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Measurements to 100 Megacycles with the -*hp*- Frequency Counter

THE -*hp*- Model 524A Frequency Counter has substantially simplified measurements of frequency wherever it has been used. To measure frequencies up to 10 megacycles with the 524A, it is only necessary to connect the unknown frequency to the counter. The counter does the rest, displaying the measured frequency quickly and accurately on a direct-reading digital system. The counter is in wide use in laboratory and production frequency measurement applications in which non-technical personnel easily make precision frequency measurements that formerly required skilled personnel using a combination of several instruments.

The 524A circuits directly count frequencies as high as 10 megacycles, the highest frequency capability of any commercially-available counting circuits. Nevertheless, the inherent attractiveness of the counter method has generated a wide demand to extend the method to much higher frequencies. Thus far, this has not seemed practical in commercial instruments although under laboratory conditions counters can be made to operate considerably above 10 megacycles.

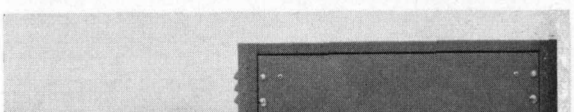

Fig. 1. *New -hp- Model 512A Frequency Converter at left above extends frequency measurements with the -hp- 524A Frequency Counter to 100 megacycles while retaining simplicity and accuracy of frequency counter method. See also Fig. 4.*

It is practical, however, to provide a simple, straightforward heterodyne device to enable the counter to be used with frequencies as high as 100 megacycles. Such a device is the -*hp*- Model 512A Frequency Converter shown in Fig. 1. This converter subtracts an integral multiple of 10 megacycles from the frequency to be measured and provides the remainder at its output terminal to be measured by the counter. For example, if a frequency of, say, 98.75 megacycles is to be measured, the converter will subtract 90 megacycles from this value and will pass 8.75 megacycles to the frequency counter. Since the 8.75-megacycle value is within the 10-megacycle capacity of the counter, the counter will display this value directly. To determine the unknown frequency, then, it is only necessary to add the frequency counter reading to the value subtracted by the converter. This addition can easily be performed mentally, because the converter directly indicates the frequency value it has subtracted and because this value is always an integral multiple of 10 megacycles. Thus, the operation of the equipment is still very simple and non-technical production personnel can make frequency measurements to 100 megacycles quickly and accurately.

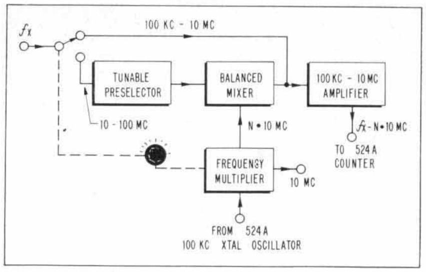

Fig. 2. *Basic circuit arrangement of converter.*

OPERATION

Fig. 2 shows the general circuit arrangement of the converter. The frequency to be measured is applied through a tunable preselector to the mixer stage. The difference frequency resulting from mixer action is applied to the video amplifier and thence to the output terminal of the converter. The local oscillator frequencies for the mixer are integral multiples of 10 megacycles which are obtained by multiplying the output of the precision 100 kc oscillator in the 524A counter. The multiplied frequencies thus have the same accuracy as the 524A oscillator (1 part per million short term or 2 parts per million per week). A calibrated switch in the multiplier circuits selects the multiple of 10 megacycles necessary for proper converter use.

To operate the converter, the preselector is first tuned to the frequency to be measured. An electron ray tube mounted at the front panel indicates when the preselector is tuned. The controls on the preselector are calibrated so that, instead of indicating directly the unknown frequency, they indicate the multiple of 10 megacycles that should be selected by the frequency multiplier switch.

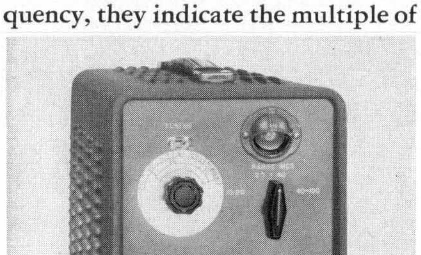

Fig. 3. *Panel view of new -hp- Model 512A. Dual type indicator tube is used to indicate both preselector tuning and output voltage level.*

Measuring frequencies with the equipment thus reduces to three simple steps: (a) measuring the approximate frequency with the preselector, (b) setting the selector switch to the proper multiple of 10 megacycles, and (c) adding the reading of the 524A counter to the frequency indicated by the frequency multiplier switch.

MEASUREMENT TECHNIQUE

In any heterodyne system in which the local oscillator frequency is close to the heterodyned frequency, there is possibility for ambiguity. Thus, when measuring a frequency of, say, 49.98 megacycles, the preselector will indicate only that the frequency is approximately 50 megacycles. If the local oscillator switch on the converter is then set to 50 megacycles, a reading on the counter of 0.02 megacycles should be obtained. The question is whether this reading should be subtracted or added to the 50-megacycle local oscillator frequency.

This example demonstrates that the system should be designed so that the local oscillator frequency will not be worked close to the frequency to be measured. For this reason the lower frequency limit for the output amplifier in the converter has been designed to be approximately 100 kc. So that holes will not occur in the measurement range, then, the preselector tuning control is calibrated in such a way that the local oscillator frequency will not be selected to be within 100 kc of the unknown. Thus, the dividing points on the tuning dial in Fig. 3 correspond to unknown frequencies of 10.1, 20.1, 30.1, etc., megacycles. As a result, the counter readings will always lie between 100 kc and 10.1 megacycles.

This arrangement calls for a special technique when measuring a frequency that lies on or very near the dividing lines on the preselector tuning dial. In such cases the local oscillator switch should always be set to the lower of the two possible local oscillator frequencies as a first approach. If a frequency of 60.05 megacycles were to be measured, for example, the local oscillator selector switch should be set to 50 megacycles so that a counter reading of 10.05 megacycles would be obtained. The measurement can be double-checked, if desired, by setting the local oscillator to 70 megacycles, in which case a reading of 9.95 megacycles would occur. Subtracted from 70 megacycles, this again gives the value of the unknown as 60.05 megacycles.

MEASUREMENT ACCURACY

Use of the converter with the 524A counter does not reduce the accuracy with which measurements can be made. The function of the converter is to multiply the counter oscillator frequency and subtract the multiplied value from the unknown. Since multiplication does not change the accuracy of the standard frequency, the converter does not change the accuracy of the overall measurement.

The counter is accurate within 1 count ±2 parts per million per week. The possible error of 1 count is an irreducible error that is inherent with any discrete gate operating with an arbitrary frequency. The possible error of 2 parts per million per week is the tolerance in the operation of the precision crystal-controlled oscillator in the counter. This possible error can be reduced where there is available a frequency standard of higher accuracy than the oscillator in the counter. The counter is provided with a special terminal to accommodate such an external standard.

SENSITIVITY AND FREQUENCY RANGE

When working with frequencies in the megacycle region, it is common that the available voltage levels are rather low when considered from a measurement standpoint. For this reason the sensitivity of the converter has been made relatively high. At frequencies above 10 megacycles, an input to the converter of 10 millivolts will result in sufficient converter output (1.4 volts rms) to operate the 524A counter. The input impedance of the converter at 10 megacycles and above is approximately 50 ohms.

As stated earlier, the higher frequency limit for the converter is 100 megacycles. The lower frequency limit, however, has been designed to extend down to 100 kc, considerably below the 10-megacycle capacity of the counter. This arrangement makes the converter especialy convenient for applications such as crystal-grinding work where the entire range of crystals from low frequency units to high frequency overtone type crystals can be measured without changing any connections in the measurement set-up*.

In the region from 100 kc to 10 megacycles the 512A operates as an amplifier rather than a converter. In this range the preselector is switched out of the circuit with the result that a minimum input voltage of 0.1 volt is required. The input impedance in this range is approximately 1000 ohms.

10-MEGACYCLE OUTPUT

One of the special features of the converter is that it provides at all times a 10-megacycle frequency for external use. This frequency is obtained by multiplying the 100 kc standard frequency supplied by the counter and thus has the same accuracy as the counter oscillator. If an external standard is used, the 10-megacycle frequency will have the same accuracy as the external standard.

*Correspondence invited where higher frequency ranges are desired for the converter.

> **1953 WESTERN ELECTRONIC SHOW AND CONVENTION**
>
> The annual Western Electronic Show and Convention will be held this year in San Francisco at the Civic Auditorium from August 19-21. This event is a combined trade show and IRE convention with more than 350 booth exhibits in the show and 25 technical sessions in the convention.
>
> The *-hp-* exhibit will be located in booths 1111 and 1112. You are cordially invited to visit these booths and to talk with *-hp-* engineers. On display will be the new Model 512A described in this issue together with many other *-hp-* instruments.

The 10-megacycle frequency is convenient for making a quick check of the precision of the gating circuit in the counter. The fast gate in the counter is accurate within 0.1 microsecond, and, since the counter is capable of counting at a 10-megacycle rate for sampling times up to 10 seconds, a total of 100 million counts can be measured. The precision of the fast gate can be quickly established by measuring the accurate 10-megacycle frequency from the converter for a 10-second interval. Since the 10-megacycle frequency is derived from the time base that operates the fast gate, the check is independent of the accuracy of the 100 kc oscillator in the counter or the external standard, as the case may be.

The 10-megacycle output is provided at a level of 2 volts rms into a 50-ohm load.

MULTIPLIER DESIGN CONSIDERATIONS

Considerable care is required in the design of a frequency multiplier when it is to be used with a precision frequency counter. Unless precautions are taken, multiplier circuits may introduce undesirable phase modulation. In many multiplier applications this modulation is not of prime importance, but in applications involving frequency counters it can lead to serious errors.

Phase modulation occurs in multiplier circuits primarily because of unequal attenuation of the a-m sidebands in the multiplied frequency. The a-m sidebands occur as a result of the fact that the multiplied frequency will be modulated by the fundamental frequency. If the selectivity characteristic of the multiplier attenuates one sideband more than another, phase modulation results.

The effect of phase modulation is to cause some cycles of the multiplied frequency to be expanded in time while others are compressed. This effect will be carried into the difference frequency produced by mixing the multiplied frequency with the unknown. Although the average number of cycles per second will not be changed, there is danger that the compressed cycles may oc-

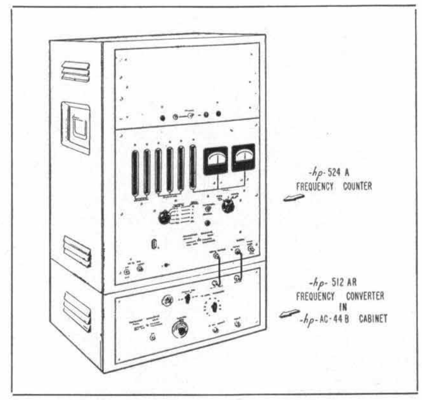

Fig. 4. *-hp- Model 512AR (rack-mounting style of Model 512A) can be mounted in -hp- AC-44B cabinet as shown above to make convenient bench installation.*

cur closer in time than the resolving time of the counter when high difference frequencies near 10 megacycles are being measured. Some cycles of the difference frequency would then be "lost" with resulting errors in the reading of the counter.

Even more important, however, is the case with the cycles of the difference frequency that are expanded in time. When low difference frequencies around 100 kc are being measured, the expanded cycles may cause the instantaneous difference frequency to fall below the nominal 100 kc cutoff of the output amplifier so that, again, some cycles would be lost.

If phase modulation occurs in any stage of a multi-stage multiplier such as is used in the converter, the frequency deviation in cycles per second will be increased by the multiplication factor of the remaining portion of the multiplier. In the design of the multiplier the limit for the deviation in the 90-megacycle local oscillator frequency was set at ±5 kc or 0.005% as being realistic. Therefore, no stage of the multiplier must introduce more than 0.01% of frequency deviation.

To insure that phase modulation is held to the extremely low value necessary if errors are to be avoided, several precautions have been taken in the design of the multiplier. First, the amount of amplitude modulation introduced by the multiplier circuits has been minimized by dividing the multiplier into four

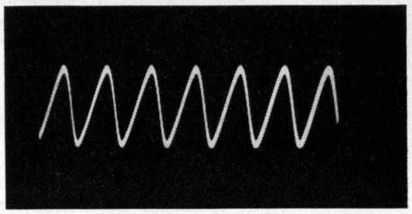

Fig. 5. *Oscillogram of 100 kc output from 512A obtained by mixing external 90.1-megacycle frequency with 90-megacycle converter frequency. Freedom from phase modulation indicated by relatively sharp trace obtained.*

stages so that no one stage multiplies by a large factor. In combination with this consideration, the tuned circuits in the multiplier have been designed with a reasonably high Q so that the decay in tank voltage from cycle to cycle is small.

Second, the coupling coefficient between the tuned circuits in the multiplier have been carefully controlled to achieve a sharp, symmetrical, and stable pass band characteristic. Coupling between the circuits has been made less than the critical value so that the resulting pass band characteristic will be narrow and will discriminate against the a-m sidebands that are generated. Further, inductive coupling between the tuned circuits has been avoided in favor of capacitive coupling which has two advantages for multiplier applications. First, the coupling coefficient depends on the values of capacitors in the network and is not influenced by the inductances. Second, the pass band characteristic can easily be adjusted to be symmetrical. By contrast, when coupled inductances are used at these frequencies, the coupling often becomes a combination of inductive coupling as well as capacitive coupling due to stray capacity between the coupled inductances. Such coupling does not have a symmetrical pass band so that one of the a-m sidebands would be affected more than the other.

The results of the design precautions are illustrated in the oscillogram shown in Fig. 5. Fig. 5 shows a 100 kc difference frequency produced by applying a 90.1-megacycle frequency to the converter. Freedom from phase modulation is indicated by the sharp oscilloscope trace obtained in the time exposure used in making the oscillogram.

—*Dexter Hartke*

SPECIFICATIONS
-*hp*-
MODEL 512A
FREQUENCY CONVERTER

FREQUENCY RANGE: As amplifier for -*hp*- 524A: 100 kc to 10 mc.
As converter for -*hp*- 524A: 10 to 100 mc.

INPUT VOLTAGE: Requires 0.01 volts minimum in range from 10 to 100 megacycles, 0.1 volts from 100 kc to 10 mc.

STANDARD MIXING FREQUENCY: Multiplies 100 kc output of -*hp*- 524A frequency counter; accurate within 1 part in 10^6 short term or 2 parts in 10^6 per week.

OUTPUT VOLTAGE: On minimum rated input, provides 1.4 volts rms (required voltage to operate 524A frequency counter). 4 volts rms maximum output.

10-MEGACYCLE OUTPUT: Provides special 10-megacycle output at same accuracy as standard 100 kc frequency applied to converter; supplied at level of 2 volts into 50 ohms.

IMPEDANCE LEVEL: Input and output, approx. 50 ohms except input is approx. 1000 ohms below 10 mc.

CONNECTORS: Both input and both output connectors are BNC type jacks.

ACCESSORIES FURNISHED: Two 5-foot cables (one with 50-ohm termination) supplied in addition to attached power cord. Cables provided with BNC type plugs.

POWER: Operates from nominal 115-volt, 50/60 cycle source; requires approx. 100 watts.

PHYSICAL CHARACTERISTICS:
Cabinet mount: grey panel, wrinkle finish case, approx. 7" wide x 11" high x 14" deep; net weight 26 lbs.; weight packed, 36 lbs. Specify -*hp*- 512A. *Rack Mount:* grey panel, approx. 19" wide x 7" high (std. RTMA panel) x 14" deep; net weight 32 lbs.; weight packed, 42 lbs. Specify -*hp*- 512AR.

AVAILABLE ACCESSORIES

MATCHING CABINET FOR -hp- 524A: wrinkle finish, approx. 22½" wide x 9" high x 16" deep. Attaches securely to bottom of -*hp*- 524A cabinet. Net weight 24 lbs.; weight packed, 34 lbs. Specify -*hp*- AC-44B.

Includes: (1) Necessary cables to interconnect -*hp*- 524A and -*hp*- 512A.

(2) Conversion kit for low-serial -*hp*- 524A, to provide BNC connector output for 100 kc mixing frequency (where required).

PRICE: -*hp*- 512A Frequency Converter, $350.00.

-*hp*- 512AR Frequency Converter, rack-mount $355.00.

-*hp*- AC-44B Cabinet, $20.00.
Prices f.o.b. Palo Alto, California
Data subject to change without notice.

NEW REPRESENTATIVES APPOINTED

Effective July 1, 1953, the following representatives were appointed for the northeastern part of the United States. The engineers staffing these offices are all thoroughly familiar with electronic measurement problems and have represented -*hp*- in their areas for many years.

GREATER NEW YORK AREA INCLUDING NORTHERN NEW JERSEY:

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Mr. Pete Lahana

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HORMAN ASSOCIATES
with offices at

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2017 "S" Street, N.W.
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