

## LAYMAN:

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Modulation is the science of placing intelligence on a carrier. This carrier can be a radio frequency, sound wave ( your voice for example ), or beam of light. Mathematicians call it "convolution", which has nothing to do with a simple explanation. The main point is to get the information from here to there so that someone can understand it.

There are various forms of modulation used on the familiar every day radio. Amplitude modulation used in the AM band ( 500 - 1600 kHz ), and frequency modulation ( 88 - 108 MHz) used on the FM band, are two examples.

Modulation normally requires "bandwidth", that is, a spread in frequencies. In the AM broadcast band, the radio station uses 10 kHz of bandwidth. In the FM band, the station is authorized to use 200 kHz of bandwidth. Stations are allocated frequencies on the dial so that the band spreading of one station does not cause interference with the adjacent station.

**Ultra Narrow Band modulation is a very unique modulation concept for transmitting digital information that does not require a spreading of the bandwidth, therefor 20 to 50 times as many radio stations could be put on the dial.**

There are other digital modulation methods, known as the "NRZ line code" methods, that can compress the bandwidth used when transmitting. They are called Line Codes because they can also be used on wire lines. The most noteworthy of these is Quadrature Amplitude Modulation ( QAM ), which can compress the bandwidth used to as little as 1/8 that normally expected. They do so however at a tremendous loss in power. To compress the bandwidth 10/1 would require 10,000 times as much power to transmit the message the same distance as a station that did not use this form of bandwidth compression, namely multiple bits per symbol.

Ultra Narrow Band modulation is in a different class, employing a modulation method known as "Minimum Sideband" phase modulation that has no power loss due to the bandwidth compression because it does not use multiple bits per symbol. The trick is to find a coding and modulation method for the data that uses a minimum, or almost zero bandwidth.

The first method to be effectively employed, VMaxSK, was based on a patented coding method that alters the well known BPSK\* modulation method. This method places all of the modulation into two very narrow frequency islands, or sidebands, only one of which is transmitted. At this point it is totally in compliance with all of the standard engineering rules. This coded phase method may seem to violate all the rules, but all it really does is to embody the important feature that enables all the ultra narrow band methods to function. This method has been superceded by a newer simpler, easier to use, method called VminSK, or MSB.

\* Bipolar Phase Shift Keying.

Ordinary modulation methods such as AM and FM create a carrier plus sidebands, The carrier remains unchanged and the sidebands add to it to cause the modulation, and since the sidebands

are necessary, they must be transmitted along with the carrier, using a broad bandwidth. The VminSK methods alter the carrier by abrupt phase changes placing all of the necessary transmitted power in a single information bearing (carrier) frequency. This single carrier frequency has all the information that needs to be transmitted. Any sidebands that are created are not required and can be removed by filtering.

It can be shown mathematically that there is little or no loss in power due to phase shift coding using this method. A signal to noise improvement can be obtained by means of special very narrow band filtering to remove most of the noise and any frequencies other than the single frequency of the carrier.

Bandwidth, or rather bandspread, which is the bandwidth occupied, is normally dependent upon a carrier frequency and two sidebands. These sidebands are the feature that causes bandspread. If they can be removed, there is no bandspread. Conventional theory holds that this is impossible, because all of the modulation information is in the sidebands. The old VMaxSK method transmitted one of the sidebands, so this rule was not violated. The newer VminSK method has no necessary sidebands, hence appears to violate this rule. This is not the case however, as can be mathematically proven.

Frequency modulation was known as far back as 1922. The first effective demonstration was by Major Armstrong in 1936. Armstrong's method involved the use of phase modulation with audio sine waves, which caused sidebands, mathematically identified as Bessel functions. A paper given by Dr. Howe in 1939 showed clearly that if rectangular waves were used instead, there would be no Bessel products as sidebands and no frequency spread. In other words, no sidebands related to the phase modulation, hence zero spread in the transmitted frequency.

The concept was ignored because the available filters in 1939 could not take advantage of the abrupt phase changes and digital modulation was not being used. In order to make VMinSK work, special filters had to be developed that had the necessary zero group delay characteristics to accept the required abrupt, near instantaneous, phase changes.

### **Communications using abrupt phase change modulation without sidebands became possible with zero group delay filters.**

With no sidebands, only a single frequency needs to be transmitted, if the modulation is to be found in that single frequency. Professor Howe's analysis proved this mathematically. It has now been proven physically in hardware that this can be done. With VMaxSK, that single frequency was a sideband converted to be used as a carrier. Later it was found that using the carrier itself ( VminSK ), with abrupt phase changes to indicate the data, was a better method because it was much easier to filter. Thus Ultra Narrow Bandwidth modulation was finally achieved.

The bandwidth required for a typical Ultra Narrow Band signal is insignificant compared to that required for a non-coded signal transmitted at the full bandwidth. The distance that can be covered with the same amount of power is more than twice that for the full bandwidth signal.

It is this extremely narrow bandwidth that permits more stations to be placed in the same space on the radio dial.

Or, as is most often the case, since the FCC has allocated a fixed frequency space, the data rate can be increased tremendously with actually improved signal to noise performance. For example, the ordinary Cellular telephone channel is allocated 40 kHz of space. Using the prescribed analog FM method of modulation, the maximum digital data rate is 19,200 bits/second. Using UNB modulation, the rate can be increased to more than 10 million bits/s. This is a 500 to one increase in throughput.

What can Ultra Narrow Band modulation be used for? There are many uses:

- 1) Cellular phones, with VideoConferencing, or video surveillance.
- 2) Satellite links operating at 100 times the present data rates in the allocated space, with smaller dishes.
- 3) FM Subcarriers at 10,000,000 bits/s instead of the present 20,000 b/s. High definition TV can be transmitted on the FM subcarrier.
- 3) Studio to transmitter links for broadcasters at 100 times the present rates.
- 4) Remote pickup units for broadcasters. Sound and Video can be returned to the studio from light weight backpacks instead of van loads of equipment.
- 5) Police radio with sound and video from the scene, with 'Instant Photo' returns.
- 6) Military surveillance.
- 7) Wireless Internet connections.
- 8) Doubling the number of TV stations on a Cable System.

Shannon and Nyquist:

Several theories were advanced just before and after WW2 that have proven to be almost inviolate. Since then, **engineers have delighted in seeming to get around them, while not actually doing so.**

The most respected, and most questioned of these theories, is known as Shannon's Limit, a theory proposed by Claude Shannon, that says in layman's terms, "if the noise level is equal to the signal level, you can't tell them apart". Recently there have been coding methods developed that seemingly defeat this rule ( Turbo Coding, used on deep space probes).

Another of these theories is one proposed by Harry Nyquist, which defines the required, or minimum bandwidth, needed to communicate. This theory says essentially that "to transmit an audio tone or digital signal, the bandwidth required is equal to the modulating frequency".

Digital information can be transmitted in a narrower bandwidth by using a coding scheme that uses multiple bits placed together in a block known as a symbol, but this does not violate the Nyquist bandwidth rule since the modulating frequency is reduced proportionally. However, there is a penalty to pay. For example, combing the data into 10 bits per symbol requires 1/10 as much bandwidth, but 10,000 times as much power to maintain the same error rate.

The two theories are tightly bound to one another. Shannon's Limit assumes that the Nyquist 'bandwidth', is being used. Shannon's limit is lowest when only one bit per symbol is used. Under that condition, using the Nyquist bandwidth, the limit is a signal to noise ratio of 1/1, usually defined as 0 decibels.

Ultra Narrow Band modulation is a unique way to overcome Nyquist's Bandwidth ( but not Nyquist's sampling rate ) without violating Shannon's Limit. The data is first encoded, using one bit per symbol that encodes the signal into a single frequency that varies abruptly in phase, but not frequency. When used at radio frequencies, it modulates a carrier without producing the two sidebands, separated as required by Nyquist's theorem. The ultra narrow band carrier method bandwidth is only 1 Hz wide. Thus a signal only 1 Hz wide is transmitted through special very narrow bandwidth filters. The ordinary AM radio uses two sidebands that spread cross 10,000 Hz.

Noise power is directly related to bandwidth, so that the amount of received noise is very low when using ultra narrow band filters. Since VMaxSK and MSB require almost no bandwidth, the theoretical signal to noise ratio required for excellent data transmission approaches Shannon's Limit, which is 1/1, or 0 dB for any 1 bit per symbol method. In practice, VMSK and MSB require half as much power as normal methods for the same error rate.

Another theorem by Harry Nyquist ( 1923 ) is the "Sampling Theorem", which says - "you must sample each data bit at least once to see if it is there, or isn't there." Of course, the bit can be sampled more than once to confirm that it is indeed there, or to locate the timing of the edges of the bit. VMinSK modulation requires sampling at the carrier, or intermediate frequency (synchronous detecting). This is many times higher than Nyquist requires for sampling at the data rate. The bandwidth is still theoretically 1 HZ for MSB, but as the data rate increases in terms of bits per second, the sampling rate (IF Frequency ) must increase proportionally. The detected signal must be sampled at the Nyquist sampling rate, which is equal to the Intermediate frequency, but greater than the data rate, or at a frequency equal to the Nyquist bandwidth. The Nyquist bandwidth for UNB methods is the Intermediate Frequency. The data must use 6 or more cycles at the IF, so the data rate is lower. Actually, NRZMSB can use data rates as high as 1/3 the Intermediate Frequency.

Digital modulation methods are usually defined in terms of "bandwidth efficiency", which is expressed in terms of "bits/sec./Hz". The highest bandwidth efficiency achieved using the conventional 'NRZ Line Code' modulation methods is 10 bits per sec. per Hz. ( 1024 QAM). This is accompanied by a loss of 40 dB, or 1/10,000 in the ratio of the signal to noise ratio (loss of power ). For this reason it is not used.

The old VMaxSK method was a "Biphase" method with demonstrated bandwidth efficiencies much greater than 100 bits/sec./Hz, with no loss in signal to noise ratio or transmitted power. The new synthesized UNB equivalent signals offer greater bandwidth efficiencies.

Engineers delight in playing games with the theories of Nyquist and Shannon. For example, Nyquist's rules say that to transmit an audio tone of 1,000 Hz, a bandwidth of 1,000 Hz is required.

However, if the tone is transmitted *single sideband with suppressed carrier*, like VmaxSK, and the carrier is reinserted later in the receiver, only 1 Hz of bandwidth is required. A variation of this trick has been used since WW1. Obviously there is a way to get around Nyquist's rule.

It can be conclusively proven mathematically, according to Shannon's Limit ( *misinterpreted* ), that this narrow 1 Hz bandwidth, combined with a 1,000 Hz modulating frequency, would require more power than is available at Niagra Falls to transmit the signal across the room.

Despite this, Amateur Radio operators have transmitted a 1 kHz audio signal from Texas to Boston with less energy than that generated by a birthday cake candle. All that is needed is a very narrow bandwidth filter.

In neither of the above examples have either Nyquist's or Shannon's theories been violated or shown to be invalid. It is just that they have been *misinterpreted* by those making the calculations.

There are probably a dozen combinations of coding and modulation that will result in the ultra narrow band signal. Most of them have now been covered by issued patents, or patents pending.

VMaxSK uses the single sideband trick discussed above. The other methods synthesize a signal that is the equivalent of that sideband. For the technically minded, papers have been written on these subjects and are presented here and on other sites. Several magazine articles have been published as well. The UNB method, based on a carrier without sidebands, has been published in peer reviews and one forthcoming encyclopedia published by John Wiley.

Interestingly, Prof. Howe published a paper in 1939 that showed the signal resulting from a rectangular wave phase modulating a carrier is a single frequency, with no frequency spread due to Bessel products. This is precisely what is done in all ultra narrow band methods. The ultra narrow band methods are practical embodiments of Prof. Howe's observations. There has been no prior use of this observed characteristic because the required filters were not known to be available until 1996.