NUMA TECHNOLOGIES

Period-to-Digital Converter FM Detection

TB - 1

Technical Brief

C. R. Crego
Senior Staff Scientist

Introduction

In this technical brief, we document the process and results of digital FM detection using NUMA Technologies' NT3xx Period-to-Digital (P/D) Converters. In a typical FM communications receiver, NUMA Technologies' digital FM detection scheme employs the NT3xx P/D for "sampling" the IF frequency, using a "zero-crossing" period measurement process. FM information obtained by this period measurement technique is typically sampled at a relatively "low", down-converted IF frequency, and sent via data bus to a Digital Signal Processing microprocessor (DSP).

In the DSP, the modulating signal is extracted from the period-measurement data using a software-based "transfer function". In the implementation of the transfer function, a precise, linear, and mathematically analytic solution is realized for FM detection. This method produces very accurate results with an excellent signal-to-noise ratio and low total harmonic distortion. Subsequent to the transfer function's operation, the option exists to condition the extracted signal by a software-based filtering process, before outputting the signal to a D/A converter. The output of the D/A is the detected, modulating signal, which is passed on to the receiver's output stage.

Two examples are provided which show sample DSP transfer functions and their related bit resolution and signal-to-noise ratio, for two separate, low IF frequency detection schemes. We also provide SINAD test data, which was measured on a commercially available, two-way trunking communications receiver retrofitted with an NT302 P/D detector. The test results turned out to be most favorable for the NT302 P/D - based detector; The receiver's noise figure (NF) was found to be uniformly lower over a wide range of signal input levels when compared to the same test run on the unmodified receiver. Similar measurements were also made on a "stand-alone" NT302 P/D, and when compared to a similar detector's capabilities, the results were again, very favorable.

The primary intent of this technical brief is to describe the conceptual aspects of a digital FM detection scheme, based on NUMA Technologies' NT3XX Period-to-Digital P/D converter. Consequently, it falls beyond the scope of this document to address other FM receiver design criteria, which includes, but is not limited to the following: image rejection, spurious response, dynamic range, and alternate channel selectivity. It is the task of the designer to address these issues on a case by case basis, since individual design requirements vary widely.

Derivation of Parameters for FM Detection Using the NT3xx P/D

In the NUMA Technologies' NT3xx FM detection system, instantaneous signal amplitudes are obtained using a "zero-crossing" period measurement process. In this type of sampling process, the periods between zero-crossings of an FM signal are measured using a very accurate clock / oscillator, effectively "digitizing" each period into a "count". The digitized samples are subsequently processed by a transfer function procedure in a DSP microprocessor, that accurately extracts the modulating signal information. Below, the steps necessary for understanding the critical parameters in the operation of a zero-crossing detector are presented.

With regard to zero-crossing FM detection in general, consider two successive zero crossing events occurring during a pure, sinusoidal waveform half-cycle; The period between the zero-crossings, "T0x", is measured by counters which track the number of clock / oscillator periods, "N0x", expiring during that time. This relationship is given by

$$T0x = N0x * Tclock, \quad (1)$$

where Tclock is defined as the clock / oscillator's period. Since the "full-cycle", instantaneous frequency value, "F0x", associated with this zero-crossing event is inversely proportional to the measured period between the zero-crossings, we can write down a relation between period and frequency, valid over a half cycle:

$$T0x = 1 / (2 * F0x). \quad (2)$$

Now, by setting equation (1) equal to equation (2), and solving for N0x, we substitute the reciprocal of the clock / oscillator's frequency, 1 / Fclock, for Tclock, and find an expression that relates instantaneous frequency to zero-crossings:

$$N0x = \tfrac{1}{2} Fclock / F0x. \quad (3)$$

Assuming no noise is present, the range of valid counts is bounded by the full deviation bandwidth (Fbw) extrema -- fmax and fmin -- centered about the IF frequency, where the fmax and fmin values are equal to ± ½ Fbw, respectively, and fmin is equal to -fmax. Based on equation (3), the maximum possible number of clock counts in a given zero-crossing event is

$$Nmax = \tfrac{1}{2} Fclock / (Fif - fmax), \quad (4)$$

Likewise, the minimum possible number of clock counts in a given zero-crossing event is

$$Nmin = \tfrac{1}{2} Fclock / (Fif + fmax). \quad (5)$$

(N.B.: The relationship between the count extrema, Nmin and Nmax, and the modulating signal amplitude may be stated as follows: The minimum valid count number, Nmin, corresponds to the highest amplitude modulating signal level, while the maximum valid count number, Nmax, corresponds to the lowest amplitude modulating signal level, in a noise-free environment.)

From the extrema defined in equations (4) and (5), a valid "count sampling range",

$$N = Nmax - Nmin + 1, \qquad (6)$$

may be defined, and used in the determination of the effective, system bit resolution:

$$R = 3.322 \log10(\quad N + 1) \text{ bits}. \qquad (7)$$

From the effective bit resolution, R, the signal-to-noise ratio may calculated, based on the (exact) Nyquist sampling theorem, which is:

$$SNR = 6.02 R + 1.76 + 10 \log10(½ Fsamp / Ffbw) \text{ dB}. \qquad (8)$$

In equation (8), the "Fsamp" term is defined as the NT3xx P/D sampling frequency, while "Ffbw" is the full, analog bandwidth of the incoming signal to be sampled (for reference, see Analog Devices "High Speed Design Seminar 1990" publication, pg. I-44). The last term in equation (8), relating Fsamp and Ffbw, corresponds to "oversampling", defined as sampling a signal at a rate greater than the Nyquist rate. By inspection, it is easy to see that the last term in equation (8) reduces to zero when the sampling frequency, Fsamp, is equal to twice Ffbw, producing the industry standard expression for SNR; i.e., "6.02 R + 1.76". Of some note is the effect of the third term on the SNR when the sampling frequency falls below the Nyquist sampling frequency; the ratio of Fsamp to Ffbw becomes fractional, subsequently producing a decrease in the SNR. For reference, the Nyquist frequency bandwidth for an FM receiver is

$$Ffbw = 2 (Fif + ½ Fbw). \qquad (9)$$

Block Diagram of a Typical NT3xx P/D FM Detection Implementation

A block diagram of an FM detector employing the NT3xx P/D converter is shown in Figure (1) below.

In the NUMA Technologies NT3xx P/D FM detector, as shown in the block diagram in Figure (1), FM signal input is provided by a multifunction synthesizer, and fed to NUMA Technologies' EVAL-1 Evaluation Board. The EVAL-1 board provides signal limiting, zero-crossing period measurement / FM detection using the NT3xx P/D, and DSP signal processing. The detected output from the EVAL-1 board is output for display on any appropriate output device. The EVAL-1 board requires nine volts of DC power.

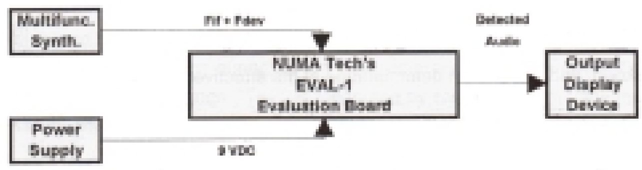

Figure (1): Block Diagram of FM Detection using NT3xx P/D Converter

FM Detection Using The NT3xx P/D Converter

In applying the NT3xx P/D Converter to FM detection, NT3xx P/D zero-crossing period measurements are input to the DSP in the form of "counts", where they are subjected to a special "scaling" procedure. The scaling procedure is accomplished using a software-based "transfer function", which exploits the DSP's full "n-bit" range of values. The transfer function processes the incoming count data by determining the modulating signal amplitude found in a "lookup table" (LUT) array of data values. The LUT is created off-line in advance using a proprietary algorithm, with the values based on equations 4 through 6 for a given set of frequency values.

To demonstrate the NT3xx P/D FM detector concept, two examples are presented which show how all of the above relationships tie in together. Required frequencies for each example are defined below, in Table (1), and are considered to be representative of a typical communication system employing the NT302 P/D FM detection process.

In Figure (2), the results of example (1) are presented. From equation (5), a value of 971 is found for Nmin and from equation (4), 1030 is found for Nmax. The associated IF frequency count value, 1000, is easily found by setting F0x = Fif in equation (3). The Nmin and Nmax values represent the valid limits of NT3xx P/D count output, corresponding to the deviation bandwidth limits centered about the IF frequency. Therefore, from equation (7), about 6 bits of resolution are found, with a corresponding SNR of about 50 dB as determined by equation (8).

Example #	**Fclock(Mhz)**	**Fif(Khz)**	**Fbw(Khz)**
1	100.00	50.00	3.00
2	100.00	25.00	3.00

Table (1): Parameters for two NT3xx P/D detection examples

In Figure (3), the results of example 2 are presented. We note here a valid count range of 1887 to 2127. Of particular interest to the system designer is the fact that the bit resolution has increased to about 8 bits, with a corresponding SNR of approximately 59 dB. The increase in bits -- and ultimately SNR -- is related to the fact that we have decreased the IF frequency by a factor of two, which subsequently increases the "count range", W N, by about a factor of four (the four-fold increase in count range that resulted from doubling the IF frequency is a function of the relative, individual ratios of the system clock to the two individual IF frequency bandwidths, while holding the deviation bandwidth constant).

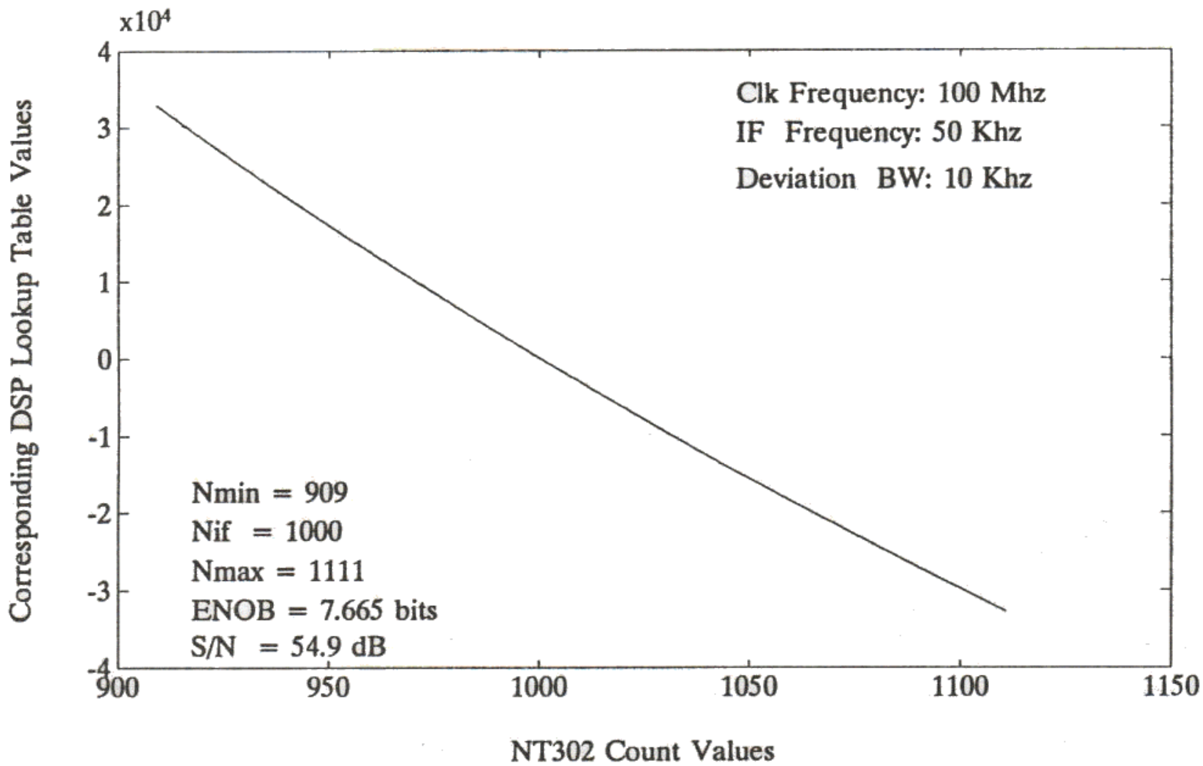

Figure (2): Representative output for Example 1.

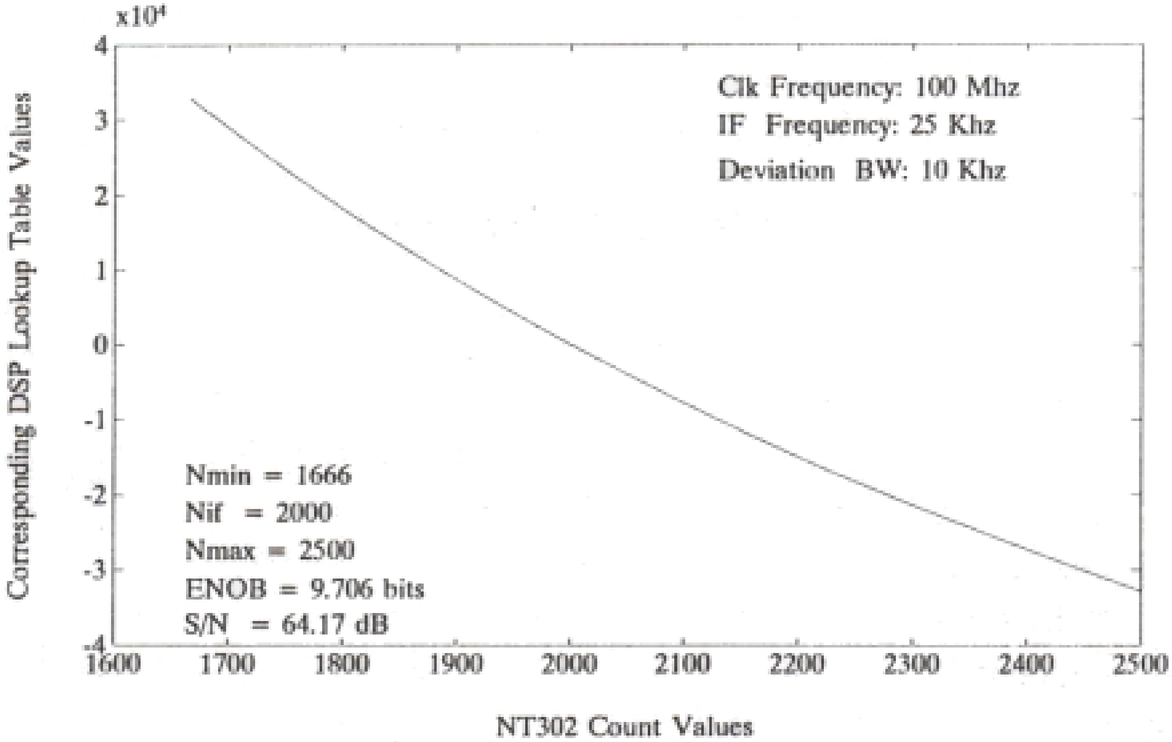

Figure (3): Representative output for Example 2.

Results of Laboratory SINAD Testing

In order to verify the benefits in using the NT3xx P/D as a detector, we replaced the detector in a commercially available two-way trunking radio with an EVAL-1 board, and made SINAD measurements for a typical range of input signal levels. Tests were run on both the "stock" receiver and the "modified" receiver using an RF input frequency of 935.0375 Mhz, deviating to a depth of 1.5 Khz at a 1 Khz modulation rate. The input signal levels spanned a range of -127 dBm to -90 dBm. In reviewing the results of the measurements shown in Figure (4), one immediately notes an improvement in NF.

To further quantify the NT3xx P/D as a detector, a SINAD test was carried out on a stand-alone NT302 P/D, and the results are shown in Figure (5). The test was run at an FM IF frequency of 25 Khz, with 1.5 Khz deviation depth at 1 Khz modulation rate. The solid line plot represents "noise + distortion", while the dashed line represents "noise + distortion + 30% amplitude modulation". For comparison, similar curves for a Motorola, MC3359 Low Power Narrowband FM IF Detector, are shown in Figure (6). Note the steep slope of the curves associated with the NT302 P/D part, as compared to the curves for the MC3359 part.

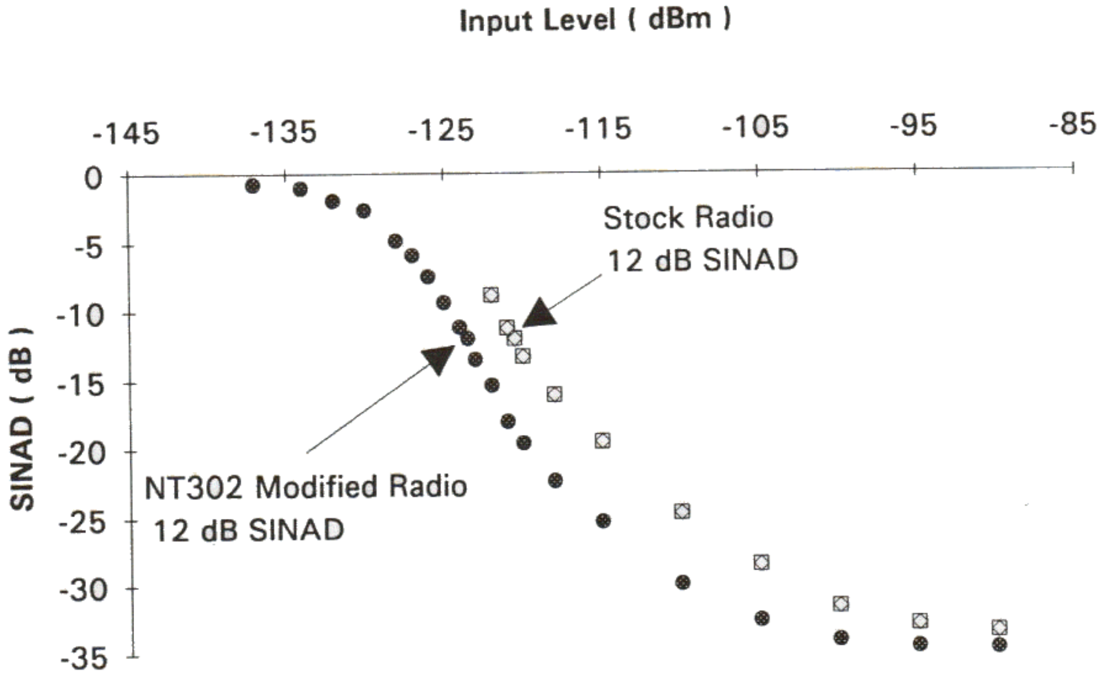

Figure (4): SINAD Test of 2-Way Trunking Receiver as Stock Radio and modified with NT302 P/D FM Detector

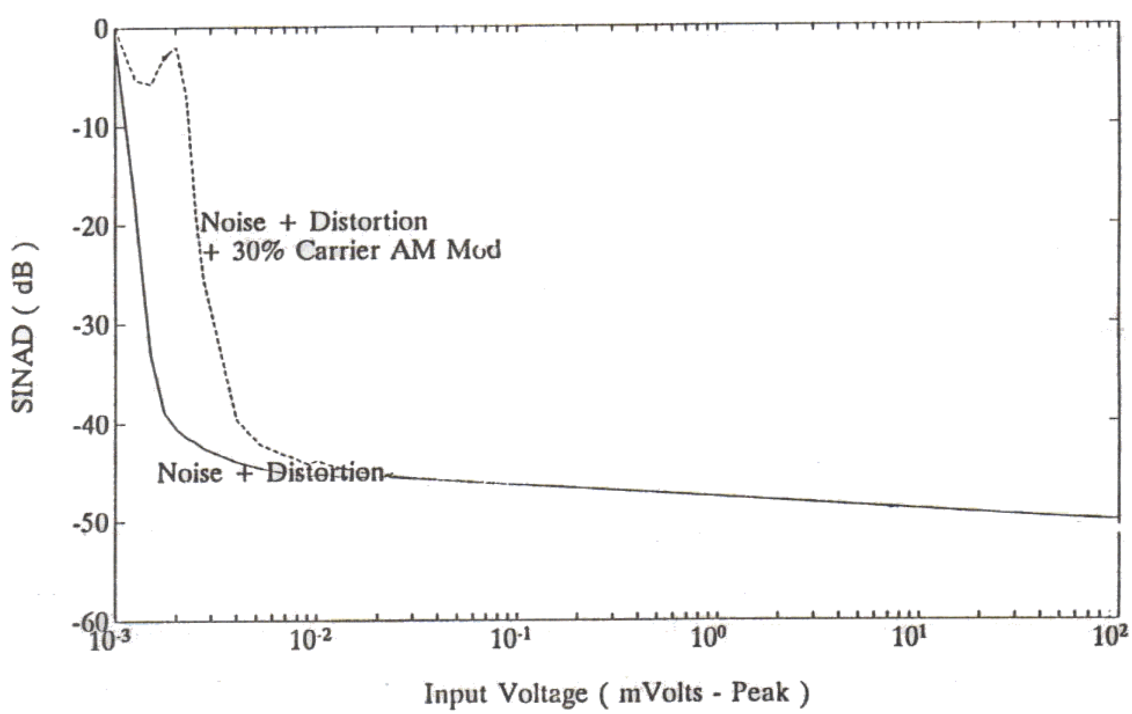

Figure (5): Signal + Noise plot for NT302 P/D as an FM Detector.

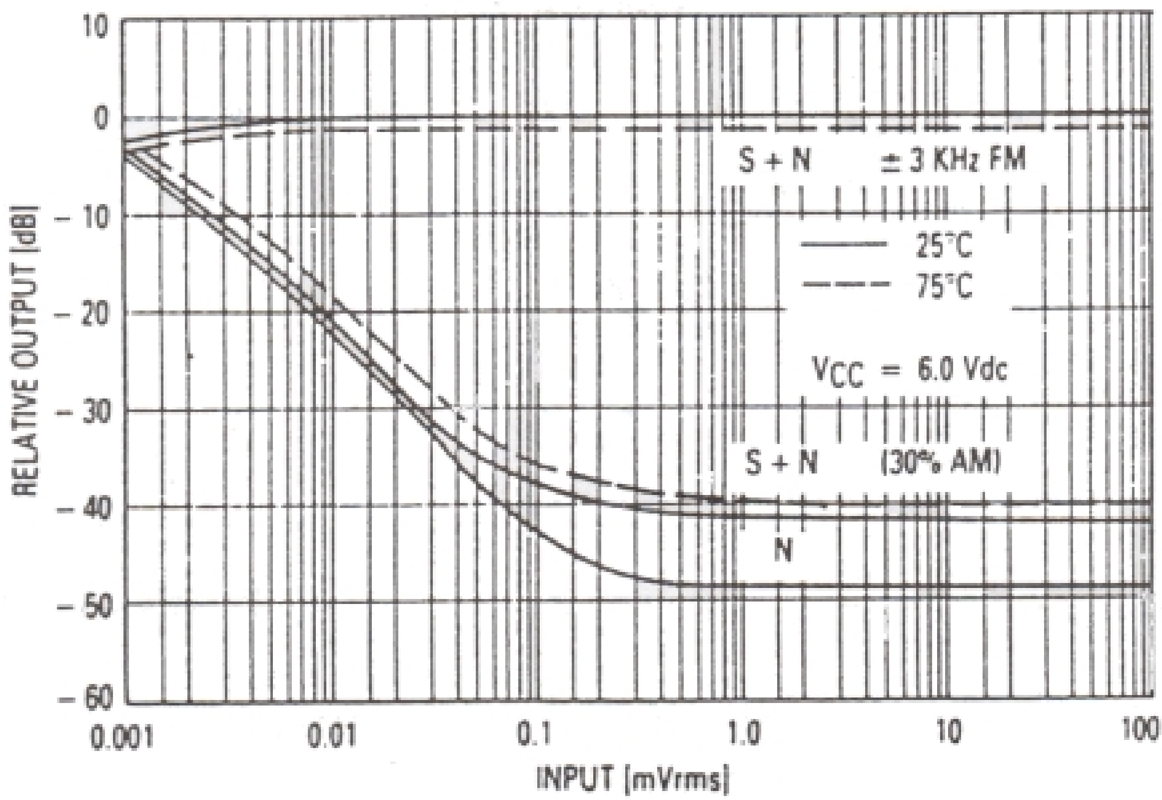

Figure (6): Signal + Noise plot for a Motorola MC3359 Low Power FM IF Detector.

In Conclusion

We have documented a digital FM detection method using NUMA Technologies' NT3xx Period-to-Digital (P/D) Converter, which employs a "zero-crossing" period measurement process. We derived equations that linked zero-crossing measurements to the instantaneous frequency, and exploited the relationships in producing a DSP-based detection transfer function that extracts the detected signal's amplitude. Because DSP-based processes are inherently linear, excellent signal-to-noise ratios with low harmonic distortion are observed. It was shown by means of examples that the best signal-to-noise ratios were produced by the NT3xx P/D FM detector when the IF frequency was roughly several times the frequency value of the full deviation bandwidth.

Examples of SINAD testing on the NT302 P/D were presented, to quantify the device as an FM detector. The first test involved modifying a commercial, two-way trunking receiver with the NT302 P/D detection process, and measuring the SINAD as a function of input over a wide range of input signal levels. The second test was a stand-alone device test, in which the NT302 P/D was compared to a Motorola MC3359; a competing FM detection device. In both cases, the NT302 P/D showed superior performance to the competing systems, as noted improvements in NF were observed.