FM Stereo Radio Principles

By G8MNY (Updated Jan 18)
(8 Bit ASCII graphics use code page 437 or 850, Terminal Font)

Being involved with 30 short term radio stations in UK (RSLs) since 1994 & now a perminant station, here is part of a talk I do on it, on the technical side.

AUDIO

There are 3 main parameters to Audio quality.

FREQUENCY RANGE

Here is the approximate frequency plot for some audio sources. Note that the old disk system was not really limited & special equipment can do Quad audio with high frequency sub-carriers!

```
│Sub Sonic│<- - - - - - - Human ear response - - - - - - - ->│Ultra Sonic >
│I            BASS                MID               TREBLE
│N    <- - - - - - - - - - - -Disk H i F i- - - - - - - - - - - - >
│F       < - - - - - - - - - -C.D. H i F i- - - - - - - - - - - >
│R          <- - - - - - - - Broadcast HiFi - - - - - - - - - >
│A             < - - - - - - Original Cassette- - - - - - ->
│               <- - - - - — A.M. Radio - - - - - ->
│ F E E L I N G             < - - - COMMS - - ->
└───┬────┬──┬───┬────┬───────┬───┬────┬───────┬───┬────┬──┬─┬──┬>Frequency
DC 10   20  30  50  100     300 500   1k      3   5   10 15 20 30kHz
```

CDs are the best source most people are familiar with, its frequency range is limited by the 44kHz sampling rate & the requirement to filter off all the frequencies higher than 22kHz to stop aliasing mixes caused by the sampling rate.

Broadcast FM is limited to 15kHz to stop problems with the stereo pilot used. But 15kHz represent a good compromise for the upper limit which is why it was chosen.

Broadcast AM (EU) uses 9kHz chanel spacing, so in theory 4.5kHz should be the upper limit, but in practice 6kHz is the limit (-40dB @ 9kHz) to make it sound a bit better.

Comms Audio is the smallest bandwidth that can easily be understood, but not having any treble there is confusion over F & S, B P E G D, M N letter sounds!

I have not included Digital Broadcast, as the quality is quite variable, from near CD quality, right down to phone call quality, dependent on the data rate assigned for a particular programme/ch.

SIGNAL TO NOISE RATIO
This is the measure of unwanted noises below the wanted sound..
e.g. Hiss & Hum, or windage/engine noise, Neighbours/street noises etc.

```
 0dB | Noisy Conversation
 10  | Poor Comms, NORMAL CAR
 20  | Fair Comms
 30  | VERY QUIET CAR                        AM RADIO
 40  | Typical Cassette Tape, Living rooms
 50  | Reel-Reel tape, Dolby Cassette
 60  | New Vinyl Record                      FM RADIO/TV SOUND
 70  | Mini disk (unmasked noise)
 80  | Dat tape.                             DAB
 90  | Perfect Digital CD, apparent Minidisk
100  |
110  |
120  | Ear Threshold Signal : Silence to Pain ratio
```

With Digital sources there is also "Quantization Noise/Distortion", which is due to the sample step size, & is a set No of dBs below any sound level.

HARMONIC DISTORTION
This is the amount of unwanted signals generated in harmonics of the wanted signal, in the audio pass band of interest. It is usually very dependent on the level, except for digital systems where it is a mathematical design feature. Note the ear generates these too!

It is measured as a % of the signal, so 10% = -20dB in harmonics.

```
  %    dB
 10  + -20 Cheap AM Radio at high Volume, Comms Audio
  5  + -26 Film Optical Sound
  3  + -30 Cassette & Reel Tapes
  1  + -40 Quality Valve Amps                AM BROADCAST
 .5  + -46 High Quality Disk,                FM BROADCAST
 .3  + -50 Most Loudspeakers??
 .1  + -60 Most AF Amps,                     DAB, NICAM
0.05 + -66 Good modern AF Amps.
0.03 + -70 Most Digital AF sources.
```

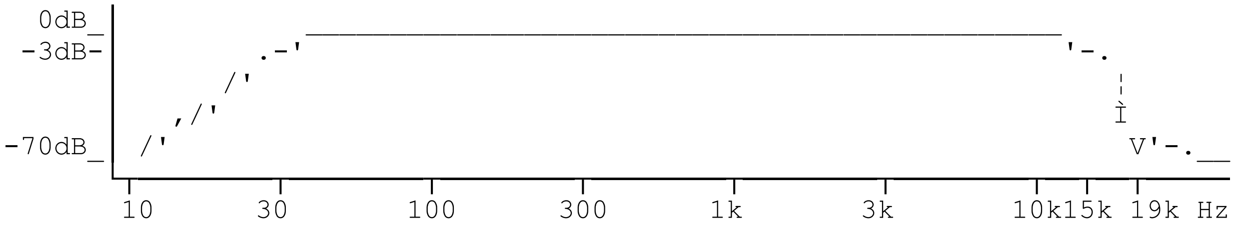
Sometimes the above parameters are joined together in a "Signal In Noise And Distortion" (SINAD) rating for measured RF signal level of a Rx.

FM EMPHASIS
The FM Radio system suffers noise level that rises with frequency. To mask this the treble is lifted on Tx & cut on Rx, this substantially reduces the hiss, & top end harmonic distortion, but at the loss of treble peak loudness!
e.g. with a time constant of 50uS (75uS USA) 15kHz is lifted by 14dB, that is 14dB less peak loudness at 15kHz, or only 20% of max level after de-emphasis.

```
+14dB_| TX Response        |  Rx Response          |Overall Response |
      |             ,/T  0dB_|  _________       0dB_|   _____________  |_100%
      |           ,/       | /  Flat  `\          | /         `.   |
  0dB_|  _________./ 6dB/O |       6dB/O`\        |/            `. | `.Level
      | /Flat       Lift 14dB_|          Cut  `\     |               `.|
      |_____________________ |____________________ |_________________|_ 0%
        30Hz  1kHz  15kHz      30Hz  1kHz  15kHz     30Hz  1kHz  15kHz
```

15kHz WALL FILTER
As the treble is lifted & there is a requirement the audio does not interfere with the 19kHz stereo pilot tone, & higher frequencies of the stereo system, so a matched pair of sharp audio cut off filters are needed. The filter time delay MUST be the same, as the stereo image positioning you hear is all about treble timings.

Other audio tailoring may reduce the subsonic audio as well.



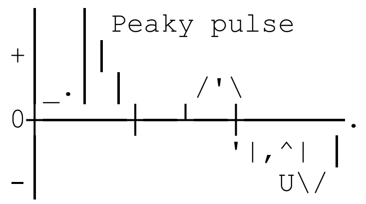
LIMITING
As FM must not be over deviated to keep the bandwidth down, a limiter is used, this is unlike a simple clipper used on comms Tx that lets the signal distort.

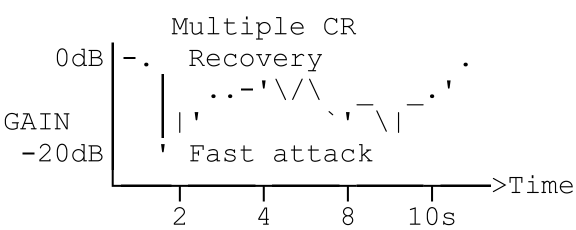
Broadcast limiters have fast attack to cope with the spikiest peak, & with several decay time constants, mask the limiter's breathing effects. Complex limiters may also treat the treble separately with separate faster time constants, as the treble content will be a more prominent part of the pre-emphasised signal. Any peaks then left not properly gain limited (hardly any) then get hard clipped.

To maintain the stereo image both left & right gains must be tracked together!

The result is a signal that has it's ± peak value accurately limited, but sounds perfect! With a good limiter you should not be able to tell the difference between live studio feed & off air with limiting of around 12-20dB.

The peak values result in the actual FM deviation, which ensures the correct overall Tx bandwidth.

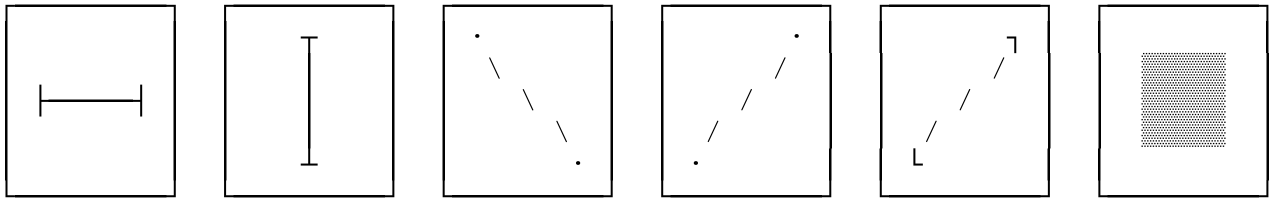




The result is a signal that has it's ± peak value accurately limited, but sounds perfect! With a good limiter you should not be able to tell the difference between a live studio feed & off air even with high limiting levels of around 12 - 24dB used for AM.

As the limiting process must have fast attack times to handle all the peaks one half cycle will Rx a different compression factor to the other half cycle, this results in some low frequencies down to DC being added to the signal.

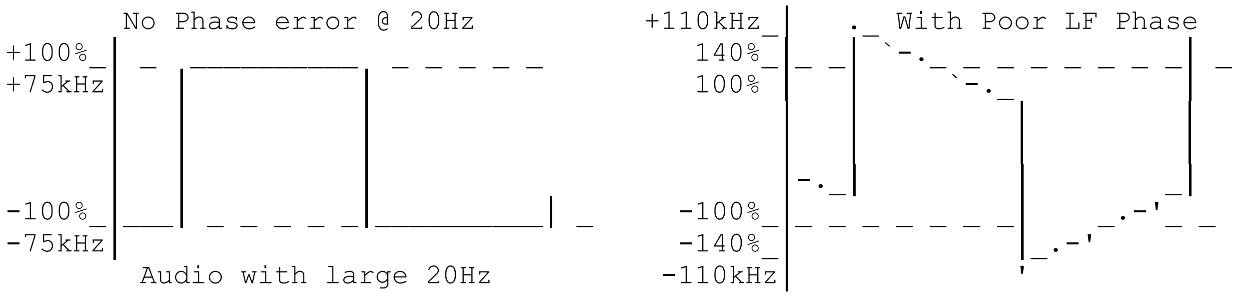
A scope X-Y plot of Stereo (Pilot tones filtered off)



Limited Left only | Mono Right | Anti-phase @ 45° | 2D Stereo (behind U) | Hard Limited Pattern | Stereo fills ±75kHz Box

If you set up a scope (or PC) to display broadcast audio you can see the stations that run hard limiting, as they end up with a tightly defined box filled all the time. This is not that they have clipped audio with distortion, but quickly acting AGCs do that do not generate AF harmonics. The result is very LOUD audio, each audio frequency can still have 40dB or so dynamic range, but the overall modulation is 100% nearly all the time (each millisecond). Such stations can be a strain on the hearing to listen to!

BAD LF RESPONSE AFTER LIMITER
It is also important that there is no phase distortion between the limiter & the Tx over the frequencies to be transmitted. If there is the limited signal can actually get larger....



Audio with large 20Hz content limited to just fit inside this 20Hz envelope.

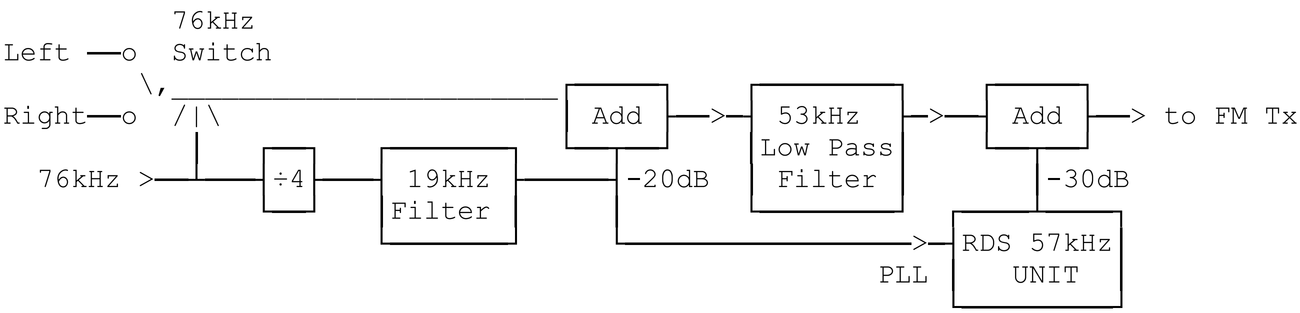
-3dB @ 20Hz
Tx Peaks now seriously over modulated

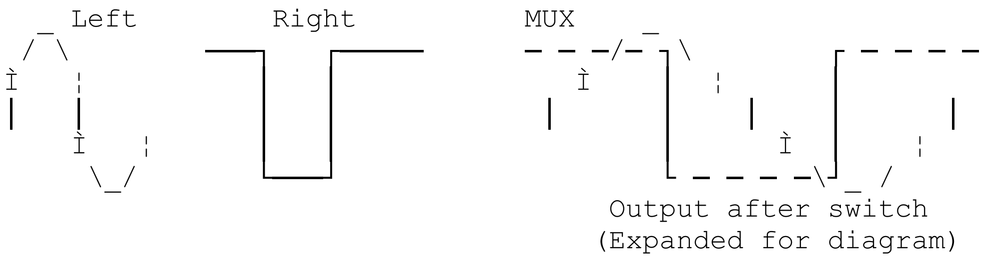
The same problem occurs in an AM Tx, where the poor LF phase response on high level Modulation Transformers cause unexpected hard clipping on certain AF envelope waveforms. (not the AF's LF content!)

In practice an FM Tx will have another hard limiter (clipper) to protect it from accidental over modulation.

STEREO MULTIPLEX
The system used for all stereo radio broadcasts is known as the Zenith-GE Pilot Tone System (so-called after the names of the two companies who devised it). It has been designed to be fully compatible with Mono FM radio Rx & without too much increase in bandwidth.

The MUX signal can be made with a 38kHz Double Side Band exciter fed with a LR difference signal, & added to the mono signal. But modern linear switching electronics, means the simpler methord is now used. That is to take a sample of the left & right channels every 38kHz. So a switch samples the left or right channels @76kHz, to keep the Rx's switch in step a locked 19kHz sinewave pilot tone is sent at -20dB (10%) below peak level. The phase of the pilot tone is critical to good channel seperation.



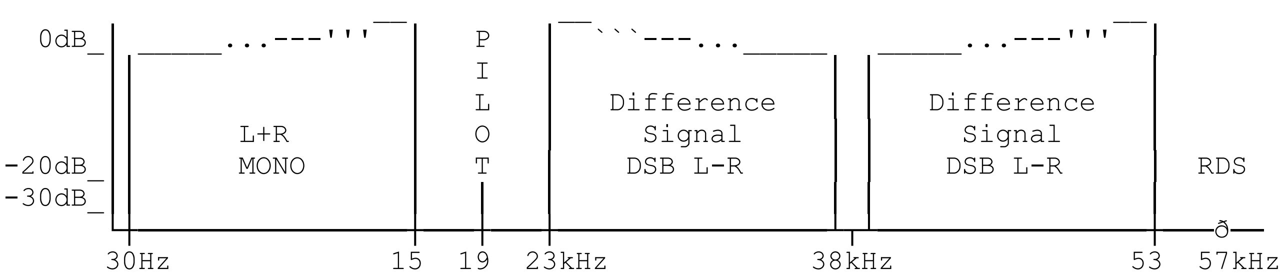


The low pass filter @ 53kHz used, must have low phase shift (group delay) so that the timings of the stereo samples are no affected. In some designs digital tricks are used to null out the 2 & 3rd order harmonics of the switching process (76kHz & 114kHz), so a less aggressive "lower distorting" low pass filter can be used.

RDS (Radio Data System, similar to ARI system in Germany)
This is data phase modulated on to a 57kHz carrier that is phase locked to the 19kHz, so it actually reduces the overall modulation & is added at 2-3% to the MUX output. The data is QPSK @ 1187.5Hz (76kHz/64) which only occupies about 2kHz bandwidth (seen as 2 data Carriers). It contains many features, not many supported by stations, the common ones are...

- PS = Station Service Name
- PI = Tx ID code, up to 256 stations in a network
- AF = Alternative Frequency list (radio searches this on weak signal)
- CT = Time
- TA & TP = Traffic Flags, allows radio to change AF source/level.
- PTY= Programme Type 16 types, e.g. Jazz, News, Pop. etc.
- RT = Radio Text, e.g. current song title

MUX BASEBAND SPECTRUM



To achieve good channel separation linear frequency & phase response is needed between the Tx coder & the Rx decoder. Reduced levels or phase shift @ 38kHz make the channel separation poor (tending to MONO), & increased HF gain widens the channel separation.

The increase in baseband bandwidth from 15kHz for mono to 53kHz for stereo causes about 20dB loss in overall signal to noise ratio on an FM system. As it adds in, not just the noise from 3x the bandwidth (9dB), but the very poor signal to noise, of the higher frequency stereo difference signal that you Rx on FM systems. The resultant "noise" in the stereo image appears as noise from behind you....

```
   LEFT       RIGHT
         o^o
        [   ]
         \_/

        NOISE
```

TX SPECTRUM
The Bessel Functions shows the FM sideband harmonic levels, for any particular modulation index. For mono the modulation index is peak Dev/Mod 75kHz/15kHz = 5 but this analysis is less useful for real very complex signals.

This is where Carson's rule for minimum bandwidth needed, can give clearer indication.

Bandwidth = 2x Peak Dev + 2x Highest Mod Freq

This gives the bandwidth of sidebands needed for NO distortion. But it does not take into account, that the levels of the highest modulation frequency are only 3% (-30dB) of the peak deviation, with resultantly weak sidebands.

```
             Deviation
    Mod   <-2x 75kHz ->  Mod          0dB_|         _         |_100%
   <57.5> ┌────────────┐<57.5>            |        / \        |
  ______|            |______       -20dB-|        |   |       |-10%
 |                          |            _|      /'      `\     |_
 |                          |      -40dB‾|  ./'           `\.  |‾1%
─┴─────────────┴────────────┴─          ─┴──┴──────┴─────┴───┴──┴─
 < - - - - - - 265kHz - - - - >    -60dB        100kHz           0.1%
   Theoretical Full Bandwidth         More Typical bandwidth
 of RDS Stereo Broadcast signal    as seen on spectrum analyser
     for ZERO distortion.             under heavy modulation.
```

TX RF Harmonics & Mixes
These should all be > -60dBc, so added filters are normal. On multiple Tx sites there is a risk of PA mixing, where RF from a nearby Tx can be Rx at the Tx PA at enough strength to cause a Mix. A narrow resonant channel filter or directional coupler (Circulator/isolator) in the Tx feed can protect the Tx from these signals.

```
\|/             TYPICAL  TX  SITE  LINE  UP
 |
 └─><─┌──────────┐─┌──┐─┌──┐─┌─────┐─┌──────┐─┌──────────────────┐─o-o─<L STUDIO
 Rx+Tx│CIRCULATOR│─│PA│─│FM│─│ RDS │─│STEREO│─│PRE EMPHASISED    │─o-o─<R FEED
Signal│OR FILTER │ │  │ │Tx│ │CODER│ │CODER │─│STEREO LIMITER    │ | |
      └──────────┘ └──┘ └──┘ └─────┘ └──────┘ └──────────────────┘ | |
                   \|/  \|/    Data   Mono          \|/          Backup
                  Power Mod   flags                Levels        Source
```

Also see my buls on "FM Deviation Calibration", "AM Broadcast principles" & "1W @ 531kHz MW system".

Why Don't U send an interesting bul?

73 de John G8MNY @ GB7CIP