FM MULTIPLEXING
WHY, WHEN AND HOW TO USE IT

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To many electronic communications specialists, multiplexing means Single Sideband Suppressed Carrier (SSBSC) for all practical purposes, any dissertation in the technical books on modulation leave no doubt in the reader's mind that SSBSC takes the cake for efficiency in bandwidth and power density. The widespread use of SSBSC for high density message channels certainly supports this view.

There are however, certain types of services that are served better by some form of Frequency Modulation (FM) multiplexing. The advantages of FM Multiplexing and the implementation of these services are the subject matter of this paper.

WHAT ARE THE ADVANTAGES OF FM MODULATION?

First of all, what are the advantages of FM Multiplexing over SSBSC? As with all comparative discussions, we must put equal constraints upon the processes to be compared. In this case, we constrain power density but require greater Signal-to-Noise Ratio (SNR) than the available power density will permit.

Information theory immediately suggests that some parameter must be expanded. That remaining parameter is bandwidth. While a base-band signal could be modulated by some form of information spectrum spreading, such as pulse code modulation (PCM), perhaps augmented by Bi-Phase or Multiphase modulation, a more direct solution to the desired spectrum spreading is direct FM Modulation.

It can be shown through information theory concepts that given equivalent spectrum spreading (and equivalent spectrum information density function), similar Signal-to-Noise Ratio (SNR) results will be obtained no matter which multiplexing scheme is used. Thus, if higher SNR are required than the transmission power avails, the thing to do is to chose the simplest and most cost effective spectrum spreading technique. If very wide band-widths are available, or the data rate can be slowed down (such as in data from space probes), then digital techniques really come to the forefront and are clearly preferable.

In many applications in everyday terrestrial and satellite transmission the SNR requirement is beyond that possible with the power levels available and yet the extreme bandwidth requirements of straight digital transmission are also not available. Some engineers attempt to overcome this limitation of digital transmission by modulating the data bit stream with a multiphase modulator. So instead of only 0 and 1, we have 0, 1, 2, and 3 and even systems with 0, 1, 2, 3, 4, 5, 6, 7, and even higher. This does reduce the band width required for transmission but the SNR comes closer and closer to analog transmission. It is in this in-between bandwidth area that FM transmission really comes into its own. With FM Multiplexing it is quite easy to exactly tailor each signal into any bandwidth allocation and yet obtain SNR equivalent to that possible with digital transmission using multiphase modulation.

The greatest difference between optimal digital multiphase modulation and direct FM Modulation given the same bandwidth and power available, is that the digital system as it approaches its SNR limits will fail cataclysmically (lose lock) while the direct FM System degrades gracefully (gradually decreasing SNR).

Many applications requiring high SNR fare better with graceful degradation than cataclysmic failure, such as program audio where reduction in SNR only causes more background noise but does not destroy the music itself. The human mind tends to overlook minor degradation such as increased background noise, while it will rebel at total loss of the music with possible replacement by high level crashes (if not muted in time).

Direct FM Modulation can thus be seen as an excellent solution to some difficult transmission problems and that, in fact, is the main reason that direct FM has been used for TV audio and FM Stereo transmission systems.

There are however still some other advantages besides SNR control. One of them is that the base-band output level is substantially independent of variations in transmission levels and that the phase of the recovered base-band signal is stable without the use of special pilot frequencies and their attendant instabilities. This is in sharp variance with the consequences of using SSBSC to transmit these kinds of services. Rather exotic and expensive ancillary devices must be used on SSBSC systems to bring these parameters under control.

FM MULTIPLEX ON TERRESTRIAL MICROWAVE FACILITIES:

Since most terrestrial microwave systems are themselves frequency modulated, then FM Multiplexing becomes FM-ON-FM Modulation.

The most widespread use of FM-ON-FM on wideband microwave systems has been to transmit FM audio with video for television transmission. In the early days of TV, this was done mostly for Studio-To-Transmitter (STL) links, but is now used routinely for long haul transmission of TV audio signals as well.

Many microwave common carrier operators have now expanded the use of FM Multiplexing on TV microwave channels to add program audio and stereo transmission as well as facsimile, telemetry and supervisory control services. FM multiplex channels can also be sub-multiplexed with voice grade SSBSC to yield up to 24 voice grade channels per FM multiplex channel. In all, five or more FM multiplex channels may be operated above the video signal to increase the revenue to be derived from a microwave channel.

STEREO PROGRAM TRANSMSSION SYSTEMS:

Stereo program service can be transmitted by two distinct methods. The most direct consists of sending the left and right signals on two different FM multiplex frequencies on a single microwave channel. The other consists of sub-multiplexing the two signals upon a single FM multiplex channel.

Dual channel stereo transmission is quite straight forward in that two identical channels are used, with no requirement for special sub-multiplexing equipment. The disadvantage is that two FM multiplex channels are occupied to transmit one program. The advantage is that the SNR is identical to a monaural channel.

Sub-Multiplexed transmission of stereo programs use only one FM channel, but do require that the left and right channels be somehow combined into one channel. The advantage is occupancy of only one channel but the disadvantage is possible additional equipment and also poorer signal to noise ratio because the combined left and right signal can not occupy any more bandwidth than a single monaural channel. Thus, under the best of circumstances the combined (single channel) stereo transmission system must have a SNR at least 6 dB worse than the comparable monaural channel. The SNR degradation may be quite acceptable, so long as it is above specification for that type of service.

Many possible sub-multiplexing techniques are possible for transmitting single channel stereo. Frequency division and time division sub-multiplexing both offer possibilities.

However, for certain types of services, it is advantageous to use the form of multiplexing already in use at the broadcast transmitter in the USA and Canada, as well as some other locations. This stereo scheme consists of taking the sum of the left and right channel (L+R) and the difference between them (L-R) and transmitting L+R on the base-band (40-15000 Hz) and the L-R by DSBSC frequency division multiplex at 23-53 KHz. To reconstruct the suppressed 38 KHz L-R carrier a 19 KHz pilot is also transmitted.

Many remote communities can not support their own stereo transmitters and TV transmitters and therefore rely upon imported signals that are distributed to users by way of a community cable TV system. Frequently the imported signals must be transmitted by way of microwave facilities to these remote communities. The same microwave channel that brings in the TV signal may then also transmit one or more stereo program channels. For this application the stereo signal may be received from an existing radio station, perhaps quite some distance away, down converted to the FM multiplex frequency, then transmitted via the microwave facility to the community at the remote location. The FM multiplex channel may then be up-converted to the desired frequency for distribution over the community cable system.

This is a case where stereo may be transmitted over a single channel without necessitating any additional sub-multiplexing equipment. This plan however, suffers from some drawbacks. First of all, the FM deviation used by FM broadcasters is not the optimum for transmission over microwave systems thus introducing more noise from microwave transmission than necessary. Secondly, intermodulation products generated within the microwave system will create very annoying whistles in the demodulated signal.

When NTSC color is being transmitted on the microwave base-band, the resultant whistles occur at 6.532 KHz, 9,202 KHz and 15,734 KHz. Since these frequencies are not harmonically related, they produce a particularly penetrating sound which can quite destroy listening pleasure during soft passages of music. Of course, two multiplex channels could be used, thus getting rid of the first two frequencies. But now stereo de-multiplexing and re-multiplexing equipment must be provided which can only degrade stereo separation, distortion, ETC.

Another solution using the original multiplexing scheme, is to enhance the deviation from the +/-75 KHz being transmitted from the originating station to the full +/-237 KHz capacity of the FM multiplex channel. This would reduce microwave channel induced noised by 10 dB.

The intermodulation induced whistles can then be removed by inserting very sharp notch filters at 15.734 KHz, 31.468 KHz, and 47.202 KHz. The last two demodulate against the 38 KHz carrier to create the lower frequency beat tones. Note that the upper two notch filters only remove one sideband at each interfering frequency. Thus the other sideband continues to deliver music even though that frequency has been suppressed to remove the whistle. The FMU611CA stereo transmission system built by FM SYSTEMS, INC. operates on these principles.

A basic philosophy regarding transmission of stereo signals can be formulated as follows:

1. If the stereo signal as presented to the microwave facility is in two separate channels, the most preferable transmission scheme is to retain the separation and transmit the signal on two FM multiplex channels.

2. If the stereo signal as presented to the microwave facility is pre-multiplexed, it is most preferable to transmit the signal over one broadband FM multiplex channel.

FM MULTIPLEX ON SATELLITE FACILITIES:

There are currently three basic systems for transmitting TV audio and monaural or stereo program service through satellite facilities

The first is to transmit all audio type signals via SSBSC through a different satellite transponder than that which is transmitting the video signal. This requires two transponders, with also the attendant dual transmitters and receivers. This procedure, while still used extensively, is being replaced by either the second or third system to be described.

SUBCARRIER MULITPLEXING:

The second system consists of multiplexing one or more FM Sub-carriers above the video signal on one transponder, very much in the manner of FM multiplexing on terrestrial microwave systems. The principal differences with the terrestrial microwave is that intermodulation products tend to be less since only one repeater point is involved and that noise problems are worse since received carrier-to-noise level is much poorer than normal terrestrial microwave practice. The future may see much higher transmitted satellite power and thus better carrier-to-noise level, but attempts to reduce receiver cost by using less expensive receiver antennas and low noise amplifiers will tend to nullify such gains.

SCPC MULTIPLEXING:

The third system consists of transmitting the video, TV audio and any other services, each separately FM modulated upon its own carrier frequency within a single transponder (or even ½ transponder). This necessitates operating at a reduced carrier power so that the total power as received in one transponder at the satellite will not drive the transponder into non-linear operation. Operation in the saturated mode would result in severe splattering of the signal with consequent interference to adjacent services operating in other transponders. The disadvantage is that each signal must now operate at lower power level. The advantage is that various signal sources scattered about the satellite radiation “footprint” may simultaneously transmit signals to the same transponder which will then be re-transmitted to all receiving locations.

This obviates the need to bring all signals to be transmitted to a single location, such as is required by the second system. This third system is frequently identified as the single channel per carrier (SCPC) system. Many national networks now use the SCPC system, whereas most international transmissions currently use the first or the second system.

INTERCONNECTION OF TERRESTIAL AND SATELLITE FACILITIES:

Common voice grade services may be interconnected at earth stations by way of group and supergroup connectors where both facilities use standard SSBSC multiplexing, however wider band signals such as 15KHz program service require special handling.

Where both the terrestrial and satellite facility is FM sub-carrier multiplexed. The initial practice was to demodulate and re-modulate at the earth station, where essentially similar FM deviation (by the base-band) is used. A better solution is to connect through by way of a sub-carrier coupling filter such as FM SYSTEMS, INC. SCF611 if the sub-carrier frequencies are identical, or by way of a sub-carrier translator such as the SCT611CA if the sub-carrier frequency must be shifted. This approach by-passes the distortions created by back-to-back modulation steps at the earth station, with consequent improvement of overall signal quality, reduction of component count and system cost.

Where the terrestrial facility is modulated by FM sub-carrier and the satellite is modulated by SCPC FM multiplex, it is still possible to avoid the back-to-back modulation step at the earth station. FM SYSTEMS, INC. makes the direct up-link converter from sub-carrier to SCPC and the down-link converter from SCPC to sub-carrier multiplexing. Both devices by-pass the back-to-back modulation steps otherwise necessary at the earth station. Both devices are equipped with provisions for monitoring the program as it passes through the earth station.

SUMMARY:

While the SSBSC modulation plan is undeniably the workhorse of terrestrial and satellite communications systems, the system design engineer must keep an eye open to FM multiplexing where unusual factors are present. These special considerations that indicate use of FM multiplexing include:

1. Services requiring very close control of transmission amplitude.

2. Services requiring very close control of phase and signals polarity.

3. Services requiring grater signal-to-noise ratio than SSBSC can provide on a given facility.

4. Services requiring wider bandwidth than can conveniently be provided with standard SSBSC multiplexing.

5. On satellite facilities, where it is desirable to originate services from a multitude of locations without bringing all the signals to a central transmitting earth station.

6. Where it is desirable to drop off 12 to 24 voice grade channels to a branching facility at an I.F. coupled terrestrial microwave repeater site without demodulating and re-modulating the entire base-band and installing the requisite L carrier terminals.