APPLICATION NOTES

APPLICATION NOTE 1

A METHOD OF MEASURING THE CHARACTERISTICS OF FREQUENCY MODULATED SIGNALS AT CARRIER FREQUENCIES FROM 10 MEGACYCLES TO 12.4 KILOMEGACYCLES AND ABOVE

INTRODUCTION

The need for a rapid and accurate means of measuring the characteristics of frequency-modulated signals at microwave carrier frequencies has become increasingly important with the growing complexity of electronic instrumentation. This Application Note describes a straightforward direct-reading system capable of measuring frequency modulation of rf carriers from 10 megacycles to 12,400 megacycles, and above, and which is unaffected by incidental amplitude modulation and reasonable amounts of carrier-frequency drift. Carrier-shift and deviation measurements as well as measurements of the detected modulation can be made easily and accurately. Carrier deviations produced by complex waveforms can be measured to an accuracy of 5% and, with care, accuracies of 2% can be obtained when measuring sinusoidally-modulated carriers.

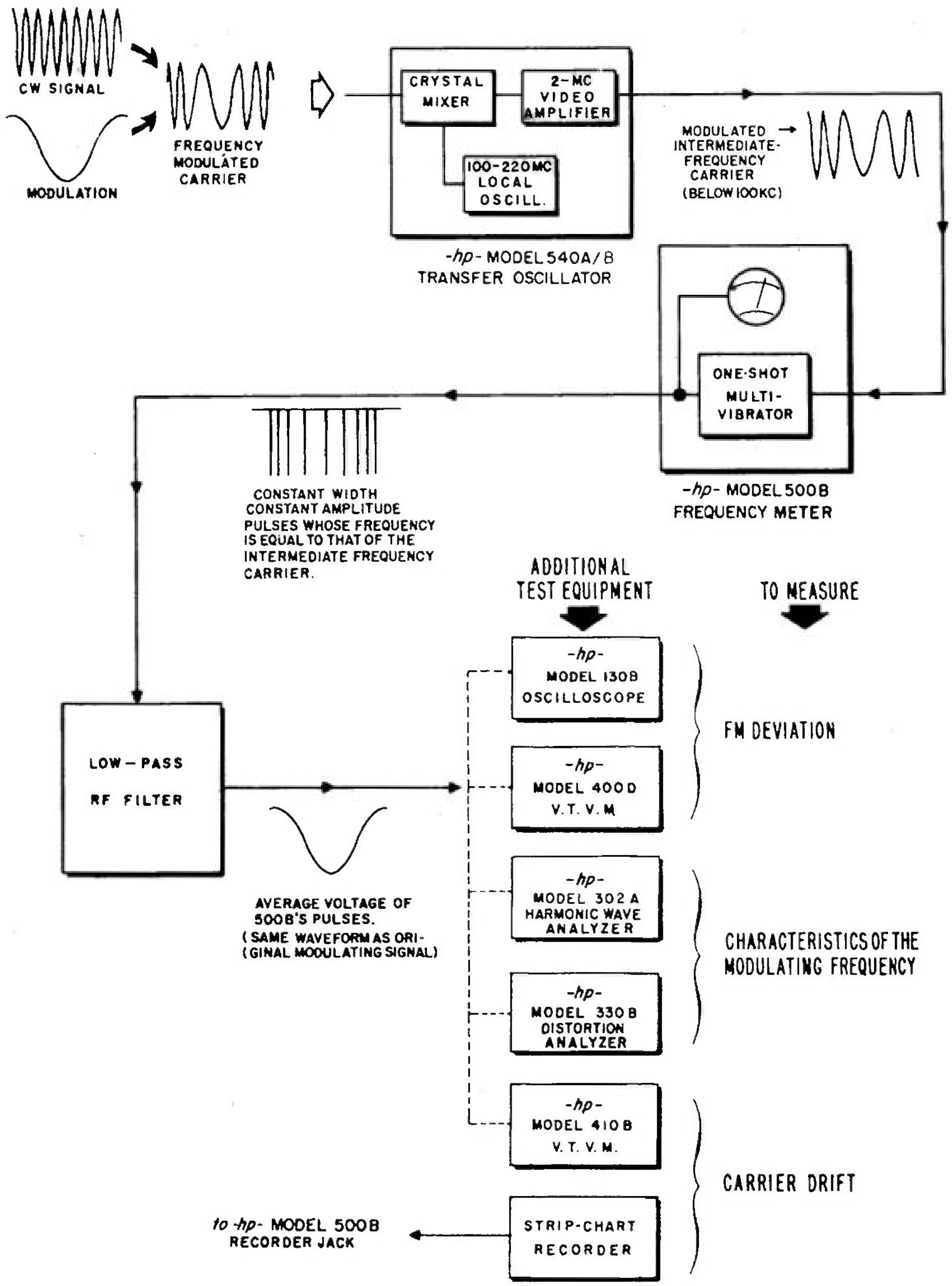


Figure 1. Layout and Operation of Basic System Required To Measure Frequency Modulation Characteristics.

DESCRIPTION OF THE BASIC SYSTEM

The basic system for measuring frequency-modulation characteristics is shown in Figure 1 and consists of an ⓗⓟ Model 540A or Model 540B Transfer Oscillator, and ⓗⓟ Model 500B Frequency Meter and a low-pass filter. The unknown frequency-modulated signal is fed into the Transfer Oscillator. Here it is combined with harmonic frequencies generated by a crystal mixer from the ⓗⓟ 540 100 to 220 mc internal oscillator. The oscillator is adjusted to produce an intermediate output frequency which falls within the 100-kc passband of the 500B Frequency Meter. This intermediate-frequency carrier is amplified in the ⓗⓟ 540, indicated on the internal oscilloscope and coupled to the Frequency Meter.

The ⓗⓟ 500B Frequency Meter serves as a linear discriminator and converts the intermediate frequency carrier into a train of constant-amplitude, constant-width output pulses -- one pulse for each rf input cycle (see Figure 1). The average current of these pulses is directly proportional to the intermediate frequency and is used to operate the 500B's internal milliammeter, which is calibrated in kc. These pulses also appear at the 500B's PULSE OUTPUT connector and are fed to the low-pass filter.

The low-pass filter is designed to block the 500B's output pulse train and pass the average voltage of the pulses. The voltage varies at the rate of the original modulating frequency and has an ac amplitude directly proportional to the degree of frequency deviation. The output from the filter is then connected to additional test instruments which measure the average voltage of the pulses to indicate frequency deviation, carrier drift and the characteristic of the modulation.

FREQUENCY DEVIATION MEASUREMENTS

Frequency deviation can be easily measured in at least two ways. One way uses an oscilloscope to show the deviations caused by both simple and complex waveforms. The other uses an ac vacuum tube voltmeter to indicate sinusoidal frequency deviation on a meter scale.

Deviations can be read directly from the face of an oscilloscope whose vertical sensitivity is adjusted to obtain a predetermined deflection for a known input frequency. For example, deviations of 10 kc per centimeter will be indicated if the vertical sensitivity is adjusted to give a trace deflection of 10 centimeters above the no-input trace position when a 100-kc unmodulated signal is applied to the ⓗⓟ 500B Frequency Meter.

The ac vacuum tube voltmeter has the advantage of indicating the frequency deviation caused by sinusoidal modulation directly on a meter scale rather than on an oscilloscope screen. This system can be calibrated by loading the output of the low-pass filter with a 20,000 ohm potentiometer (equal to the 500B's PULSE OUTPUT jack characteristic impedance) and adjusting the dc output of the filter to a predetermined level for a known unmodulated input frequency. For example, if the potentiometer was adjusted to indicate 10 volts on an accurate dc vacuum tube voltmeter when a 100-kc unmodulated signal was applied to the 500B, the system would be calibrated to indicate 10-kc deviation for every .707 volts read on an ac RMS-reading vacuum tube voltmeter.

A more convenient alternative method of measuring frequency deviation using an ac vacuum tube voltmeter would be to adjust the dc output from the filter to produce 1.414 volts as read on an accurate dc vacuum tube voltmeter when a 100-kc unmodulated signal is applied to the 500B. This arrangement would allow deviations to be read directly since the initial adjustment to 1.414 volts dc compensates for the RMS-reading scale of the ac vacuum tube voltmeter and obviates the necessity for multiplying meter readings by 1.414 to obtain true deviations.

CARRIER DRIFT MEASUREMENTS

A broad indication of carrier drift over nominal periods of time can be obtained by observing the range of variation of the ⓗⓟ 500B's meter readings. Drift measurements may be recorded by plugging a 1-ma. recorder into the ⓗⓟ 500B's RECORDER jack. A low-pass filter is not required for this application because of the filtering already present at the jack.

MODULATING FREQUENCY AND WAVEFORM MEASUREMENTS

Modulation frequencies and waveforms can be observed on an oscilloscope connected to the output of the low-pass filter. Total distortion and harmonic content can be measured directly on the ⓗⓟ 330B Distortion Analyzer and ⓗⓟ 300A Harmonic Wave Analyzer. These measurements are relative and hence special calibrating procedures are not required.

LOW-PASS FILTER DESIGN CHARACTERISTICS

The low-pass filter is designed to block the pulse train from the 500B and pass only the resultant average voltage of the pulses. The cutoff frequency and the sharpness of the filter depend upon the degree of peak-to-peak carrier deviation and the highest modulating frequency since the sum of these two frequencies and the guard band between them, required by the finite slope of the cutoff characteristic, must not exceed the 100-kc pass band of the 500B.

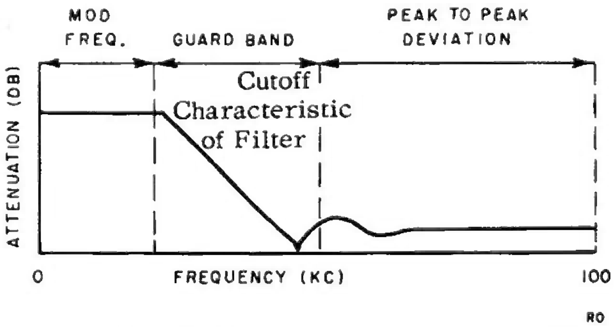
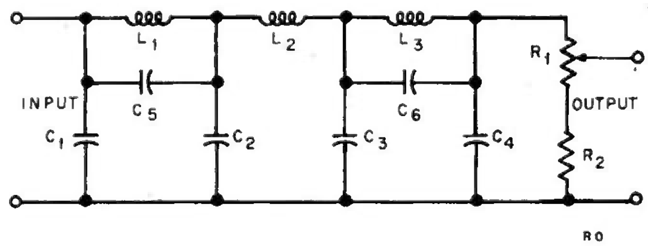


Figure 2. Low-Pass Filter Design Requirements

Figure 2 illustrates this condition. The upper limit of the modulating signal is slightly below the point at which 3 db attenuation occurs. The lower limit of the peak-to-peak deviation is slightly above the lowest frequency at which maximum attenuation occurs. The guard band lies between these two limits.

These requirements limit the maximum peak-to-peak carrier deviation and modulation frequency which can be handled by the system. To obtain maximum range of measurements a sharp cutoff low-pass filter is generally used. However, if low modulating frequencies and small deviations are to be measured, a simple rc filter with more gradual cutoff characteristics can be used.

As a practical matter, the cutoff characteristic of the three-section low-pass filter shown in Figure 3 is sufficiently sharp to enable its use in a wide variety of applications. The guard band of this filter is equal to twice the maximum modulating frequency. Thus the basic fm-measuring system equipped with this filter can handle modulating frequencies up to 33 kc at very low deviations or peak deviations up to 50 kc at very low modulating frequencies. If greater peak deviations must be measured, a filter with sharper cutoff characteristics can be used or a system of frequency division employed.



F_{co} Cutoff frequency in kc (slightly higher than the highest modulating frequency)

R_1 20,000 ohm potentiometer

R_2 Small variable resistor adjusted to obtain 10 volts dc across $R_1 + R_2$ with a 100-kc unmodulated signal applied to the ⓗⓟ 500B frequency meter.

$$L_1, L_3 = \frac{4{,}700 \text{ millihenry}}{F_{co}} \qquad C1, C4 = \frac{5{,}970\ \mu\mu f}{F_{co}}$$

$$L_2 = \frac{6{,}360 \text{ millihenry}}{F_{co}} \qquad C2, C3 = \frac{13{,}910\ \mu\mu f}{F_{co}}$$

$$C5, C6 = \frac{2{,}320\ \mu\mu f}{F_{co}}$$

Figure 3. Design Information for a Simple 3-Section Low-Pass Filter

The maximum peak deviation this three-section filter will handle is given by the relationship:

$$D_p = 50 - 1.5\ F_{mod}$$

where D_p is the maximum peak deviation and F_{mod} the maximum modulating frequency. For example, the maximum peak deviation the basic system can handle with a maxium modulating frequency of 15 kc is 27.5 kc:

$$D_p = 50 - 1.5\ (15) = 50 - 22.5 = 27.5 \text{ kc.}$$

From this discussion it is apparent that a rough idea of the maximum modulating frequency and the degree of peak-to-peak carrier deviation must be known to successfully design a low-pass filter. In many cases these quantities are known. However, if the degree of deviation is unknown, the ⓗⓟ 540A Transfer Oscillator and ⓗⓟ 524B Electronic Counter can be used for a rough determination. This method of determining peak-to-peak carrier deviation is described on pages 13-14 of the 540A instruction manual.

THE MEASUREMENT OF WIDER DEVIATIONS USING FREQUENCY DIVISION

If the deviations to be measured are greater than the capabilities of the basic system, the intermediate-frequency carrier produced by the transfer oscillator must be divided to reduce the peak-to-peak deviation so the sum of the modulating frequency, the divided peak-to-peak deviation and the guard band of the filter falls below the 100-kc upper limit of the ⓗⓟ 500B Frequency Meter. In this case the system is measuring divided deviations therefore deviation measurements made at the output of the filter must be multiplied by the divisor to obtain actual deviations.

Frequency division affects only the deviation of the frequency-modulated carrier; it will not reduce the modulating frequency. Consequently a system equipped with the three-section low-pass filter described above would still be limited to modulating frequencies up to approximately 33 kc.

To determine an approximate divisor for a system using the three-section filter shown in Figure 3, use the relationship:

$$\text{Divisor} = \frac{D_p}{50-1.5\,F_{mod}}$$

where D_p is the peak deviation and the F_{mod} is the modulating frequency. For example, if a 6-kc modulating frequency produces a 320-kc peak deviation, the approximate divisor would be:

$$\text{Divisor} = \frac{320}{50-1.5\,(6)} = \frac{320}{50-9} = \frac{320}{41} = 8$$

In practice, a division by 10 would give almost the same degree of resolution and would be easier to use when multiplying the meter readings to obtain actual peak deviations.

After the approximate divisor has been calculated, Table I can be used to determine how the frequency division can be accomplished using one of the ⓗⓟ Electronic Counters of the ⓗⓟ 520A High Speed Scaler.

The operation of a system employing frequency division is the same as that of the basic system, except that the 540A's local oscillator should be adjusted until the 500B Frequency Meter reads an intermediate-frequency carrier of 100 kc minus the divided peak deviation. This places the carrier deviation in the upper portion of the 500B's 100-kc range and maximizes the portion available for modulation and guard band requirements.

Using the previous example and 10 for a divisor, the 540A's local oscillator should be adjusted until 68 kc is read on the 500B:

$$\frac{\text{320-kc peak deviation}}{10} = \text{32-kc divided peak deviation}$$

100 kc (500B upper frequency limit)	−	32 kc (divided peak deviation)	=	68 kc (intermediate-frequency carrier)

The maximum modulating frequency which can be handled by the filter shown in Figure 3 can then be determined by the relationship:

$$\frac{50d-D_p}{1.5\,d} = \text{maximum modulating frequency}$$

where d is the divisor and D_p the peak deviation. Again, using the previous example, the maximum modulating frequency for a three-section filter of the type shown in Figure 3 would be 12 kc:

$$\text{Maximum Modulating Frequency} = \frac{50\,(10)-320}{1.5\,(10)} = \frac{500-320}{15} = 12\text{ kc}$$

PEAK-TO-PEAK DEVIATIONS IN EXCESS OF 2 MEGACYCLES

If peak-to-peak deviations greater than 2 mc are to be measured, a wide-band amplifier must be substituted for the Transfer Oscillator's internal 2-megacycle video amplifier and a resistive load connected across the mixer output to broaden the frequency response of the crystal mixer. No modification of the 540A is required since both the wide-band amplfier and the resistive load are connected externally. The value of the resistive load must be equal to, or less than, the total capacitive reactance of the ⓗⓟ 540A crystal mixer, the external cabling and the input circuitry of the external wide-band amplifier. The specific value of the resistive load (R_x) can be determined in terms of capacitive reactance (X_c) by the equation:

$$R_x = \frac{500X_c}{500-X_c}$$

where R_x and X_c are in ohms and

$$X_c = \frac{1 \times 10^6}{2\,F\,(C+20)}$$

where F is the frequency of the intermediate frequency carrier in megacycles and C is the external capacity in $\mu\mu$f. These equations are valid when

TABLE I
FREQUENCY DIVISION USING
HEWLETT-PACKARD ELECTRONIC COUNTERS

1. Determine the amount of division required.
2. Refer to Table and if necessary, remove tubes or crystal diodes from the counter or scaler.
3. Apply the frequency to be divided to the input connector of the scaler or counter used.
4. Couple out the divided frequency at the point described in the Table by means of a 10:1 rc voltage divider probe. If a probe is not available use a 10 $\mu\mu$f capacitor in series with a single wire or low capacity lead.

WARNING

To avoid burning out crystal diodes by shorting plates or clamp supply voltages, turn the counter or scaler off when connecting into its circuits.

TYPICAL DIVISION RATIOS

Divide By	hp 520A High (1) Speed Scaler	hp 523B Electronic Counter	hp 524A Electronic Counter	hp 524B Electronic Counter
2	Attach probe to junction of R53 and R54.		Attach probe to junction of R430 and R431.	Attach probe to junction of R304 and R305.
4	Remove V15. Attach probe to junction of R69 and R7.		Remove V410. Attach probe to junction of R445 and R446.	Remove V214. Attach probe to junction of R316 and R317.
8	Remove V15. Attach probe to junction of R79 and R80.		Remove V10. Attach probe to junction of R454 and R455.	Remove V214. Attach probe to junction of R335 and R336.
10	Attach probe to junction of R79 and R80.	Attach probe to pin 5 of the TENS counter plug-in unit.	Attach probe to junction of R454 and R455.	Attach probe to junction of R335 and R336.
16	Remove V15. Attach probe to pin 6 of V18.		Remove V410. Attach probe to pin 6 of V301.	Remove V214. Attach probe to pin 6 of V219.
20	Attach probe to pin 6 of V18.		Attach probe to pin 6 of V301.	Attach probe to pin 6 of V219.
40	Remove CR41. Attach probe to pin 6 of V19.		Remove CR303. Attach probe to pin 6 of V302.	Remove CR251. Attach probe to pin 1 of V220.
80	Remove CR41 and CR44. Attach probe to pin 6 of V20.		Remove CR303 and CR 305. Attach probe to pin 6 of V303.	Remove CR251 and CR254. Attach probe to pin 6 of V221.
100	Attach probe to OUTPUT connector.		Attach probe to pin 6 of V305.	Attach probe to pin 1 of V223.

(1) The input to the hp 520A must have a minimum rate of rise of 10 volts per microsecond and a minimum amplitude of 5 volts.

the 540A's VIDEO GAIN control is set to a minimum to reduce the shunt capacity of the crystal mixer to approximately 20$\mu\mu$f. External capacitance should be held to a low value to prevent unnecessary loading of the crystal output and thus subsequent reduction in measurement sensitivity.

USE OF THE ℎ𝑝 540 TRANSFER OSCILLATOR FROM 10 MC TO 12.4 KMC AND ABOVE.

Input signals from 100 megacycles to over 5 kilomegacycles can be measured by the ℎ𝑝 540A and from 100 mc to 12.4 kmc by the 540B without additional equipment. Between 100 mc and 220 mc, pulling effects between the input frequency and the 540 local oscillator must be prevented. This can be accomplished by either holding the input signal to a low level or by heterodyning the third harmonic of the unknown signal with the second harmonic of the 540's fundamental (this beat will be found on the 540's dial at 1.5 times the input signal frequency). In this case, the input signal's deviation will be multiplied by three and hence deviation readings must be divided by three to obtain true deviations. In addition to requiring a division of the deviation readings, multiplication of the input frequency deviation may require intermediate-frequency division since the combination of peak-to-peak deviation, maximum modulating frequency and guard-band requirements might easily exceed the 100-kc upper limit of the 500B.

The ℎ𝑝 540 can be used from 10 mc to 100 mc if the unknown input signal is relatively constant in amplitude, has little incidental amplitude modulation and is rich in harmonics. If strong harmonics are not present, a harmonic generator or a high level amplifier inserted before the Transfer Oscillator may be used to generate them. Again, it should be remembered that the use of harmonics of the input signal will multiply the input frequency deviation requiring division of the deviation readings and may require intermediate-frequency division.

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