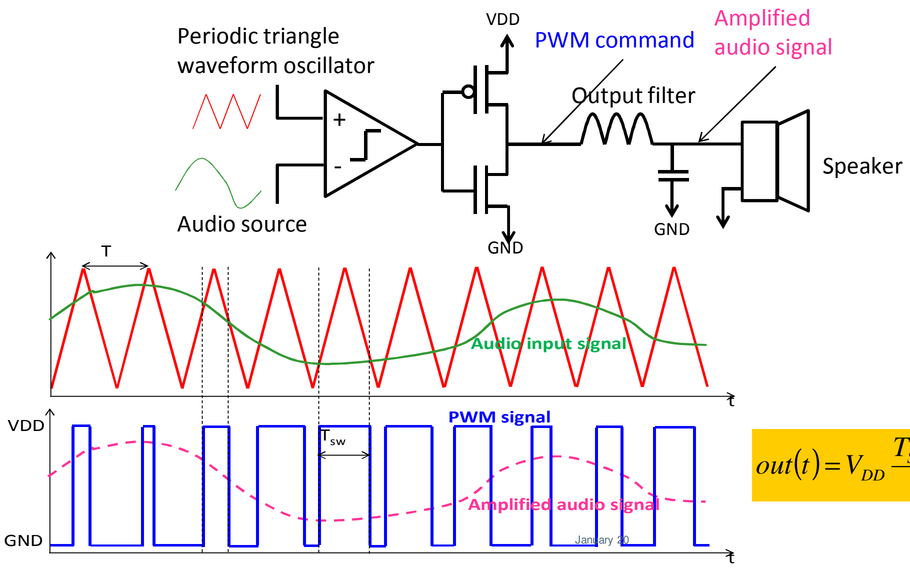
EMC Problem

Reduce radiated emission of class D amplifier with Spread-Spectrum Frequency Modulation (SSFM)

This problem is measurement oriented to evaluate the radiated emission produced by the output of a class D amplifier and how spread-spectrum frequency modulation (SSFM) can help reducing electromagnetic emission without additional filtering components.

In this problem, the studied component is the MAX9768 from Maxim, mounted on MAX9768EVKIT evaluation board. It is a 10 W mono class D speaker amplifier for audio applications in low power portable devices (notebook computer, Multimedia monitor, GPS navigation system…). The principle of a class D amplifier is described in the figure below. The output filter is required to remove high frequency content of the output current that may produce intolerable electromagnetic emission. But the MAX9768 proposes to reduce emission further by using the SSFM, which consists in modulating the frequency of the PWM command in order to spread the spectrum of the electromagnetic emission, leading to a reduction of the spectral density.



$$out(t) = V_{DD}\frac{T_{SW}(t)}{T}$$

In normal condition, the PWM frequency is set at 300 kHz by an internal oscillator. But the MAX9768 provides an input for an external clock reference, whose frequency is four times the PWM frequency. If this external clock is frequency-modulated, the PWM command is also frequency-modulated.

The radiated electromagnetic emission of the output cable is under concern. According to its manufacturer, the MAX9768 is compliant to the EMC standard EN55022. To make it simple, the electric field produced by any equipment which embeds this component at 3 m must be less than 40 dBµV/m. Although the standard characterization of radiated emission relies on tests in anechoic chamber, we propose the following simple evaluation method: a current probe is clamped around the output cable to measure the current that circulates on it. Based on the current extraction, the far-field radiated emission will be estimated. The current probe TESED MD4070 is used in this problem. Its bandwidth covers the range 10 kHz - 1 GHz. It embeds an internal amplifier to increase its sensitivity. Its transfer impedance is supposed constant and equal to 4 Ω (without amplifier) or 150 Ω (with amplifier).

<u>Connection of the MAX9768EVKIT:</u>

- Connect a 8 Ω speaker to the terminals J5 and J6 of the board through a 1 m cable.
- Connect a 10 V power supply to terminals J4 and J3.
- To use the internal 300 kHz oscillator (normal mode), let the jumper JU6 in position 1-4.
- To use an external clock reference (e.g. to use SSFM), let the jumper JU6 open and connect a 0-3.3 V 1.2 MHz square signal between SYC and SGND connectors. In this problem, the generator Agilent 33500B will be used to provide an external clock, modulated or not.

To measure the current along the output cable, clamp the current probe MD4070 around the cable and connect its output to a spectrum analyzer. If necessary, activate the internal amplifier. The following parameters will be used for the spectrum analyzer:

- reference level = 80 dBµV, attenuation = 0 dB
- Min. frequency = 10 kHz and max. frequency = 30 MHz
- RBW = 3 kHz
- Trace mode: Max hold (to capure worst-case emission) or Clear write

Verify all the connections before switching on the 10 V power supply. If the spectrum analyzer is overloaded, switch off the internal amplifier of the current probe.

In the first part of the problem, the radiated emission of the component and its output cable is investigated without SSFM (fixed-frequency clock).

1. Connect all the equipment. Power the class D amplifier. Provide an external unmodulated 1.2 MHz clock reference to the class D amplifier. Observe the spectrum of the current circulating on the output cable. How could you qualify the measured emission spectrum produced by the amplifier activity ?

2. Why can we suspect the class D amplifier and its output cable to be the likely origin of radiated emission issues ?

3. Connect the current probe to measure the differential-mode current.

a. Measure the voltage at current probe output at the following frequencies: 300 kHz, 900 kHz, 1.5 MHz and 2.1 MHz. Express the voltage in dBµV.

b. Compute the differential current values at these different frequencies. Express it in dBµA.

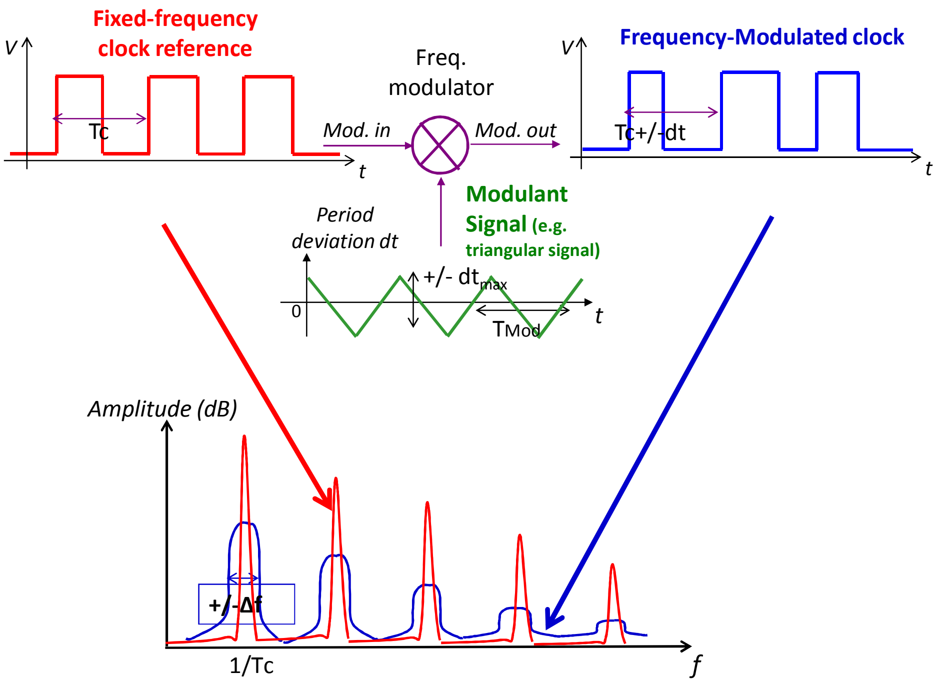
c. Estimate the far-field emission produced by the output cable at 3 m. Express the electric field in dBµV/m.

d. If only the differential-mode radiated emission is considered, is the product compliant to the 40 dBµV/m limit ?

4. Repeat the same question for the evaluation of common-mode radiation. Do the test at the following frequencies: 300 kHz, 600 kHz, 1.2 MHz, 1.8 MHz, 2.4 MHz. Should we neglect the influence of common-mode current ? Why ?

If only the common-mode radiated emission is considered, is the product compliant to the 40 dBµV/m limit ?

In the second part of the problem, the effect of SSFM on electromagnetic emission is investigated. The principle of SSFM is illustrated below. It consists in a frequency modulation (FM) of the fixed-frequency clock reference, i.e. a periodic or random change of period of the clock reference. In frequency domain, fixed-frequency clock reference produces a harmonic spectrum, where the energy is concentrated at some frequencies multiple of the fundamental frequency. With SSFM, the spectrum is spread over a larger bandwidth. If the energy of the clock reference signal, it results in a reduction of the spectral power density which may reduce electromagnetic emission.



Principles of SSFM

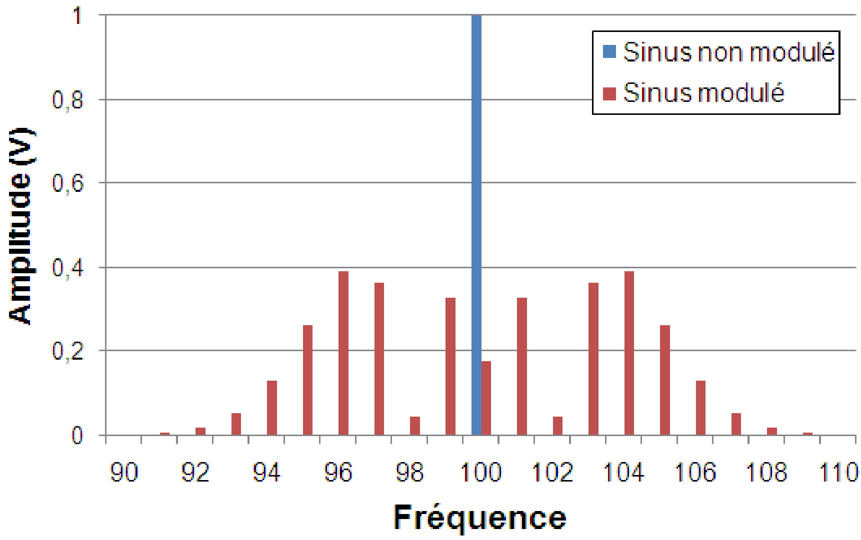
The reduction of the emission depends on the type of modulant signal (modulation shape) and frequency modulation parameters:

- FM frequency, i.e. the frequency of the modulant signal ($F_{mod} = 1/T_{mod}$)
- Deviation frequency +/- Δf, i.e. the maximum frequency variation of the fundamental frequency due to the modulation.

In case of a sine waveform for the clock reference and the modulant with normalized amplitude, the frequency modulated signal expression can be written according to the following form, where f(t) is the instantaneous frequency and m_d is the modulation index.

$$S_{FM} = \cos(2\pi f(t)) = \cos(2\pi (F_C + df \cos(2\pi F_{\mathrm{mod}} t))t)$$
$$= \cos\left(2\pi F_C\left(1 + \frac{df}{F_C}\cos(2\pi F_{\mathrm{mod}} t)\right)t\right) = \cos(2\pi F_C (1 + m_d \cos(2\pi F_{\mathrm{mod}} t))t)$$

As example, the following figure compares the spectra of a 100 MHz sine waveform and the same sine waveform frequency modulated by a sine waveform modulant. In this example, the clock frequency F_C = 100 MHz, the modulant frequency F_{mod} = 1 MHz and the deviation frequency df = +/- 5 MHz, so that the modulation index m_d = 5. The amplitudes of non modulated and modulated signals are similar so that they have the same energy. The example shows clearly the spectrum spreading effect and the reduction of spectral density. The modulated signal spectrum is made of an infinite number of spectral rays separated by 1 MHz (F_{mod}).



Comparison of spectra of unmodulated and frequency-modulated sine waveform (modulant shape = sine, Fc = 100 MHz, Fmod = 1 MHz, md = 5

The exact computation of the signal bandwidth B is not trivial, but Carson rule provides a convenient approximation, as given by the following formulation. With the previous example, the bandwidth of the modulated signal is 12 MHz which is consistent with the plotted spectrum.

$$B = 2F_{\mathrm{mod}}(1 + md)$$

5. With the Agilent 33500B generator, any signal can be modulated by pressing the button 'Modulation'. It gives access to the following parameters:

- modulation type: FM
- modulant shape: sine, square, triangle, up-ramp, down ramp, gaussian noise. By default, select triangle
- Deviation: from 10 to 100 kHz. By default, set 10 kHz.
- FM frequency: from 10 to 50 kHz. By default, set 10 kHz.

a. Set all the modulation parameters to their default value. Activate the SSFM and observe the effect on the common-mode current. What is emission reduction with the default parameters ?

b. Change the FM frequency and test the effect of different values. What is the effect on the emission spectrum ? Is there a significant reduction ?

c. Same question with the frequency deviation ?

d. Compare the effects of changing simultaneously FM frequency and deviation, but with constant modulation index.

e. Same question but with different modulation index.

f. Propose FM frequency and deviation to optimize the emission reduction. With these parameters, test the influence of the modulation shape. What is the best modulant shape for the emission reduction ?

6. The proposed modulation configuration is the following:

- modulant shape: triangular
- FM frequency = 10 kHz
- Frequency deviation = 20 kHz

The EMC tests defined by EN55022 requires a RBW equal to 10 kHz. Compare the emission reduction with RBW = 3 kHz and 10 kHz.

a. What is the impact of the RBW of receiver on the emission reduction ? Is it normal ?

b. IF the RBW is known, how should we select the modulation parameters ?