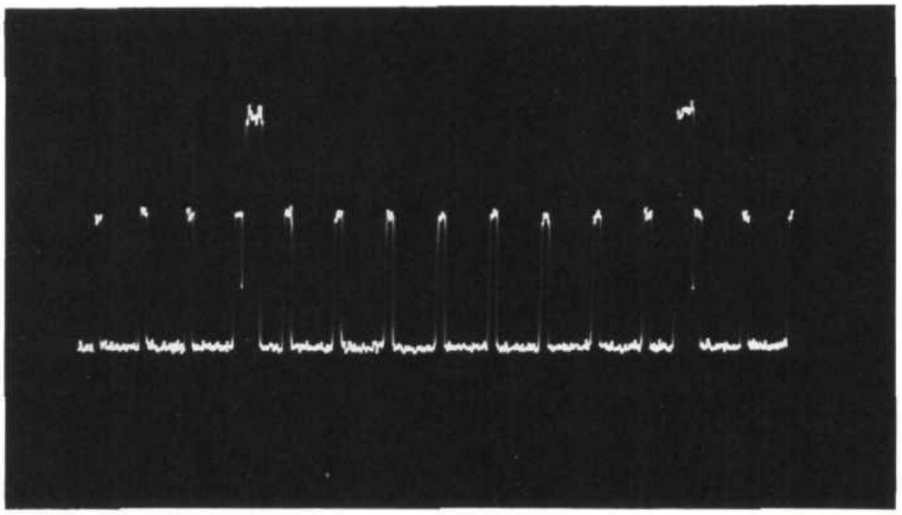
Using APD for Noise Measurement

One of the most difficult problems in RFI (radio frequency interference) and EMI (electromagnetic interference) measurement is to find a detector whose response doesn't mask the process that is being measured. For instance, a quasi-peak detector (commonly found in EMI measuring instruments) provides output that is a weighted average most sensitive to the peak voltage and small levels below the peak. Such a detector cannot be used to measure the rapidly changing amplitudes often encountered with white noise. What is needed for these measurements is a true RMS detector. The spectrum analyzer-5180A combination provides this detection capability. The data for the noise process being monitored is sampled, perhaps many records of data are collected in the 5180A, and an amplitude probability distribution is generated. In EMI and RFI noise analysis, the APD of the noise is the end goal, because the APD is a useful characterization of the noise process. Since these measurements are usually specified at some frequency with a particular bandwidth, the spectrum analyzers variable resolution bandwidth is used for properly controlling the measurement bandwidth, thus assuring that the waveform recorder is capturing the proper signals.

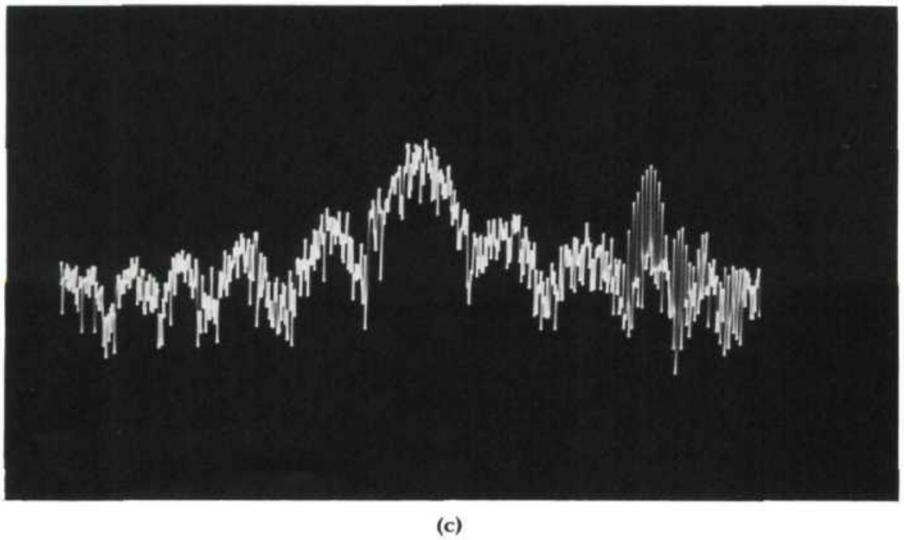
If the noise process being monitored is broadband, a wide dynamic range measurement may be required, since broadband noise is usually characterized by a continuous low level occasionally punctuated by strong noise bursts. For example, atmospheric noise typically exhibits amplitude variations as large as 90 dB. Since spectrum analyzers such as the 8566A and 8568A can provide displayed dynamic ranges of 90 dB (when LOG 10 dB/div display mode is selected), the spectrum analyzer-5180A is ideal for broadband noise monitoring. This 90 dB display range from the spectrum analyzer is mapped onto the 1024 vertical steps (60 dB dynamic range) of the 5180A. Thus, the resolution of the data captured by the 5180A will be 90 dB/1024 vertical steps ~ .1 dB/vertical step.



(a)



(b)



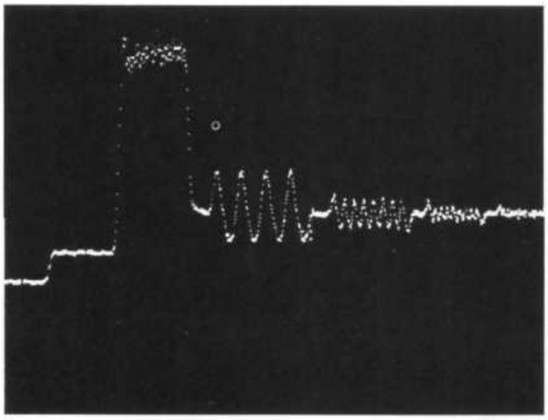
(c)

Figure 10. Two Pulsed RF signals (carrier frequency near 16 GHz) existing simultaneously generated the APD of 10a. 10b shows the captured time domain envelope of the signals (note different duty cycles and pulse widths). 10c shows the spectrum. With more complex modulations, the time and frequency domain views may not be useful, while the APD will exhibit a modulation-dependent shape.

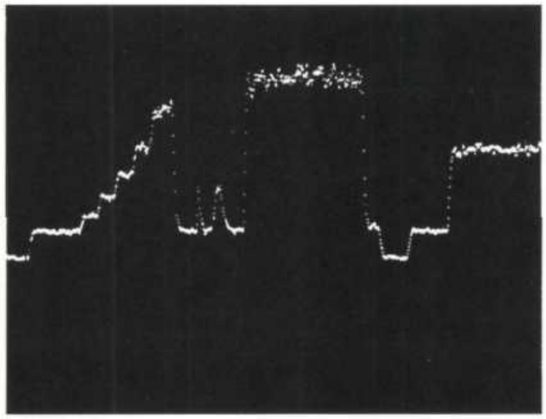
COMMUNICATIONS

A time-domain version of almost any communications signal can be captured and analyzed using the spectrum analyzer-waveform recorder combination. The only restrictions when using the video output interconnection from the spectrum analyzer are that the video will see amplitude variations only (so it can't be used to detect FM — see section on using the IF interconnection) and the bandwidth of the communications signal must not exceed 3 MHz, since this is the maximum bandwidth that the 8565A Spectrum Analyzer can pass.

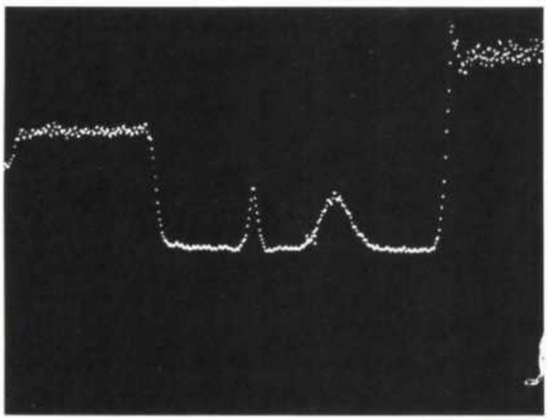
A familiar and illustrative example of capturing communications signals is provided by television broadcast signals. With the 8565A in zero-span, the filter center frequency was centered on the video portion of the transmission from a local UHF channel. Several examples of waveforms captured from this signal are shown in Figure 11.



(a)



(b)



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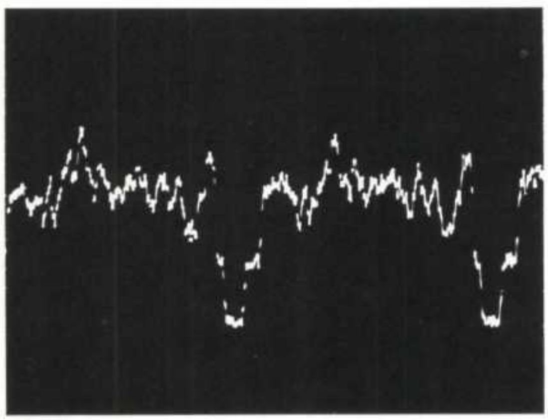


(d)

Figure 11. Photos a and b show test signals transmitted between frames. Photo c is a zoomed version of b. Photo d shows two lines of the actual picture.

RADAR

Since radar systems are one of the most common sources of microwave energy, it is no surprise that there are applications for the spectrum analyzer-5180A combination in this area. For pulse measurements, the maximum resolution bandwidth should be chosen on the spectrum analyzer to allow the best possible reconstruction of the original pulse. Using the 3 MHz resolution bandwidth on the 8565A Spectrum Analyzer, pulses having widths as short as 500 nanoseconds can be accurately captured. This value of pulse width is also a good minimum for the 5180A Waveform Recorder, since the 5180A's maximum sample rate of 50 nanoseconds per sample would obtain 10 samples during the pulse, which is a practical minimum for good visual reconstruction of the demodulated pulse.

A benefit of using the 5180A to capture the pulses is that, once armed, the 5180A will capture any signal that appears. A single RF burst can be captured just as well as a repeating pulse train. Thus, signals that suddenly appear for short duration will not be lost by the 5180A. Examples of captured pulse waveforms are shown in Figure 12.

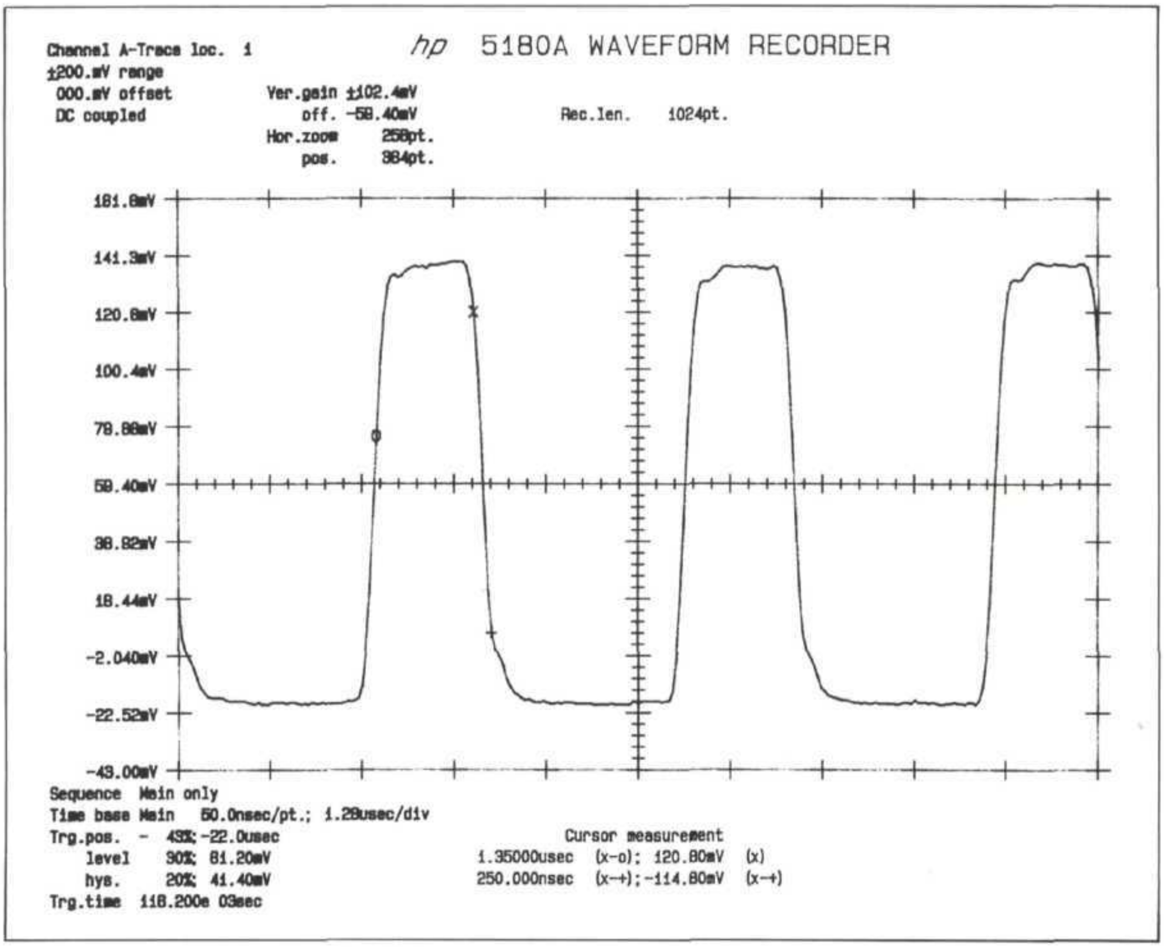


Figure 12a. Pulse Train captured using HP 5180A waveform recorder.

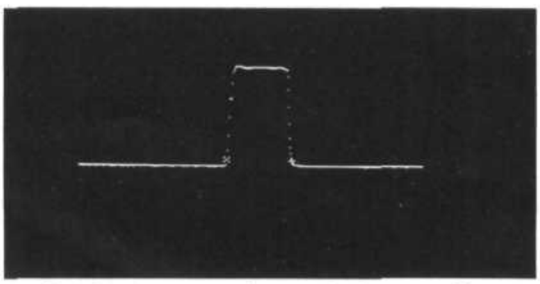


Figure 12b. A single microwave pulse completely captured by using the 5180A's pre-trigger capability. Only one pulse was generated.

Another measurement that is useful on Moving Target Indication (MTI) Radar Systems is pulse to pulse amplitude jitter. Amplitude jitter is one term in the MTI improvement factor (the improvement factor is an indication of a given MTI system's capability to detect a moving target return from a high level of stationary clutter (noise return) and has a 20 log ($A/\Delta A$) effect on this factor, where A is the pulse amplitude and ΔA is the pulse to pulse (interpulse) amplitude change). Typical MTI requirements for amplitude jitter call for jitter no worse than 40 to 50 dB. The 5180A Waveform Recorder can resolve amplitude to better than 60 dB (0.1%), so it can make the amplitude jitter measurement.

USE THE QUANTIZED DATA TO COMPUTE TRUE RMS VALUES

Although this is a general capability of the 5180A in any measurement application, the 5180A can be used with a spectrum analyzer to provide true RMS detection capability on microwave signals. This is true because the 5180A captures a point-by-point copy of the detected input signal. After outputting the captured data to a controller, the samples may be converted to power, a mean value computed, and the square root taken. The result will be a *true* RMS measurement. Such measurements are especially useful on signals having unknown statistical properties, since filters that can be made to correct for *known* statistical characteristics are not applicable to these signals.

Applications (Using the IF Interconnection)

It might seem that there is no point in capturing an IF from the 8565A Spectrum Analyzer in the 5180A since the IF center frequency is 21.4 MHz and the 5180A's maximum sample rate is 20 MHz. On the surface, it appears that aliasing of the sampled IF signal will cause the 5180A data record to be completely meaningless. The reason why this is untrue is explained in the following discussion on sampling theory.

REQUIREMENTS FOR COMPLETE SAMPLING OF ANY INPUT SIGNAL

Although it is often written that the sample rate required to recover the information from a given input is $f_s > 2 \bullet f_{max}$ (f_s is the sample rate, f_{max} is the highest frequency component in the input), this inequality is not as general as possible. The general expression, though less simple, leads to a very interesting result. In order to completely recover any input signal from the sampled input data the minimum required sample rate is

$$f_{s(min)} > \frac{2 \bullet f_{max}}{\text{Integer part of } [f_{max}/(f_{max} - f_{min})]}$$

This expression degenerates into the less general form when $f_{min} = 0$. In words, this general expression says that it may be possible to completely recover a bandlimited signal with a sample frequency smaller than any frequency in the input signal!

A perfect application for making use of this concept is provided by the 21.4 MHz IF from the spectrum analyzer. The bandwidth of this IF is determined by the resolution bandwidth setting. Choosing the widest possible bandwidth (3 MHz), the minimum sample rate for complete recovery of the IF is

$$\frac{2 \bullet 22.9}{\text{Integer } [22.9/(22.9\text{-}19.9)]} = \frac{45.8}{7} = 6.5429 \text{ MHz}$$

Figure 13 shows the relationship between the input signal (the IF in this case), the sample rate (and its harmonics), and the sampled version of the input.

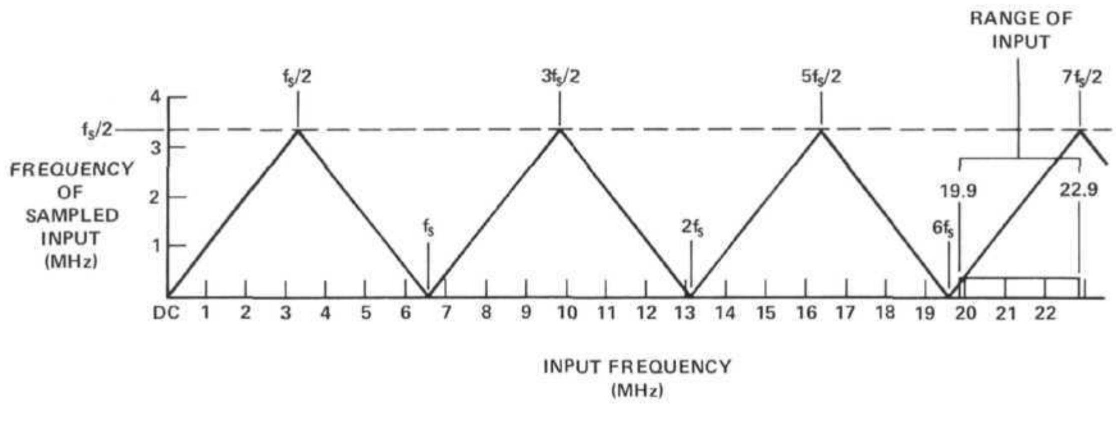
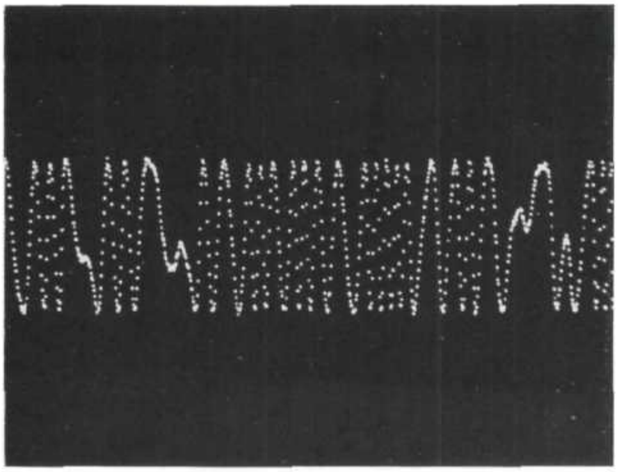


Figure 13. The relationship between the sample rate (f_S) and its harmonics, the input signal (19.9-22.9 MHz), and the sampled input (always in the DC-f_S /2 range). In this example f_S = 6.5429 MHz, the minimum sample rate for complete signal recovery.

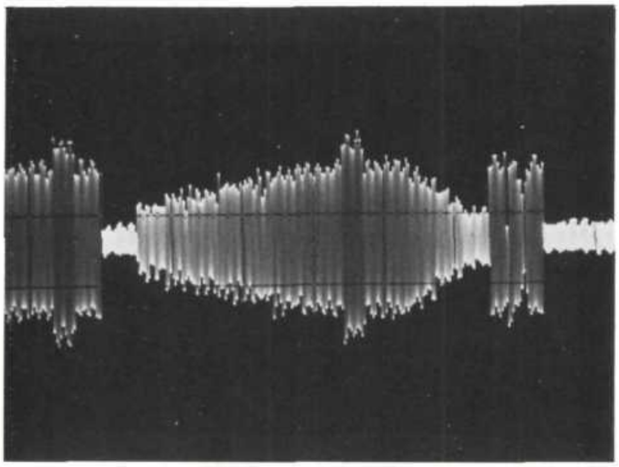
This figure illustrates the requirements for completely recovering the input: not only must the sample rate exceed twice the bandwidth of the input signal (6 MHz in this case), it must also be positioned so that no harmonic of $f_S/2$ falls on any part of the input signal. If a harmonic did fall within the range of the input signal there would be some pairs of input frequencies that would have the same apparent frequency after sampling, and the input could not be recovered. This problem with sample rate harmonics is taken into account by the general expression for minimum required sample rate. There are many other sample rates above 6.5429 MHz that could be used for complete signal recovery, 6.5429 MHz is simply the lowest sample rate that will work. The 5180A can accept an external input as a sample clock, so an odd sample rate such as 6.5429 MHz can be achieved by using a synthesizer as the external sample driver.

WHY CAPTURE THE IF?

Unlike the detected video output on the 8565A Spectrum Analyzer, which demodulates AM only, the IF contains all of the modulation that is on the input signal. Thus, there may be information on the IF that is lost in the detected video output. By capturing the IF from an input of unknown modulation there is no danger of losing information. Returning to the television broadcast signal example, it now becomes possible to extract the audio portion of the transmission by centering the analyzer filter at the appropriate frequency. Since this part of the transmission requires far less bandwidth than the visual transmission, we can take advantage of the variable bandwidth capability of the spectrum analyzer and reduce the filter resolution bandwidth to 100 KHz (plenty of bandwidth for an audio transmission). By reducing the bandwidth, the chance of capturing unwanted portions of the transmission is reduced. The captured IF of the audio transmission is shown in Figure 14. Had this same signal been captured using the video interconnection, the result would have been only a DC level, since the signal isn't amplitude modulated. The other photograph in Figure 14 is the captured IF of the visual portion of the transmission. This signal contains the same information as the captured video output of Figure 11 —the information is just in a different form (the visual portion of the transmission is amplitude modulated).



(a)



(b)

Figure 14. Photo a shows FM on the audio portion of UHF television transmission.
Photo b shows the IF of a portion of the video transmission.

Conclusion

The applications cited in this note don't begin to exhaust the measurement uses for the spectrum analyzer — 5180A Waveform Recorder combination. As has been shown, the remarkable frequency and time-domain capabilities that are brought together by these two instruments can be used to provide solutions to a wide range of measurement problems.

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