APPLICATION NOTE 20

SIGNAL GENERATOR OUTPUT ATTENUATORS

One of the features which has made hp 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 hp 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 to the 4th have been achieved.

The simple relation between attenuation and geometrical dimension results from the behavior of a waveguide beyond cutoff. For, when a waveguide is excited by a frequency greater than its cutoff frequency, the excitation energy dies away exponentially with distance from the point of excitation. Or, 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. hp 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 to the 4th. 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 ⓗⓟ 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 the following checks may be performed using normal measurement bolometer and video detection techniques with standard laboratory equipment.

In general, the calibration procedure for the whole system is as follows:[4] The probe is pulled back slightly from the excitation point so that the generator output as read by a Model 477B Thermistor Mount and a Model 430C Power Meter is about -10 dbm with the signal generator power meter at "set level".[5] The attenuator is then locked in place and the frequency response of the pickup probe is determined by checking the variation in output with frequency on the 430C. Then the frequency at which the response error is halfway between its extremes is chosen and the attenuator piston is slipped with respect to the dial to make the absolute output correspond with the dial reading. This spaces the probe frequency response error equally above and below the absolute level.

After making basic power set vs frequency response around -10 dbm, a tracking check can be made to the sensitivity limit of video detection using standard measuring techniques. For instance, a driving source could be connected directly to a barretter mount for measurements from -10 dbm down to noise level. This is because a barretter mount approximates square law detection characteristics in the range of -10 dbm to its sensitivity limit, which might be -45 dbm before noise level is reached.

An alternate method would be to couple an unloaded crystal detector of the ⓗⓟ 420 type, through a precision attenuator (ⓗⓟ X382) to a signal generator, such as an ⓗⓟ 620A. Then, by increasing the signal generator's attenuation from its -10 dbm reference level, while decreasing that of the precision attenuator an excellent accuracy check may be obtained of the signal generator's attenuation down to approximately -40 or -45 dbm. The attenuator linearity is then checked by measuring the output with the Model 415B Standing Wave Indicator to as low a level as possible (about -40 dbm).

Linearity from -40 to -127 dbm 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 couples through the double shielded cable of the attenuator probe directly from cavity leakage. Even double shielded cables such as RG55/U will leak when the signal level across it is 80 db. 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 general, instruments on the ⓗⓟ production line are tested within their frequency range 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 -80 to -100 dbm.

Straightforward laboratory receivers can be made quite easily for checking leakage or attenuation linearity by using ordinary crystal mixers, and another laboratory generator as the local oscillator (see figures 1 and 2). For checking leakage, the local oscillator should be in the fm mode, the crystal mixer coupled to a laboratory 30 mc IF amplifier of the ⓗⓟ K01 344A type, and then its output presented on a standard oscilloscope. This receiver can normally be calibrated by running the attenuator of the generator under test down to approximately -100 dbm and watching the spectral pattern on the oscilloscope. After the calibrating input is removed from the signal generator, a simple dipole is placed at the input of the mixer (figure 1), and is used to probe around the repaired cavity to insure that leakage is down around -80 to -100 dbm.

By inserting a known precision rf attenuator between the laboratory receiver's input and the signal generator under test, and replacing the oscilloscope with an ⓗⓟ 415C Standing Wave Indicator (figure 2), the same receiver can be used to run a substitution measurement on the attenuator down to the sensitivity limit of the system; and thereby obtain a check of attenuation linearity. The procedure is to set the attenuator of the signal generator under test to approximately -10 dbm, and then reference the standing wave indicator about 5 db above noise level. All of the additional attenuation is set into the precision attenuator. Then as the signal generator's attenuation is increased, the external attenuation is decreased until the reference point is regained. Simple substitution measurements can now be made.

Of course, any standard sensitive receiver may be used for this application as well as spectrum analyzers or other types of superheterodyne detectors. 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. Tests made to actually check signal generators to -127 dbm are extremely difficult because of the narrow bandwidth required in the receiving system. Generally, these systems require synchronous detection of the IF frequency and automatic frequency control on the local oscillator similar in the manner to the Weinschel VM-1B system. This system is extremely sophisticated and involves a parallel IF substitution, null detector approach, for excluding power instabilities while making substitution

[4] Calibration procedures for individual signal generators are described in the instruction manuals.

[5] Except for the Models 608 and 612, accuracy is not specified for the first 7 to 10 db of attenuation because the existence of higher order modes near the excitation source causes a slight non-linearity in the attenuation vs distance curve in this region.

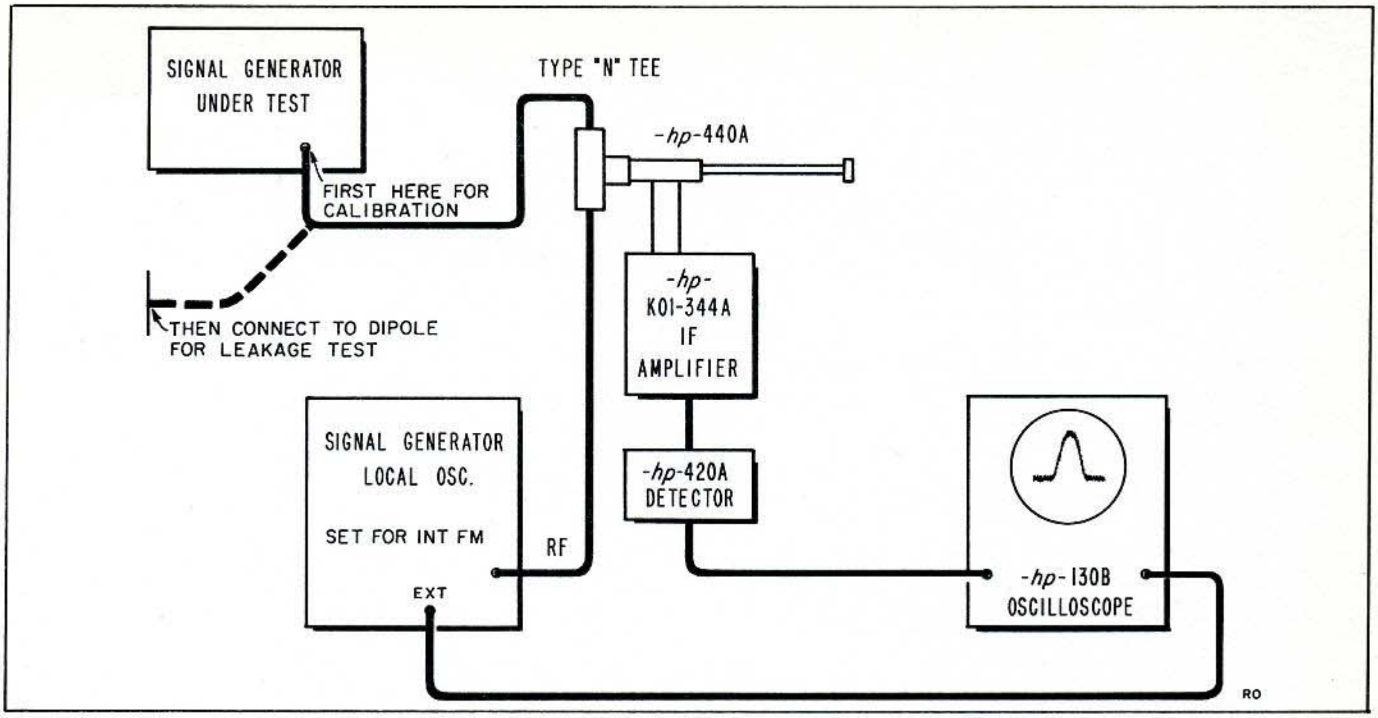

Figure 1. Leakage

measurements. Although it is felt that the Weinschel system gives excellent repeatable results, it is rather expensive for general maintenance or testing of signal generators. Tests made with substitution techniques are felt to be adequate for confirming Hewlett-Packard's basic generator specifications.

CONCLUSION

The two factors which affect the specified accuracy of ⓗⓟ signal generator output attenuators are waveguide dimensions and probe frequency response.

Both can be checked; waveguide dimensions by mechanical instruments and probe frequency response by electrical instruments. If both are within specifications, specified attenuator accuracy is assured.

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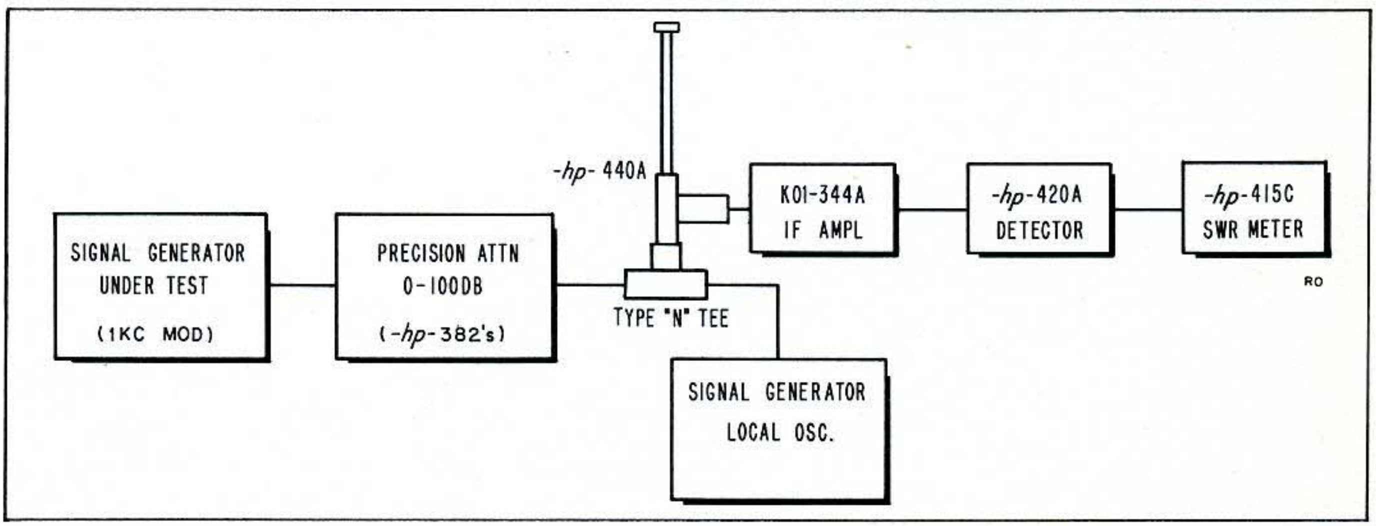

Figure 2. Attenuation Linearity