APPLICATION NOTE 2

MEASURING FREQUENCY FROM VHF UP TO AND ABOVE
18 GC WITH TRANSFER OSCILLATOR/COUNTER TECHNIQUES

Introduction

High speed electronic counters such as the Hewlett-Packard 524 series can be used to measure frequency accurately under a wide range of conditions. Various accessories used with the basic counters make it possible to extend the measurable range up to 18 gc and above.

Frequency range of interest, desired accuracy, unknown signal strength, and budget limitations will influence the choice of instruments and the method of measurement.

Equipment

Equipment applicable to the various frequency ranges is summarized in table I.

Counters in the ⓗⓟ 524 series and the 5243L or 5245L may be used with the transfer oscillator/counter technique. Time base stability (which largely determines accuracy of frequency measurement) and method of count presentation are the most important differences between them. These characteristics for these Hewlett-Packard counters are summarized in table II.

TABLE I. EQUIPMENT FOR MEASURING FREQUENCIES UP TO AND ABOVE 18 GC

	ELECTRONIC COUNTERS			FREQUENCY CONVERTERS				Trans. Osc.	Amp.	Harm.Mix.	High Freq.
	5243L	5245L	524	5253A/B	525A	525B	525C	540B*	491C	P932A	Mixer
Up to 10.1 mc	x										
		x									
			x								
Up to 20 mc	x										
		x									
Up to 50 mc		x									
10.1 to 100 mc	x			x							
		x		x							
			x		x						
50 to 512 mc	x			x							
		x		x							
100-220 mc	x			x							
		x		x							
			x			x					
100-510 mc	x			x							
		x		x							
			x				x				
220 mc-12.4 gc	x			x				x			
		x		x				x			
			x			x		x			
12.4-18 gc	x			x				x		x	
		x		x				x		x	
			x			x		x		x	
Over 18 gc	x			x				x	x	x	x
		x		x				x	x	x	x
			x			x		x	x	x	x

* Existing 540A Transfer Oscillators, now discontinued, can be used for frequency measurements between 220 mc and 12.4 gc when used with the ⓗⓟ 934A Harmonic Mixer, and from 12.4 to 18 gc when used with the ⓗⓟ P932A Harmonic Mixer.

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TABLE II. 524 SERIES COUNTERS

	Time Base Stability [1]	Method of Count Presentation
524B	1 part in 10^6 short term 2 parts in 10^6 per week	6 neon indicator decades and 2 meters
524C/D	3 parts in 10^8 short term 5 parts in 10^8 per week	8-place: Nixie/neon
5243L 5245L	5 parts 10^{10} (1 sec. av.) 3 parts 10^9 per day	8-place rectangular nixie
[1] Time Base Stability specifies only the amount which the time base oscillator will drift. Absolute accuracy is determined by the calibration technique employed.		

Frequency Range

Direct measurement of frequencies up to 10.1 mc, 20 mc, or 50 mc is possible by using, respectively, the 524 series electronic counters, the 5243L, and the 5245L Electronic Counters. By using the 525A Frequency Converter plug-in with any of the 524 series, frequency measurement is extended to 100 mc; the 525C plug-in will extend the measurement range from 100 mc to 512 mc. And the 5253A or 5253B Frequency Converters accomplish the same thing for the 5243L or 5245L Electronic Counters, but over a greater frequency range; the 5253A Frequency Converter will extend measurement capability, for either counter, from 88 mc to 512 mc and the "B" version does the same but from 50 mc to 512 mc. All of these frequency converter plug-in units mount directly into the counter cabinet. The basic frequency range of the counters is retained even while the plug-in units are installed.

Frequencies up to 12.4 gc may be measured easily by using a counter and a frequency converter with the Transfer Oscillator, 540B. In the transfer oscillator technique, an unknown frequency is compared with a harmonic of a fundamental frequency in the 100-220 mc range generated within the transfer oscillator. An oscilloscope and mixer for making the comparison are included in the transfer oscillator.

A Model P932A Harmonic Mixer can be used to extend the frequency range of a counter/transfer oscillator combination upwards to 18 gc. A similar technique, using appropriate mixers and accessory equipment will further raise the upper limit of accurate frequency measurement to 40 gc.

If a printed record of the measured frequency is desired, an hp Model 562A Digital Recorder can be used with the counter. Variation of frequency as a function of time can be recorded in two ways. A digital clock can be installed in the Digital Recorder to print the time of measurement with each frequency reading; or a strip chart recorder can be driven by the analog output from the 562A, or a 580A or 581A Digital-to-Analog Converter may be substituted if a print-out recorder is not required.

Typical instrument arrangements for measuring in the various frequency ranges are illustrated under Basic Measuring Systems.

Accuracy

Accuracy of frequency measurement with the counter/transfer oscillator technique is influenced by 1) counter accuracy, 2) inherent stability and "setability" of the transfer oscillator and 3) the operator's comparison accuracy. In actual practice, accuracies as high as 1 part in 10^7 are achieved with a clean cw unknown. More accurate readings are difficult to obtain because of incidental frequency modulation of the transfer oscillator fundamental.

Fundamental frequencies can be read to ±1/2% accuracy directly from the transfer oscillator dial. Thus, the transfer oscillator can be used independently to measure frequency where 1/2% accuracy is sufficient.

Improved Accuracy and Drift Measurements

An auxiliary instrument manufactured by the Dymec division of Hewlett-Packard increases the measurement accuracy to that of the counter employed by eliminating two sources of error: 1) frequency drift, 2) comparison error. The Dymec Model DY-5796 Transfer Oscillator Synchronizer directly relates the frequency of the hp Transfer Oscillator to the frequency of the signal being measured. When the Synchronizer is used, the 540B tracks the frequency of the measured signal and any tendency for the 540B to drift is immediately compensated by a phase-lock control loop. This same feedback system makes the comparison error negligible. See figure 4.

Besides giving you counter accuracy frequency measurements to 12.4 gc, Model DY-5796 allows you to make long term measurements of drift. Klystron frequency drift can be reduced to 1-part in 10^6 per week with the Dymec 2650 Oscillator Synchronizer*.

A kit which increases the sensitivity of the frequency control circuit of the hp Models 540A and 540B is available from Dymec so that you can modify your present instrument for use with the Transfer Oscillator Synchronizer. You can obtain modified 540B Transfer Oscillators from Dymec.

For more information on the DY-5796 Transfer Oscillator Synchronizer and the H06-540B, write to Dymec, 395 Page Mill Road, Palo Alto, California, or to your local hp representative.

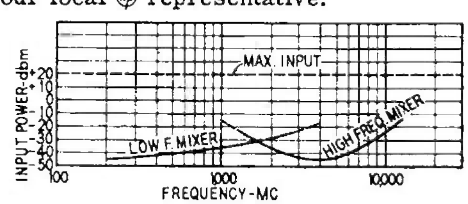


Figure 1. Typical Input Sensitivity, Model 540B Transfer Oscillator

* For further information about this technique write for the hp Journal: Vol. 13, No. 9-10. Alternatively, your hp field representative will be glad to answer your questions.

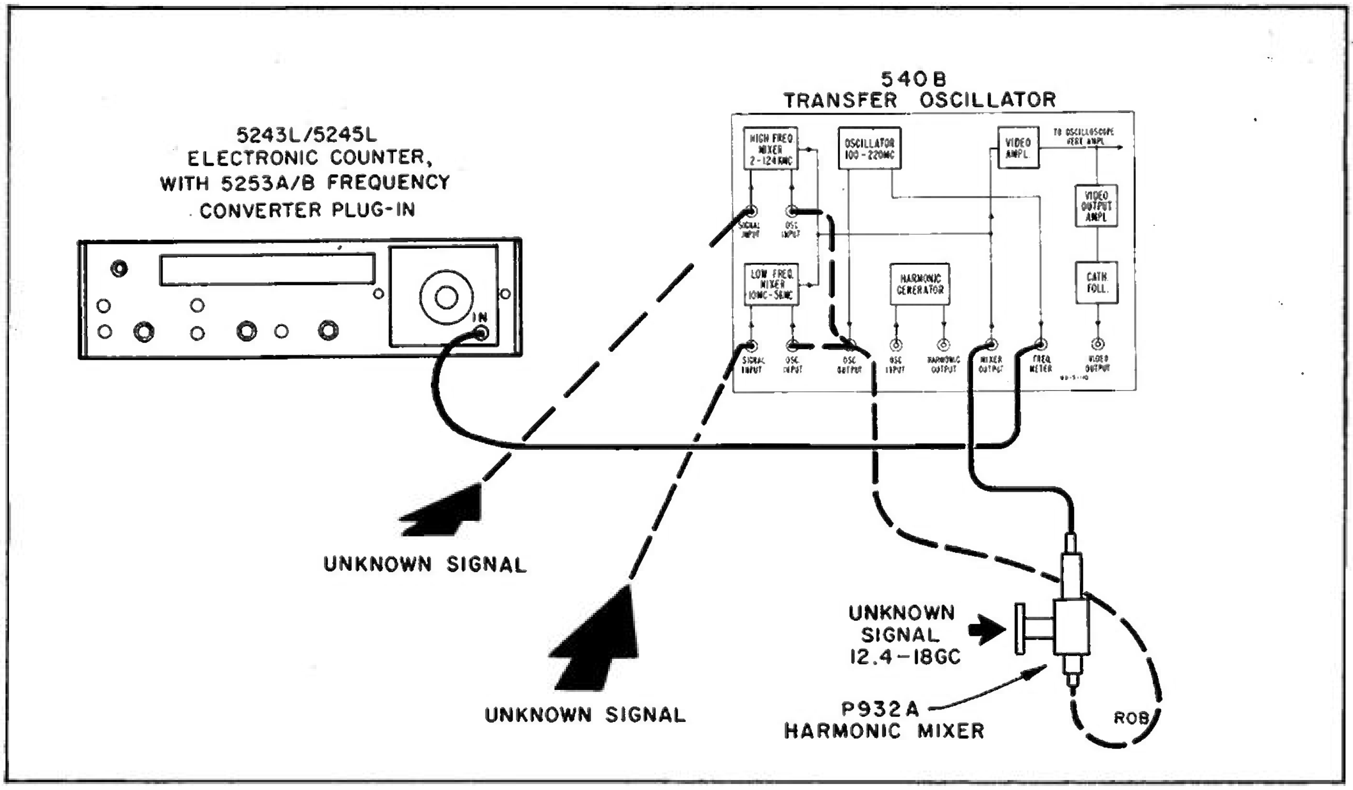
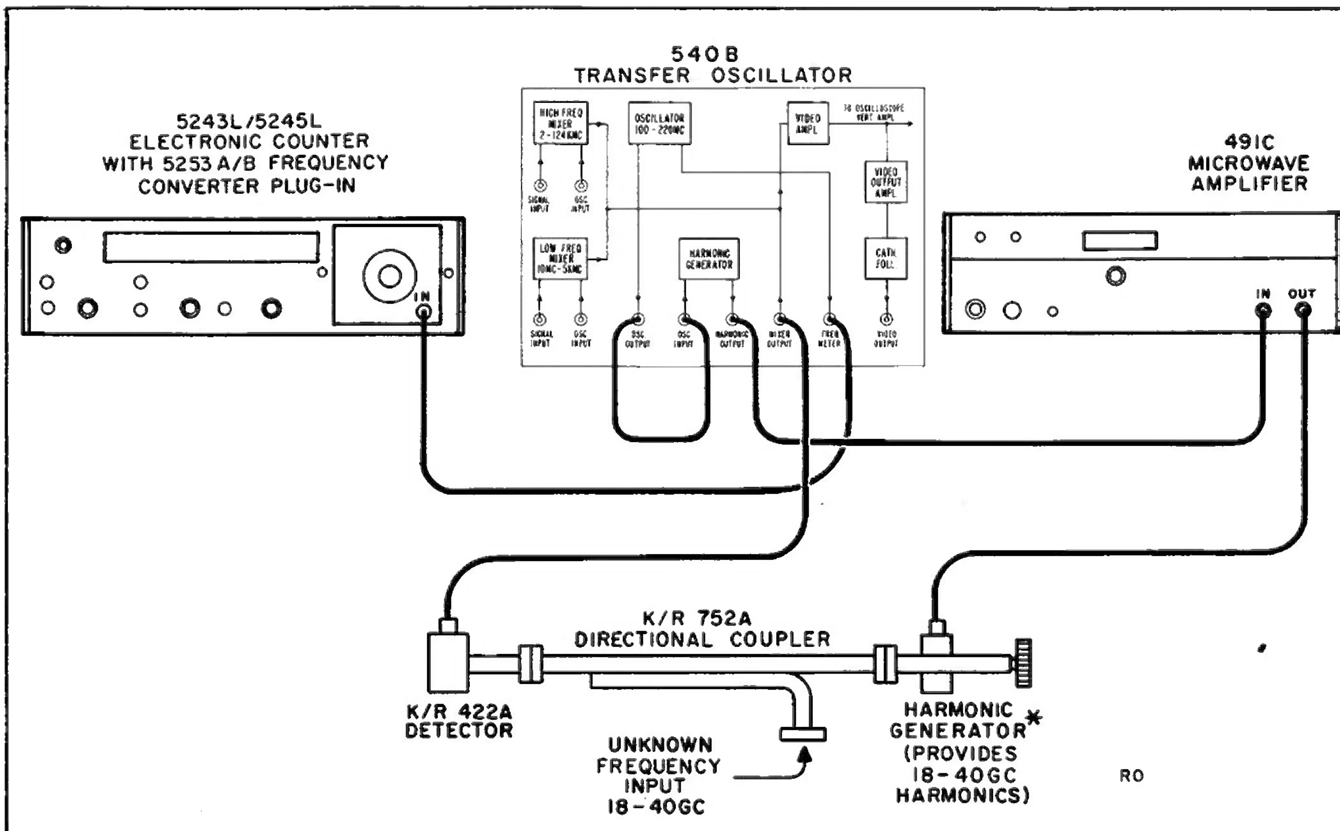


Figure 2. Frequency Measurement to 18 gc with the Model 540B Transfer Oscillator



*Microwave Associates 789, 915, 1039C, or 1043C (K band) or 513E (R band) crystal detector mounts.

Figure 3. Frequency Measurement above 18 gc with the 540B Transfer Oscillator

Input Signal Strength

Below microwave frequencies, ample power is normally available to drive directly the counter and the frequency converter. With the 540B Transfer Oscillator, however, microwave frequencies are of interest; and power level of the unknown signal assumes greater importance that will influence what specific combination of instruments can be used. Figure 1 shows typical input sensitivity for the 540B Transfer Oscillator.

Basic Measuring Systems

The most flexible group of instruments for general purpose frequency measurements up to 12.4 gc consists of the appropriate counter and frequency converter, and a 540B Oscillator.

The range of measurable frequencies can be increased to 18 gc by adding a P932A Harmonic Mixer to this basic group.

The basic measuring system using the 540A and 540B Transfer Oscillator is shown in figure 2.

Figure 3 shows a suggested arrangement for measuring frequencies above 18 gc with the 540B Transfer Oscillator. In this arrangement, harmonics in the 2-4 gc region are generated in the 540B, by use of the internal harmonic generator, amplified in the microwave amplifier, and applied to a waveguide crystal mount which generates other harmonics in the 18-40 gc regions. The difference frequency between one of these harmonics and the unknown is detected in a second waveguide crystal mount and applied to the video amplifier of the 540B for presentation on the internal oscilloscope.

The method described here is used regularly by hp for measuring K and R band frequencies by means of the following procedure:

1) Set the unknown frequency.

2) Knowing approximately the frequency of the unknown:

   a. Set a sub-harmonic on the 540B.

   b. Adjust Traveling Wave Tube helix voltage.

   c. Tune the harmonic generator until a beat appears at the detector.

Note: The 3 parts of step 2 are interdependent and may have to be repeated to obtain a beat from the detector.

Frequency Measurement

Complete instructions for frequency measurement with the 540B Transfer Oscillator are given in the instruction book. In all cases the Transfer Oscillator is adjusted for a zero-beat condition between some 540B harmonic and the unknown input frequency as

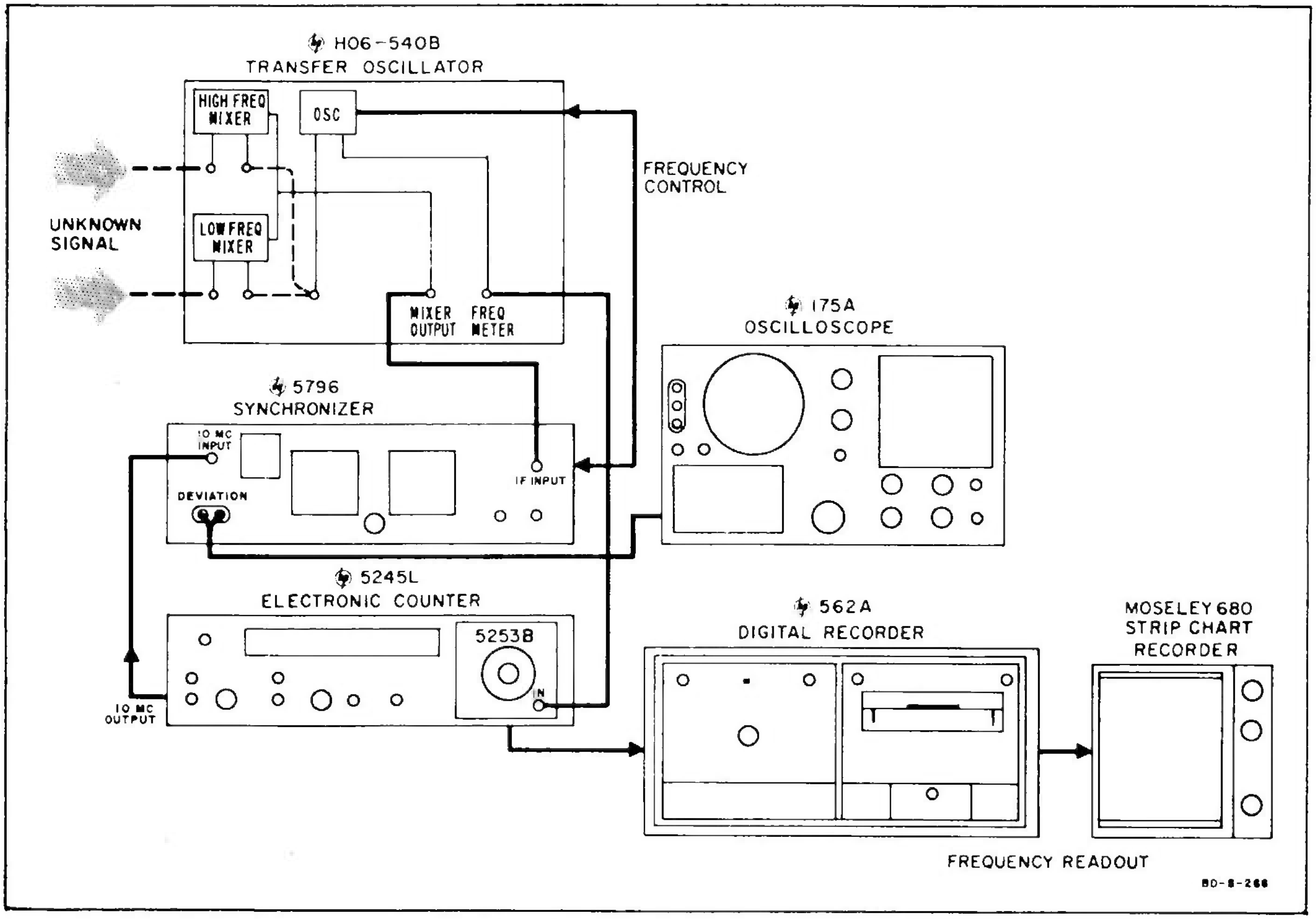


Figure 4. Frequency Measurement to 18 gc using the Dymec 5796 Synchronizer

observed on the oscilloscope. The fundamental frequency of the Transfer Oscillator is then read on the Model 524 Electronic Counter and multiplied by the proper harmonic number to give the frequency of the signal being measured.

In many cases the approximate frequency of the unknown signal will be known with enough accuracy to indicate the proper harmonic number. However, in case of doubt, or if the unknown frequency cannot be approximated, the harmonic number can easily be calculated. The Transfer Oscillator's fundamental is measured for two adjacent zero-beat conditions, and the harmonic numbers are calculated from the equations:

$$N_1 = \frac{F_2}{F_1 - F_2}$$

and $$N_2 = \frac{F_1}{F_1 - F_2}$$

Where N_1 and N_2 are the harmonic numbers of F_1, the higher, and the F_2, the lower, of the two adjacent fundamental frequencies.

Greater care must be used when measuring higher frequencies because of the progressively closer spacing and decreasing strength of the harmonics from the Transfer Oscillator. In some cases, the Traveling Wave Tube Amplifier recommended for measurements above 18 gc might prove worthwhile at lower frequencies if difficulties are found in making accurate readings because of low signal level. However, accurate results are relatively easy to achieve since the Transfer Oscillators have high stability and the Counter/Converter combination provides up to nine-digit resolution.

As an example of resolution at higher frequencies, consider a measurement which might be made at 18 gc. If the 83rd harmonic of the Transfer Oscillator were used for this measurement, typical readings would be:

540 fundamental frequencies

F_1 = 219.512 mc

F_2 = 216.867 mc

F_3 = 214.286 mc

Then N_2 (harmonic number of F_2) would be

$$\frac{F_1}{F_1 - F_2} = \frac{219.512}{2.645} = 83$$

$$\frac{F_3}{F_2 - F_3} = \frac{214.286}{2.581} = 83$$

Therefore

$$F_{unknown} = 83 \times F_2 = 83 \times 216.867 = 18 \text{ gc}$$

As a further check

82 x 219.512 = 18 gc

83 x 216.867 = 18 gc

84 x 214.286 = 18 gc

This example shows that an error in harmonic order will be detected easily, even if computations are made on a ten-inch slide rule.

Measurement Accuracy

Accuracy of measurement is influenced in general by the following:

- Signal Stability
- Accuracy of Zero Beat
- Stability of 540B Frequency Output
- Accuracy with which 540B fundamental is measured

Excellent setability and flexible presentation of the 540B make possible comparison with "clean CW Signals" to 1 part in 10^7.

Short term stability of the 540B is specified as 20 parts per million per minute after only 30 minutes warmup. When temperature becomes stabilized, stability may be expected to increase by at least an order of magnitude. Since measurement of fundamental usually requires only one second, 540B stability is rarely significant, and measurement of the 540B fundamental to 1 part in 10^7 or better, several orders of magnitude better than with wavemeters, is easily made. Summed up, the particular factors that would influence accuracy could be stated as: ± time base accuracy of counter, ± zero beat resolution, ± short term frequency drift of 540B Oscillator.

System accuracy, therefore, is usually limited by the stability of the signal being measured. If noise, frequency modulation, amplitude modulation are high, this system often provides the only means of accurate measurement.

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