pair of opposing muscles. The body then alternately tenses opposing muscles to gain a sense of their position. Those vibrations occur at frequencies of 10 Hz.

You might have experienced a good analogy of that concept if you've ever driven an old car with a lot of play in the steering wheel. That play in the steering produces a dead zone around the control position that maintains a straight motion down the road. The dead zone can be handled in one of two ways: You can hold the steering steady, let the car wander off to one side until the error becomes excessive, and then jerk the wheel to correct your course. Or, you can rock the wheel back and forth through the dead zone, sensing the end control points and slowly controlling them to maintain a steady and straight path.

The latter method provides smoother control, and is akin to adding a small oscillation to a servo loop that exactly matches the amplitude of the dead zone. It should be mentioned that the frequency of that oscillation should be greater then the response time of the feedback loop to provide smooth control.

Now back to the muscle-pair example. Under stress and the action of adrenaline, the opposing muscles become more highly tuned and responsive. The dead zone of the muscle pairs is then reduced and the body becomes ready for fight or flight. Consequently, the micro vibrations of muscle pairs diminish with stress.

Because the membranes that form the vocal cord are controlled by three such muscle pairs, it is believed that the pitch of a person's voice will also experience a low-frequency modulation, and the level of that modulation should be inversely related to the level of stress. Those vocal tremors are found in the 7- to 15-Hz range, and are referred to as physiological or micro tremors.

It is believed that micro tremors produce both frequency modulation as well as amplitude modulation. Because micro tremors are small, they are usually inaudible and must be detected electronically. That type of detection is very difficult because human-voice frequencies are by nature quite variable.

In the mid seventies, Alan Bell, Charles McQuiston, and Wilson Ford

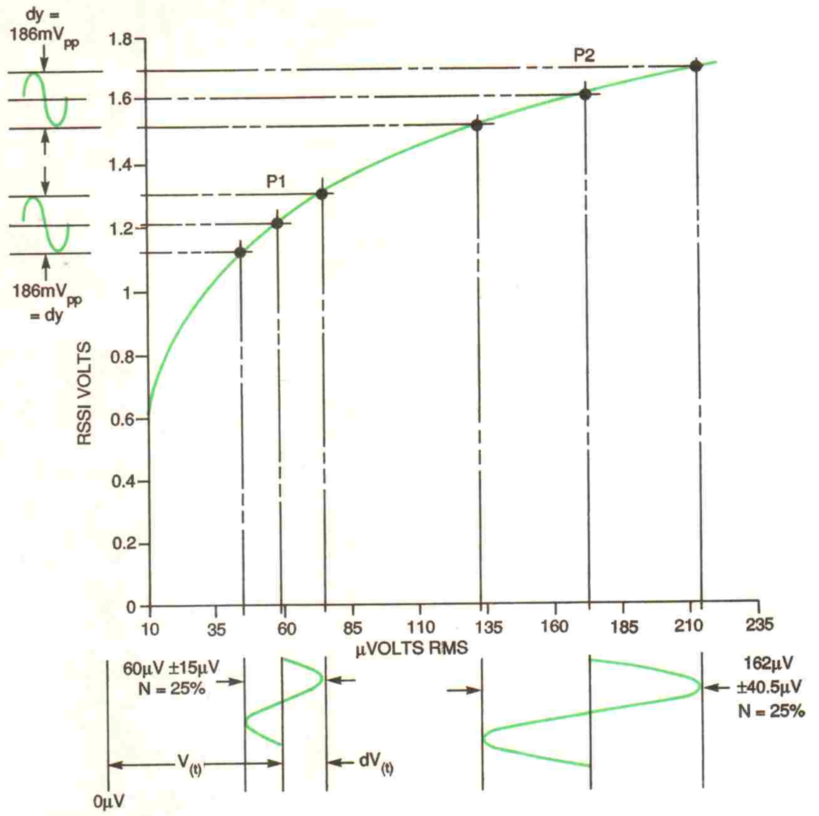

Fig. 1. Shown here is a small portion of a linear plot of Received Signal Strength Indicator (RSSI) response. Note that the slope or gain around small-input-signal-point P1 is high while the gain for a larger signal at a higher point, P2, is smaller.

received a patent on the Psychological Stress Evaluator (PSE). The PSE detects the resulting frequency modulation produced by micro tremors and produces a complicated output signal on a chart recorder. That chart is interpreted by a skilled examiner, as are polygraph results.

A few years after the introduction of the PSE, Fred Fuelleris invented the Vocal Stress Analyzer (VSA). The VSA works by detecting low-frequency amplitude vibrations in the subject's voice. Such amplitude modulation of the voice generates upper and lower sidebands. To determine the degree of stress, the VSA measures the amplitude of those sidebands.

To interpret the results of either a PSE or VSA machine, you must undergo extensive training. Who uses them? Mostly, the machines are bought by investigators, insurance claims adjusters, and law enforcement agencies. The machines are quite expensive, costing a couple-thousand dollars including training.

A Simpler Approach. The Voice-Stress Analyzer described here is based on a new detection scheme that directly measures the percentage of amplitude modulation in a voice. The chip that makes the Analyzer design possible is the Signetics NE614 high-performance FM-IF integrated circuit. While designed for cellular radio service, that 16-pin IC includes a complete successive-detection logarithmic amplifier with a dynamic range of over 90 dB, and a low frequency response due to its DC interstage coupling.

Pin 5 of the NE614 is the detected output and is called the RSSI (Received Signal Strength Indicator) line. The RSSI output level is a full-wave-rectified signal, which we'll refer to as y, that represents the logarithm of the signal input. That means that the level of amplitude modulation (dy) on the RSSI output is a direct measure of the percentage modulation (N) of the carrier ($V_{(t)}$) and is independent of its amplitude and frequency. That property of logarithmic response is of significant importance to the Voice-Stress Analyzer because the normal