An Overview of Non-Linear Junction Detection Technology for Countersurveillance

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Abstract

Non-Linear Junction Detectors (NLJD's) have been used in Countersurveillance for many years. Some security professionals have a very high opinion of them, while others (because of bad experiences using them) believe that they are of little value. The purpose of this article is to help the security professional understand some of the issues that should be considered when using or purchasing a non-linear junction detector. *When these technical issues are understood, an NLJD can prove to be a very useful tool for Countersurveillance.*

Why Use an NLJD?

Most people that are not familiar with spying technology think of bugging devices as mainly transmitters. However, professional investigators or "spies" will use many electronic devices that do not utilize radio frequency transmissions. This is the forte of the NLJD because the NLJD will detect and locate any electronic device regardless of whether or not the device is powered.

NLJD False Alarms

The most common problem with using an NLJD is detecting false alarms. Normal commercial electronic devices such as a telephone or clock will provide a response to the NLJD because they also contain electronics. It is usually obvious when commercial devices generate a response, however, false alarms may also be generated by metallic objects that do not contain electronics. Therefore, a quality NLJD must be capable of providing good discrimination between true semiconductor junctions and false alarm junctions. This article will discuss many of the technical issues and solutions associated with minimizing false alarms.

Nonetheless, because of bad experiences with NLJDs, many professionals believe that you must use an NLJD in conjunction with either an X-ray machine or some other device that provides imaging capability to minimize false alarms. Use of an X-ray machine often results in many difficult problems. You must have access to both sides of the wall; there is a radiation safety hazard; and it is difficult to travel with an X-ray machine. In most cases, I would recommend using a Borescope if necessary. A borescope only requires that a small, repairable hole be drilled to view the inside of most structures. A small portable borescope is included in the optional toolkit with the REI ORION. One very promising technology that I have encountered is the Rascan-2 imaging system developed in Moscow. It is a very portable RF imaging system, but the resolution is only about 2 cm.

The Basic Theory of an NLJD

The NLJD antenna radiates objects to determine the presence of electronic components. When this transmitted signal encounters semi-conductor junctions (diodes, transistors, etc…), a signal is returned at harmonic frequency levels due to the non-linear characteristics of the junction. However, false alarms are often a problem because two dissimilar metals that are joined, touching, or corroded will also return harmonic signals because of the non-linear characteristics of the junction. These we will refer to as false junctions. Graphs of the current and voltage characteristics are provided in Figure 1.

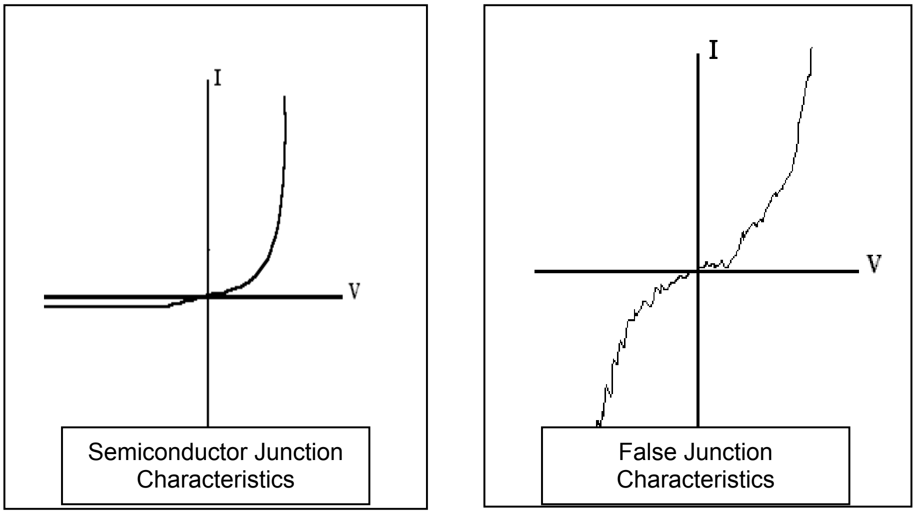

Figure 1 - Non-Linear Junction Characteristics

Comparing 2nd and 3rd Harmonics

Because of the differences in the non-Linear characteristics between Semi-conductor junctions and False Junctions, the 2nd and 3rd harmonic signals will have different intensities. When a NLJD radiates a semiconductor junction, it results in a 2nd harmonic stronger than the 3rd harmonic. A false junction returns a 3rd harmonic that is stronger than the 2nd harmonic. The figures below describe this effect.

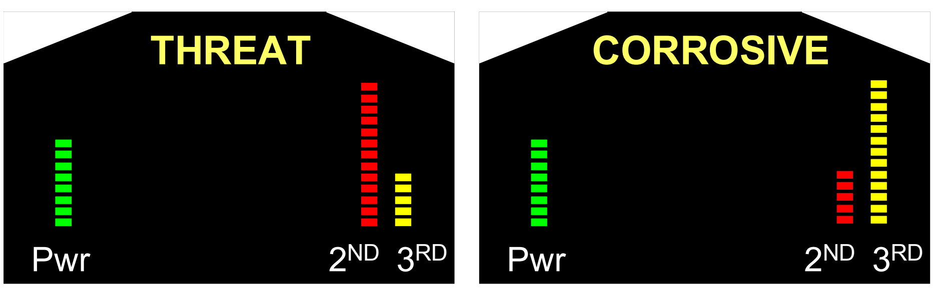

Figure 2: ORION Comparison of Harmonic levels (A – Semiconductor, B – False Junction; Bargraphs on the right are the 2nd and 3rd harmonic levels)

Quality NLJD's will have the capability to compare the received signal strength of both the 2nd and 3rd harmonic. This feature greatly assists the user in discriminating between true semiconductor junctions and false junctions. This feature typically results in a much more expensive NLJD because it implies that the unit has two receivers. It is also very important that NLJD's with both 2nd and 3rd harmonic receiving capabilities provide good RF isolation because the receiving functions must not interfere with each other. After evaluating many NLJD's from around the world, it appears that many units do not have good RF isolation. This means that a pure semiconductor junction may still appear to have a fairly strong 3rd harmonic and a pure false junction may appear to have a fairly strong 2nd harmonic. Therefore, even though the unit has the ability to receive both harmonics, it is often very difficult to distinguish between semiconductor and false junctions. If the NLJD has the capability to detect 2nd and 3rd harmonics, it is very important that the two receive functions are calibrated and do not interfere with each other.

The REI ORION realizes this important feature by using patented receiver process designed by the engineers at REI. This patented process ensures that the two receive functions cannot interfere with each other while providing continuous display of both 2nd and 3rd harmonics.

The Quieting Effect

Many Professionals rely on a "quieting effect" to identify junctions as described in Figure 3.

If you are listening to the demodualated audio of the return harmonic from a semiconductor junction, you will hear the noise level decrease significantly as you approach the junction. Then, as you move away, the noise level will increase again before it returns to normal. The audio will reach its lowest level directly over the device and swell on either side of it.

As you move the NLJD closer to a false junction, the audio noise may increase until you are directly on top of it or in some cases the noise level will decrease in a similar fashion to a semiconductor junction. As you move away from it again, the audio noise will return to the normal environmental noise.

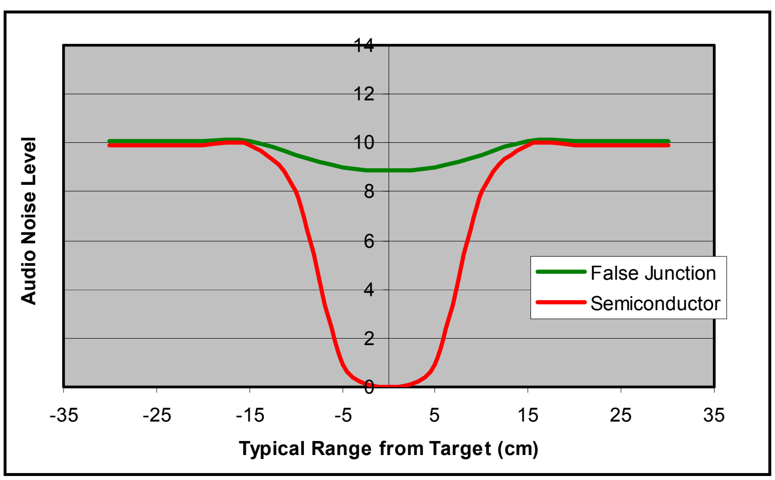

Figure 3: Noise Curve of an Electronic Device and False junction

It is important to realize that the fundamental theory of the quieting effect is a very simple process. Basically, if an NLJD is transmitting a signal with no modulation, then the received harmonic signal will also have no modulation and therefore will have an audio quieting effect. The audio demodulation required for the “quieting effect” could be done using continuous wave or pulsing systems as described later in this article.

There are some Russian NLJD models that advertise a “20K mode” that rely on the quieting effect as a method of discriminating types of junctions. Based on my knowledge and experimentation I do not believe that this is a reliable method for discriminating between semiconductor and false junctions. Some false junctions are easily identified using the quieting effect based on the noise level, but many false junctions also have a quieting effect. The ORION provides a 20K mode for quieting effect analysis, but in fact, the normal FM continuous wave audio is a more effective mode of using the quieting effect.

Other Uses for Audio Demodulation in an NLJD

Often when one is using an NLJD, it is possible to not only detect electronics, but it may also be possible to classify the electronics based on audio demodulation. For example, when detecting some tape recording devices, it is possible to hear the audio from the tape recorder head using the NLJD audio demodulation. Furthermore, if the NLJD provides good audio demodulation, it is often possible to hear the video synchronization pulse when detecting many chip cameras. *Furthermore, using FM demodulation, it is sometimes possible to hear periodic or unique audible sounds resulting from phase-shifts in active electronic devices.* <u>Therefore, it is important to practice using a NLJD so that audio sounds peculiar to specific detected devices can be easily recognized.</u>

Furthermore, if a false junction is detected, one can easily discriminate between semiconductor junctions and false junctions by listening to the audio while providing a physical vibration to the junction (which is usually done by pounding on the wall with your fist or a rubber hammer). A false junction will break-up and a crackling sound will be heard. The true junction will remain silent. <u>An NLJD unit must provide good quality audio demodulation of both AM and FM modulated harmonics to take advantage of this audio effect for discrimination.</u>

In the ORION, there is a mode that uses a Continuos Wave transmit signal with a 1KHz FM modulated tone. Using this method, a tremendous detection range can be realized by relying on the user’s ability to hear the FM demodulated tone from the high quality receiver. While the visual bargraph display may only show a very small response, which may be interpreted as noise, the audible tone provides unquestionable detection of a Non-Linear Junction. <u>Using an FM modulated tone can provide a tremendous increases in detection range if the receiver has good quality audio and isolation from the transmitter. However, the modulated tone mode does not provide any positive discrimination between semiconductor junctions and false junctions.</u>

Pulsing versus Continuous Wave

Most of the NLJD's that have been developed around the world are continuous wave (CW) devices that transmit a continuous narrow band signal with no interruption. However, there are a few NLJD's that utilize a pulsed waveform that provides some advantages. Pulsing provides the advantage of conserving battery life if the transmitter is properly designed. For example, a receiver may be designed to sample the received signal at a rate that is sufficient for human hearing and viewing while turning the transmitter off for significant periods of time between samples. This will reduce the need for large batteries and power supplies. Furthermore, to support the quieting effect function described above, a NLJD that operates using Continuous Wave (CW) transmission must have good quality low noise amplifiers in the receiver and good quality demodulation circuitry to provide audio for the quieting effect. However, another method of demodulating the audio is to transmit a pulsed waveform. If the pulse repetition frequency of the pulsed waveform is above audible hearing, then a simple AM demodulation circuit can be used to provide good quality demodulated audio. <u>It does not matter if the NLJD is a pulsing transmitter or a CW transmitter as long as the audio receiving function has been properly designed to provide good audio, and the unit is easy to use. The REI ORION provides both AM and FM audio using a pulsed waveform for AM demodulation and a CW waveform for FM to provide the maximum benefit of the quieting effect.</u>

Frequency Interference

Most NLJDs are fixed frequency devices, but some have multiple transmit channels. Unlike the REI ORION, most NLJD's are limited to either a single frequency channel or a small frequency range. Because of the increasing number of wireless communication devices and governmental regulations these limited frequency NLJD's will often have conflicts with other electronic devices. If the NLJD is operating on a frequency that may also be occupied by another transmitter, the NLJD may have very erratic and unreliable readings. This is a common problem in the United States especially in larger cities, and to my knowledge, the REI ORION is the only NLJD that is designed to address this problem. <u>Because of these problems, an NLJD should be frequency agile and automatically search for quiet channels on which to operate to avoid frequency interference from other devices.</u>

Power Level and Sensitivity

Many people compare NLJD performance based on transmit power because it is a relatively easy concept to understand. However, it is important to realize that the receiver sensitivity is just as important as transmit power when comparing actual detection performance. It is important to understand that a low power NLJD with a quality receiver may have much better detection performance than a very high power unit with a poor receiver. It is also very important to consider that the high power unit may cause unintentional damage to electronics *or even be dangerous to humans*. I have been told that the Russian high-power impulse models provide additional power to insure that the semiconductor junction is activated. This is a false assumption. A diode represents the simplest form of a semiconductor junction and provides a great deal of insight into the theory of NLJD operation. Electronic Engineers often model a diode as a simple current switch that allows current to flow for a positive bias voltage. However, this is an over simplification that should not be used when analyzing NLJD theory. A semiconductor junction not a simple "ON or OFF" function; it is a well-defined continuous exponential function described in Figure 1 and in the equation below:

$$I = I_o \cdot \left(e^{\frac{q \cdot v}{K \cdot T}} - 1 \right)$$

where Io is the leakage current,
q is the electron charge,
K is Boltzman's constant,
T is the temperature,
V is the voltage across the diode.

Therefore, a low power NLJD may have better performance then a High power NLJD if the low power NLJD has a better receiver.

To my knowledge, the ORION is the only NLJD in the world that employs digital signal processing (DSP) techniques to further improve the sensitivity of the receiver. The ORION provides the ability to greatly increase detection range by sampling the receiver output and integrating the results. The user can manually program the signal processing integration gain to optimize the use of the unit.

Furthermore, to my knowledge, the ORION is the only NLJD in the world that employs automatic power control algorithms. In the ORION, if the receiver is saturated, the unit automatically reduces transmit power so that the junction can be evaluated. When the received signal strength returns to normal, the transmit power returns to the original state.

These features (DSP gain control and automatic power control) make the ORION very easy to use without having to constantly adjust the operational characteristics while performing a sweep.

Ergonomic Considerations

When using an NLJD it is very important to be able to get a good view of the display to interpret the unit response. In some units, the display is located on a transceiver unit that must be worn on your shoulder or neck. In my opinion, this is the least effective method of displaying information because it is difficult to view the response information while moving the antenna over various surfaces. Other units have a display that is built on the unit handle. This is an improvement, however, if the display is not very prominent (such as a LCD type display), it is difficult to read the display while using the antenna. The best type of display is a very bright display that is built on the antenna head and can be viewed and easily read from many angles. Having the display build into the antenna head allows the user to view the display and the antenna sweep location simultaneously. If the user cannot easily view the display, the performance of the sweep is degraded because the ability to interpret the harmonic results is degraded.

NLJD's have historically been very heavy and bulky pieces of equipment. With the exception of the REI ORION, all of the units that I am currently aware of have a transceiver module that must be worn over your shoulder or around your neck while holding an antenna assembly. In all of these units, the transceiver unit is heavy and there are cables that connect the antenna assembly to the transceiver. These cables often interfere with the use of the device by hanging on furniture or knocking valuable items off of desks. After discussing ergonomic issues with many Countersurveillance professionals from around the world, the conclusion is this: if the display is difficult to see and the unit is tiring to use, it does not matter about the detection range or discrimination capability of the unit because the user will not perform an effective sweep. An NLJD must be comfortable and easy to use to ensure an effective sweep.

Conclusions

It is important to understand that there are two processes taking place when using a NLJD (1) Detecting the Non-linear Junction and (2) Discriminating between a semiconductor junction and false junction. A NLJD should be judged on both the detection range and discrimination capability of the unit.

It is my opinion that the best figure of merit for a NLJD is *detection range* is the penetration depth of the NLJD into physical structures that exist in the sweep area. However, the concept of *detection range* should be properly understood and only be used for comparing NLJD's when the NLJD models are tested under identical conditions. *Furthermore, great detection range is not necessarily a good thing because you may simply be detecting electronic devices in the next room such as computers or telephones. When using an NLJD, the unit must have not only sufficient detection range but the ability to be properly adjusted (usually using the transmit power, or in the case of the ORION adjusting the DSP gain) for the desired penetration depth into the material being searched.*

Historically, models of NLJD from the United States relied solely on comparing the 2nd and 3rd harmonic for discrimination. However, It is also important to utilize audio methods such as the quieting effect and applying a physical vibration to discriminate between types of junctions. For maximum reliability, a good NLJD should have multiple methods of discriminating between semiconductor and false junctions.

As previously stated, there are many differing opinions about the use of NLJD's. In the United States, there are some professionals that believe that you must use an NLJD to perform a credible sweep while other professionals believe that NLJD's should not be used because of too many false alarms or other technical problems. These opinions vary because people have widely different experiences using NLJD's due to the issues discussed in this article. The ORION by REI was engineered to address all of the technical and ergonomic issues discussed in this article. *The ORION provides both continuous wave and pulsing modes that are optimized for maximum detection range, comparison of 2nd and 3rd harmonic levels, and very effective discrimination.* With its compact size, the entire unit fits into a case that is only slightly larger than a briefcase and weighs less than 3.5 pounds (1.6Kg). There are no *external* cables to snag on furniture or heavy modules to hang over the users shoulder and cause fatigue.

As the author of this article, I attempted to be completely objective about the technology considerations involved in purchasing and using a quality NLJD. As the General Manager of REI, I am of course biased towards the REI ORION. Nonetheless, I hope that you found this article an interesting discussion of NLJD technology.