FIELD MEASUREMENT OF FM DEVIATION

Daniel W. Nimrod
U. S. Army Aviation Technical Test Center
STEBG-SD-I
Ft. Rucker, AL
36362-5276

ABSTRACT

This paper briefly reviews past techniques for measuring FM deviation and discusses the limitations of past technology. Graphs of the Bessel functions are presented in terms of decibels (dB), offering a better method of measurement when used with a modern spectrum analyzer.

Key Words: FM Deviation; Field Measurement; Spectrum Analyzer.

INTRODUCTION

FM signal generators are often not reliable for measuring deviation, even when modulating with a single sine wave. When modulating with a complex waveform such as PCM/FM or FM/FM, the deviation meter becomes useless. To provide the maximum telemetry signal while remaining within legal bandwidth limits it is imperative to be able to accurately measure FM deviation of complex waveforms.

The availability of excellent oscilloscopes, spectrum analyzers, and receivers has significantly changed our ability to accurately calibrate and measure FM deviation. Many of us tend to stand with old “tried and true” methods that, in our experience have been good enough, but do not truely reflect the transmission bandwidth limitations of modern test ranges.

The purpose of this paper is to briefly revue past calibration methodology and its limitations, and to present curves that make it possible to calibrate and measure deviation accurately and conveniently, when used with a modern spectrum analyzer.

PAST TECHNOLOGY

All techniques for measuring FM deviation known to this author rely on using a receiver that has been calibrated by using an FM signal generator or transmitter that is modulated by a single sine wave. When modulated by a single sine wave, the spectrum output of the devise is predicted by the Bessel function of the first kind, found in many texts and handbooks in various forms. A form that is easily useable for computer expansion is:

(1) $$J_n(\beta) = \sum_{k=0}^{\infty} \frac{(-1)^k \beta^{n+2k}}{2^{n+2k} k!(n+k)!} , \quad (n=0,1,2,.....)$$

where \$ = Modulation Index (MI) in radians;
n = order of the carrier (0) or sideband (1,2,3...);
k = kth term of an infinite expansion.

Fortunately, for any value of the argument \$, the series converges rapidly. The Bessel function of the first kind is a generalized solution to several physical problems, but for the solution of a carrier modulated by a single sine wave, the argument \$ is by definition the Modulation Index (MI) and is defined by:

(2) $$\beta = \textbf{Modulation Index (MI)} \equiv \frac{\textbf{Peak Frequency Deviation}}{\textbf{Modulating Frequency}} .$$

The carrier term, J_0, and the first two sidebands, J_1 and J_2, from Eq. (1) are illustrated in Fig. 1 for Modulation Index (MI) from zero to five. The higher ordered sidebands are not shown in Fig. 1 and are not needed for this paper, but each sideband sequentially rises up from zero similar to J_1 and J_2. For a modulation index of five, there are at least ten sets of significant sideband pairs. When unmodulated, MI = 0 and all of the power is in the carrier term. As the MI is slowly increased, the carrier term decreases and the missing power from the carrier appears in the sidebands.

Values of the Bessel functions are normalized, and are proportional to the voltage or current; when squared, they are proportional to the power associated with the carrier and each of the sidebands. Since the power output of an FM transmitter is constant regardless of modulation, it follows that for any MI the sum of the squares of the carrier term and each of the sidebands must equal 1, just as it does for the unmodulated carrier (do not neglect that each sideband appears in pairs). This provides an easy check when manipulating the Bessel function with a computer to test that enough terms in the expansion on k have been carried out and that all significant sidebands have been considered.

Receiver Setup

The receiver should be set as it is to be used after the deviation has been set or measured. Guidelines for setting the IF bandwidth and the demodulation bandwidth are provided in both Ref. 1 and Ref. 2 for various forms of modulation. Normally the video output level of the receiver is dictated by a tape recorder input level.

The use of a receiver for calibration of deviation relies on the fact that the video output of a receiver is directly proportional to the deviation, within certain limitations. The first limitation is that there must be no compression or limiting of the video output. The second limitation is that for most receivers switching the IF bandwidth or the demodulator bandwidth will change the video output voltage.

Deviation Measurement

Stations having receivers with spectrum display units (SDUs) typically used the zero crossings of the carrier or first sideband occurring at approximately MI of 2.405 and 3.832, respectively, to measure deviation. There were no means for measuring the amplitudes of carrier or sidebands, but it was possible to observe on the SDU the nulling of these signals, using a single sinewave modulating frequency. The SDU has in-band noise, so it is not possible to measure the carrier or sideband going to zero amplitude; it is only possible to measure that the carrier or sideband go below the noise. It is therefore adviseable when using this method of measurement that a strong signal be used.

It is because the zero crossings occur at difficult values of MI that it is difficult to use this method of measurement. For example, let us assume it is desired to calibrate an FM transmitter for ± 250 kHz peak deviation. Using Fig. 1 it may be seen the carrier has zero amplitude at approximately MI = 2.405. Using Eq. (2) with a peak deviation of 250 kHz and MI of 2.405 the modulating frequency can be calcul to be 103.95 kHz. Using a sine wave at 103.95 kHz to modulate a signal generator, slowly increase the modulation level from zero until the carrier vanishes into noise on the SDU. At this point the deviation is 250 kHz. The video output of the receiver may now be adjusted to a convenient peak-to-peak voltage with an oscilloscope. If a new modulation source such as FM or PCM is now introduced, adjusting the level to provide the same peak-to-peak voltage on the video output will provide a peak deviation of 250 kHz for the complex waveform. Subject to the limitations previously mentioned, other deviations will be proportional to the video output voltage.

It is easy to obtain an odd modulating frequency such as 103.95 kHz on modern frequency synthesizers, but required endless tweeking on old signal generators, and it was difficult to determine the errors involved if the correct modulating frequency was not exactly achieved. Similar problems occur when using the first sideband nulling at MI = 3.832, or other sideband crossings; the procedure is the same. The numbers were always difficult, and one was always left with the question of the depth of a null in noise. This system did, however, provide a method for measurement, or at least an estimation of deviation, when no other method for measurement was available.

MEASUREMENT BY SPECTRUM ANALYZER

Modern spectrum analyzers are capable of direct measurement of the relative amplitudes of the carrier or any sidebands in decibels. The advantages of this method of measurement are manifold in that it offers a means of measurement using only mental multiplication, it is useable for a continuous modulation index, and in most cases provides redundancy of measurements. The method is to present the relative amplitudes of the respective Bessel functions in terms of decibels (dB), a form that is readily useable by spectrum analyzers, without regard to the actual signal generator or transmitter output power.

The equation used to make plots of these functions requires the Bessel functions to be squared, proportional to power:

$$\text{Relative Power (dB)} = 10\log\left(\frac{J_n(\beta)}{J_m(\beta)}\right)^2. \tag{3}$$

These functions are plotted in Fig. 2 for the modulated carrier referenced to the unmodulated carrier, and for the first sideband referenced to the modulated carrier. Fig. 3 shows the second sideband referenced to the modulated carrier, and the second sideband referenced to the first sideband.

To use the conditions of the previous example, to achieve a deviation of 250 kHz, using a modulation index of 2.5 times a modulating frequency of 100 kHz provides a peak deviation of 250 kHz. Referring to Fig. 2, at MI of 2.5 on the curve for J_1/J_0 we read that it should be about 20 dB. Using 100 kHz modulating signal, increase the modulation of a signal generator until the first sideband (J_1) is about 20 dB above the carrier (J_0) on a spectrum analyzer, using 10 dB/division sensitivity on the spectrum analyzer. Referring to Fig. 3, note that on the curve for J_2/J_0, the second sideband (J_2) is about 19 dB above the carrier, and verify this condition on the spectrum analyzer. Finally, also on Fig. 3, on the curve for J_2/J_1, note that the second sideband (J_2) should be about 1 dB below the first sideband (J_1). To verify this condition the spectrum analyzer sensitivity should be changed to 2 dB/division. We have now evaluated MI three different ways, and determined that under present conditions the signal generator is outputting 250 kHz deviation.

Returning now to the first example on nulling the carrier at MI = 2.405, and the discussion on knowing how deep a null is in noise, let us now consider the curve on Fig. 2 for

$J_0(\$)/J_0(0)$ this curve is for the modulated carrier referenced to the unmodulated carrier. If the unmodulated carrier is 20 dB above noise, a fairly strong signal, from this curve it is evident that below noise would be below -20 dB, or that portion of the curve between MI of approximately 2.22 and 2.61. For a modulating signal of 103.95 kHz, the deviation thus “measured” is between about 231 and 271 kHz, leaving us with an uncertainty of about ±20 kHz from the desired deviation of 250 kHz. The curves presented in Fig. 2 and Fig. 3 make it easily discernable whether the MI is 2.4, 2.5 or 2.6, showing drastic and measureable changes in this region.

In most cases of measurement, only mental multiplication is necessary, using frequencies in powers of ten to achieve the desired deviation. There is always redundancy of measurements except at the zero crossing for MI = 2.405, and even then one very accurate means of measurement is offered. It is only necessary to calibrate a receiver using Fig. 2 and Fig. 3 with a spectrum analyzer, and adjust the video output of the receiver.

CONCLUSION

Using the curves presented in Fig. 2 and Fig. 3 of this paper, it is possible to adjust transmitter and signal generator deviation very accurately, for any form of modulation. The curves provide redundancy of measurement in most situations, and also rely on measuring solid peaks of sidebands instead of measuring into noise.

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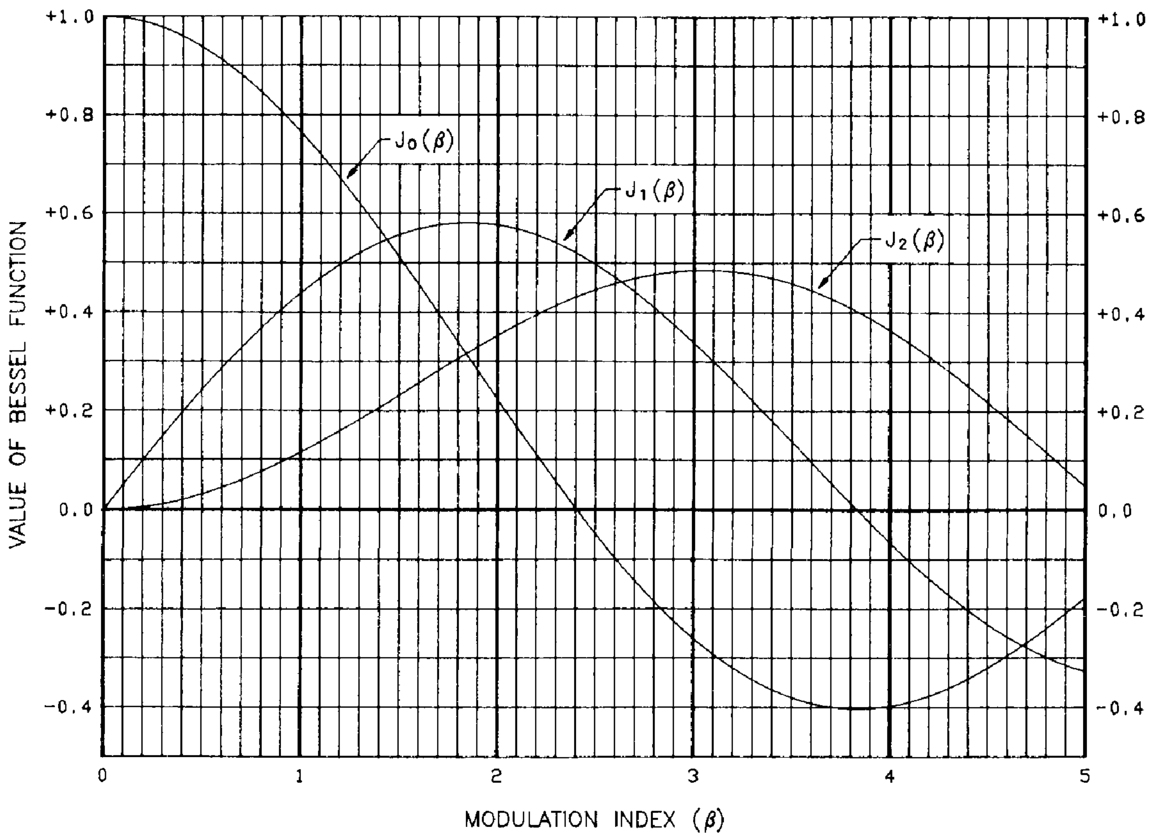

Figure 1 - J_0, J_1, & J_2 vs. Modulation Index

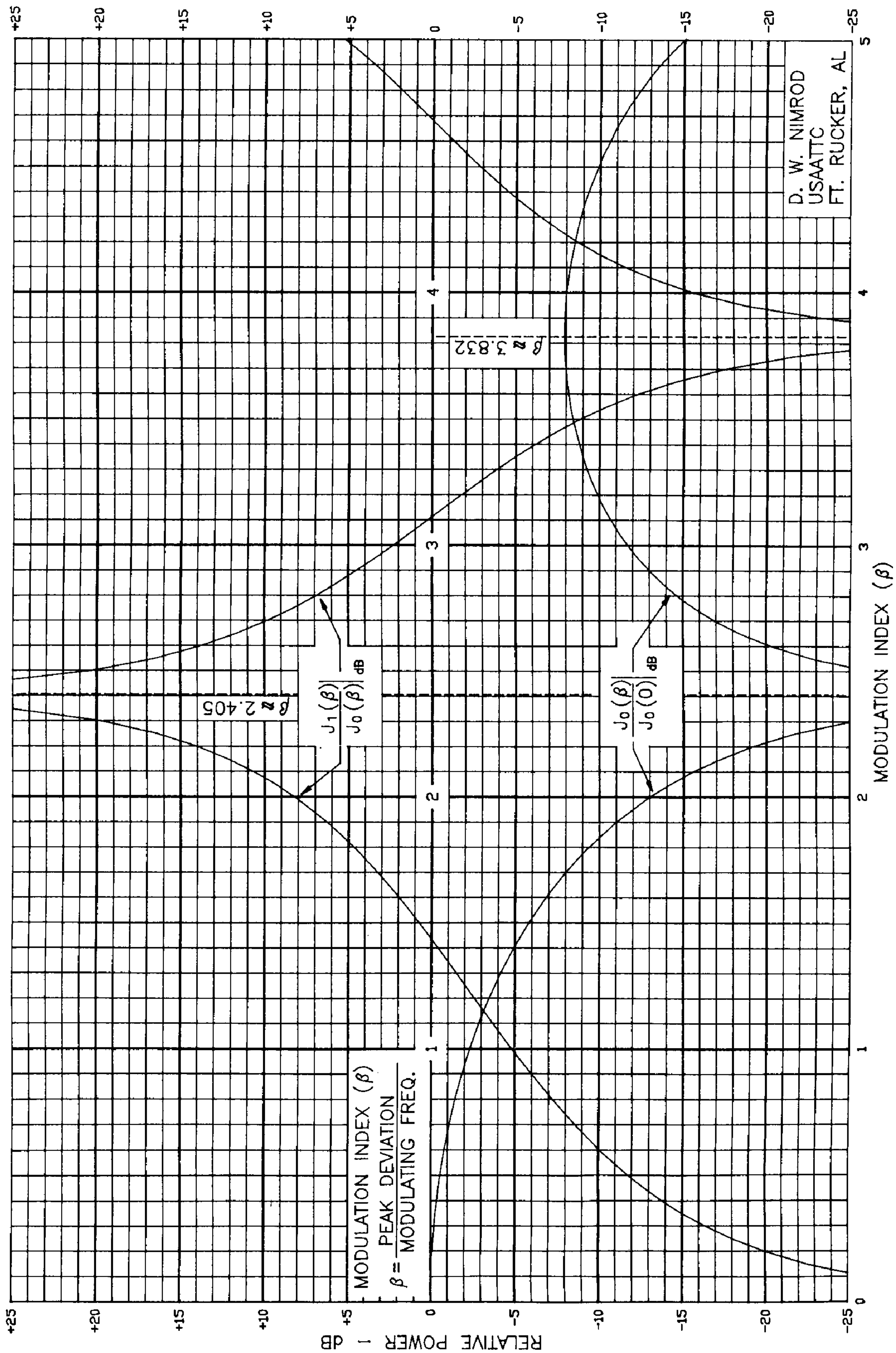

Figure 2. Relative Power vs. Modulation Index

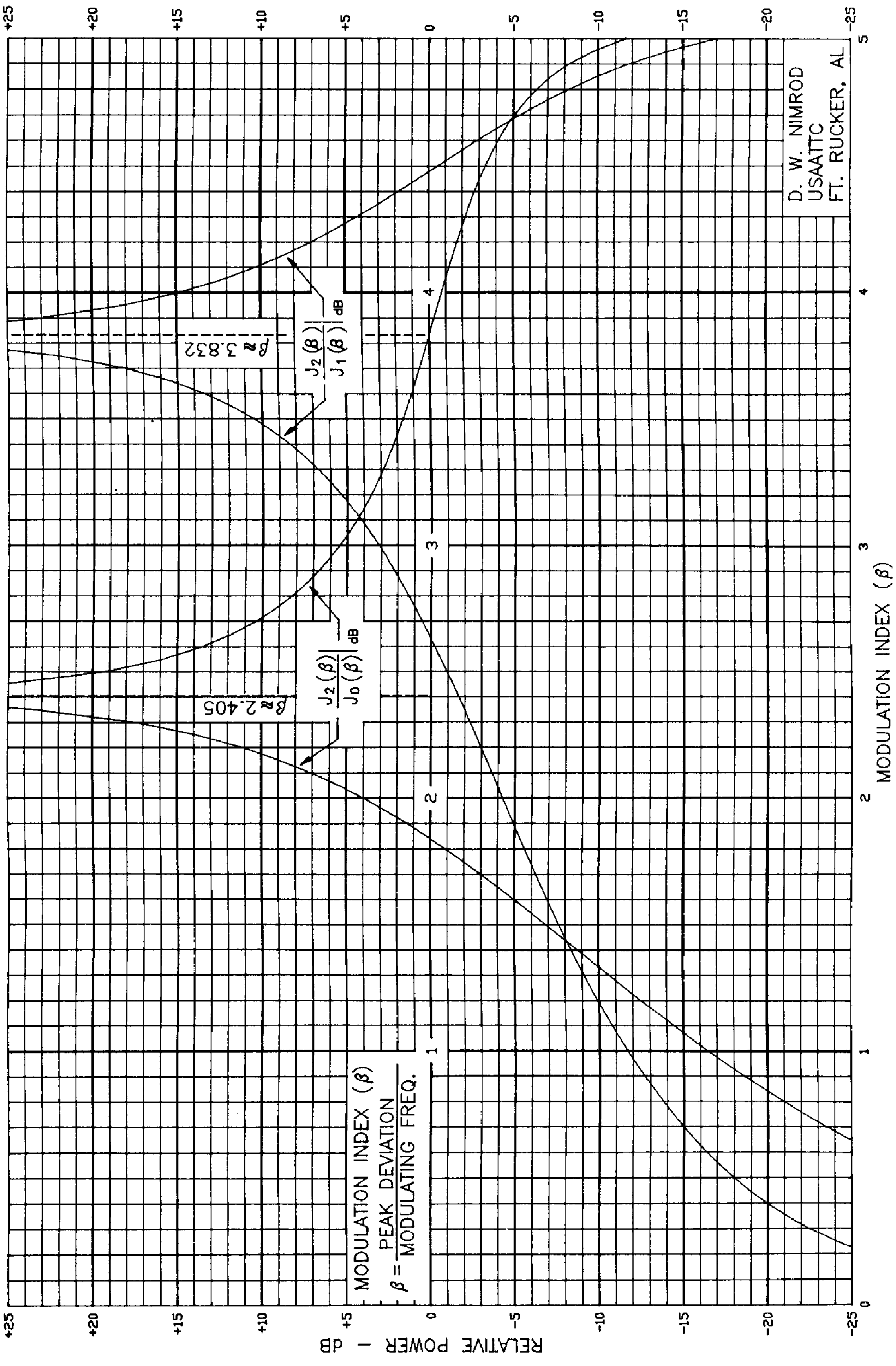

Figure 3. Relative Power vs. Modulation Index