HEWLETT hp PACKARD

HP SIGNAL GENERATOR OUTPUT ATTENUATORS

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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 attenuation depends primarily upon its geometrical dimensions.[1] 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 10^4 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: α is the attenuation per unit length (db)
λ_c is the cutoff wavelength
λ is the free space wavelength

If λ is much greater than λ_c:

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

It has been shown[2] that for the TE_{11} 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 $\lambda >> \lambda_c$[3].

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 5 ten 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 TE_{11} mode operation, a TM mode may be excited in the -10 to -40 dbm range

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[1] The effects of wall conductivity and an oxide layer on the inner waveguide surface are negligible because they contribute an error of only a few parts in 10^4. See "Corrections to the Attenuations of Precision Attenuators", proceedings IEE (Radio and Communications) Vol. 96, Part 3, p. 491, November 1949.

[2] Terman, Electronic and Radio Engineering, p. 153, McGraw Hill, New York, 1955.

[3] In actual signal generators λ is actually sufficiently greater than λ_c to make attenuation independent of wavelength or frequency. For example, the Model 612A attenuator has a radius of 0.250 inch which corresponds to a λ_c of 0.885. Using equation (1) above, the attenuation is 63.825 db/in at 450 mc (λ = 66.6 cm) and 63.817 db/in at the upper frequency limit, 1200 mc (λ = 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 λ 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.

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because of the coupling method used out of the oscillating cavity. However, a Farraday 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 superhetrodyne 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 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 80 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 geerators 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.

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[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.