1.0 Theory of Operation

The radio accepts a 1.25 Gbps (digital) data input and uses it to directly modulate the RF carrier via. On/Off Keying ("OOK" or "DDM" for "direct digital modulation"): therefore, "1s" and "0s" from the digital input directly correlate to "On" and "Off" bursts of RF which are amplitude detected by the (remote) receiver and interpreted as digital "1s" and "0s".

On/Off Keying ("OOK") is the simplest and oldest form of Amplitude Modulation ("AM"): early implementations include the Morse telegraph where a DC current was simply turned On/Off. Even today, radio amateurs routinely use AM transmissions for long range communications.

The functional implementation of OOK with a ***sinusoidal modulation signal*** is illustrated in Figure 1 where the output of the RF carrier is multiplied by an On/Off modulating signal.

1.1 Modulation by a Sinusoid

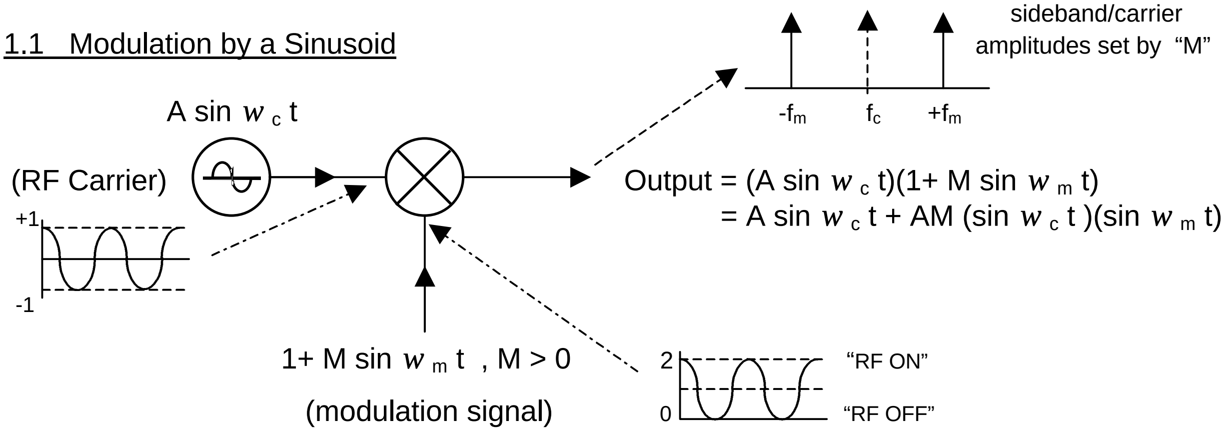

Figure 1 - Functional Implementation of OOK with a Sinusoidal Modulation Signal

Since (sinX)(sinY) = ½ cos (X-Y) + ½ cos (X+Y),

then Output = A sin w_c t + AM/2 cos (w_c - w_m)t + AM/2 cos (w_c + w_m)t

where: A sin w_c t = carrier component

AM/2 cos (w_c - w_m)t = "lower sideband" component

AM/2 cos (w_c + w_m)t = "upper sideband" component

In particular, note that

- Amplitude Modulation inherently generates a single carrier
- Amplitude Modulation (*for a sinusoidal modulation signal*) inherently generates two sidebands of equal amplitude which are equally spaced in frequency by $\pm$ w_m (the modulation frequency) from w_c (the carrier frequency)
- The sideband amplitudes relative to that of the carrier is (M/2); "M" is generally referred to as the "modulation index".

1.2 Modulation by a Square Wave

Consider the case where the modulating signal is a square wave: since the square wave is equivalent to a series of sinusoids (having various amplitudes), the RF modulated output will simply consist of the product of the carrier signal and each equivalent sinusoidal component of the square wave, thus generating many lower and upper sidebands.

For a 50% duty cycle square wave, the relative amplitudes of the equivalent sinusoidal components (and therefore the relative amplitudes of the modulation sidebands) follow the familiar (sin x)/x function (for *voltage* waveforms; for *power*, the relative amplitudes of the sidebands will follow a $[(\sin x)/x]^2$ function since (power) $\propto$ $(\text{voltage})^2$).

Note that the equivalent sinusoidal components of the 50% duty cycle square wave will consist only of sinusoids at the same fundamental frequency as the square wave and all *odd* harmonics. For a square wave having other than a 50% duty cycle, the equivalent sinusoidal components will consist of sinusoids at the same fundamental frequency as the square wave and *all* harmonics.

1.3 Modulation by a Digital Word

For the case where the modulation frequency is a digital word consisting of a defined number of bits (either 1s or 0s), the equivalent modulation square wave frequency is defined by the amplitude envelope established by the 1s and 0s in the digital word. For example, if the digital word consists of four 1s followed by four 0s, and each bit is 0.8 nS in duration, then the equivalent modulation waveform is a 50% duty cycle, 156.25 MHz square wave as shown in Figure 2).

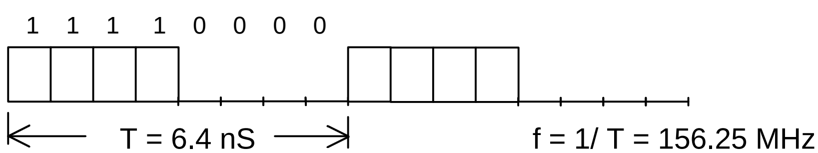

Figure 2 – Modulation Signal is a Digital Word

For the case where the digital word shown in Figure 2 is the modulation signal, the RF spectrum frequency components over a $\pm$ 800 MHz bandwidth will appear as shown in Figure 3; the relative sideband amplitudes will follow the $[(\sin x)/x]^2$ function (for *power*), and the modulation index M will determine the sideband amplitudes relative to the carrier.

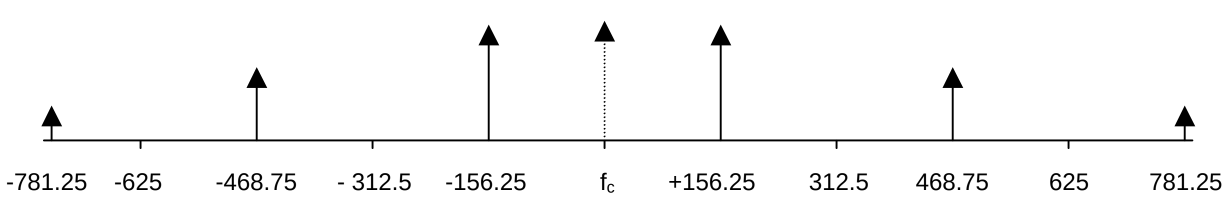

Figure 3 – RF Power Spectrum over a $\pm$ 800 MHz Bandwidth

Note that for OOK modulation *with square wave modulation signals*, the receiver bandwidth (in Hz) is equal to the data rate (in bps); for example, the receiver bandwidth needed to support a 1.25 Gbps data rate is 1.25 GHz.

1.4 Single-Sideband Operation

For square wave modulation signals, the output spectrum is theoretically infinitely wide, which of course is unacceptable for practical transmissions.

Since each sideband has a complete "copy" of signal data within it, it is feasible to transmit only a single sideband; since the two primary sidebands have the greatest energy per Hz, then either primary sideband is a good choice. Note that increasing the receiver bandwidth to "capture" additional energy beyond the two primary sidebands will actually reduce S/N because the higher-order sidebands contain much less energy per Hz (due to the sideband amplitudes following the $[(\sin x)/x]^2$ function).

Therefore, in order to meet allocated spectrum constraints, only one sideband is transmitted in the GigaLink radio: this is accomplished by band-limiting the modulated RF prior to sending it to the antenna (see Figure 4).

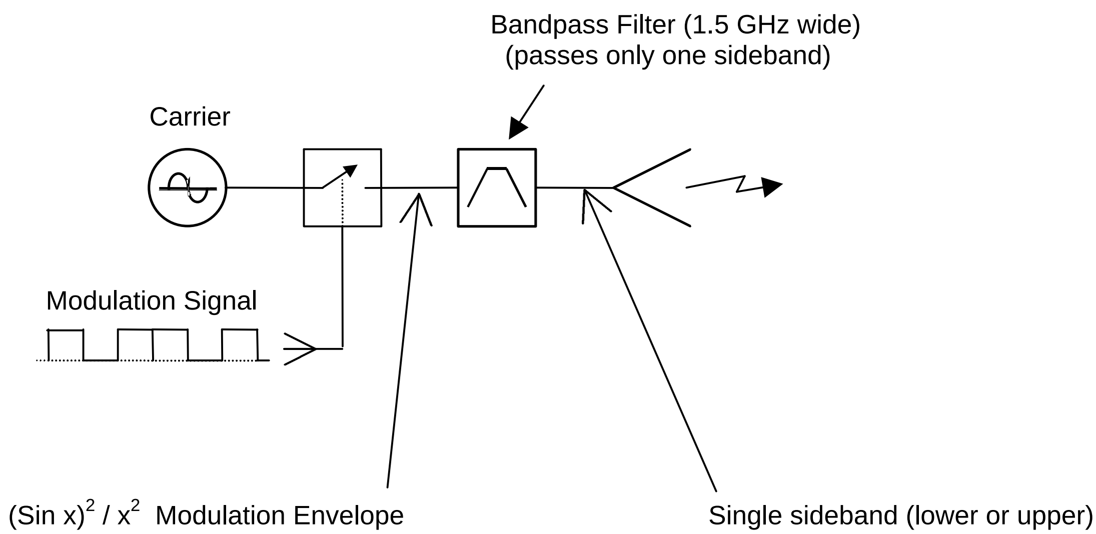

Figure 4 – Band-Limiting the Modulated RF

1.5 Radiated Spectrum

Using the test set-up shown in Figure 5, actual radiated spectrum plots are detailed below.

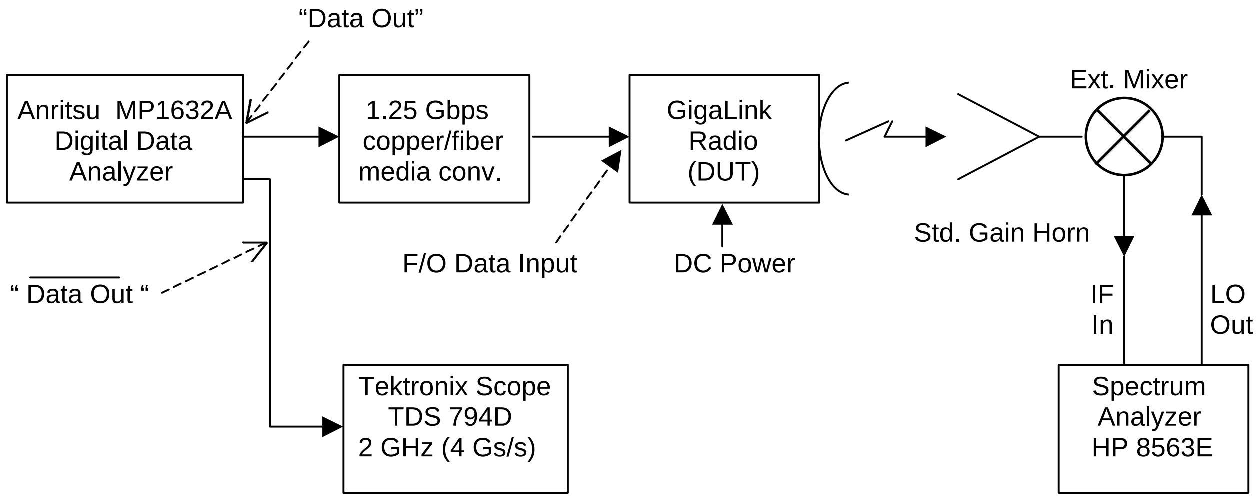

Figure 5 – Test Set-Up

For "instantaneous" observation of the entire spectrum on an average basis, the pseudorandom test pattern of the Anritsu Data Analyzer serves as the modulation data input – for this case, the display from the spectrum analyzer is shown in Figure 6 where the many sideband amplitudes are effectively attenuated by the duty cycle effect, but the entire bandpass is seen at a glance.

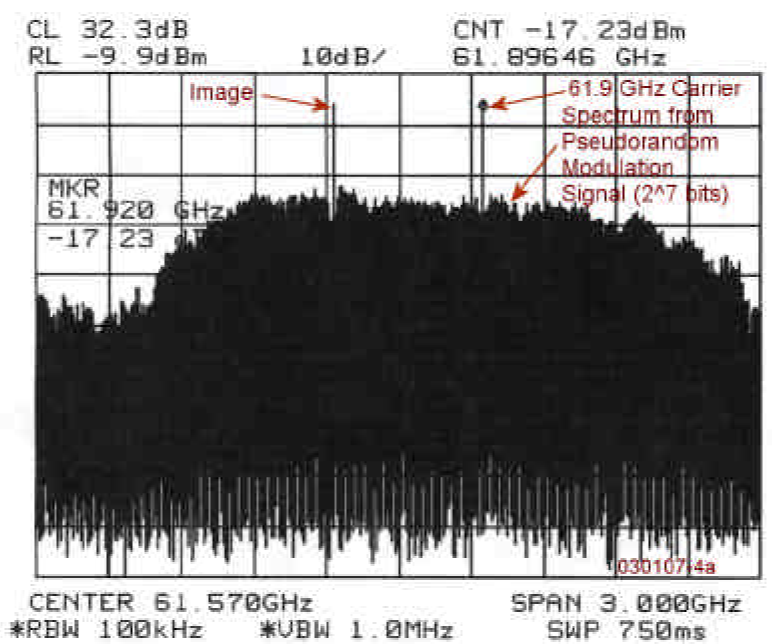

Figure 6 – Emission of Radio Terminal for Pseudorandom Data Input

Figure 7 details the radio emission for a constant digital input word composed of four 1s followed by four 0s (as detailed in Figure 2); a “blow-up” of Figure 7 showing the relative amplitudes of the carrier and the sideband is shown in Figure 8.

<u>Note that the sideband is 3.03 dB below the carrier.</u>

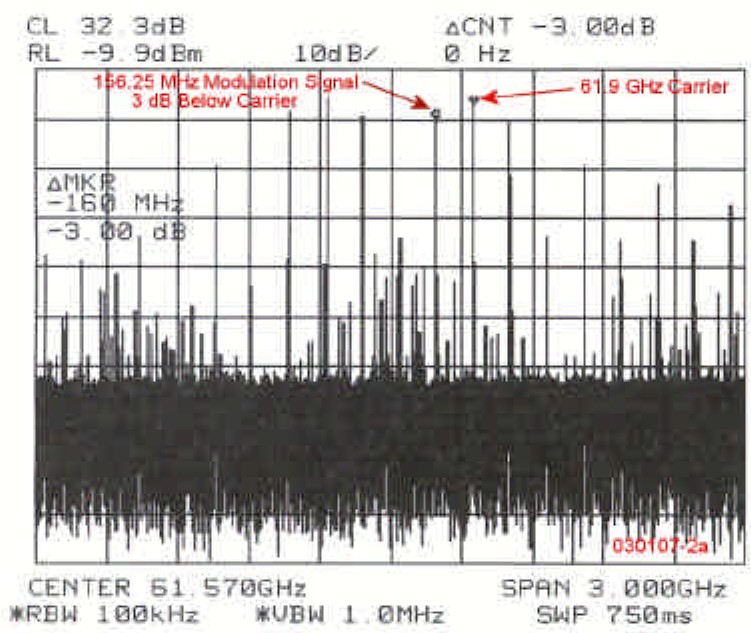

Figure 7 – Radio Emission for a 11110000 digital word (156.25 MHz Modulation Signal)

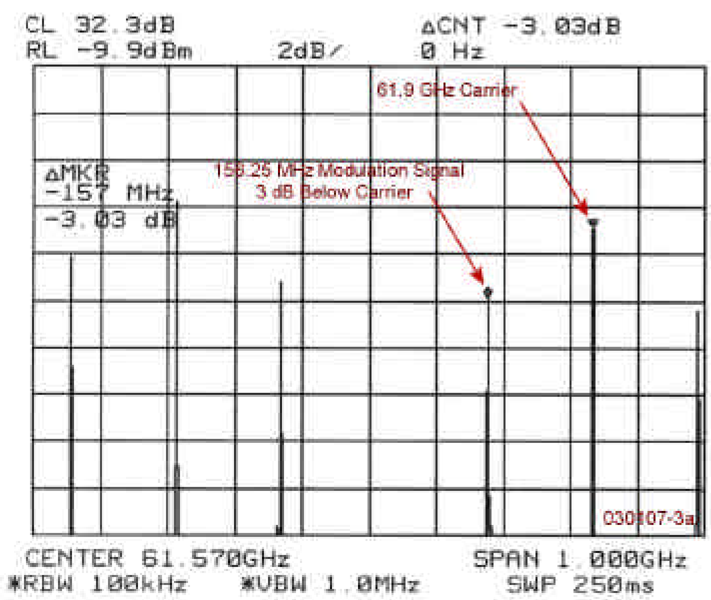

Figure 8 – Detailed View of Radio Emission for a 11110000 digital word (156.25 MHz Modulation Signal)

The digital word output (from the Anritsu) is shown in Figure 9 (as displayed on the Tektronix oscilloscope). Note that each bit is 0.8 nS wide, and that the period for the 8 bits is 6.4 nS, which establishes the modulation frequency as 1/(6.4 nS) = 156.25 MHz.

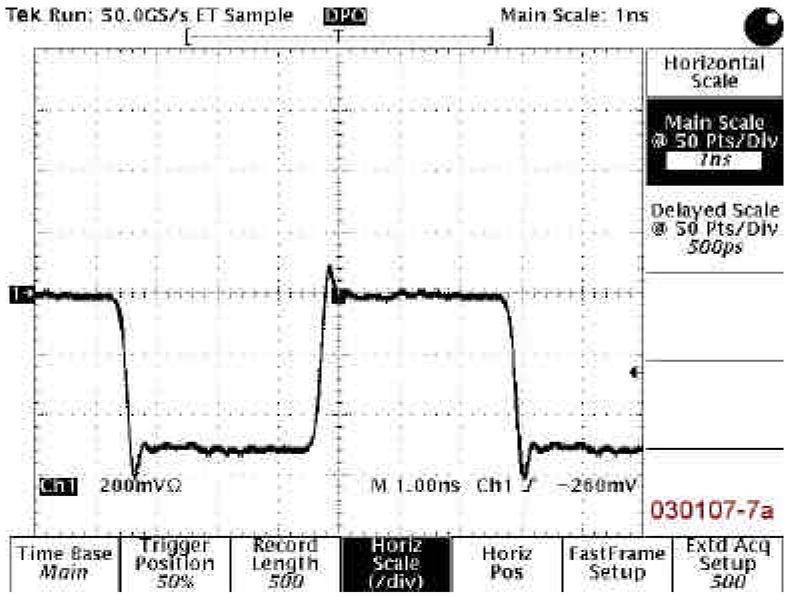

Figure 9 – Continuously Applied 11110000 Digital Word (156.25 MHz Modulation Signal)