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Abstract— **Multiple Continuous-Wave (CW) Radio Frequency (RF) signals are used in many telecommunication applications, such as frequency aggregation in LTE-Advanced (LTE-A), intermodulation distortion measurements and …, in order to use more efficiently the frequency bands that are available. In this work a new method for generating three frequencies and more, with no a-priori condition on the frequency allocation, is elaborated in theory and practical results are presented, as well.**

Keywords— frequency aggregation; CW RF signals; multi carrier; LTE-Advanced;

I. INTRODUCTION

LTE-A uses two techniques to obtain a superior data rate than its preceding technologies; Multiple-Input Multiple-Output (MIMO) and Carrier Aggregation (CA). For downlink transmission a system of up to 8x8 MIMO and for uplink transmission a system of up to 4x4 MIMO should be used depending on the user equipment [1]. CA technique permits us to exploit up to 100MHz distributed bandwidth, using up to five carriers with a maximum of 20MHz bandwidth for each carrier , over the RF spectrum. Hence, the data rates up to 3Gbps in downlink and 1.5Gbps in uplink would be achievable.

There are three types of frequency aggregation; the first one is the contiguous intra-band frequency aggregation in which all the carriers are placed, consecutively, in one frequency band. The second type is the non-contiguous intra-band frequency aggregation in which the carrier bands are not located consecutively in a single band. Finally, the third type is the inter-band frequency aggregation in which the carriers are separated in more than one frequency band [2].

Generating multiple carriers at unequal distances are, normally, performed using multiple signal generators which is not suitable for mobile application, since low battery consumption, cheap fabrication and light weight are important factors in mobile designs. There are several studies that have been made for multiple CW generation; in [3]a

method for generating four CW signals is elaborated with the expense of using four digital signal generators. In [4] 14 consecutive frequency bands are generated at multiples of 528MHz, which might be suitable, with some modifications, only for the case of intra-band CA. Also, in [5]a method for generating coherently phased multiple tones for measuring linear responses over finite bandwidths is proposed, in which an M-tone baseband signal b(t) is created and modulated on the carrier frequency fc:

$$b(t) = \sum_{n=1}^{N} A_n \cos(2\pi n \Delta f t + \alpha_n) \qquad (1)$$

Where N= (M-1)/2, Δf is the frequency spacing between tones and A_n, α_n are amplitude and phase of each tone n. Using this method one may generate non-contiguous bands by creating many tones and disabling the undesired tones but the tones are always placed at integer multiples of Δf. obviously, this method cannot be the optimum since, firstly, many tones are generated just to be turned off after, secondly, the remaining tones are integer multiples of Δf which does not give us the freedom to generate any frequency that would be desired.

In section II the mathematical procedure to generate a multitone signal with any frequency spacing is elaborated. Then, in section III the practical results supporting the theory is presented in which one 3-tone and one 4-tone signals are generated using a single signal generator and a direct application of this technique in a demodulation process is elaborated. The last part, section IV, contains the conclusion of this work.

II. M-TONE SIGNAL GENERATION METHOD

Let's take a look at a simple case of generating a 2-tone signal, hence:

$$x(t) = \Re_e(e^{j2\pi f_1 t} + e^{j2\pi f_2 t}) \tag{2}$$

With x(t) as the RF signal with tones at f_1 and f_2. By a simple calculation one may obtain:

$$x(t) = \Re_e(2\cos(2\pi\frac{f_1 - f_2}{2}t)e^{j2\pi\frac{f_1 + f_2}{2}t}) \tag{3}$$

In the case of 3-tone RF signal:

$$x(t) = \Re_e(e^{j2\pi f_1 t} + e^{j2\pi f_2 t} + e^{j2\pi f_3 t}) \tag{4}$$

Using (3) one can obtain

$$x(t) = \Re_e((I_3 + JQ_3)e^{j2\pi f_{c3}t}) \tag{5}$$

Where

$$I_3(t) = (1 + 2\cos(2\pi\frac{f_1 - f_2}{2}t))\cos(2\pi\frac{f_1 + f_2 - 2f_3}{4}t) \tag{6}$$

$$Q_3(t) = (-1 + 2\cos(2\pi\frac{f_1 - f_2}{2}t))\sin(2\pi\frac{f_1 + f_2 - 2f_3}{4}t) \tag{7}$$

$$f_{c3} = \frac{f_1 + f_2 - 2f_3}{4} \tag{8}$$

One may develop the case with 4 tones using the same concept as:

$$x(t) = \Re_e((I_4 + JQ_4)e^{j2\pi f_{C4}t}) \tag{9}$$

Where

$$I_4(t) = I_3(t)\cos(2\pi f_k t) - Q_3(t)\sin(2\pi f_k t) + \cos(2\pi f_k t) \tag{10}$$

$$Q_4(t) = I_3(t)\sin(2\pi f_k t) + Q_3(t)\sin(2\pi f_k t) + \sin(2\pi f_k t) \tag{11}$$

$$f_k = \frac{f_1 + f_2 + 2f_3 - 4f_3}{8} \tag{12}$$

$$f_{c4} = \frac{f_1 + f_2 + 2f_3 + 4f_3}{8} \tag{13}$$

By continuing this method, any multiple-tone signal can be generated.

III. EXPERIMENTAL RESULTS

A. Signal generation:

Two practical cases were studied to generate 3-tone and 4-tone signal. The in-phase and quadrature components were generated using MATLAB® and loaded to the Agilent EXG vector signal generator N5172B. The downloaded I/Q data were modulated using the I/Q modulator integrated in N5172B. The spectrums are depicted by MATLAB® using the data obtained by the Rohde & Schwarz FSIQ-40 spectrum analyzer

Fig. 1(a) shows the three desired fundamentals at unequally spaced frequencies of 1.021 GHz, 1.034GHz and 1.09GHz. Also, due to nonlinearities of the mixer, that up-converts the baseband signal to RF frequency range, some intermodulation components appear which are not disturbing, since the Spurious Free Dynamic Range (SFDR) is more than 51dB, moreover, in Fig. 1(b) and (c) the 2nd and 3rd harmonics, generated due to mixer nonlinearities, are presented, respectively.
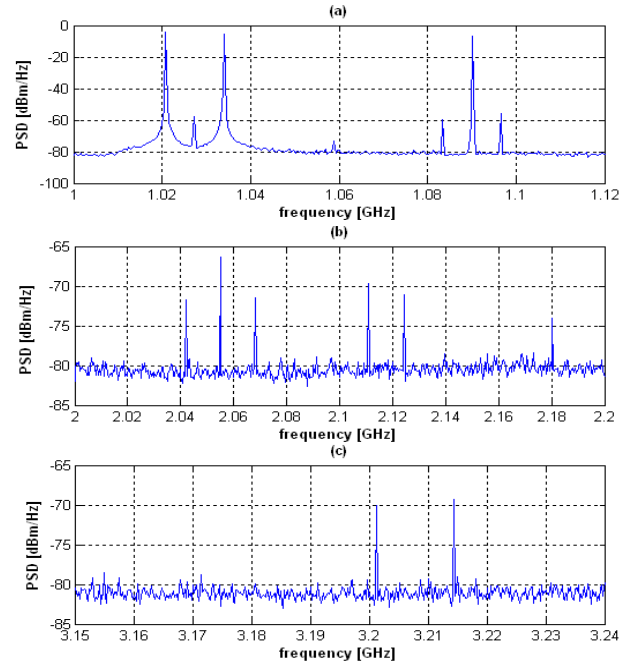

Fig. 1. (a) Fundamental frequencies of a 3-tone signal with frequencies at 1.021 GHz, 1.034GHz and 1.09GHz. (b) Weak 2nd harmonics. (c) Weak 3rd harmonics.

Fig. 2(a) shows the four desired fundamentals that are generated at unequally spaced frequencies of 1.021 GHz, 1.034GHz, 1.062GHz and 1.075GHz, also, due to nonlinearities of the mixer, that up-converts the baseband signal to RF frequency range, same as the case of 3-tone

signal generation, some intermodulation components appear which are not disturbing, since the SFDR is more than 52dB, moreover, in Fig. 2(b) and (c) the levels of the 2nd and 3rd harmonics, generated due to mixer nonlinearities, are shown, respectively.

B. 3-tone signal application

In this section, a 3-tone signal with tones at 2.8 GHz, 2.818 GHz and 2.85 GHz, is applied to the test bench depicted in fig.3, which is a modified version of the test bench in [6], as a Local Oscillator (LO) signal. The 3-tone LO signal must down-convert the 3 RF signals, with bandwidths of 67.5 KHz, at 2.8002 GHz, 2.8187 GHz and 2.8512 GHz to the baseband frequencies at 200 KHz, 700 KHz and 1200 KHz, respectively. Once the signal is down-converted, the demodulation can be proceeded as explained in [6].

 Fig. 4 shows the three down-converted RF signals at desired baseband frequencies of 200 KHz, 700 KHz and 1200 KHz. Also, one can observe that the channels are not disturbed by any spurious signal as it was required for the demodulation of the signals in [6].

IV. CONCLUSION

A new method for generating multitone signals with any frequency spacing using a single generator was proposed in this work. The I/Q components of the multitone signal were generated and the baseband signal is modulated using a dummy carrier, which does not appear among the final tones. The experimental results for two cases of 3-tone and 4-tone signals were illustrated, moreover, an application of this technique was given as a 3-tone LO generator in an LTE-A demodulation process.
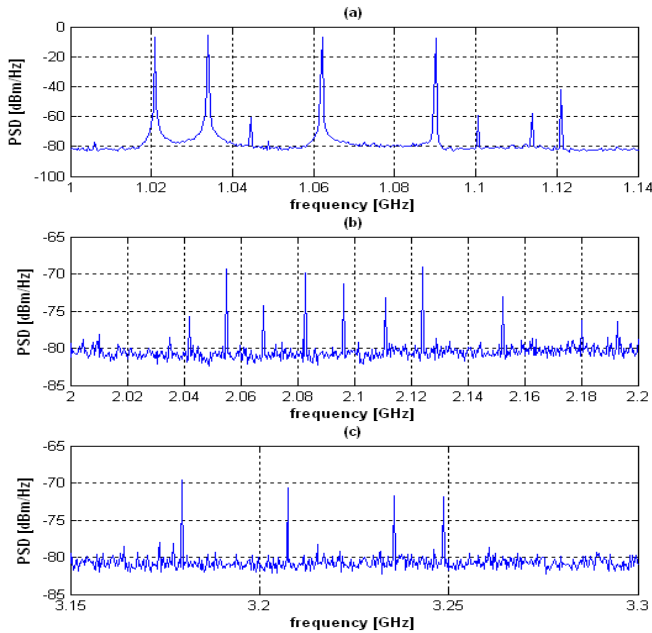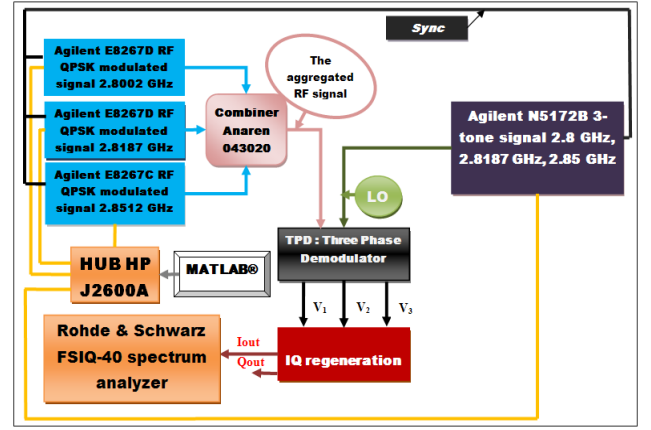

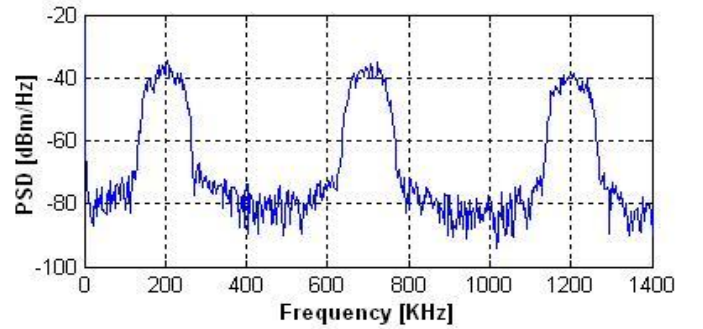Fig. 3. Test bench for the demodulation of RF signal aggregated in frequency.

Fig. 4. Three clean baseband channels at 200 KHz, 700 KHz and 1200 KHz with no spurious frequency

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Fig. 2. (a) Fundamental frequencies of a 4-tone signal with frequencies at 1.021 GHz, 1.034GHz, 1.062GHz and 1.075GHz. (b) Weak 2nd harmonics. (c) Weak 3rd harmonics.