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# 4

# Hints for making Better Microwave Counter Measurements



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With the advancement of technology, there is an increasing tendency for measurement tools to overlap each other's capabilities. Spectrum analyzers can now measure frequency (a function once reserved for counters), microwave counters can now measure power (a function once reserved for power meters), universal counters can now measure microwave frequencies (a function once reserved for microwave counters), and so on. Furthermore, this same advancement in technology in general has created unique measurement problems. This note will deal with some of these measurement issues for microwave counters.

There are several types of counters that can make microwave frequency measurements:

- Universal counters (timer/counters) and RF counters (frequency counters) can now extend their frequency measurement capability into the low to mid microwave range (usually to 5 GHz, and in some cases to 12.4 GHz).

- Continuous Wave (CW) microwave counters typically measure frequency to at least 20 GHz, and to as high as 50 GHz. Most of these counters can make power measurements as well, using the same input for both frequency and power measurements.

- CW microwave counter/power meters are a combination of a microwave frequency counter and a true power meter in one package. Frequency and power measurements are made using separate inputs. Power is measured with an external power sensor, yielding a more accurate measurement.

- Pulse and CW microwave counters measure pulsed microwave signals (typically found in military applications) as well as CW signals.

Since CW microwave counters are far and away the most popular of these types of microwave counters, this note will deal primarily with them.

# When to use a Microwave Counter versus a Spectrum Analyzer

A spectrum analyzer is a powerful instrument that is considered by most to be a basic microwave tool. However, using a spectrum analyzer to make microwave frequency measurements may not be the optimum solution. Purchasing a microwave counter is definitely the more economical decision. Typically, a 20 GHz spectrum analyzer is at least three times the price of a 20 GHz microwave counter: a high premium to pay if the requirement is only for measuring the frequency of microwave signals.

A microwave counter can offer several other advantages as well. If high resolution frequency measurements and/or rapid measurement times are required, a microwave counter will always yield a 1 Hz resolution in 1 second. Not all spectrum analyzers will. Of course a counter is easier to use, especially for novices. The size and weight of a counter are generally less than those of a spectrum analyzer, making counters a truly field-portable instrument when an internal battery is added. The HP 53150 Series Microwave Counters are good examples of all of these points.



# HINT

# 2

## Measuring Digitally Modulated Signals

Measuring the carrier or center frequency of a modulated signal with a microwave counter has always been a difficult task. If frequency modulation (FM) was used, the accuracy of the measurement was related to both the modulating signal's symmetry and the linearity of the modulator, neither of which were typically well known prior to making the measurement. With amplitude modulation (AM), the signal always needed to be within the counter's sensitivity, making pulse-modulated or single-sideband signals almost impossible to measure without special techniques, often involving delay lines or envelope detection. These difficulties resulted in a classic rule-of-thumb: either the carrier's modulation must be turned off (thereby interrupting service) or the signal must be measured prior to modulation. This rule-of-thumb still has merit with digitally modulated signals.

Modern digital modulation is a combination of AM, phase modulation, and often pulse modulation. The latter is employed in Time Division Multiple Access (TDMA) plans where each user is assigned not only a specific channel frequency, but also a specific time slot during which transmission is allowed. The most typical implementations of this TDMA technique are the NADC (US), PHS/PDC (Japan) and GSM (worldwide) standards which are applied to cellular/PCS and wireless local loop (WLL) implementations for both voice and data.

In addition, the signal spectrum is often deliberately spread using either frequency hopping (FHSS) or a pseudorandom sequence (CDMA). The former is used in several wireless local area network (WLAN) implementations and the latter is the heart of the various CDMA networks including WLAN, cellular/PCS, and low earth orbit satellite (Iridium and Globalstar).

Digitally-modulated signals represent special problems for measuring the carrier frequency with any degree of accuracy. Figure 1 (a, b, and c) shows the typical spectrums of three of these signals: PHS, NADC and GSM. Each one of these standards uses different data rates, modulation schemes and spectrum shaping filters that result in different degrees of uncertainty when measuring the signal. Since a microwave counter displays an average frequency during its measurement (gate) time, longer gate times will result in better accuracy if the transmitted data is truly random. If it is not (due to either the data itself or an imperfect modulator), the spectrum is skewed to one side or another resulting in an unpredictable reading bias. This bias would, at first glance, seem like an insurmountable measurement problem. However, it can be used to actually improve the measurement accuracy under certain circumstances.

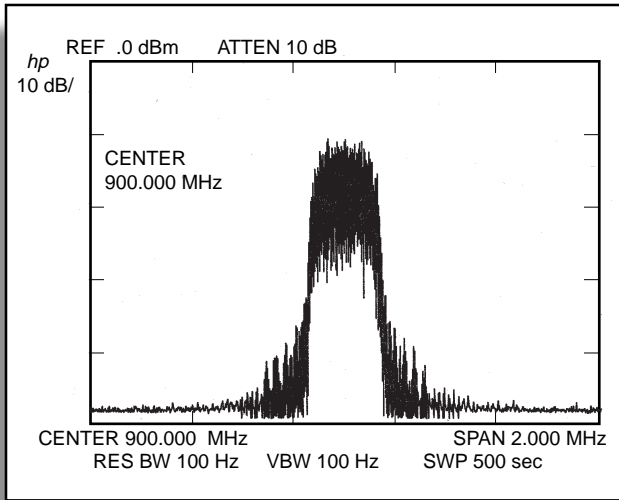


Figure 1a. PHS typical spectrum

To understand why, it is useful to consider that the modulator typically used in digital modulation schemes is a quadrature modulator. This type of modulator is essentially a single sideband, suppressed carrier modulator. When presented with an all-zero data stream, the spectrum basically becomes a single-tone (sideband) with a suppressed carrier. The offset of this sideband from the suppressed carrier is related to the data rate and the modulation scheme employed, but it is always fixed in any given digital standard. This is graphically illustrated in Figure 2 where a GSM spectrum is shown with all zeros as data. The single sideband is precisely offset one quarter of the bit rate (67.708 kHz or 270.833 kb/s divided by 4) above the suppressed carrier. Thus, the exact carrier frequency can be calculated easily by measuring the sideband itself, assuming the data rate is known and the data can be set to all zeros.

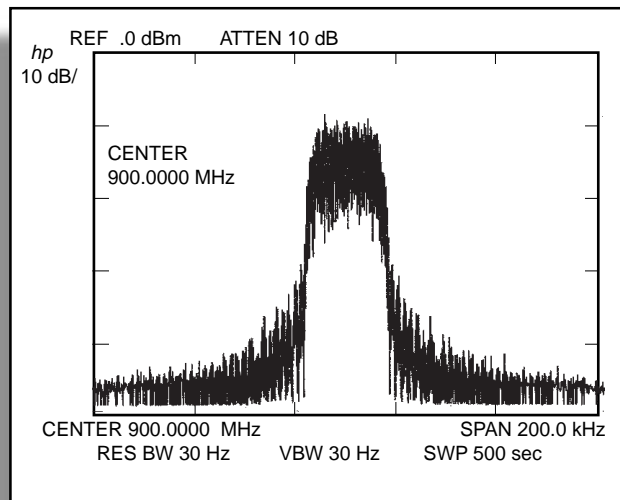


Figure 1b. NADC

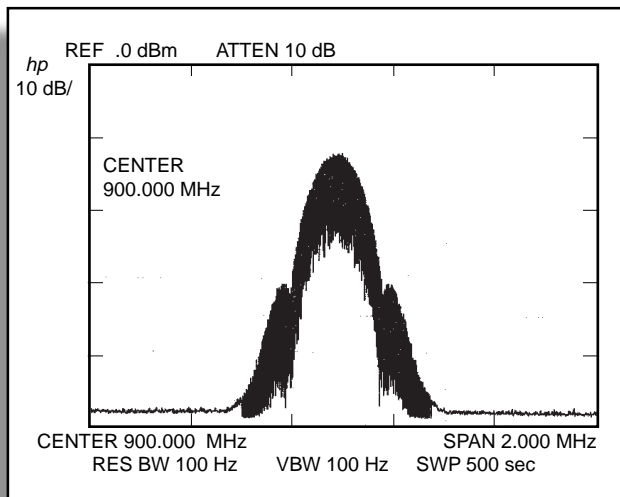


Figure 1c. GSM

A modern microwave counter, like the HP 53150 Series Microwave Counters with “offset” capability, can perform this calculation automatically. For transmission standards which use other modulation techniques, the offset is similarly fixed and predictable as summarized in Table 1.

Another factor to consider when employing this “all zero” technique is whether or not the carrier signal is also being pulse modulated or burst (TDMA standards only). The direct measurement of such a burst signal must be made with a counter capable of pulse measurements. Alternatively, the frequency can be measured before the pulse modulator by a CW microwave counter.

Spread spectrum systems cannot be measured using this technique as the spreading method (CDMA or FHSS) inherently interferes with the measurement. For these systems a microwave counter will only measure the approximate center value of the assigned channel.

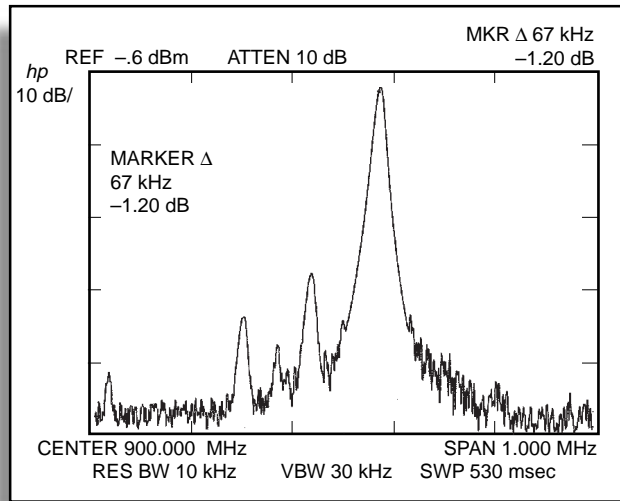


Figure 2. GSM spectrum with an “all zeros” pattern

Table 1

Standard	Modulation Type	Data Rate	All Zero Sideband
GSM	GMSK	270.833 kb/s	Data Rate/4 above (+67.708 kHz)
NADC	$\pi/4$ DQPSK	48.608 kb/s	Data Rate/16 above (+3.038 kHz)
PHS	$\pi/4$ DQPSK	384 kb/s	Data Rate/16 above (+24 kHz)
PDC	$\pi/4$ DQPSK	42 kb/s	Data Rate/16 above (+2.625 kHz)
DECT	GFSK	1152 kb/s	Data Rate/4 below (-288 kHz)
TETRA	$\pi/4$ DQPSK	36 kb/s	Data Rate/16 above (+2.250 kHz)

# Making Sense of Power Measurements with a Microwave Counter

Most CW microwave counters have the ability to measure the input signal's microwave power as well as its frequency. Typically, a Schottky diode is used as the power sensing device. This diode is part of the sampler downconversion assembly, which converts the microwave signal to an intermediate frequency that the counter actually counts. The effective match (SWR) is limited by the entire complex sampler structure. As a result, the typical match of a microwave counter is inferior to that of a power meter sensor, which has only a single diode or thermocouple device in its microwave structure.

In addition, as the power measurement and downconversion of a microwave counter are done virtually at the front panel input connector, a cable must be used to bring the signal to the instrument's input. This cable adds its loss and match characteristics to the measurement, a factor typically not part of power measurements using a microwave power meter. It is clear that the match and, therefore, the accuracy of a power measurement using a microwave counter cannot be as accurate as that of a microwave power meter.

Nevertheless, the HP 53150 Series Microwave Counters still make very useful power measurements. With short, high-quality cables, typical overall measurement accuracy can be better than

$\pm 2.5$  dB up to about 20 GHz. The key to this accuracy is the careful factory calibration of the counter's power measurement with respect to both frequency and level. For example, the counter diode's frequency response is measured every 50 MHz from 50 MHz to the counter's maximum frequency: approximately 400 points for a 20 GHz counter and almost 1,000 points for a 46 GHz counter. Since the counter measures the frequency of the incoming signal, it is a simple matter of the internal microprocessor making the adjustment for the power measurement diode's frequency response. This is the reason the counter *must* make a frequency measurement before it can make a power measurement. Without the frequency measurement, the correction for frequency response of the power measuring diode would not be known and the resulting measurement uncertainty could be quite large.

Since a microwave counter operates over a typical input power range of +10 to -30 dBm, its power-sensing diode operates over a similar range. Unfortunately, over this range the diode goes from square law to linear characteristics with a transition zone in between. Rather than trying to correct this mathematically via a complex polynomial, a power-calibration look-up table is stored in the counter's memory. This table characterizes the actual

power sensing diode in the sampler in 1 dB steps over the 40 dB dynamic range at 4 to 6 frequencies (depending on the counter's frequency range). This ensures proper compensation for deviations from square law.

The result is that the accuracy of the HP 53150 Series' power measurements is quite good at the counter's input connector (better than  $\pm 1.5$  dB to 20 GHz over its 55°C operating range). When combined with a short, high-quality, microwave cable, measurement accuracies of better than  $\pm 2.5$  dB can be expected to about 20 GHz.

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## Improving the Accuracy of Counter Power Measurements

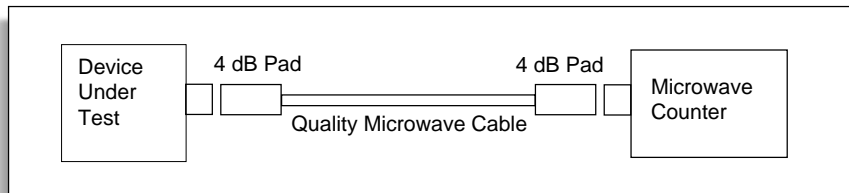
When better accuracies are required, a microwave counter may still be able to do the job. Several measurement techniques can be used to improve accuracy of the counter's power measurement. Improving the match of, or compensating for, the insertion loss of the cable associated with getting the desired signal to the counter can improve measurement uncertainties. These techniques typically improve the power measurement uncertainty at the test point to below  $\pm 1.0$  dB over a wide frequency range, and even better at low frequencies (below 3 GHz) or over narrow bandwidths (1 GHz or so).

The first of these techniques improves the match of the measurement by minimizing the interaction between the counter's input and the microwave cable connected to it. This involves putting a quality, fixed microwave attenuator (pad) between the input cable and the counter. A value as small as 3 dB is useful although 4 to 6 dB is preferred. For example, since the HP 53150 Series input match is typically 10 dB (2:1 SWR) to 10 GHz, a 3 dB pad improves it

to roughly 16 dB (1.4:1 SWR) while a 6 dB pad improves it to 22 dB (1.17:1 SWR). This assumes the match of the pad is much better than 25 dB. Since real-life, high-quality pads have a match of around 20 to 25 dB, more than about 6 dB of attenuation will not improve the effective match of the counter's input. Note that a 16 to 20 dB figure is the typical match of power meter sensors in this frequency range.

A similar pad at the test point will isolate the cable from the source to be measured. This preferred measurement technique is illustrated in Figure 3. The down side to this technique is that the signal level is reduced by the total attenuation of the test set-up: the insertion loss of the cable — up to 1.5 dB for a quality 1 meter cable at 10 GHz) plus the 2 pads (6-12 dB). Thus, the effective lower end of the measurement is reduced by roughly 10 dB, changing a  $-30$  dBm measurement limit to  $-20$  dBm, for example. If this amount of insertion loss is a problem, using a single pad at the worst SWR point (typically the counter) is an effective compromise.





**Figure 3. Recommended power measurement set-up.**

An alternative technique is to reduce uncertainty by calibrating the cable's insertion loss variation with frequency over the range of frequencies that are expected to be measured. This technique involves making an insertion loss measurement with a reference power meter at each frequency point of interest. This insertion loss can then be subtracted from the actual microwave counter's reading to improve measurement uncertainty. With the HP 53150 Series' unique Power Correction mode, the storage of the insertion loss data and subsequent subtraction can be done automatically. This mode stores up to 10 insertion loss/frequency points, then linearly interpolates between

these points should the measurement fall between them. Since nine different front-panel setups can be stored, characteristics for up to nine separate cables can be stored. Alternatively, a single cable with up to 90 calibration points can be stored.

Of course, the best possible measurement accuracy will be achieved by combining the above two techniques when possible.

# Hewlett-Packard CW Microwave Counter Selection Guide

- Three models:
  - HP 53150A 20 GHz Counter
  - HP 53151A 26.5 GHz Counter
  - HP 53152A 46 GHz Counter
- Simultaneous frequency and power measurements with analog peaking indicator. Power measurement accuracy to  $\pm 2$  dB and better.
- Power Correction mode for cable loss compensation.
- Truly field portable: small, lightweight, rugged, optional internal battery, optional soft carrying case.
- ATE ready: HP-IB and RS-232 interfaces standard, SCPI language programming, optional rack mounting kit.
- Laboratory features: frequency and power offsets, measurement averaging, relative (delta) frequency and power measurements, resolution and sample rate control, instrument set-up save and recall, optional oven timebase.

For further information, visit our web site at Access HP: <http://www.tmo.hp.com/> or call your local HP office and ask for the HP 53150 Series Product Overview.



HP's full-featured CW microwave counters for field, factory, or lab





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