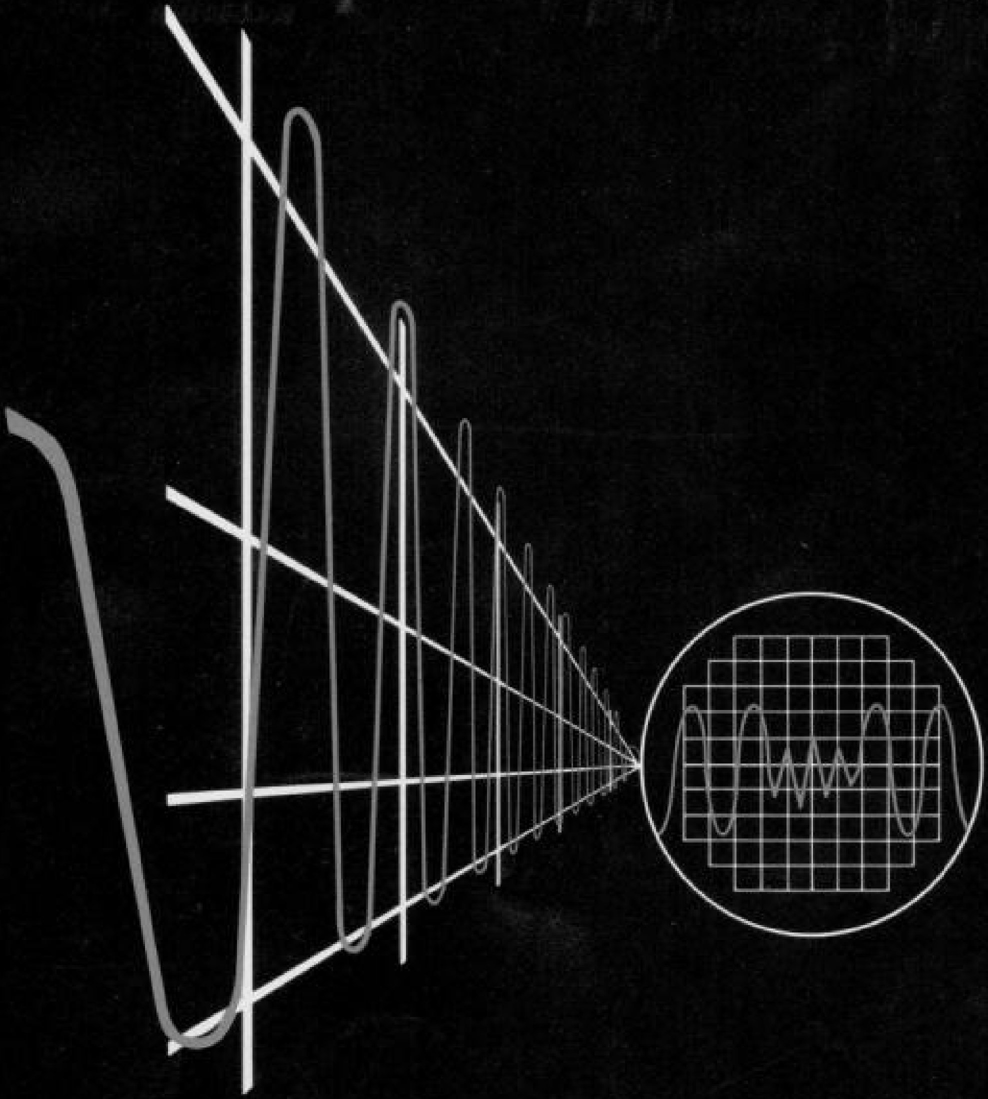
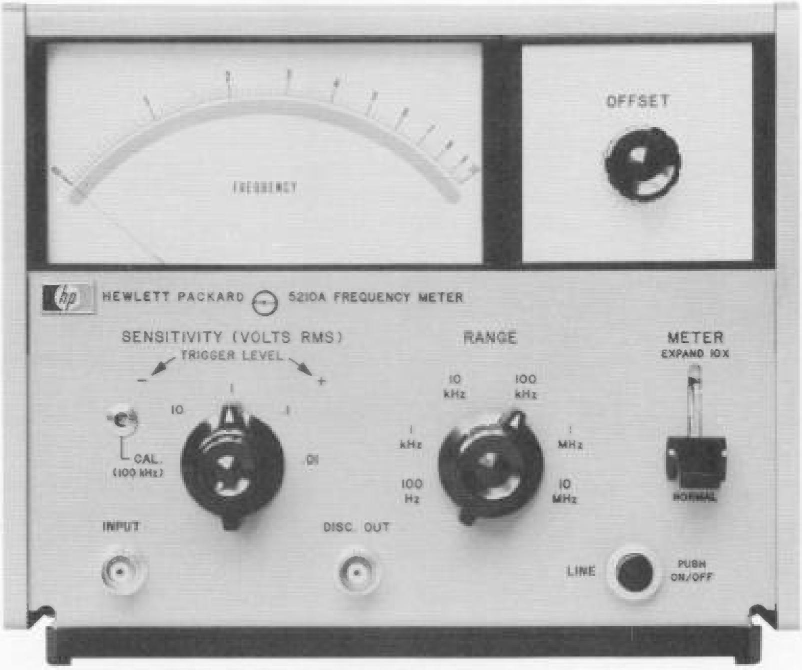


FM AND PM MEASUREMENTS

HP 5210A/B
APPLICATION NOTE 87

FM AND PM MEASUREMENTS

APPLICATION NOTE 87



MODEL 5210A

FREQUENCY & TIME DIVISION

HEWLETT hp PACKARD

PALO ALTO, CALIFORNIA

02404-1

W125

APRIL 1967

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SECTION I

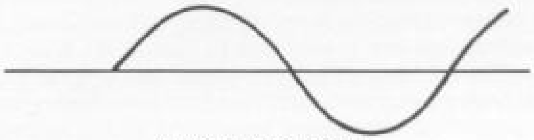
GENERAL INFORMATION

INTRODUCTION

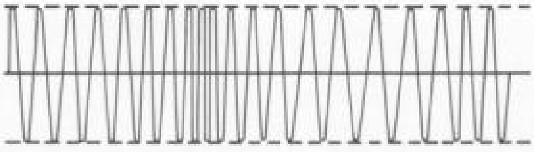
This application note illustrates a number of applications, in particular FM measurements, that have been made possible by the HP 5210A Frequency Meter/FM Discriminator. Typical examples of the applications will be illustrated with complete block diagrams of set-ups and photographs of oscilloscope displays.

GENERAL FM AND PM INFORMATION

Before we start on the actual applications it will be useful to recapitulate some of the basics of frequency modulation (FM) and phase modulation (PM).* See Figure 1.



(a) MODULATING SIGNAL



(b) FREQUENCY MODULATED SIGNAL

Fig. 1. Frequency modulation

Both phase and frequency modulation are special cases of angle modulation. Generally angle modulation can be expressed as an a-c wave

$$e = A \sin \theta(t) \qquad (1)$$

and

$$\omega_i = \frac{d\theta}{dt} \qquad (2)$$

where $\theta(t)$ is made to vary in some manner with a modulating signal $e_m(t)$; $\omega_i = 2\pi f_i$ = instantaneous angular velocity and f_i = instantaneous frequency.

If the phase $\theta(t)$ varies linearly with the modulating signal, we are talking of phase modulation. In the special case where the modulating signal is a sine wave,

$$e_m = a \sin \omega_m t \qquad (3)$$

we have the expression:

$$e = A \sin \left\{ \omega_c t + m_p \sin \omega_m t \right\} \qquad (4)$$

where $\omega_c = 2\pi f_c$ = angular velocity of the carrier, $\omega_m = 2\pi f_m$ = angular velocity of the modulating signal, and $m_p = \Delta\theta$ = modulation index or phase deviation. It is characteristic for a PM signal that the phase deviation be proportional to the peak amplitude of the modulating signal.

If the instantaneous frequency as defined in equation (2) varies linearly with the modulating signal, we are talking of frequency modulation. If the modulating signal is a sine wave we have:

$$e = A \sin \left\{ \omega_c t + \frac{2\pi \Delta f}{\omega_m} \sin \omega_m t \right\} \qquad (5)$$

where Δf = frequency deviation and $\frac{2\pi \Delta f}{\omega_m} = \frac{\Delta f}{f_m} = m_f$ the modulation index (in some literature called β).

It is characteristic for an FM signal that the frequency deviation be proportional to the peak amplitude of the modulating signal and independent of the modulating frequency.

Equations (4) and (5) show that for a sinusoidal modulation FM and PM are the same with the exception that the modulation index $m_p = \Delta\theta$ is constant in case of PM and $m_f = \frac{\Delta f}{f_m}$ varies inversely with f_m in case of FM.

It is useful to remember that the rate of variation about the carrier frequency is called the modulation frequency and the amount the signal varies away from the carrier is called the frequency deviation. The carrier frequency is the long term average value of the instantaneous frequency.

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*For more details on this subject see for example Terman: Electronic and Radio Engineering, 4th edition, Chapter 17, pg. 586-595, McGraw-Hill, 1955.

SECTION II

THE HP 5210A/B FREQUENCY METER/FM DISCRIMINATOR

FEATURES AND BENEFITS

The HP Model 5210A Frequency Meter/FM Discriminator is an analog instrument that directly measures frequency and repetition rate of signals from 3 Hz to 10 MHz. The reading is independent of input voltage waveforms. Measurement of noisy signals is facilitated by a calibrated sensitivity control, which can be set to discriminate against signals below given levels. A trigger level control will vary the trigger level for measurements of signals with asymmetrical components. A special log linear scale permits accurate 1% readings between 10% and 100% of full scale. With the calibrated offset (Option 01) the effective accuracy is up to 0. 2% of full scale range.

The 5210A is also a wideband highly linear FM discriminator (typical 0.025%) with a 1 MHz output bandwidth, excellent for precise measurements on FM and PM signals. With use of a series of accessory filters (HP 10531A) on the discriminator output the following measurements are made possible; frequency deviation, modulation index, frequency response, distortion, incidental FM, FM noise, "wow" and "flutter", all to better than 100 dB below carrier frequency. Recorder outputs both of the potentiometric and the galvanometric type are provided.

In table 1 is shown a summary of features and benefits of the 5210A/B.

MEASUREMENTS POSSIBLE WITH THE 5210A

With the introduction of the 5210A/B the following basic measurements have been made possible: direct, analog, frequency measurements up to 10 MHz; measurements on FM and PM signals with carrier up to 10 MHz and modulating frequencies up to 1 MHz; and frequency and phase deviations as small as parts in 10^5. These measurements are made practical by the highly linear, wideband FM Discriminator and the HP 10531A Filter Kit, a set of plug-in discriminator output filters.

The photographs of Figures 2 and 3 give a good idea of the operation of the discriminator. The top trace of Figure 2 shows portions of a sawtooth swept signal. The lower trace shows the unfiltered discriminator output, namely constant area pulses synchronous with every second input cycle. Figure 3 shows the discriminator output with a 1. 5 kHz low-pass filter plugged in the 5210A. Note that the sweep speed on the slope is 20 times slower than on Figure 2. The carrier components (half the input frequency) in the

Table 1

FEATURES	BENEFITS
Expanded scale	Increased resolution and accuracy
FM discriminator with 0. 025% linearity (typical) and 1 MHz bandwidth	Precise measurements of FM and PM signals
Calibrated offset (Option 01)	Increased resolution, measuring speed and accuracy
Plug-in discriminator output filters (HP 10531A Filter Kit)	Suppresses carrier frequencies, thus enabling measurements of deviation as small as 1 part in 10^5
3 Recorder outputs, galvanometric, 10 mV and 100 mV potentiometric	Permanent records, monitoring
Internal crystal calibration with 0. 01% accuracy	High accuracy independent of line frequency with high degree of repeatability
5210B Tachometer calibrated directly in r/min	Convenient for tachometry
Log-linear meter scale	Resolution from 10% to full scale is approximately equal to accuracy, which is 1% of reading, not of full scale
Solid state design	Reliability, ruggedness, compactness, light weight and wide temperature range
MOSFET input	Wide dynamic input range; high input impedance

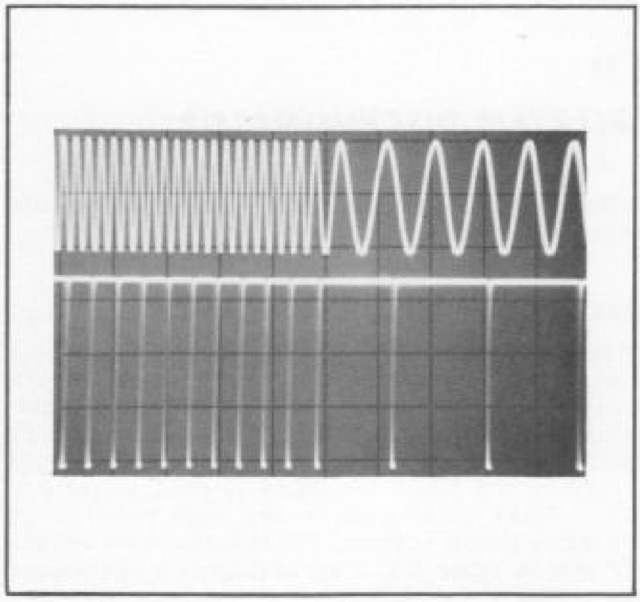

Fig. 2. Input to 5210A (upper trace), and unfiltered discriminator output. Scale: 1V/cm and .1 ms/cm. Sweep: 10 - 30 kHz, rate 100 Hz, sawtooth.

unfiltered output are completely suppressed. The selection of the cutoff frequency for the low-pass filter determines the attenuation of the carrier frequency components (see Figures 4 and 5). The user can select either maximum flat amplitude response (Butterworth filter) or maximum flat delay response (Bessel filter) merely by changing eight resistor values in the small resistor board that plugs into the filter board. Resistor values for the two types of filters are given in comprehensive table form in the Operating and Service Manual accompanying each 5210A/B.

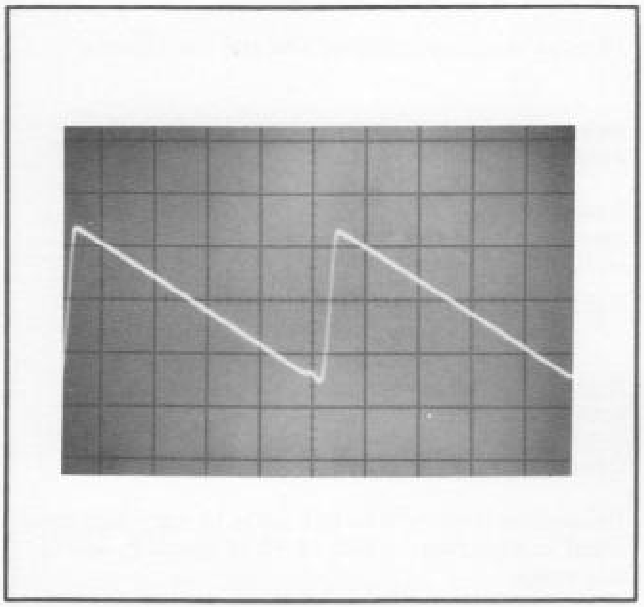

Fig. 3. Filtered discriminator output. Scale: .1 V/cm and 2 ms/cm. Low pass cutoff, f_{co} = 1500 Hz.

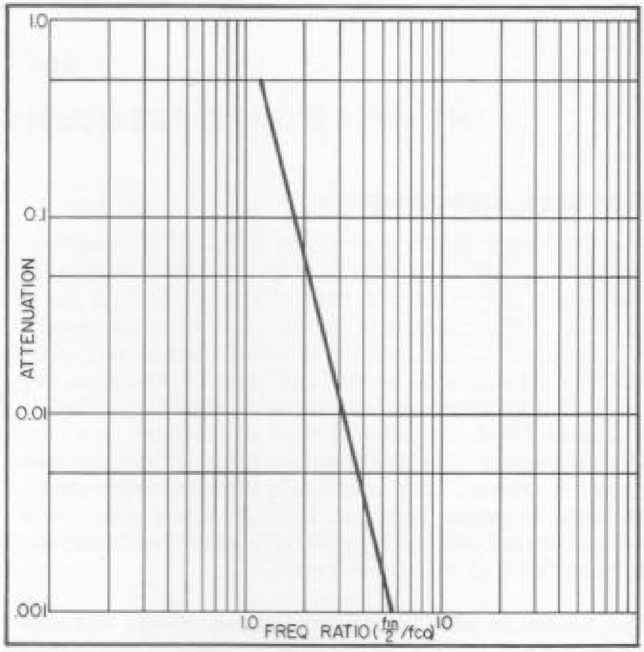

Fig. 4. Attenuation of carrier ripple vs carrier ripple frequency/filter cutoff frequency.

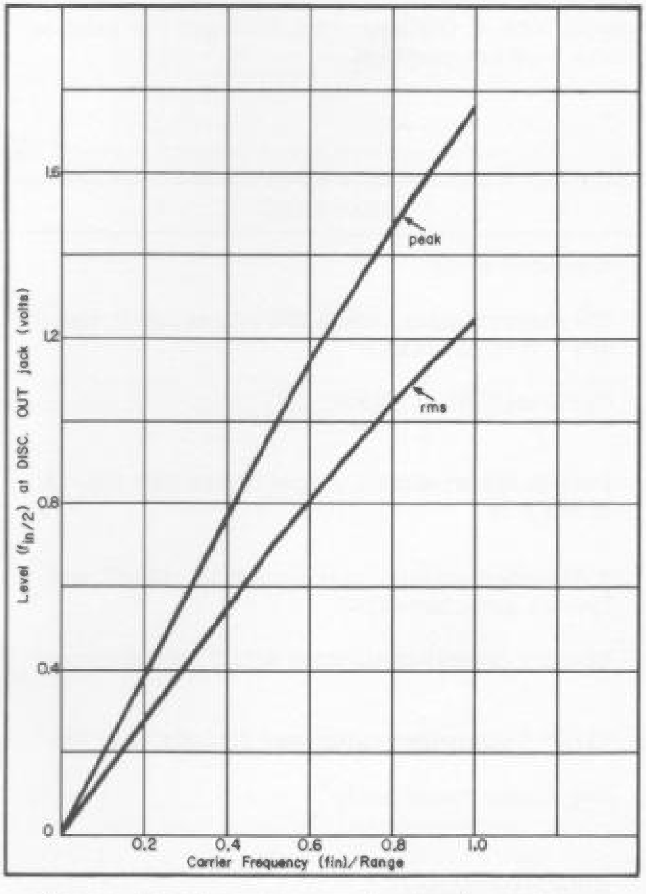

Fig. 5. Discriminator carrier level output vs input frequency/full scale frequency.

SECTION III

APPLICATIONS

Since essentially all the measurements using the discriminator have the purpose of determining deviation and the modulating frequency of an FM signal, we will in all the measurements use low pass filters from the HP 10531A Filter Kit. Let us start with a case where we have a signal that has intentionally been frequency modulated.

DIRECT FM

Before using the 5210A, the discriminator output has to be calibrated. This is done by means of the internal crystal calibrator and a dc voltmeter. (The very simple procedure is described in the Operating and Service Manual.)

The simplest case of FM measurements is when the carrier frequency is 10 MHz or lower. The basic setup is shown in Figure 6. Since the carrier frequency is readily within the frequency range of 5210A, the setup becomes very simple. The FM signal is fed directly to the input. The filtered discriminator output V_d will now be a replica of the modulating signal. The frequency deviation Δf is calculated from the following expression.

$$V_d = \frac{\Delta f}{\text{full scale frequency}} \times 1V$$

If V_d is measured peak-to-peak, Δf will be peak-peak value. The modulating frequency can be seen directly on the scope or, if a detailed analysis is required, a wave analyzer like the HP 302A can be used.

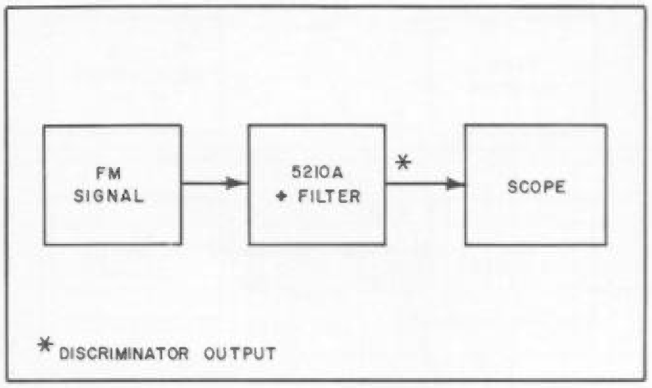

Fig. 6. Direct FM demodulation

DOWN CONVERTED FM

For carrier frequencies above 10 MHz the 5210A FM Discriminator cannot be used directly. However, there are two ways to bring the carrier frequency within the range of the 5210A. One is by down conversion, which requires a mixer and a local oscillator, another is by scaling or frequency division as described under FM Microwave Demodulation on page 8 . A setup is shown in Figure 7, making use of the HP Model 10514A balanced mixer and a HP Model 3200B VHF Oscillator as local oscillator.

The setup is based on the fact that a frequency conversion does not change the information present in the signal in form of frequency modulation (or phase modulation). This means that frequency deviation and modulating frequency remains unchanged by the frequency conversion, only the carrier frequency is changed. (This is true, providing there is no FM present in the local oscillator. Any FM on the local oscillator will appear in the converted output as well as the FM to be measured.)

Let us illustrate what is happening during down conversion with an example. Assume a 100 MHz carrier with 1% peak deviation, i. e., 1 MHz peak at a 10 kHz rate. By mixing the signal with a 95 MHz stable local oscillator a difference frequency of 5 MHz can be extracted from the mixer. Since the FM information is unchanged by the down conversion, we still have a 1 MHz peak deviation at a 10 kHz rate. Considering that our carrier is now 5 MHz we have now a 20% peak deviation. In other words, the effective sensitivity of the deviation measurement has been increased by a factor of 20. This is particularly desirable where the frequency deviations are small. There are limits, though, to the increase in effective sensitivity. The carrier frequency f_c must be larger than Δf peak.

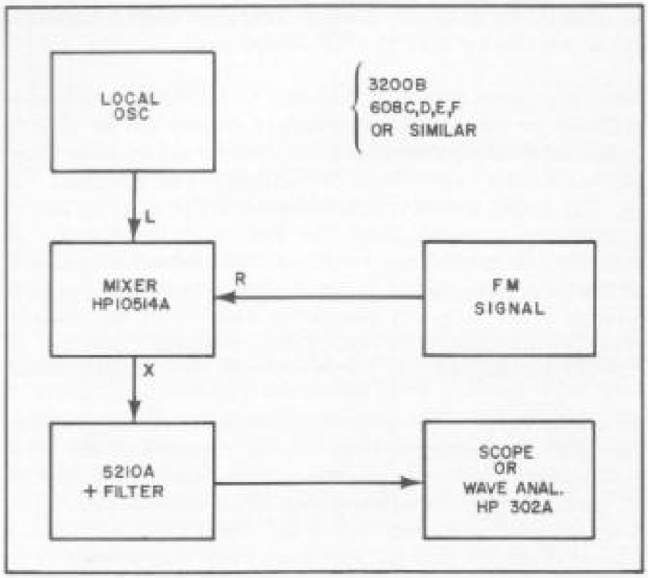

Fig. 7. Down converted FM demodulation

$$f_c > \Delta f \text{ peak}, \qquad (1)$$

this is an absolute limit.

The 5210A and the output filters will impose further limits on our signals: the maximum instantaneous frequency, $f_c + \Delta f$ peak should not exceed full scale frequency on the 5210A. However 120% of full scale frequency is useable without significant deterioration of performance (linearity) of the 5210A.

The cutoff frequency, f_{co} of the output filter, will impose further limits on the lowest value of the instantaneous frequency, depending on the amount of carrier ripple that can be tolerated on the discriminator output. Let us look at our example again. With a 10 kHz discriminator output bandwidth we could use a 10 kHz low pass filter. For at least 56 dB (see Figure 4) attenuation of the fundamental carrier component (1/2 of input frequency) the lowest value of the instantaneous input frequency must be at least 10 times f_{co} (fin/2 at least 5 times f_{co}) or

$$\frac{f}{f_{co}} \geq 10 \quad (2) \qquad \text{or} \qquad f \geq 10\, f_{co} \quad (3)$$

Since the lowest value of f is $f_c - \Delta f$ peak we have

$$f_c - \Delta f \text{ peak} \geq 10\, f_{co} = 100 \text{ kHz} \quad (4)$$

In our example $f_c = 5$ MHz; from (4) we now get

$$\underline{\Delta f \text{ peak}} \leq f_c - 10 f_{co} = 5 \text{ MHz} - 100 \text{ kHz} = \underline{4.9 \text{ MHz}} \quad (5)$$

From the above we can see that in case of large deviations it is desirable to have f_c equal to approximately half full scale frequency. This is very easy to obtain in case of down conversion with a tuneable local oscillator like the HP 3200B.

The fact that any FM present in the local oscillator will occur in a down converted signal gives rise to some additional considerations when measuring incidental FM or very small deviations. The residual FM on the local oscillator should be at least an order of magnitude smaller than the FM to be measured. In addition it should be realized that measurements of frequency deviations of less than 1 part in 10^5 at the 5210A input (i. e. at the down converted signal frequency) become difficult since residual noise of the 5210A will begin to interfere with the measurement.

One way to diminish this problem is to reduce the difference frequency between the FM signal and the local oscillator, considering the above mentioned limits. If this is done, the low-pass filter cut-off frequency will have to be reduced as well, which in turn reduces the maximum modulation frequency component to be measured.

Thus any FM system can readily be evaluated with regards to frequency response and, if a wave analyzer is used on the discriminator output, with regards to distortion.

MEASUREMENTS OF SMALL DEVIATIONS

There are various forms of small deviation measurements which are of interest, such as incidental FM. With reference to signal generators, incidental FM is often referred to as the FM occuring as result of amplitude modulation of the signal. In addition the amount of FM present in CW mode is often referred to as residual FM.

Another form of incidental FM is "wow and flutter" in tape transports. The following paragraphs will go into detail on the measurement of incidental FM.

FLUTTER MEASUREMENTS

With audio equipment flutter and wow is usually measured with a 3 kHz carrier and in a 200 Hz bandwidth, from .5 Hz to 200 Hz. * The setup for this measurement is shown in Figure 8a and b. On Figure 8a a 3 kHz tone is recorded on the tape recorder. It is necessary that the frequency is stable, at least an order of magnitude better than the flutter and wow to be measured. HP types 204A, 651A/B oscillators, 3300A Function Generators or 5102A Synthesizer or equivalent stable signal sources are suitable. ** Figure 8b shows the actual flutter measurement. The 3 kHz tone is played back and fed into the 5210A, which has a 200 Hz filter in the discriminator output. If a voltmeter or wave analyzer is used on the output, the filter should be a Butterworth type (maximum flat amplitude response). If a high sensitivity oscilloscope is used, the filter should be a Bessel type (maximum flat delay response).

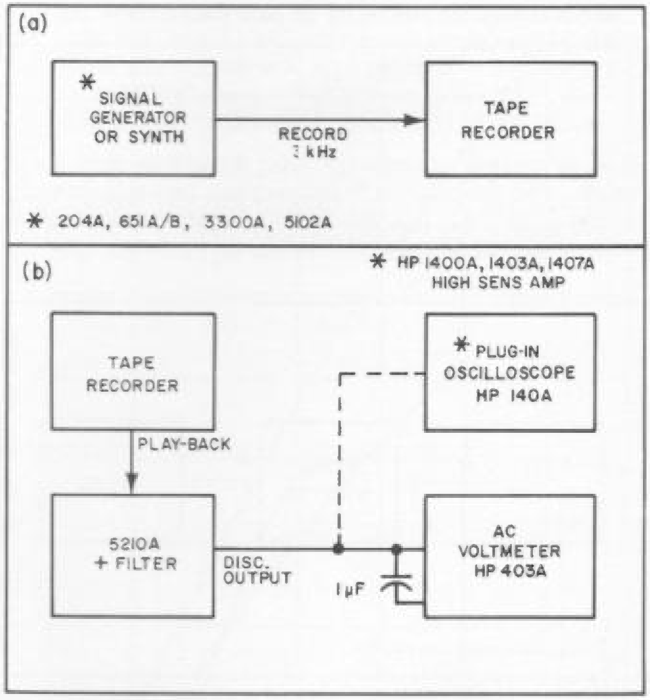

Fig. 8. Flutter measurement

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*See NAB Standard Magnetic Tape Recording and Reproducing (Reel to Reel), April 1965, or IRE Standards on Sound Recording and Reproducing, Methods for Determining Flutter Contact, 1953.

**Another possibility is to use flutter test tapes such as Ampex Flutter Test Tapes 31316-01 (15 ips, 1/4 inch tape) or 31326-01 (7.5 ips, 1/4 inch tape). This will give a measurement of play-back flutter only.

The filtered discriminator output is a measure of the flutter and wow. It can either be observed on a high sensitivity scope like the HP 140A with a 1400A (100 μV/cm), 1407A (50 μV/cm) or 1403A (10 μV/cm), plug-in vertical amplifier, a low frequency responding voltmeter such as the HP 403A (1 mV full scale) or a wave analyzer.

To evaluate the filter performance and the amount of carrier ripple that can be tolerated, let us assume we want to measure 0.1% rms flutter.

With 3 Hz rms deviation (0.1% of 3 kHz) the 5210A will be on the 10 kHz range. A deviation of 3 Hz rms corresponds to(3/10,000) · 1V = .3 mV rms on the discriminator output.

The "no input" noise on the discriminator output is typically < 40 μV rms with the 200 Hz filter (measured with a HP 400F Voltmeter). The output filter will roll off with 24 dB/octave and reach a maximum attenuation of better than 60 dB. This will result in a carrier ripple comparable to the noise. To insure that the carrier ripple is negligible the discriminator output is filtered with an additional 1 μF which will add another 6 dB/octave with a 3 dB point at ~ 270 Hz (the filtered discriminator output has a constant 600 ohm output impedance). The resultant filter curve is shown on Figure 9. The lower frequency cut-off is determined by the load on the discriminator output since it is ac coupled with 100 μF and 600 ohm output impedance. In this case, the load is the 403A, i.e., 2MΩ. This will give a lower cut-off of less than 0.1 Hz, which is lower than the voltmeter (1 Hz).

With carrier ripple and noise < 40 μV (checked with 3 kHz from oscillator directly into the 5210A), we can now make a meaningful measurement of 0.1% rms flutter. The measured rms value will be (rms addition):

$$\sqrt{0.3^2 + 0.04^2} \cong .302 \quad \text{or}$$

an error of < 1%. Considering that the meter is moving constantly due to the random character of flutter, this is a fully satisfactory result. One word of caution should be given here: the voltmeter can only tell the rms value of flutter in the passband of the filter. It gives no information about the components of the flutter. A fast way to get this information is to take a scope-picture of the flutter. This is done in Figure 10 (peak-peak flutter is approximately 0.8%). This picture shows that in the flutter from this machine there is a large component of approximately 8 Hz, probably stemming from a drive gear. This observation is confirmed by a measurement with a wave analyzer. On the 403A voltmeter the average flutter reading was approximately 0.22% rms.

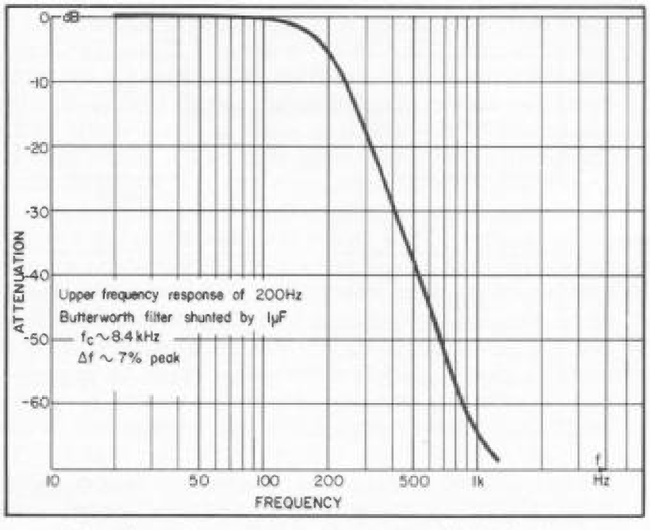

Fig. 9. Frequency response of 200 Hz low pass filter shunted by 1 μF.

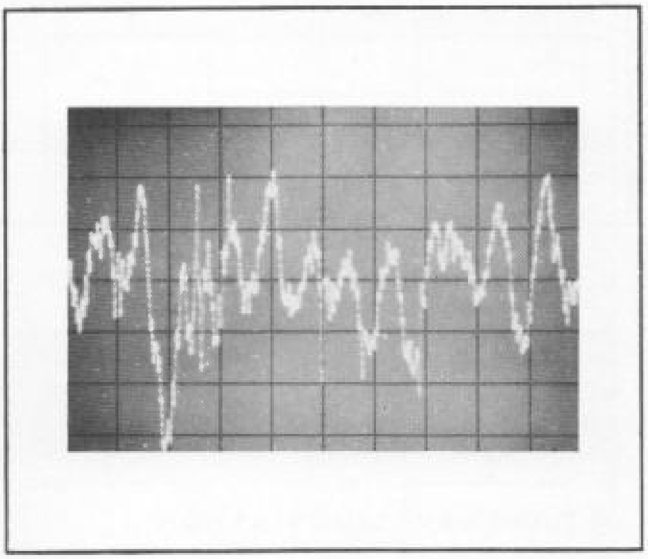

Fig. 10. Actual flutter on a battery-operated tape recorder. Scale: 1 mV or .3% p-p flutter/cm and .1 s/cm.

INCIDENTAL FM ON SIGNAL GENERATORS

The measurement of incidental and residual FM is in principle identical to the measurement of flutter and wow, inasmuch as the deviations to be measured are very small. For generator (carrier) frequencies of 10 MHz and less, the setup is shown in Figure 11; the high-pass filter shown may not be necessary, but will remove eventual low frequency additive noise signals (low frequency noise signals superimposed on the input signal, which can cause variations in the trigger point, which in turn will appear as FM at the output and cause errors in the measurements). The limit on the deviations that can be measured is now mainly determined by how far the FM frequency components are from the carrier frequency. If the deviations are smaller than can practically be resolved directly, it is possible to increase the effective sensitivity by down-conversion using a setup as shown in Figure 12. Again, the stability of the local oscillator is very important for the end result, since any FM on the local oscillator will show up on the discriminator output. The setup of Figure 12 must be used if the carrier frequency is higher than 10 MHz (the mixer and the

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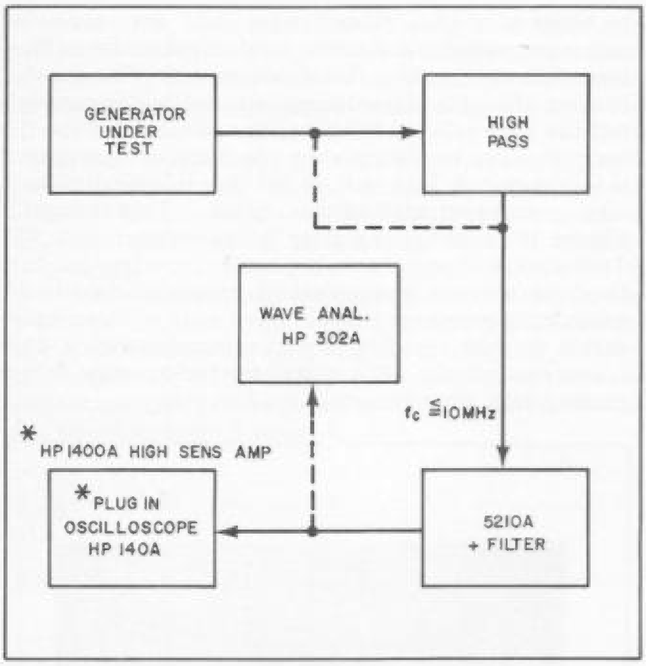

Fig. 11. Incidental FM measurement

3200B will handle up to 500 MHz). If the carrier frequency is less than 30 MHz, a low pass filter will be necessary to remove the sum frequency out of the mixer, since this may upset the operation of the trigger in the 5210A and thus the whole measurement.

FM MICROWAVE DEMODULATION

The 5210A in connection with the 5245L Counter plus the 5255A Frequency Converter makes an excellent setup for FM microwave demodulation all the way through X-band (12.4 GHz). Figure 13 shows the setup for carrier frequencies from 3-12.4 GHz. The first down-conversion is done in the 5255A. The Aux. Output (from the video amplifier 1-200 MHz) is down converted in the 10514A Mixer with a 3200B as local oscillator. The filter chosen for the 5210A will naturally depend on the modulating frequencies. For carrier frequencies in the range from 0.2 to 3 GHz the 5254B plug-in frequency converter will do the job equally well; it has the AUX OUT on the front panel as well.

One other method of FM demodulation in the microwave region is shown in Figure 14. Instead of making a second down conversion, the output of the plug-in converter is divided by 10 to bring the carrier within range of the 5210A (10 MHz or less). If so desired this can be accomplished by using a separate 5245L or 5246L as a scaler. A simpler way to do this is to take the signal out at the output of the first decimal counter assembly (DCA) in the counter. This can be done by connecting a scope probe (10 MΩ/10 pF) to pin 4 of connector XA17. The signal level here is adequate to drive the 5210A without apparent disturbance of the counter operation. It is necessary to have the counter function switch in manual start, to avoid the disturbance of the gating. When using this method for FM demodulation it must be remembered that included in the 5255A is a ÷4 scaler. This, in connection with the ÷10 in the first DCA, gives a measured deviation on the discriminator output that is 40 times too small. If the 5254B is used in place of the 5255A, the resulting division ratio will be 10. It is important to remember that whenever the FM signal is scaled or divided down, the deviation will be scaled with the same factor. This is not the case when the signal is heterodyned or down-converted; the deviation remains unaffected by this operation. We can thus straight away see the advantages and disadvantages with the two suggested methods for FM microwave demodulation: in case of double down-conversion an extremely high sensitivity can be obtained, so the method is particularly well suited for small deviations. It does require a mixer and a local oscillator extra. The second method is particularly good for larger deviations, where the division by 40 or 10 can be tolerated. It requires a minimum of equipment. In both cases the carrier frequency is readily available on the coun-

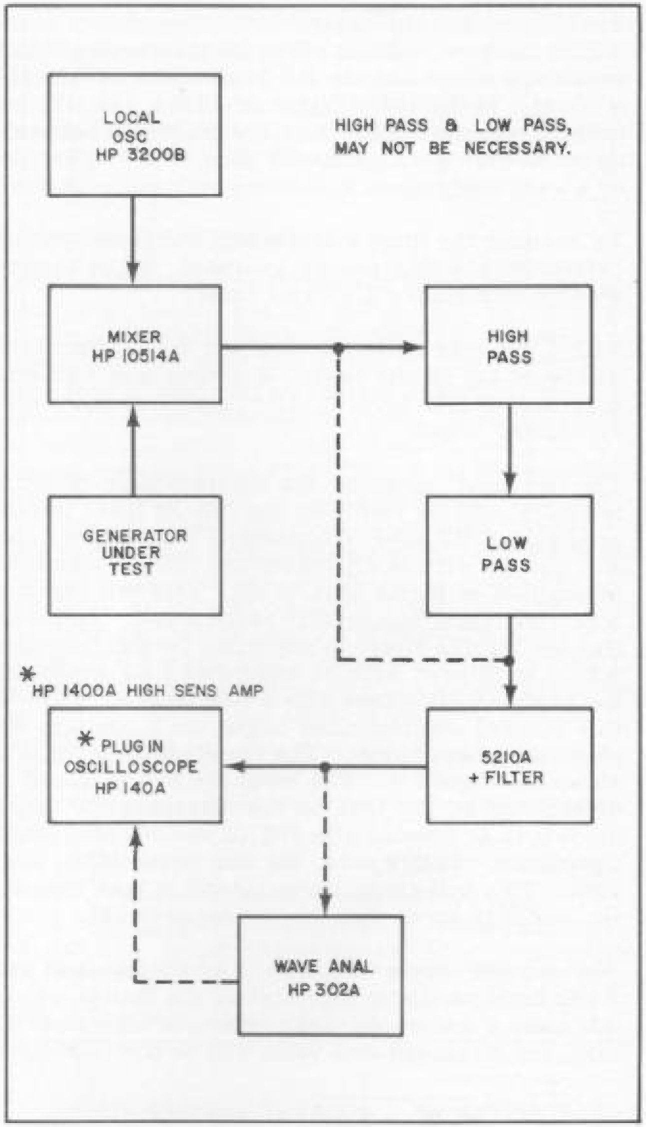

Fig. 12. Incidental FM measurement with down conversion

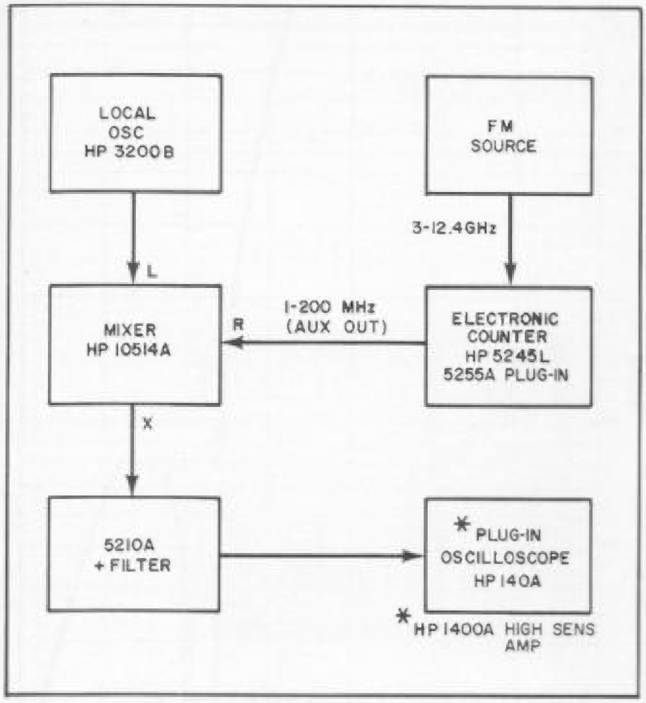

Fig. 13. FM microwave demodulation double down conversion.

ter. (The carrier frequency is the sum of counter reading and converter dial reading, in the usual manner for heterodyne frequency converters.) In the first method the average carrier frequency is displayed continuously, in the second method the function switch has to be moved to FREQUENCY to read average carrier frequency. Thus the setups will readily give all information about the FM signal.

SWEPT FREQUENCY MEASUREMENTS

Since the 5210A is supplying a dc voltage proportional to the input frequency, it lends itself very well to certain types of measurements. On X-Y plots, for example, the recorder output can be used to drive the frequency axis directly. An example of this is shown in Figure 15. This setup will take a manual frequency spectrum. If an X-Y recorder (such as Moseley 7035A) is used as an output device, the recorder output from the 5210A would be used for the X-axis drive. The advantage of using a 5210A here is the extremely high linearity of the frequency to dc conversion.

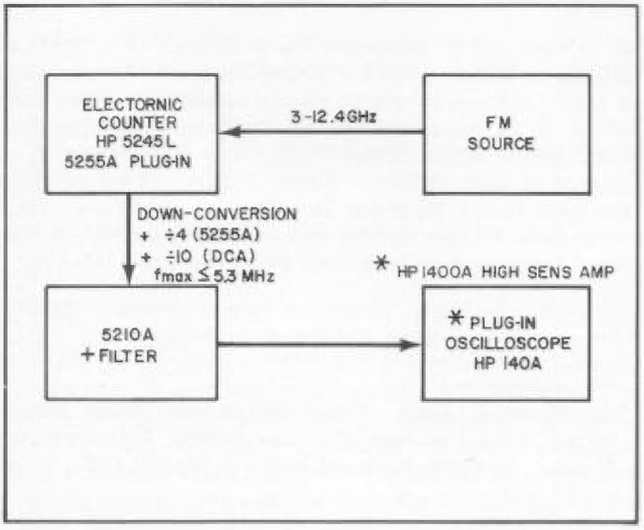

Fig. 14. FM microwave demodulation, down conversion plus frequency division.

In the case of fast changing frequencies applied to the network under test, the output device could be an oscilloscope and the discriminator output from the 5210A could be used for the horizontal deflection. Again the high linearity of the 5210A would result in very useful results.

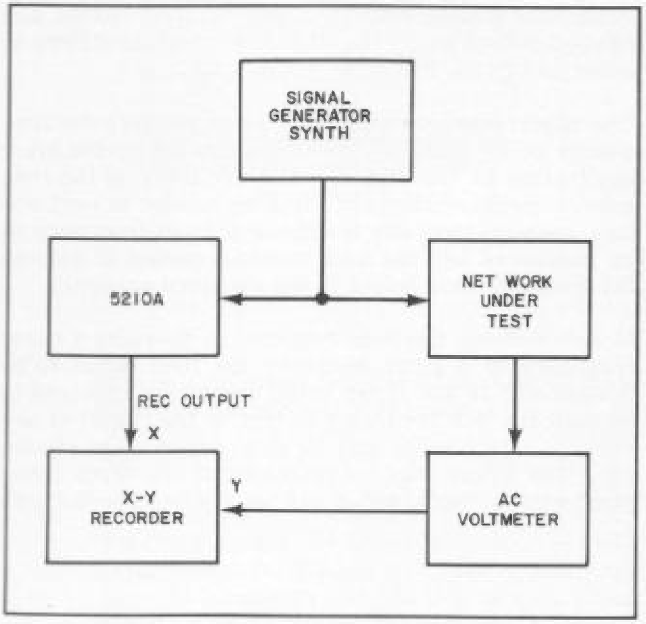

Fig. 15. Swept frequency measurement

PHASE MODULATION MEASUREMENTS

As we saw in an earlier paragraph (page 1), in a PM system the phase of the carrier varies linearly with the modulating signal. This is different from FM systems where the instantaneous frequency varies linearly with the modulating signal. For the relationship between frequency and phase we have the following expression:

$$\omega = 2\pi f = \frac{d\theta}{dt}$$

where θ is the phase of the carrier.

Since the discriminator output of the 5210A is proportional to frequency deviation, one way to obtain phase deviation is to integrate the discriminator output. However, in general the output of the discriminator is not large enough to make this a feasible solution.

A better technique* is to plot the discriminator output directly as function of frequency and then to draw lines of constant phase deviation on the plot according to the expression:

$$-V_d = \frac{\Delta\theta_n}{f_{FS}} \cdot f_n$$

where f_{FS} is the full scale range factor in Hz/V and sub-n indicates that the expression is valid for sinusoidal components of the PM signal. Thus $\Delta\theta$ can be read directly from the plot or calculated from the above expression.

SIGNAL BURSTS AND CHIRPED PULSES

Frequency measurement of short duration bursts and chirped pulses using the 5210A with output filters is described in the following paragraphs.

The discriminator output voltage represents the frequency of an input signal within a short period after application of the signal. The accuracy of the frequency measurement and the time needed to perform this measurement are functions of input frequency to be measured and the time constant needed to smooth the discriminator output to the required accuracy.

In determining the time required to measure a burst frequency to a given accuracy the first factor to be determined is the filter cutoff frequency required to smooth the discriminator output to the required accuracy. This value may be determined from Figure 16. The graph may be entered with the error (carrier voltage ripple) which can be tolerated in the output voltage. The ratio of the filter cutoff frequency to the carrier frequency required for this error can then be determined. Then knowing the filter cutoff frequency the time required for the maximally flat delay filter to approach its final value within the prescribed error may be determined from Figure 17. The dashed part of Figure 17 is due to the very small (0.8%) overshoot in the Bessel Filter. The error first approaches the final value (0% error) at .97/f_{co} and then overshoots to 0.8% error before returning to final value.

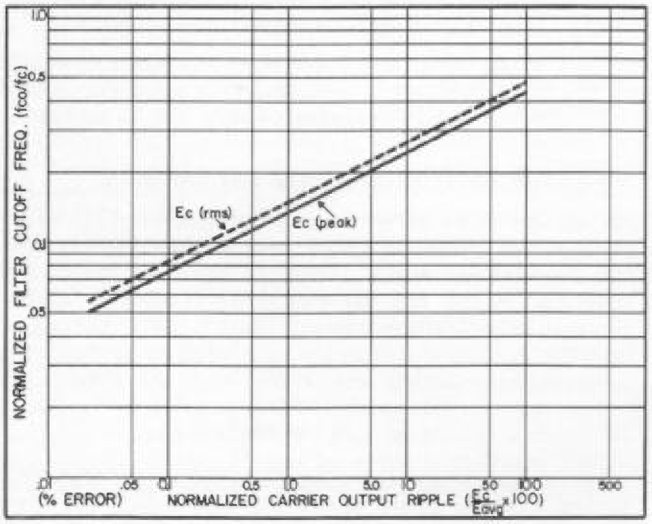

Fig. 16. Filter cutoff frequency versus percent error due to carrier ripple

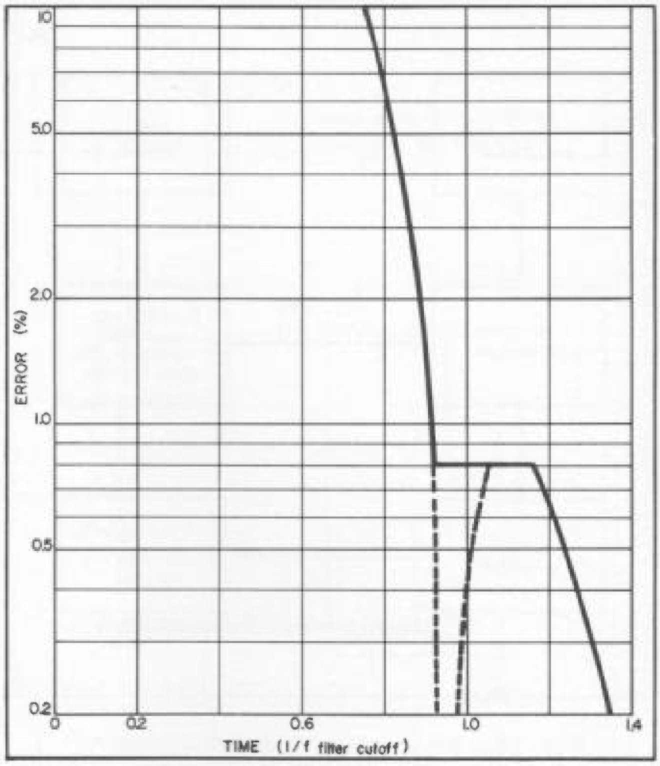

Fig. 17. Error tolerable versus time to final value within tolerance

EXAMPLE

It is desired to measure the frequency of a burst of pulses to within ± 3.0%. From Figure 16 we see that a 1.5% peak error due to ripple requires a filter cutoff of 0.16 times the carrier frequency (not the discriminator output frequency). The filter cutoff frequency is then 16 kHz. From Figure 17 we see that the time to a 1.5% error is 0.9 x 1/f_c or 56 µs. Thus less than 6 input cycles are needed to determine the input frequency to less than 3% error near 100 kHz.

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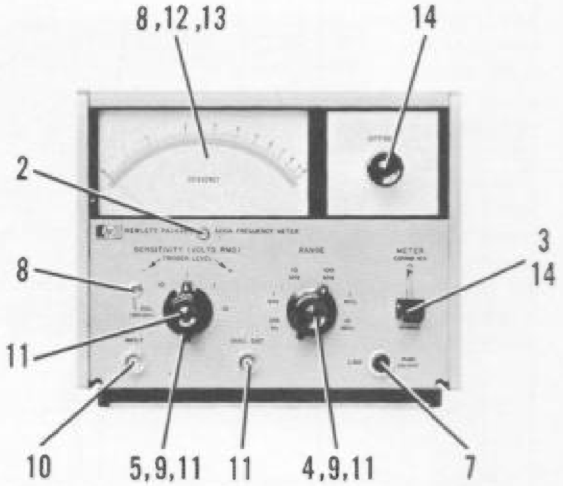
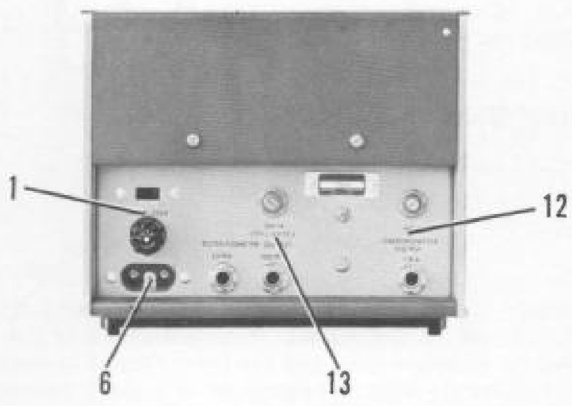
*See Peter R. Roth: Phase Noise and Phase Modulation Measurements with the Analog Frequency Meter. Hewlett-Packard Journal, March 1967, p. 18.

APPENDIX I

MODEL 5210A FRONT AND REAR VIEWS





1. Check 0.25 ampere fuse for 115 or 230 volt ac operation. Set slide switch to expose numbers which correspond with ac line voltage used.

2. Check meter pointer mechanical zero.

3. Set METER lever switch to NORMAL.

4. Set RANGE switch to 100 kHz.

5. Set SENSITIVITY switch to CAL (100 kHz).

6. Connect ac power cord supplied.

7. Push LINE switch to apply power and allow 10 minute warmup. Red light on indicates power applied.

8. Adjust CAL control with screwdriver for full scale (10) on meter.

9. Set SENSITIVITY switch to 10 and RANGE switch to 10 MHz.

10. Apply signal at INPUT jack with BNC cable supplied or hp 10003A probe.

11. Adjust TRIGGER LEVEL, SENSITIVITY, and RANGE controls for a stable meter indication. Set TRIGGER LEVEL at the center of the portion which provides the stable reading. Best operation results when the SENSITIVITY control is set to least sensitive range which gives a stable indication. See page 12 for the procedure to measure frequency modulation and deviation at the DISC OUT jack.

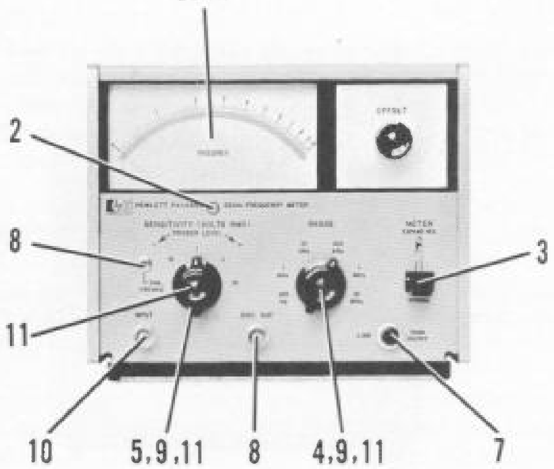
12. To record, connect a 1000 to 2000 ohm recorder at the GALVANOMETER OUTPUT telephone jack. With meter reading full scale (use CAL position and 100 kHz range), adjust GAIN control for recorder full scale.

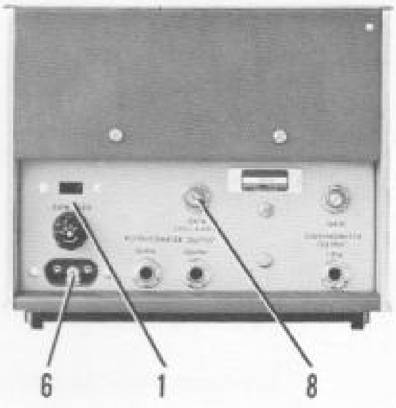
    Note: With a galvanometer recorder connected, potentiometer recorder and discriminator outputs are disabled.

13. To record, connect a 100 mv or 10 mv full scale recorder to the appropriate POTENTIOMETER OUTPUT telephone jack. With meter reading full scale (use CAL position and 100 kHz range), adjust GAIN control for recorder full scale.

    Note: Either a galvanometer or potentiometer recorder can be used, but not both at the same time.

14. For expanded measurement, set METER switch to EXPAND 10X and adjust OFFSET control to position the meter pointer at a reference point. This point represents the input frequency value and a change from this value can be measured.





1. Check 0.25 ampere fuse for 115 or 230 volt ac operation. Set slide switch to expose numbers which correspond with ac line voltage used.

2. Check meter pointer mechanical zero.

3. Set METER switch to NORMAL.

4. Set RANGE switch to 100 kHz.

5. Set SENSITIVITY switch to CAL (100 kHz).

6. Connect ac power cord supplied.

7. Push LINE switch to apply power and allow 10 minute warmup. Red light on indicates power applied.

8. Adjust CAL control with screwdriver for full scale on meter. With no output filter board installed, set DISC OUT voltage to 1 vdc using rear panel Disc Gain control. One volt peak-to-peak now represents zero to full scale peak-to-peak deviation.

   Note: With no output filter board installed, the DISC OUT voltage is proportional to the input frequency. The dc component is proportional to the average input frequency and the ac components are proportional to input frequency changes. In addition, there are ac components at one half the input frequency and its harmonics. The level of these harmonics is 1.9 volts rms with the meter reading full scale. To make useful measurements of modulation components, a low pass filter (Accessory 10531A, see page 13, or a wave analyzer such as the HP Model 302A can be used.

9. Set SENSITIVITY switch to 10 and RANGE switch to 10 MHz.

10. Apply signal at INPUT jack with BNC cable supplied or hp 10003A probe.

11. Adjust TRIGGER LEVEL, SENSITIVITY, and RANGE controls for a stable meter indication. Set TRIGGER LEVEL at the center of the portion of its range which provides the stable reading. Best operation results when the SENSITIVITY control is set to the least sensitive range which provides the stable indication.

FM Measurement

APPENDIX II

ACCESSORIES AND OPTIONS FOR THE 5210A/B

LOW-PASS OUTPUT FILTERS (ACCESSORY)

The HP 10531A Filter Kit provides a series of three plug-in low pass filters which can be adjusted to cover frequencies from 100 Hz to 1 MHz. These filters provide rejection of carrier and carrier harmonics while passing modulation components. Thus it is possible to measure deviations as small as 1 part in 10^5 of the carrier frequency at modulation frequencies up to 20% of the carrier frequency using the HP 302A or 310A Wave Analyzers or similar narrow band voltmeters on their most sensitive ranges. The cut-off frequency is selected by the user according to his needs by changing filter circuit resistors. These resistors are preassembled on smaller boards that plug in on the filter board; their values, corresponding to the desired cut-off, are given in the manual supplied with the instrument.

CALIBRATED OFFSET, OPTION 01

The calibrated offset, Option 01, provides for display of any of the 10 major divisions* on a separate full meter scale (the EXPAND scale) when the METER switch is in the EXPAND X10 position. This feature effectively adds a significant figure to frequency readings made in the NORMAL mode.

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*Six major divisions on 5210B.

APPENDIX III

HP INSTRUMENTS FOR USE WITH THE 5210A/B

DEVICES FOR MEASURING DISCRIMINATOR OUTPUT

OSCILLOSCOPES

140/141A Oscilloscopes

Main Frame: 10 x 10 cm display. Internal graticule, no parallax. Beam finder. Accepts horizontal and vertical plug-ins (seventeen available). 140A: $595. 141A only: variable presistence, storage, price: $1275 (without plug-ins).

Vertical Plug-ins (high sensitivities)

1400A:	100 μV/cm from dc to 400kHz, differential amplifier, $250.
1403A:	0.1 Hz to 400 kHz (0.9 μs rise time) (to 200kHz at 10 μV/cm and to 300kHz at 20 μV/cm), $475.

Horizontal Plug-ins (time bases)

1422A:	21 ranges 1 μs/cm to 5 s/cm, triggering to 500 kHz, $225.
1420A:	22 ranges 0.5 μs/cm to 5 s/cm, triggering to 20 MHz, $325.
1423A:	23 ranges 0.2 μs/cm to 5 s/cm, triggering to 20 MHz, trigger hold-off, $450.

130C Oscilloscope

All purpose, 200 μV/cm from dc to 500 kHz. Identical horizontal and vertical amplifiers. Time base: 21 ranges 1 μs/cm to 5 s/cm. Sweep magnifier x 2 to x 50. Price $695.

WAVE ANALYZERS

302A Wave Analyzer

Frequency range 20 Hz - 50 kHz. 30 μV to 300V full scale. 7 Hz bandwidth (3 dB). Automatic frequency control. Frequency restorer puts out sine wave proportional with component measured. Price: $1800.

310A Wave Analyzer

Frequency range: 1kHz to 1.5 MHz (200 Hz bandwidth), 5kHz to 1.5 MHz (1000 Hz bandwidth), 10 kHz scale. Automatic Frequency Control. Frequency restorer puts out sine wave proportional with component measured. Price: $2200.

VOLTMETERS

A variety of HP ac voltmeters are well suited for measuring the discriminator output.

Model	Freq. Range	Volt. Range, F.Sc.	Comments	Price
400E	10Hz-10MHz	1 mV-300V		285
400EL	10Hz-10MHz	1 mV-300V	Linear dB scale	295
400F	20Hz-4MHz	100μV-300V	100kHz LP filter, switchable	275
400FL	20Hz-4MHz	100μV-300V	Linear dB scale	285
400GL	20Hz-4MHz	100μV - 1000V	100kHz LP filter, Linear dB scale	290
403A	1 Hz - 1 MHz	1 mV - 300V	Battery operated	275
403B	5 Hz - 2 MHz	1 mV -300V	Battery/ac operated	310
3400A	10Hz-10MHz	1 mV-300V	True rms meter	525

EQUIPMENT FOR DOWN CONVERSION

10514A/B Mixers

Input/output frequencies: "L" and "R" ports: 200 kHz to 500 MHz; "X" port: dc to 500 MHz. Designed for 50Ω systems. Excellent balance at all ports. Flat response and low insertion loss. 10514A, price $180. 10514B, model for printed circuit board mounting.

LOCAL OSCILLATORS

3200B VHF Oscillator

Frequency range: 10-500 MHz in six bands. Excellent stability, low cost, compact. Output more than 4 mW across 50Ω. Frequency doubler probe available. 3200B, price: $475.

608 Series VHF Signal Generators

The 608 series signal generators are highly stable with very low incidental and residual FM and have versatile modulation capabilities and calibrated output attenuator (0.1 μV to 0.5V).

Frequency Ranges:
608C, E: 10-480 MHz;
601D: 10-420 MHz;
608F: 10-455 MHz, all in five bands.

OSCILLATORS (cont'd)

The models 608D, E, F have slightly better incidental FM specifications than 608C. In addition, 608E, F have a residual FM specification.

Prices: 608C: $1250; 608D: $1350; 608E: $1450; 608F: $1600.

SYNTHESIZERS

For very exacting requirements a frequency synthesizer will make an excellent local oscillator, with extremely low phase noise and frequency deviation. Output frequencies: 5105A: 0.1 to 500 MHz (0.1 Hz min. increment); 5100A: 0.01 Hz to 50 MHz. Non-harmonic spurious signals: 5105A: 70 dB below selected frequency, 5100A: 90 dB below selected frequency. Harmonic signals: 5105A: 25 dB below selected frequency; 5100A: 30 db below selected frequency.

Prices: 5100A/5110A (synthesizer/driver): $8,150/ $4,350. 5105A/5110B (synthesizer/driver): $9,150/ $4,350.

FREQUENCY CONVERTERS

5255A Frequency Converter:

3 - 12.4 GHz range, 100 mV rms sensitivity. Using harmonics of 200 MHz comb spectrum. Plug-in unit to be used with a HP 5245L or 5246L Electronic Counter. Prices: 5255A, $1650; 5245L, $2950; 5246L, $1800.

5254B Frequency Converter

0.2 - 3 GHz range, 50 mV rms sensitivity. Plug-in unit. Price: $825.

5253B Frequency Converter

50 - 500 MHz; 50 mV rms sensitivity. Plug-in unit. Price: $500.

RECORDERS

680A Strip Chart Recorder

This is a precision servo potentiometer instrument with a 5" writing width chart: one each of ten spans and eight speeds may be selected by the user. This instrument features all solid state circuitry, high accuracy, fast response, high common mode rejection, synchronous chart drive, and full view tilting chart magazine. The accuracy is better than 0.2% of full scale with 0.1% of full scale resettability. Choice of ink pressure, or electric stylus available. Suitable input devices are the 562A Digital Recorder with analog output option, or the 580A Digital-Analog Converter. $750.

7035A X-Y Recorder

A high performance, low cost, servo potentiometer X-Y recorder designed for use in applications where high dynamic performance is not required. Metric scaling is optional. Each axis has an independent servo system with no interaction between channels. Features include solid state circuitry. AUTOGRIP electric paper hold-down, guarded input, electric pen lift. Input resistance on 100 mV/inch input is 1 MΩ. Floating inputs. Slewing speed 15 inches/s. Accuracy ±0.2% at full scale. Linearity ±0.1% of full scale. Optional external time base available. $895. Higher performance X-Y recorders also available.

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