Introduction

The improvements in audio quality in playback systems in theater and home have driven improvements in production equipment and techniques to meet greater expectations. Wireless microphone systems have benefited from advances in DSP (digital signal processing) in the same manner as mixing, recording and playback equipment. DSP has added features and functions to wireless microphone systems that are not feasible in the analog realm.

The Lectrosonics Digital Hybrid Wireless® system* uses innovative technology to combine the advantages of digital audio with the advantages of analog RF transmission, to deliver the superior sound quality of a digital audio system and the excellent RF performance of an analog wireless system. A proprietary algorithm encodes the digital audio information into an analog format which can be transmitted in a robust manner over an analog FM wireless link. The receiver employs state-of-the-art filters, RF amplifiers, mixers and detector to capture the encoded signal and a DSP recovers the original digital audio.

This digital/analog hybrid technique has some very beneficial properties. Because the information being transmitted is digitally encoded, immunity to noise is much higher than using compandor noise reduction. Because the encoded audio is sent in analog format, spectral and power efficiency and operating range are not compromised.

Under weak RF conditions, the received signal degrades gracefully, like an analog system, delivering as much usable audio as possible at maximum range.

For this discussion, wireless microphone system designs are divided into three general categories:

- Analog
- Pure Digital
- Digital Hybrid

The most fundamental requirement for a wireless system is to provide a reliable RF connection between transmitter and receiver. If this radio link is problematic, the other features and attributes of the system are in essence meaningless. One of the first considerations, therefore, is the reliability of the RF link.

While the radio spectrum covers an enormous range of frequencies, Digital Hybrid Wireless systems are especially valuable for operation within television channel allocations between 470 and 862 MHz.
**Occupied Bandwidth**

Government regulations in almost every country limit the bandwidth that wireless transmissions can occupy. The US and European spectral masks are good examples.

The bandwidth occupied by the transmission must remain inside the applicable spectral mask.

Analog FM transmission concentrates the power into a narrow band with minimal out of band noise above and below the carrier.

Digital modulation methods can be designed to spread across wider bandwidths or fit into narrowband TV channels. In many cases, the upper range of audio frequencies must be sacrificed to reduce the occupied bandwidth to fit inside the spectral mask.

Analog FM has an advantage in the television bands because the peak power is contained within the spectral mask. Analog transmitters can operate at the full power levels allowed by the regulations. Digital transmission must operate at a lower power level to keep the noise skirts inside the spectral mask.

As a contrast, look at the occupied bandwidth of a digital wireless transmission using a spreading technique. This example is the Lectrosonics D4 system. Note that the span in this example is 10 MHz wide.

**Intermodulation**

When two or more signals are present at any level in a non-linear electronic device, such as an amplifier, a process called *intermodulation* (IM) occurs. IM generates a number of different signals at the output of the device.

IM can be generated in a receiver in a number of places in the circuitry, especially in front-end and IF amplifiers. 2nd Order IM produces a sum and difference of the two input signals.

![Noise Skirt](image)

_Narrowband digital transmitter (not Lectrosonics)_

![Noise Skirt](image)

_D4 Spreading Digital transmitter_

**2nd Order intermodulation**
3rd Order IM involves the 2nd harmonic of one frequency mixing with the fundamental of the other frequency.

<table>
<thead>
<tr>
<th>Frequency Difference</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>650 x 2 + 600</td>
<td>1900 MHz</td>
</tr>
<tr>
<td>650 x 2 – 600</td>
<td>700 MHz</td>
</tr>
<tr>
<td>600 x 2 + 650</td>
<td>1850 MHz</td>
</tr>
<tr>
<td>600 x 2 – 650</td>
<td>550 MHz</td>
</tr>
</tbody>
</table>

3rd Order intermodulation

3rd Order IM is a primary concern in frequency coordination because the signals it generates are quite strong and occur on exact multiples that do not allow evenly spaced frequencies. The combining produces IM products that fall exactly on the frequencies in use, for example:

- \(625 \times 2 = 1250 - 600 = 650\)
- \(625 \times 2 = 1250 - 650 = 600\)

Note that the two carriers are spaced about 22 MHz apart, which generates two IM products at the same spacing above and below the carriers. The point is that IM generated in transmitters cannot be solved by wide frequency spacing and IM is just as real in digital systems as it is in analog systems. The IM products are also only 30 dB below the carriers, so they can be a serious source of interference for other systems.

Meet the Isolator

To deal with the problem of IM generated in Digital Hybrid transmitters, Lectrosonics has employed an expensive but very effective solution called an isolator. This device is positioned in the output circuit between the final amplifier and the antenna and functions as a one-way gate to suppress RF signals that could travel back into the transmitter final amplifier.

Isolator in the Lectrosonics HM transmitter

Isolators are rarely found in wireless microphone transmitters because of their high cost and significant size. The smaller they are, the narrower the bandwidth, which imposes limits on their usage. The benefits, however, far outweigh the limitations in applications where multiple transmitters must be operated in close proximity.

Multi-channel Capability

Analog FM systems centralize the energy and produce low noise skirts above and below the channel. Frequency coordination is straightforward and predictable for analog and Digital Hybrid wireless systems since both types use an analog FM radio link.

Digital wireless transmissions produce very wideband noise skirts above and below the channel, which increases the noise floor of other systems, even those greatly separated in frequency. While IM products can be predicted, calculating the broadband noise buildup is not addressed in frequency coordination software.

Because of the enormous number of calculations necessary to accurately predict IM and other types of interference, computer software has been developed to achieve results in a reasonable period of time. One of the best software packages available is called IAS (intermodulation analysis software). Visit their web site for more information:

http://www.professionalwireless.com/ias/

Even with a thorough analysis with software, a real world test must still be completed to verify the reliability of a multi-channel wireless system because external signals present in the actual production cannot be predicted. A valid test involves verifying that all the receivers are on quiet channels, turning transmitters on one at a time to verify that only the matching receiver responds, and finally turning transmitters off one at a time to make sure the matching receiver squelches as it should.
**Fringe Area Behavior**

The signal strength from a transmitter varies wildly in normal operation due to the influences of distance, obstructions and multipath reflections. When the signal dips to a low level at the receiver antenna, the receiver can produce noise bursts or hiss just before the squelch mutes the audio.

<table>
<thead>
<tr>
<th>Strong Tx Signal</th>
<th>Weak Tx Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent S/N Ratio</td>
<td>Poor S/N ratio</td>
</tr>
</tbody>
</table>

When the transmitter signal is generally weak, but the audio content is present at a sufficient level to mask background noise, the squelch threshold will be reduced to allow the system to continue to deliver audio and extend operating range.

When the transmitter signal is close to the receiver antenna and the signal is generally strong, SmartSquelch™ will be more aggressive and squelch the audio to prevent noise that can occur during a brief dropout.

This adaptive squelching behavior in Digital Hybrid receivers works to extend operating range and minimize noise automatically with no adjustments or special setup required.

**FM Capture Effect**

When multiple radio signals arrive at the receiver, the strongest signal will be the source for the audio output, and weaker signals will be overridden or suppressed.

This is called the FM capture effect. In other words, the strongest signal will “capture” the receiver.

This is one reason why an FM receiver is naturally tolerant of noise in the incoming signals.

Analog FM and Digital Hybrid receivers only need 3 or 4 dB more signal from the intended transmitter than from the noise to generate a usable audio signal to noise ratio.

Pure digital receivers typically need 12 to 14 dB or more signal from the intended transmitter to bury the noise and interference from other transmitters.

When the noise and interfering signals are strong enough to compete with the intended transmitter signal, the receiver is said to be desensitized since it can no longer deliver audio from an incoming radio signal that would otherwise be strong enough for normal operation.

**Audio Quality**

**Noise Reduction**

Analog wireless systems suffer from noise buildup in the RF link, so noise reduction techniques are needed to produce high quality audio. The most effective technique is the compander. Audio is compressed in the transmitter to allow higher average modulation in the radio link (a higher signal to noise ratio), then expanded in the receiver to restore the original dynamic range in the audio.

A single band compandor compresses and expands the entire audio bandwidth, which compromises audio quality because attack and decay timing for high frequencies are considerably different than for low frequencies to keep distortion low. So a dual-band compandor was developed by Lectrosonics to address this problem.

**NOTE:** Digital Hybrid and pure digital systems do not employ compandors.
Frequency Response

Pure digital wireless systems designed to deliver high quality audio often face a problem with the bandwidth required to cover a full audio spectrum from 20 Hz to 20 kHz. High frequency audio requires a much greater bit rate for the upper frequency range so compression is applied and in some cases the upper frequency limit is restricted to a lower range such as 15 kHz. It can be argued that this does not produce an audible result, however, almost all other professional audio equipment will normally handle an upper limit of at least 20 kHz.

Digital Hybrid Wireless systems deliver a flat response to 20 kHz as shown in the following graph.

The low frequency roll-off is adjustable to suit personal preference or as needed to deal with noise present in the production environment. In a moving vehicle, for example, low frequency energy is very dominant so the roll-off can be adjusted upward to reduce its presence in the audio picked up by the microphone. On a quiet set, such as a motion picture production studio, the roll-off can be adjusted downward to capture full bandwidth audio.

The Digital Hybrid Wireless Solution

When the aforementioned aspects of a wireless system are considered, it is easy to understand why Digital Hybrid Wireless technology has been readily adopted by audio professionals all over the world.

The benefits of the technology include:

- Efficient use of RF spectrum
- Inherent noise immunity
- Maximum transmitter output power can be used
- Minimal sideband transmission noise
- Compandor-free audio quality
- Flat audio frequency response of 20 Hz to 20 kHz
- Compatibility modes allow use with other systems

The Digital Hybrid Wireless Process

The audio entering the transmitter is first sampled at 88.2 kHz and converted to a 24-bit digital audio stream. The digital audio is analyzed by a DSP-based algorithm that attempts to predict the next audio frames on a continuing basis. The prediction is then compared to the actual audio stream that arrives a bit later and a difference (error) signal is derived.

The error signal is delivered to the output of the transmitter and transmitted with a wide deviation FM modulation. A compandor is applied to the error signal to improve the signal to noise ratio of the radio link, but no compandor is applied directly to the audio.

Inside the receiver the same predictive algorithm is operating. The error signal is received and then applied to the predicted audio stream to restore the original digital audio stream. The 24-bit digital audio is then converted back into an analog audio output.

A Digital Hybrid transmission exhibits a different behavior when viewed on a spectrum analyzer. For example, when a pure sine wave tone is delivered to the transmitter, the predictor works perfectly and there is essentially no modulation of the FM carrier since there is no error signal to be transmitted.

When the Digital Hybrid system was first introduced, a call was received at the factory from a television station that was one of the first to evaluate the new system. The station engineer connected a signal generator to the transmitter and injected a 1 kHz tone and adjusted the input gain for full modulation. He then looked at the radio signal on a spectrum analyzer, and much to his surprise all he saw was a vertical line indicating the carrier with no modulation, yet full level audio was coming out of the receiver. Puzzled, he called the factory for an explanation. Even after the explanation he was still suspicious, yet he did agree that the system worked very well and sounded very good.

When a random noise source like white noise, human speech or music is sent through the system, modulation of the FM carrier takes place because the predictor is sending a significant error signal.

The overall latency of the Digital Hybrid process is about 3.2 ms. This is roughly equal to the time it takes for sound to travel about 3 feet (1 meter) through the air.

Digital Hybrid Wireless® is a registered trademark of Lectrosonics, Inc. and covered by US Patent 7,225,135.
When was wireless invented?

The concept of a wireless microphone has been around for quite some time and it has evolved alongside the development of improved audio recording and playback systems for broadcast, motion picture and live sound applications.

The first working wireless microphone components and systems were developed in the late 1950's and early 1960's. Web searches and Wikipedia offer some interesting documentation on the history of wireless microphone development.

Just for fun, have a look at the drawing below. This graphic was part of a patent issued in England in 1917 as a concept for simultaneous recording of picture and sound via a radio link for the audio signal to eliminate the awkwardness of cables on the stage.

Notice the antenna on top of the actor's heads, with a trailing ground wired at their feet, as detailed in Fig. 2. Battery packs are shown in the diagrams for the transmitter on the camera and in the pack carried by the actors. No doubt, the size and weight of the packs would be cumbersome, to say the least.

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**British Patent 107,167**

*Accepted June 21, 1917*