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ALSO APPLIES TO OUR NEW MODEL 578

APPLICATION NOTE 201

Automated Frequency Measurement of Millimeter Waves

Accurate Measurements to 110 GHz

The trend toward higher microwave frequencies, in both military and civilian applications, has naturally produced a demand for instruments with higher frequency ranges. In general, manufacturers of counters have responded by "stretching" the upper frequency limits of their instruments by one band at a time — say, from 18 to 26.5 GHz.

Now, however, EIP Microwave has introduced a modular, microprocessor-based measuring system that can be equipped for accurate frequency counting in any or all bands. The measurement range is from 10 Hz to 110 GHz — and the accuracy at 110 GHz is the same as it is at the lower frequencies. Moreover, the modular design of the system permits a user to expand the frequency range as required, without buying unnecessary capability. The frequency range can be expanded to the full 110 GHz simply by adding auxiliary modules.

Based on EIP's popular 548A Microwave Counter, the new system uses an automated heterodyne technique to make millimeter-wave frequency measurements in about one second. Not only does the system provide laboratory-quality measurements, but is so easy to operate that it is ideal for use by production personnel with minimal training.

Previous Methods

Since most microwave counters have an upper frequency limit that is typically 18 or 26.5 GHz even when internal heterodyne down-conversion is used, measurements at higher frequencies have often been both laborious and inaccurate. One traditional approach is to use a wavemeter — a tuned cavity which absorbs signal power at its resonant frequency. Of course, as frequencies increase, cavity dimensions become smaller, and mechanical tolerances become more critical. As a result, a wavemeter used to measure frequencies in the 100 GHz range can easily provide a reading that is in error by as much as 100 MHz (0.1 percent). While careful calibration can reduce the error, the wavemeter method lacks the accuracy required in many applications, and can also be quite time-consuming.

Another common technique is to use a transfer oscillator. Here, both a known local oscillator (LO) signal and the unknown signal are fed to a phase detector whose output signal controls the LO frequency, tuning it for a zero-frequency output from the phase detector. At this point, the unknown frequency is equal either to the LO frequency or one of its harmonics. This technique provides better accuracy than the wavemeter, but requires a high level of technical skill. Not only is the test set-up difficult, but the operator must take extreme care to identify which of the local oscillator's harmonics matches the unknown frequency. For example, is it the 15th or the 16th harmonic?

The Heterodyne Technique

Another widely used approach is the heterodyne method (sometimes called "harmonic heterodyne"). In this technique, the unknown frequency is mixed with the harmonic of a known local oscillator signal to produce a signal in a defined intermediate-frequency (IF) range. This IF signal can then be down-converted by the counter for direct measurement.

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The theory is relatively simple. In mathematical terms:

$$F_x = \text{harmonic} \times \text{LO freq} \pm \text{IF} \tag{1}$$

(where F_x is the unknown frequency)

For example, suppose the LO frequency is 6 GHz, the unknown frequency is expected to be in the 100 GHz region, and the IF range is ± 250 MHz centered at 1.1 GHz. (These are typical parameters for an operator doing the job manually with hardware such as that built into a spectrum analyzer.) It will be necessary for the operator to determine:

1. Which harmonic of the LO frequency is producing the IF that is being counted.
2. Whether the IF should be added or subtracted to find the unknown frequency.

The answers to both questions can be found by manually stepping the LO frequency. If a change of 1 MHz in the LO frequency moves the IF by 16 MHz, the desired harmonic is the 16th; if the change is 17 MHz, the harmonic is the 17th, and so on.

Whether one should add or subtract the IF depends upon the way the received IF moves in relation to the change in the LO frequency. Suppose a 1 MHz change in the 6 GHz LO frequency increases the IF by 17 MHz. Obviously, this identifies the harmonic as the 17th (102 GHz), as indicated in Figure 1. Such a change also shows that the unknown frequency is lower than 102 GHz. In other words, the difference between the 17th harmonic and the unknown frequency is the IF. As the LO frequency (and hence its 17th harmonic) increases, and the unknown remains the same, the difference between them increases — thus the IF also increases. This solves the problem of the ± sign in Equation 1 — subtract the IF:

$$F_x = 17 \times 6\text{ GHz} - 1.1\text{ GHz}^* \tag{2}$$

$$F_x = 102\text{ GHz} - 1.1\text{ GHz}$$

$$F_x = 100.9\text{ GHz}$$

(* assuming measured IF = 1.1 GHz)

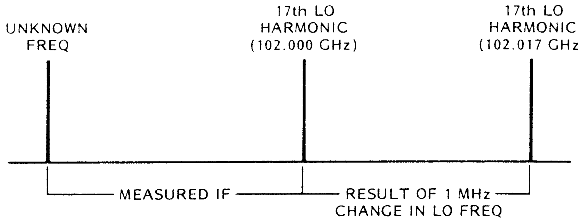

FIGURE 1

Had the IF *decreased* with an increase in the LO frequency, the procedure would have been to *add* the IF, rather than subtract it. Either way, this technique can provide extremely accurate results, depending upon two important factors: The first is the skill of the operator in establishing the proper test setup, in understanding both how to identify the appropriate harmonic, and how to decide whether to add or subtract the IF to find the unknown frequency. The second factor, of course, concerns equipment accuracy. How precisely can the LO frequency be adjusted? A slight error is magnified 17 times when the operative harmonic is the 17th. As for measuring the IF, this is not usually a problem; most microwave counters can down-convert it internally for direct counting.

Of course, the problems with the manual heterodyne technique are similar to those encountered with the other methods mentioned: The process is extremely time-consuming, and requires a highly skilled operator. An engineer in a laboratory can use such methods, but often at the expense of considerable development time. In a production environment, however, such techniques are virtually useless because of the high skill level required.

Automating the Heterodyne Process

Several years ago, the technology of microwave counters reached the practical frequency limit for direct signal inputs. EIP Microwave's Model 548A is typical in that respect. It can accept frequencies up to 26.5 GHz, down-converting them internally for counting and direct digital readout. But, in another respect, the 548A is *not* typical. It was designed "from scratch" as part of a modular system that would be able to handle increasingly higher frequencies as new applications demanded.

For the higher frequencies, the 548A uses essentially the heterodyne process described earlier, except that the internal microprocessor does virtually all the work. It determines which is the appropriate harmonic of the LO; it decides whether to add or subtract the IF (and makes the calculation); and it presents a direct, 12-digit readout of the unknown frequency. Someone with minimal training can get an accurate frequency reading in about one second — compared to perhaps an hour of an engineer's time by the older methods.

The first phase of EIP's frequency extension program permitted the 548A to count frequencies up to 40 GHz. Modules now available cover all bands up to 110 GHz. Moreover, it is not necessary to buy a new instrument to get this expanded frequency capability. Users of existing 548A's may (depending upon the options included in the instrument) either add external waveguide modules in the field or return the instrument to the factory for retrofit of the required internal circuitry.

How It's Done

For measurements in the frequency range of 1 GHz to 26.5 GHz, the Model 548A uses a YIG-tuned heterodyne converter to produce an internal IF of approximately 125 MHz. The IF is then counted directly. For frequencies above 26.5 GHz, an external waveguide mixer provides the first down-conversion step — to about 1 GHz. This signal is then fed to the counter's microwave input, where it undergoes the normal internal down-conversion to the 125 MHz IF of the counter.

As shown in Figure 2, the 548A provides the LO signal to the remote sensor (an external mixer), through a short length of cable. The mixer generates harmonics of the LO frequency and combines them with the unknown frequency to produce the first IF (which is sent to the counter via the same cable). There a diplexer separates the LO and IF signals. Thus, the unknown signal goes only as far as the remote sensor, and the cable carries only signals of relatively low frequency.

The LO signal is produced by a VCO (whose output frequency is referenced to the counter's internal time base) and a multiplier chain. The result is an LO signal of 5.28 to 6.0 GHz which is sent to the remote sensor. The first IF frequency from the sensor is in the range of 1.0 to 1.35 GHz.

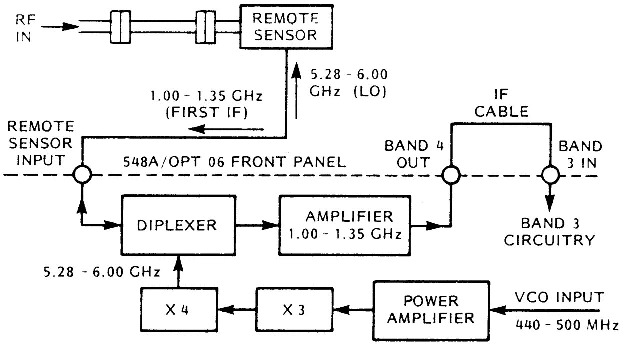

FIGURE 2

In principle, this basic heterodyne process is similar to the manual technique; the difference is that the 548A does it automatically. The microprocessor controls both the front-end YIG filter and the VCO. By varying the LO frequency and the filter frequency, the microprocessor is able to establish:

1. Which harmonic of the LO frequency is producing the IF.
2. Whether that harmonic is above or below the unknown frequency. (This tells the microprocessor whether to add or subtract the IF.)

As a result, the microprocessor is able to compute the approximate RF input frequency. From there, the process is simply a matter of down-converting the first IF so that it can be counted at the internal 125 MHz IF. Of course, the microprocessor also handles the calculations necessary to interpret the counted IF and display the unknown frequency directly. The entire process, shown in the block diagram of Figure 3, takes about one second.

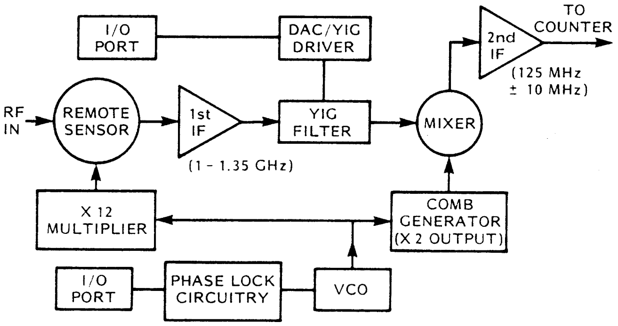

FIGURE 3

Simplicity of Operation

Unlike some microprocessor-controlled instruments, the EIP Model 548A requires no programming ability on the part of the operator. The front panel controls are much like those of any other counter, with front panel connections for four frequency bands:

Band 1:	10 Hz to 100 MHz (1 Meg, 20 pf).
Band 2:	10 MHz to 1 GHz (50 ohms).
Band 3:	1 GHz to 26.5 GHz (50 ohms).
Band 4:	Extended Frequency Options (for frequencies above 26.5 GHz).

Once the remote sensor is coupled to the waveguide carrying the unknown signal, only two cables are required. One connects the

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remote sensor to the REMOTE SENSOR input; the other connects the BAND 4 output to the BAND 3 INPUT. Band selection is then simply a matter of pressing the appropriate front panel keys to match the "Select Band" to the remote sensor in use (see Table 1).

In the event that an inexperienced operator should mismatch the select band and the remote sensor (say the operator sets-up Select Band 41 when the 60-90 GHz sensor is installed), the instrument will not be damaged, nor will it provide an erroneous reading — the display will simply indicate all zeros.

The Modular Approach

The key to the 548A's universal appeal is its "from-the-ground-up" design, that not only accommodates direct inputs from 10 Hz to 26.5 GHz, but also accepts the five extended frequency ranges. For extended frequency applications, only two options are required:

1. Option 06 — which is the internal frequency generator that provides the LO signal to the remote sensor. This option can be ordered routinely with a new instrument, or the factory can retrofit it to existing 548A's.
2. The Model 590 Frequency Extension Cable Kit — equipped with at least one of the remote sensors (Options 91-95).

As shown in Figure 4, the Model 590 Kit is packed in a convenient carrying case. It includes the two cables necessary for the test set-up, and can accommodate all five of the remote sensors that are available for extended frequency operation (see Table 1).

FIGURE 4

This modular approach has an obvious economic advantage in that the user pays only for the capability that is initially required. If in the future it becomes necessary to measure frequencies in certain additional bands, that capability can be added selectively as required — the software is already programmed into the 548A's microprocessor.

For More Information

The best way to fully appreciate the unique capability of the EIP 548A with its extended frequency option, is to see it in operation. For a demonstration, contact your nearest EIP representative, or EIP directly.

OPTIONS	91	92	93	94	95
548A/578 Select Band	41	42	43	44	42, 43
Waveguide Band	KA	U	E	W	V
Range	26.5–40 GHz	40–60 GHz	60–90 GHz	90–110 GHz	50–75 GHz
Sensitivity (typ)	−25 dBm	−25 dBm	−25 dBm	−25 dBm	−25 dBm
Waveguide Size	WR-28	WR-19	WR-12	WR-10	WR-15
Waveguide Flange	UG-599/U	UG-383/U	UG-387/U	UG-387/U	UG-385/U
Max. Input (typ)	+5 dBm	+5 dBm	+5 dBm	+5 dBm	+5 dBm
Damage Level	+10 dBm	+10 dBm	+10 dBm	+10 dBm	+10 dBm

TABLE 1

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