Introduction to FM-Stereo-RDS Modulation

Ge, Liang — Verigy, China
Tan, EK — Verigy, Singapore
Kelly, Joe — Verigy US

1. Introduction

Frequency modulation (FM) has a long history of its application and is widely used in radio broadcast. To transmit stereo music, FM is enhanced by stereo multiplexing which carries both L and R audio channel content. With the digital age, Radio Data System (RDS) enables FM to carry text information such as traffic, weather, and radio station information which can be displayed on the end-user's device interface. Currently, growing number of mobile phones and consumer mobile devices will have an integrated FM receiver feature. The FM transmitter feature is also becoming popular for allowing users to transmit audio content from their mobile devices through their car radio. To make sure the FM-related functions work well, the FM mono, FM stereo, and FM RDS functions need to be tested in production.

In this paper, we will discuss FM theory, FM stereo multiplexing and the RDS mechanism. The FM demodulation in V93000 will also be briefly introduced.

2. Frequency Modulation

Frequency modulation is realized by varying signal frequency in accordance with the modulating signal or message, as in Figure 1.

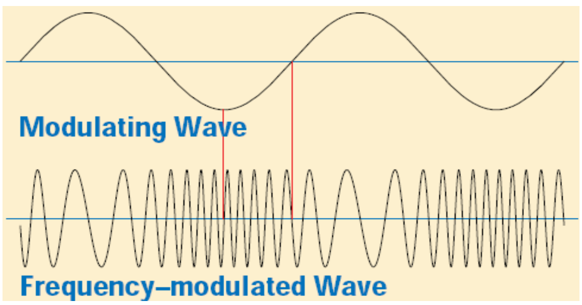

Figure 1: Frequency modulation

An important concept in the understanding of FM is "frequency deviation". For a transmitter, the frequency deviation of the carrier is directly proportional to the amplitude of the applied modulating signal. Thus an FM transmitter has modulation sensitivity, $\mathbf{K_f}$, which is frequency deviation/V. The relation between frequency deviation from the carrier (df_c) and the original signal is:

$$df_c = K_f * S_m(t) \qquad (1)$$

where $\mathbf{S_m(t)}$ is the signal before modulation, which can also be called the modulating signal, because this signal will modulate the carrier.

A somewhat complex mathematical analysis will yield an equation for the instantaneous voltage of an FM wave of the form:

$$s(t) = A_c \cos\{2\pi f_c t + m \cdot \sin 2\pi f_m t\} \qquad (2)$$

Where $\mathbf{A_c}$ is the carrier peak amplitude, $\mathbf{f_c}$ and $\mathbf{f_m}$ represent the carrier and modulating frequencies, and **m** is the index of modulation. This equation represents a single low-frequency sine wave, (f_m), frequency modulating another high-frequency sine wave (f_c).

As can be seen from the equation, **m** is equal to the peak deviation caused when the signal is modulated by the frequency of the modulating signal. Since in (2) the frequency deviation is integrated into phase deviation, **m** is a function of both the modulating signal amplitude and frequency. Furthermore, **m** can take on any value from 0 to infinity.

Pre-Emphasis and De-Emphasis

In FM, the noise increases with modulation frequency. To compensate for this effect, FM communication systems have incorporated a noise-combating system of pre-emphasis and de-emphasis. Pre-emphasis provides increased amplitude to the higher modulating frequencies prior to modulation under a well-defined pre-emphasis (high-pass filter) curve. This added amplitude will serve to make the higher frequencies more immune to noise by increasing their index of modulation. De-emphasis is just the opposite operation (using a low-pass filter) and it is done at the receiver.

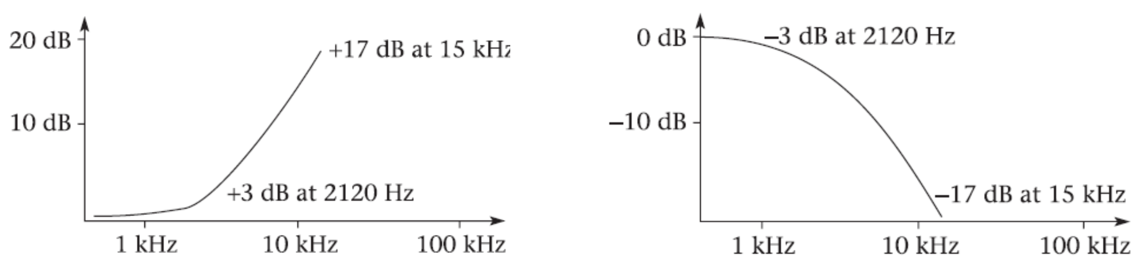

Figure 2: Pre-emphasis and De-emphasis filter

3. FM Stereo Multiplex

FM stereo broadcasting was introduced during the early 1960s. The scheme that was adopted was chosen to be compatible with the monaural FM radios that were in existence at the time. Essentially, the system performs the multiplexing of two signals and further combines them into a complex baseband signal that modulates the FM carrier. Figure **3** shows a block diagram of the typical analog-stereo generator used to drive an FM transmitter.

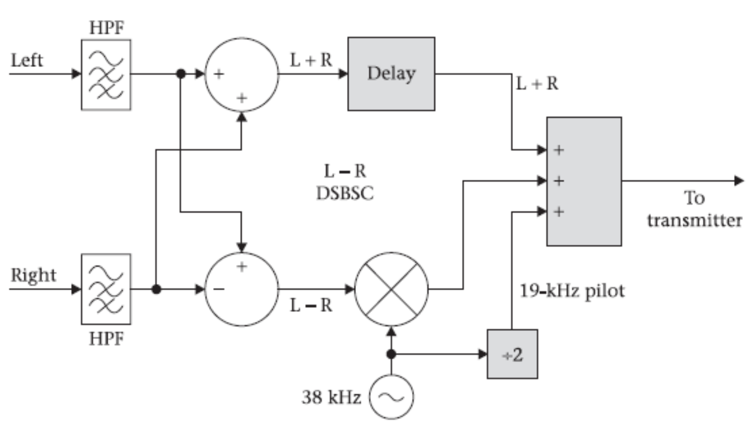

Figure 3: FM Stereo Multiplexing

A Left and Right source of audio are first pre-emphasized (HPF) and then fed to adder circuits. The output of one adder is the sum of the two signals, or the L + R signal (the monaural signal), and the output of the other adder is the difference of the two signals, or L – R. The L – R signal is applied to a balanced modulator along with a 38-kHz signal. The output of the balanced modulator is a DSBSC AM signal centered at 38 kHz. A portion of the 38-kHz signal is divided in frequency to become 19 kHz, and all three signals are applied to a summary/adder circuit at the output of the generator.

The resulting stereo-generator output-signal spectrum is shown in Figure **4**.

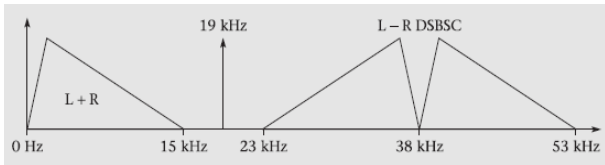

Figure 4: FM Stereo Multiplexing Spectrum

The L + R signal, which contains baseband frequencies from near 0 Hz to 15 kHz, occupies that portion of the frequency spectrum. The 19-kHz tone is pilot sub-carrier signal, which will be used at the receiver to aid in the demodulation of the received signal. The L – R signal, which has been DSBSC amplitude modulated by a 38-kHz tone, occupies the frequency range from 23 to 53 kHz.

4. FM Radio Data System (RDS)

Radio Data System is a communications protocol standard from the European Broadcasting Union for sending small amounts of digital information using conventional FM radio broadcasts. The RDS system standardizes several types of information transmitted, including time, track/artist info and station identification. RDS has been standard in Europe and Latin America since the early 1990s and is now used throughout many parts of the world.

Baseband Modulation

RDS baseband modulation is a kind of differentially-coded BPSK as in Figure **5**.

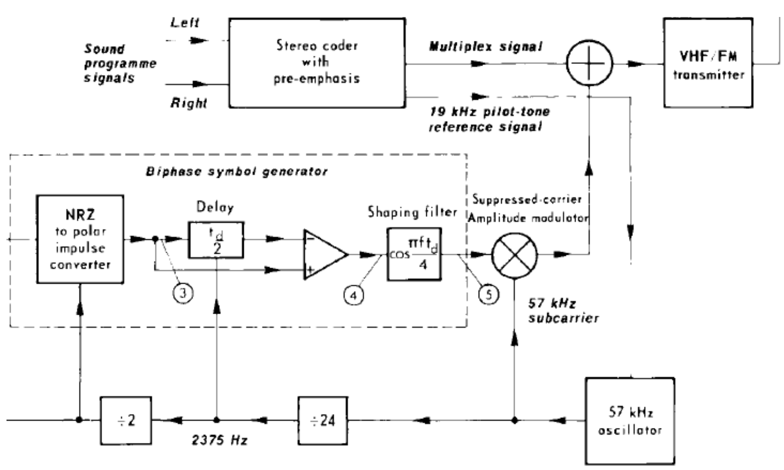

Figure 5: RDS Signal Flow Chart

The sub-carrier is amplitude-modulated by the shaped and binary-phase coded data signal.

The sub-carrier is suppressed. This method of modulation may alternatively be thought of as a form of two-phase phase-shift-keying (PSK) with a phase deviation of ± 90 degree.

The basic clock frequency is obtained by dividing the transmitted RDS sub-carrier frequency (57 kHz) by 48. Consequently, the basic data-rate of the system is 1187.5 bits/second.

The source data at the transmitter are differentially encoded. The power of the data signal around the 57 kHz sub-carrier is minimized by coding each source data bit as a binary-phase symbol. The principle of the process of generation of the shaped binary-phase symbols is shown schematically in Figure 6.

These impulse-pairs are then shaped by a filter $H_T(f)$, to give the required band-limited spectrum where

$$H_T(f) = \begin{cases} \cos\dfrac{\pi f t_d}{4} & \text{if } 0 \le f \le 2/t_d \\ 0 & \text{if } f > 2/t_d \end{cases} \qquad (3)$$

Coding structure

The largest element in the structure is called a "group" of 104 bits each. Each group comprises 4 blocks of 26 bits each. Each block comprises an information word and a checkword. Each information word comprises 16 bits. Each checkword comprises 10 bits.

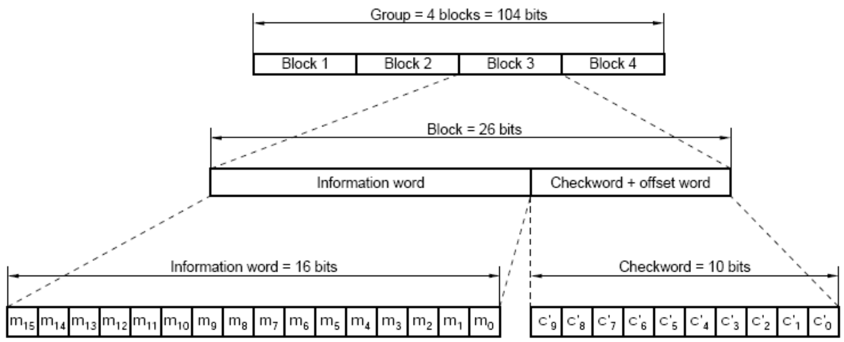

Figure 6: Structure of Baseband Coding

Work with FM Stereo

Both use a 57 kHz sub-carrier to carry data at 1187.5 bits per second. The 57 kHz was chosen for being the third harmonic of the pilot tone for FM stereo (3 x 19kHz), so it would not cause interference or inter-modulation with it, or with the stereo difference signal at 38 kHz. This is shown in Figure 7.

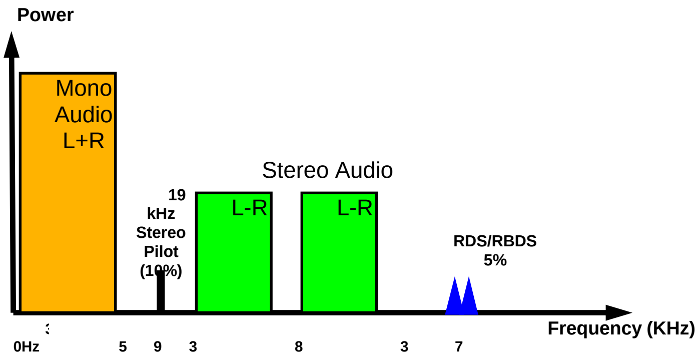

Figure 7: FM-Stereo-RDS Baseband spectrum

5. Demodulation on V93000

This section presents the demodulation used in the Verigy V93000 software and demonstrates how to demodulate a FM Stereo signal.

For TX tests, the RF output from the DUT is captured by the V93000 RF subsystem. The captured data are then fed into the V93000 demodulation engine. The FM-stereo part of processing flow of this engine for is as **Figure 8**

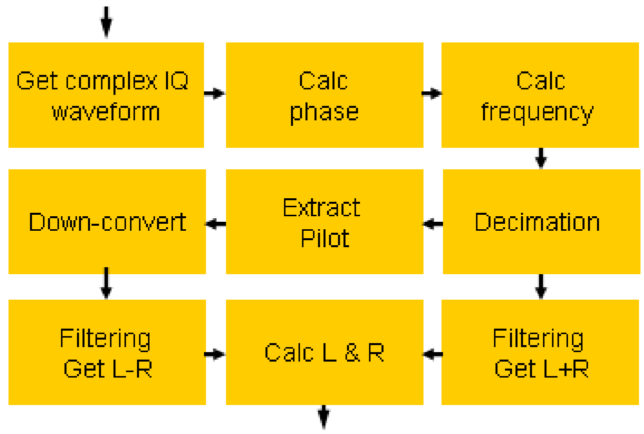

Figure 8: Signal processing flow

Although we show some details of our signal processing flow, it can be used as a black box. The only input is just sample rate **Fs** and captured **IQ** array.

FM demodulation engine outputs multiple results such as Stereo Multiplexed BB wave, L/R wave, modulation deviation, etc. the **Figure 8** shows the FM spectrum, stereo spectrum, audio wave, and audio spectrum in V93000 Signal Analyzer.

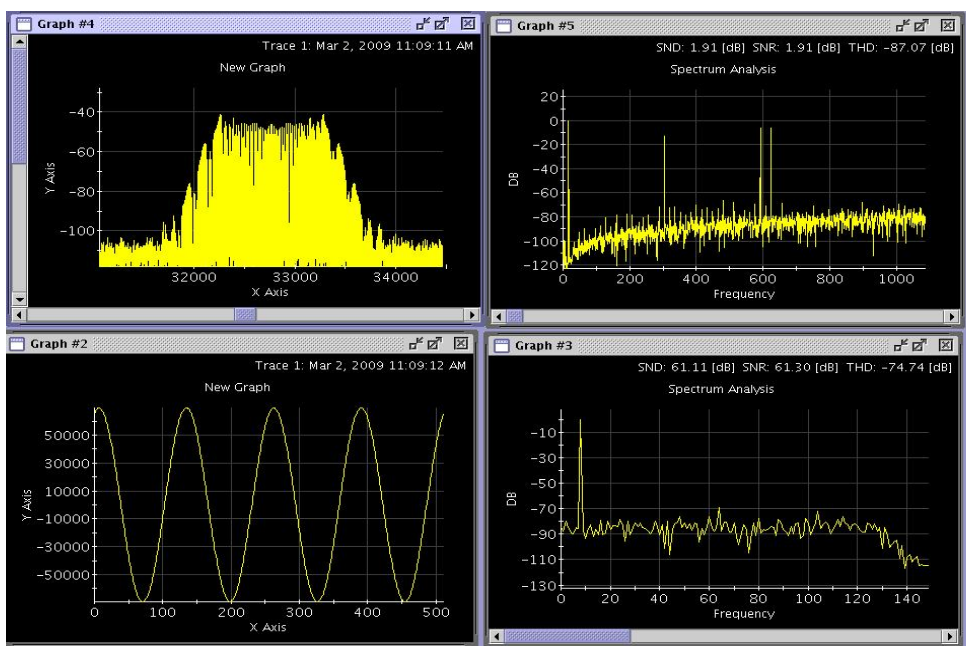

Figure 9: FM-Stereo Demodulation in V93000

For FM RX testing, often the user needs to provide a Stereo FM RDS signal to the RF RX input of the DUT. Verigy has the SW engine to generate the FM Stereo RDS signal. Alternatively, custom waveforms from the DUT design department can also be used directly. Additionally, the V93000 RF and baseband AWGs have the ability to read Agilent Technologies Signal Studio encrypted waveform files. This allows the user to be able to use the same original waveform files that are used with many bench measurement setups.

6. Conclusion

There are challenges to measuring FM-stereo-RDS, since it consists of both, digital and analog modulation. This paper has attempted to show the basics of FM-stereo-RDS Modulation and briefly how it is done with V93000. Verigy has both the generation and demodulation engine on V93000 which can be used to give stimulus to DUT or analyze the DUT output.

7. Reference

[1] IEC 62106:1999 standard (RDS)
[2] HP Application Note 150-1
[3] Leon W. Couch, *Digital and Analog Communication Systems,* Prentice 2001