MICROWAVE DEVIATION LINEARITY TEST METHOD

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Abstract

Microwave voltage controled oscillators are prominent components in state of the art communications systems. They feature among other things increased bandwidth and frequency responce. It is the intent of this paper to present a quick and reliable method to test device deviation linearity. This method uses the Bessel function measurement technique. The Bessel functions are computer generated graphs normalized to a reference unmodulated carrier vs modulation index. The presentation of this graph is the key factor in reducing the amount of data reduction necessary to present the test results in usable form. This paper also discusses the singularity problem in determining modulation index from multivariate sideband levels.

Introduction

In the course of investigating frequency modulating devices, one is invariably handicapped by the lack of a precise method for measuring linearity. Recent test equipment designs dedicated to the linearity measurement are awkward and limited in actual use. The Bessel Function Technique is a more precise method and pleasantly compatible with Frequency Domain Spectrum Analyzers (SA). Together with computer generated Bessel graphs this method has evolved into a powerful measurement tool.

Graph Discussion

1-1 Figure 1-A, 1-B are computer generated displays of Bessel functions expressed in dB. The dB form of these curves allows them to be used directly with modern SA's. The expression used to generate the point set is of the form

$$J_n(\beta) = \sum_{k=0}^{\infty} \frac{(-1)^k}{k!\,(k+n)!} \qquad (1-1)$$

Where n is an integer number describing the order of the sideband. The value of K was taken to 15 places, allowing extra digits for accuracy. Each Bessel function curve has 100 points for good graphical resolution. The computations were made for 4 sidebands plus J_O.

1-2 The choice of 4 sidebands is for practicality. Most SA's have a 10X10 or 10X8 graticule. If I allow a sideband to occupy one of 10 major divisions, then I must allow for the unubiquitous nature of the IF amplifier. It is important to consider the modulating frequency in relation to the SA IF bandwidth. Practicaly this leads to about ± 4 sidebands in addition to J_O the carrier. The graphs are true for both upper and lower sidebands of the same order since from Bessel function theory.

$$J_{-n}(\beta) = (-1)^n J_n(\beta) \qquad (1-2)$$

The upper and lower sideband will be the same amplitude from Image Theory for a modulating sinusoid. The SA measures energy as a function of frequency, so the graph display is

$$20 \log [J_n(\beta) / J_o(0)] \qquad (1-3)$$

$J_O(0)$ is a normalized unmodulated carrier. These graphs will be the focal point of the Data reduction effort. The Data Reduction Section contains a discussion of a graphical solution to non-singular Bessel equations.

Test Considerations

2-1 Proper microwave techniques are important in this type of testing. VSWR should be held to 1.2 or less. Idealy the SA should be isolated by variable precision padding. More important the padding will lessen the chance of mixer overload.

2-2 Data is taken by comparing the difference in relative amplitude of a Nth order sideband to a previously referenced unmodulated $J_O(0)$. The usual method is to set the vertical SA display of the reference carrier using an external precision atennuator in conjuction with SA display controls. For horizontal considerations pick a horizontal dispersion (MHz/div) to match the modulation frequency. Starting from zero increase modulation to a convenient level. See Figure 2-1

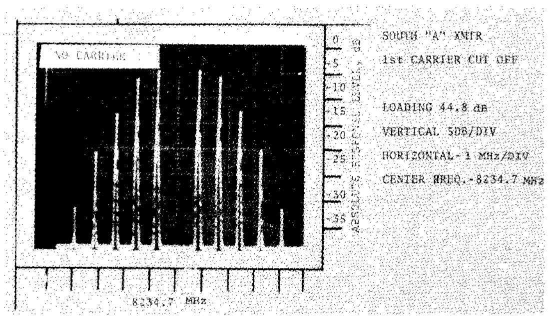

Figure 2-1

After selecting a convenient measurable display, adjust the external atennuator to bring the sideband under measurement to the assigned $J_O(0)$ mark. The difference in atennuation settings will correspond to

$$\Delta J_n(\beta_n) = (-1|J_o(0) - J_n(\beta_n)| \qquad (2-1)$$

2-3 All measureable sidebands up to J_0 should be measured, including $J_0(B)$. This information will correspond to one B function at a loading level L. From this information a plot of measured B against loading can be superposed on a plot of calculated B against loading. This process can be carried out for an infinite number of points, however, the number of data samples is at the discretion of the test engineer.

Data Reduction

3-1 Each $\Delta J_k(\beta)$ point is actually a meaningless value without additional $\Delta J_n(\beta)$ points at that level of modulation. This is so because these functions are non-singular independently but assume singularity when evaluated collectively. That is to say $\beta = F(J_n)$ is a multivariate function but $\beta = F(J_0 + J_1 + \ldots J_k + \ldots J_n)$ is a single valued function with a unique position on Fig 1-A, 1-B. The composite carrier waveform is a phased summation of the sidebands. The equation for the composit waveform for single tone modulation is

$$\begin{aligned} e(t) = A_c \{ & J_0(\beta)\cos\omega_c t \\ & - J_1(\beta)[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t] \\ & + J_2(\beta)[\cos(\omega_c - 2\omega_m)t + \cos(\omega_c + 2\omega_m)t] \\ & + J_3(\beta)[\cos(\omega_c - 3\omega_m)t - \cos(\omega_c + 3\omega_m)t] \\ & + J_4(\beta)[\cos(\omega_c - 4\omega_m)t + \cos(\omega_c + 4\omega_m)t] \\ & - \ldots J_n(\beta) \ldots \} \end{aligned} \quad (3\text{-}1)$$

Where ω_c is carrier frequency, ω_m is modulation frequency and t is time of interest

3-2 Non-linearities occur when a particular sideband does not contain the calculated energy with respect to the loading. The extent of the non-linearity will depend on the relative importance of the sideband. At light loading levels, under B=1.0, the carrier, 1st and 2nd sidebands predominate in equation 3-1. At high loading levels B=3.0 and above, Nth order sidebands increase in importance. Eventualy, at very high loadings, Energy is distributed uniformly among the sidebands.

3-3 The definition of the modulation index (B) provides the means for checking linearity for large bandwidth devices.
B is defined:

$$\beta = \Delta\omega_c / \omega_m \quad (3\text{-}2)$$

Where ω_m is the modulating frequency and $\Delta\omega_c$ is carrier deviation as expressed

$$\Delta\omega_c = |\omega_c - \omega| \quad (3\text{-}3)$$

We can see from equations 3-2 and 3-1 that the location of J_{Nth} sideband with respect to ω_c is a multiplicative integer function of ω_m. That is to say J_N can be located at $\omega_c \pm N\omega_m$. Since our testing parameters are Jo to J4, we can select the bandwidth to be checked by the appropriate choice of ω_m. A close approximation for estimating ω_m is

$$\omega_m = \left(\frac{BW}{2} - \Delta F_c\right)/2 \quad (3\text{-}4)$$

Where BW is Bandwidth of interest and ΔF_c is an approximation.

3-4 Given the J data from the SA display, the modulation index (Beta) can be correlated from Figures 1-A, 1-B. A feel of the mod index is important here. For example, the carrier J_0 crosses the -20 dB value twice for a neighborhood Beta of 2.22 and 2.60. If the variance of test data for J_0 is 0.2 in that region, then there will be some ambiquity of the value of Beta. The multivariance of Beta can be singularized by using the best fit horizontal line method.

3-5 For a particular level all measurable J values (above -50 dB) are marked on the graphs. Idealy these points should produce a straight horizontal line indexing to a unique Beta. Because of J variance this will not be so. A short order normal distribution analysis is used at this point. The straight edge was positioned to be halfway in the point spread, with half the points above and half below the line. In the process it was necessary to discard some stray points. Stray points are well off the beaten track and were easily recognized by their unreasonable values.

Graphical Analysis

4-1 All the Beta points were collected in this manner and summarized. From the collected Beta, the deviation can be computed. Equation 3-2 was used for the computation. The final data table was assembled prior to plotting the linearity graph. This data table consists of:

a. The modulating signal level in volts
b. The modulating signal level in dBm0
c. Modulation index
d. Carrier deviation

The dBm0 data is for convenience, since it is nothing more than the modulation power level reference to the test level point. It is computed from the measured signal level voltage and device impedance.

4-2 For large bandwidth devices a log plot is best. However the two points necessary to produce the calculated deviation are not on the log paper. The two points necessary are the (0mv, 0KHz) and the 1st carrier dropout point. The 1st carrier dropout point is taken from the SA. When the carrier drops out the mod index is 2.405 irregardless of sideband levels. The modulating signal level is taken at that point and used to compute the calculated graph. The measured 1st carrier dropout point was found using the technique outlined in section 3. Figure 4-1 is the calculated linearity graph. The graph was made by drawing a straight line between the zero point and 1st carrier dropout. This straight line gave all the y-intercepts necessary for the final semi-log plot.

4-3 Figures 4-2 and 4-3 are graphs of actual devices. The y-intercept comes from the linear graph as does the 1st carrier dropout point. Two items of interest are the limit of linearity and the variation of linearity. The limit of linearity is how far the device can actually go before starting to saturate. Figure 4-2 and 4-3 are graphs of medium bandwidth devices. The actual bandwidth of the device is twice the deviation. The variation of linearity is useful for developing regions or areas from which the device is to be operated. For example if the device has a large variation from linearity at light loading, then the operating point would be adjusted to a different region. But more important the variation linearity contour will be a key indicator of the inherent signal to noise ratio.

Conclusion

The computer generated Bessel function display as depicted in Figure 1-A and 1-B is a key factor in making the deviation linearity measurements simple. This simplified method eliminates tedious multivariate analysis chores. Although an understanding of the non-singularity is necessary, the rest of this method is quite straight forward and provides an easy, accurate analysis of the device deviation linearity.

References

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