Errata

Document Title: Signal Generator Output Attenuators (AN 20)

Part Number: 5989-6186EN

Revision Date: June 1965

HP References in this Application Note

This application note may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this application note copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

About this Application Note

We’ve added this application note to the Agilent website in an effort to help you support your product. This manual provides the best information we could find. It may be incomplete or contain dated information, and the scan quality may not be ideal. If we find a better copy in the future, we will add it to the Agilent website.

Support for Your Product

Agilent no longer sells or supports this product. You will find any other available product information on the Agilent website:

www.agilent.com

Search for the model number of this product, and the resulting product page will guide you to any available information. Our service centers may be able to perform calibration if no repair parts are needed, but no other support from Agilent is available.
One of the features which has made Hewlett-Packard Signal Generators so popular is their extremely wide and accurate output power levels. This output versatility is made possible by the attenuator in each signal generator output. For example, the Model 612A Output Attenuator provides an attenuation of up to 127 db with an accuracy of ±1 db. Since even precision attenuators such as the hp Model X382A do not match the performance of these signal generator attenuators, many engineers have asked how Hewlett-Packard achieves extreme accuracy over such a wide output attenuator range. The answer to the question lies in the type of attenuator which is used -- a waveguide-beyond-cutoff type.

The great advantage of this type of attenuator is that its attenuating depends primarily upon its geometrical dimensions. Thus when cutoff attenuators are very carefully constructed, great accuracies are possible. For example, at wavelengths longer than 3 centimeters accuracies as high as 1 part in 10⁴ have been achieved.

The simple relation between attenuation and geometrical dimension results from the behavior of a waveguide beyond cutoff. When a waveguide is excited by a frequency lower than its cutoff frequency, the excitation energy dies away exponentially with distance from the point of excitation (in other words, the decibels of attenuation increase linearly with distance from the excitation point).

The equation which expresses the relation between attenuation and waveguide dimensions is:

\[
(1) \quad \alpha = \frac{54.6}{\lambda_c} \sqrt{1 - \left(\frac{\lambda_c}{\lambda}\right)^2}
\]

where: \(\alpha\) is the attenuation per unit length (db)
\(\lambda_c\) is the cutoff wavelength
\(\lambda\) is the free space wavelength

If \(\lambda\) is much greater than \(\lambda_c\):

\[
(2) \quad \alpha = \frac{54.6}{\lambda_c}
\]

It has been shown² that for the TE₄₁ mode in circular waveguide,

\[
\lambda_c = 3.42 \ r
\]

where: \(r\) is the guide radius.

Substituting in (2)

\[
(3) \quad \alpha = \frac{54.6}{\lambda_c} = \frac{54.6}{3.42 \ r} = \frac{15.9}{r}
\]

Thus we see that the attenuation depends only upon the radius of the waveguide provided that \(\lambda >> \lambda_c\).

The next question that comes to mind is, how do variations in waveguide size in an actual attenuator affect attenuation? In a typical hp signal generator, the variation of waveguide size is held to less than 10 thousandths of an inch by extremely accurate manufacturing techniques. Using equation 3 we can show that this corresponds to an attenuation variation of less than 0.125 db out of 127.

The cutoff attenuator by itself then is an extremely accurate device. Hewlett-Packard has adapted this precise attenuator to a signal generator output attenuator system by delivering the RF oscillations to the cutoff waveguide where they are picked up by a probe and delivered to the front panel. The pickup probe is located in the waveguide and is driven along it through a gear by a knob located on the front panel. Since probe travel is a linear function of attenuation, the knob rotation can be calibrated directly in db.

Although the waveguide beyond cutoff type attenuators are designed for circular guide TE₄₁ mode operation, a TM mode may be excited in the 10 to 40 dbm range.

---


²In actual signal generators \(\lambda\) is actually sufficiently greater than \(\lambda_c\) to make attenuation independent of wavelength or frequency. For example, the Model 612A attenuator has a radius of 0.25 inch which corresponds to \(\lambda_c\) of 0.885. Using equation (1) above, the attenuation is 63,825 db/in at 450 mc (\(\lambda = 66.6\) cm) and 63,817 db/in at the upper frequency limit, 1200 mc (\(\lambda = 25\) cm). The total variation across the whole frequency range is then only 0.008 db/in. Since about two inches of travel is necessary to achieve 127 db, the variation of \(\lambda\) with frequency represents an attenuation variation of only about 0.016 db out of 127. Thus, we are justified in saying that attenuation is for all practical purposes independent of frequency and depends only upon waveguide dimension.
because of the coupling method used out of the oscillating cavity. However, a Faraday shield at the entrance to the "waveguide-beyond-cutoff" section, such as in the hp Models 614A and 620A, effectively reduces the effect of the TM mode. The attenuation characteristic of the TM mode, being about twice the TE\(_{11}\) mode, contributes negligible power to the probe beyond -40 dbm.

Thus, conventional power and attenuation measurement techniques, employing standard test instruments, can be used to verify signal generator output power and attenuation calibration.

In general\(^4\), calibration consists of first verifying actual power output vs frequency by measuring the output level with an accurate microwave power meter (such as hp Model 431) and appropriate thermistor mount (478A coax or 486A series waveguide mounts). This is performed at a "relatively high" power level (typically -7 to -10 dbm)\(^5\). Attenuator dial tracking can then be verified down to the -40 or -45 dbm power level using sensitive square-law detectors (such as hp 423A or 424A series crystal detectors, or barretters) in conjunction with a high sensitivity, tuned voltmeter such as the hp 415 Standing Wave Indicators. The SWR Indicator actually is an audio frequency attenuation standard calibrated for use with a square-law detector; thus detector conformance to square-law is the major determinant of measurement accuracy.

A variation of this technique is to install a precision variable RF attenuator between the signal generator and detector so that attenuation in the external RF attenuator is reduced as the signal generator output level is attenuated. A constant reference is maintained on the 415 SWR Indicator, and the Signal Generator attenuator's calibration is compared against the external RF attenuator. This method, known as "the RF substitution" technique for attenuation measurement, eliminates the effects of the detector's characteristics because the detector always operates at the same power level.

Signal generator attenuator dial tracking can be checked over a wider range if a laboratory superheterodyne receiver containing a precision IF attenuator is used as the attenuation standard. This method is commonly referred to as the "IF substitution" technique, and, since it involves linear detection rather than square-law, much wider dynamic range is feasible. Commercially available receivers with precision IF attenuators can readily check attenuation down to power levels in the -80 to -100 dbm region.

Linearity from -40 to -127 dbm actually is assured because attenuation is dependent solely upon the previously checked waveguide dimensions. The only

\(^4\)Calibration procedures for individual signal generators are described in their Operating and Service Manuals.
\(^5\)In most signal generators accuracy is not usually specified for the first 7 to 10 db of attenuation because, in the area of transition from RF oscillator cavity to waveguide-beyond-cutoff, field patterns may be slightly distorted, causing some non-linearity in the attenuation vs distance curve in this region.

mode in existence at the -40 dbm point and below is the TE\(_{11}\) mode, since all higher order modes have been attenuated much more rapidly, and are negligible. The one factor which can influence significantly the relation of power output to probe position below the -40 dbm point is leakage; that is, power that couples into the attenuator probe through the probe's shielded cable (even double shielded cable such as RG-55/U only provides some 60 db of shielding). Thus presence of a strong RF field in the vicinity of the output system could introduce errors when the signal generator output is set at low levels. This implies that a leakage check around the cavity is a very important test to make after klystron replacement or other cavity modifications, such as opening shields or breaking paint seals. In production, hp Signal Generators are tested for leakage down to the maximum sensitivity of receivers. Depending upon the particular generator being tested, it is possible to set shields and in some cases to silver paint joints so that direct cavity leakage is below the perceptible sensitivity of the test receiver. Consequently, even the minimum calibrated output level (typically -127 dbm) from hp signal generators can be utilized with confidence in its accuracy.

Straightforward laboratory receivers can be made quite easily for checking leakage or attenuation linearity by using ordinary crystal mixers, another laboratory generator as the local oscillator, and a simple IF amplifier with a video detector whose output is presented on either a voltmeter (a tuned narrowband voltmeter like the hp 415 SWR Meter improves overall sensitivity) or a standard oscilloscope. Sensitivity of this receiver can normally be easily verified simply by using the attenuator of the generator under test. A simple antenna is then connected to the input of the mixer and is used to probe around the repaired cavity to insure that any leakage is sufficiently low.

Assuming leakage is held to a minimum and the previous techniques are followed closely, excellent agreement between "waveguide - beyond - cutoff" attenuator operation and front panel calibration can be expected; and the operator may be confident that his readings are accurate and his results valid.

There are additional techniques for verifying attenuator calibration down to the -127 dbm level; these usually involve somewhat specialized instrumentation generally used in standards laboratories (the Weinschel Engineering Model VM-3 is an example).

CONCLUSION

The two factors which affect the specified accuracy of Hewlett-Packard signal generator output attenuators are waveguide dimensions and probe frequency response. Both can be checked; waveguide dimensions by mechanical instruments (with electrical verification using substitution techniques) and probe frequency response by electrical instruments. If both are within specifications, specified attenuator accuracy is assured.