A Practical Method for Measurement of FM bandwidth Modulation of Voltage-Controlled Oscillators

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ABSTRACT:
FM bandwidth Modulation is an important parameter in voltage-controlled oscillators. The importance of this parameter is especially evident in cases in which the loop bandwidth of phase locked loops is comparable with the FM bandwidth of the oscillator. In this paper, a practical method for measuring the FM bandwidth of a voltage-controlled oscillator is presented.

KEYWORDS: FM Bandwidth Modulation, VCO, Frequency Synthesizer.

1. INTRODUCTION

The frequency of a voltage-controlled oscillator is proportional to the amplitude of the input voltage. By changing the input voltage, the output frequency also changes. If the rate of changing input voltage is low enough, the output frequency will change accordingly. However, as the rate of changing input voltage increases, the output frequency deviation is limited for higher change rates. This limitation is a criterion for determining the input frequency response of a voltage-controlled oscillator. In this paper, a practical method for measurement of the bandwidth of a sample voltage controlled oscillator called HMC587 is described.

2. INPUT BANDWIDTH

In this section, we present how to calculate and measure the frequency modulation bandwidth (FM bandwidth) of the input of a sample VCO.

If a DC value is applied to the oscillator within the allowable input range, the output of the oscillator will oscillate at a frequency of f_o. Now we modulate the signal applied to the input of the VCO with frequency f_{mod} and amplitude V_{mod}. This causes a signal with frequency modulation to be generated at the output of the oscillator, which is as follows:

$$V_{out} = VSin(\omega_o t + \int 2\pi k_v * V_{mod} Cos(\omega_{mod} t)dt) \quad (1)$$

Where k_v is the input sensitivity of the VCO in Hz / V, $\omega_o = 2\pi f_o$ and $\omega_{mod} = 2\pi f_{mod}$.

The modulation coefficient β is equal to:

$$\beta = (Frequency\ \ deviation / f_{mod}) = k_v * V_{mod} / f_{mod} \quad (2)$$

By rewriting Equation 1 we have:

$$V_{out} = VSin(\omega_o t + \beta Sin(\omega_{mod} t)) \quad (3)$$

Which can be extended as Equation 4:

$$\begin{aligned} V_{out} = {} & V(J_0(\beta)Cos(\omega_o t) - \\ & J_1(\beta)[Cos(\omega_o t - \omega_{mod} t) - Cos(\omega_o t + \omega_{mod} t)] + \\ & J_2(\beta)[Cos(\omega_o t - 2\omega_{mod} t) - Cos(\omega_o t + 2\omega_{mod} t)] - \\ & J_3(\beta)[Cos(\omega_o t - 3\omega_{mod} t) - Cos(\omega_o t + 3\omega_{mod} t)] + \ldots \end{aligned} \quad (4)$$

Where the coefficients $J_n(\beta)$ correspond to the coefficients of the Bessel function and you can see the values of these coefficients for different β in the Fig. 1.

Equation 4 shows that the output of the oscillator can include the main carrier frequency and the side signals with an interval n * f_{mod} on both sides of the main frequency.

In an ideal oscillator, the modulation coefficient β remains constant by increasing f_{mod} and V_{mod} so that their ratios remain constant. However, in a real oscillator the value of β does not continue indefinitely. That is, with the constraint created by the frequency response of the oscillator tuning voltage, as the f_{mod} and V_{mod} increase, the β coefficient decreases gradually (the ratio of the

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frequency deviation at the oscillator output to the tuning input frequency changes decreases). At the point in which the coefficient β reaches its initial value of 0.707, the value of the rate of the input frequency changes determines the FM bandwidth of the oscillator.

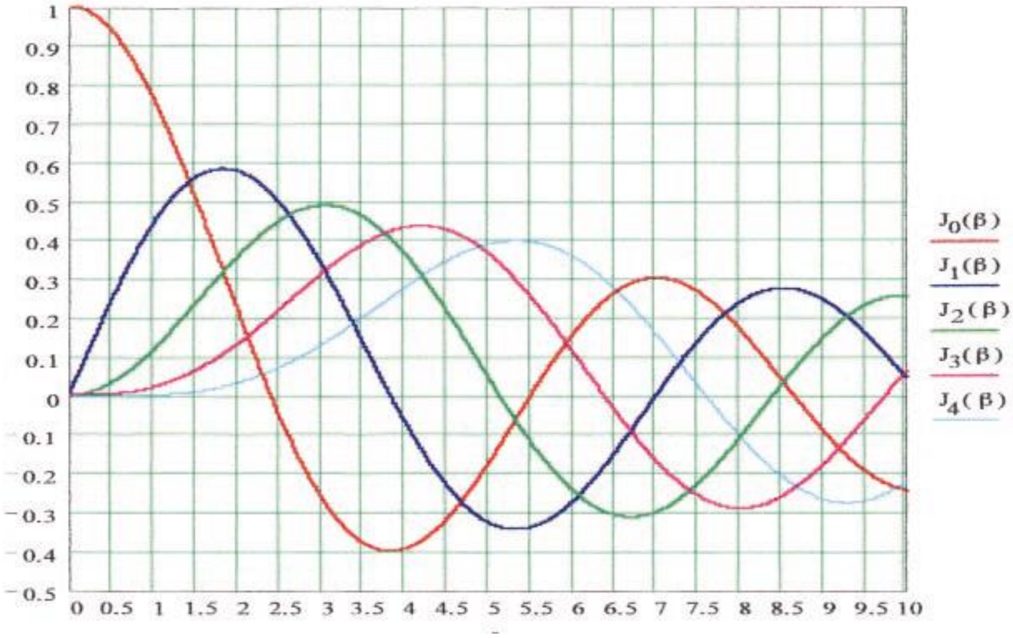

Fig. 1. The value of the Bessel function coefficients for different values of β.

3. USING THE PROPERTIES OF BESSEL FUNCTIONS TO MEASURE FM BANDWIDTH

To measure the amount of the FM bandwidth in practice the properties of the Bessel functions can be used. According to Fig. 1, when the value of the modulation coefficient β is approximately equal to 2.4, the Bessel function J_0 (β), which is the principal carrier frequency coefficient in relation 4, is equal to zero. This feature can be used to measure the FM bandwidth. For this, we first apply the desired VCO to the signal generator, power supply and spectrum analyzer according to Fig. 2 in the laboratory. One can adjust the spectrum display to the VCO output frequency and view its power value.

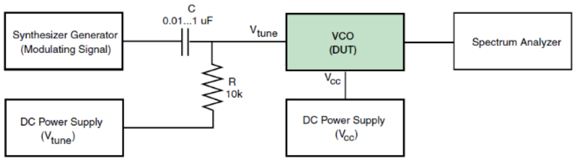

Fig. 2. Test setup.

Now, we turn on the signal generator and set the f_{mod} and V_{mod} values to apply the modulation signal to the VCO input. We set the value of f_{mod} to one tenth of the approximate value of the FM bandwidth of the oscillator and calculate the value of V_{mod} according to the following equation and considering β = 2.4.

$$V_{mod} = (\beta * f_{mod})/k_v \tag{5}$$

This reduces the amplitude of the main carrier signal in the spectrum display. Otherwise, you need to manually set the V_{mod} value. A drop value of 30dB from the measured power range for the main carrier (in the event that the modulation signal is not applied) is a desirable drop value and indicates that β has an approximate value of 2.4. Next we need to increase the value of the main carrier by increasing the values of f_{mod} and V_{mod} and keeping their ratio constant. Each time, the power of the main carrier increases. When the main carrier power value is 8dB lower than the original main carrier power (when the input modulation is off), the f_{mod} value is the same as the oscillator FM bandwidth. Note that in this case the value of β is 1.697 (0.707 of 2.4). With this value of β, the principal carrier amplitude is 0.4 (-8dB) lower than the total amplitude (β = 0). This is shown in Fig. 1.

4. TEST RESULTS

Fig. 3 shows the circuit implemented for measuring the FM bandwidth of HMC587LC4B.

The Bias-T module is used to apply the DC and RF voltages simultaneously. As mentioned in the previous section, we set the DC value to about 1 volt and turned off the RF input, i.e the modulation signal. In this case, the main carrier frequency of about 5 GHz is observed in the spectrum analyzer as shown in Fig. 4.

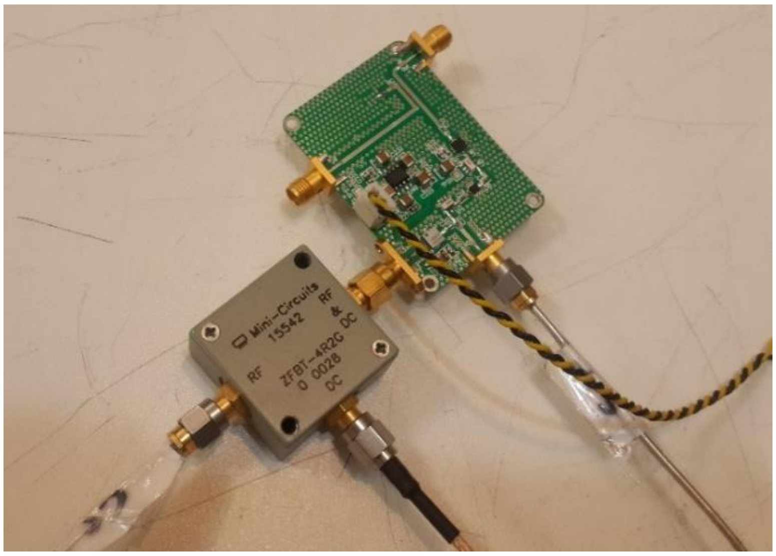

Fig. 3. Circuit implemented for measurement of FM bandwidth modulation.

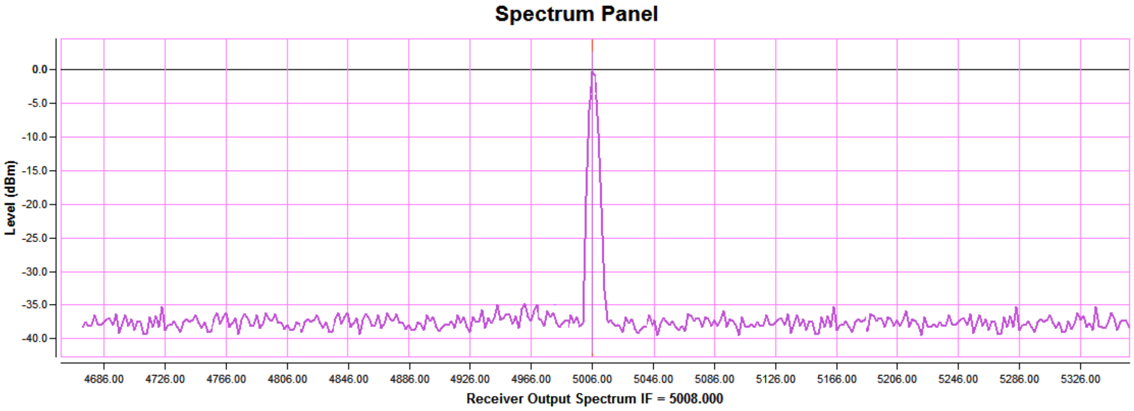

Fig. 4. Main carrier power when applying DC voltage.

Then we continued the experiment by applying a modulation signal of frequency f_{mod} and V_{mod}. We considered the modulation frequency equal to 5MHz and obtained the value of V_{mod} using equation 5, equal to 30 mV. By setting this value, the frequency range of the main carrier was high and undesirable. Therefore, it was necessary to manually adjust V_{mod}, so that the value of the main carrier signal amplitude drops sharply. Note that the value of output signal amplitude (V_{mod}), was set for 50Ω impedance, whereas in the test, the output of the signal generator was connected to the VCO input, with a different impedance. Therefore, setting V_{mod} did not match with the calculated value. As a result, a better solution was needed. The best thing that could be done to set V_{mod} was to start with the values much smaller than the calculated value (about one tenth of that value) and gradually increase the value of the signal generator amplitude (V_{mod}). According to Fig. 1, the first time in which the main carrier signal drops sharply is actually the desired point $\beta = 2.4$.

Then we continued by recording the values of the amplitude set in the signal generator for V_{mod}. That is, we increased the values of f_{mod} and V_{mod} while maintaining their ratio. Each time these two parameters increased, the amplitude of the main carrier signal in the spectrum display increased, and we recorded its value each time. Finally, when this amplitude was 8dB lower than the amplitude of the original primary carrier, we stopped the experiment and recorded the value f_{mod} as FM bandwidth. Fig. 6 shows the result of this step, which occurred approximately for the f_{mod} modulation frequency of 30MHz. Therefore, the amount of FM bandwidth at 5GHz was about 30MHz.

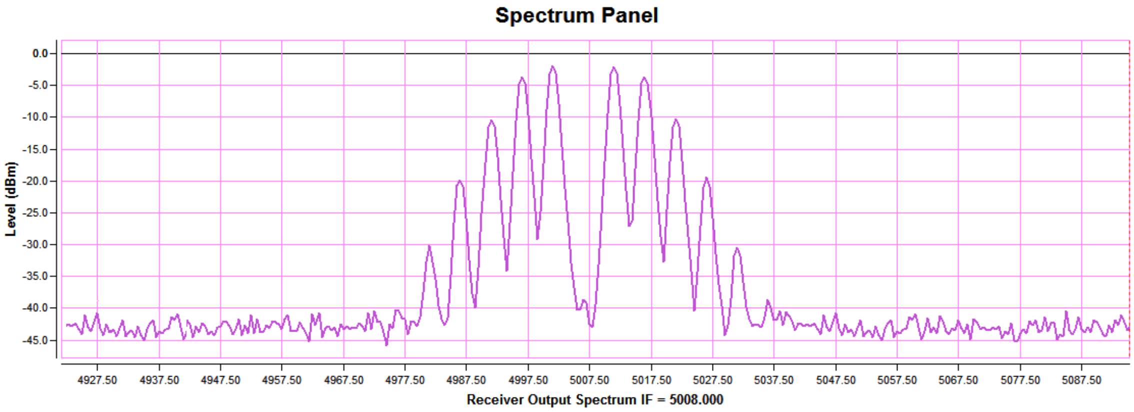

Fig. 5. Set β = 2.4 and achieve a sharp drop in the main carrier.

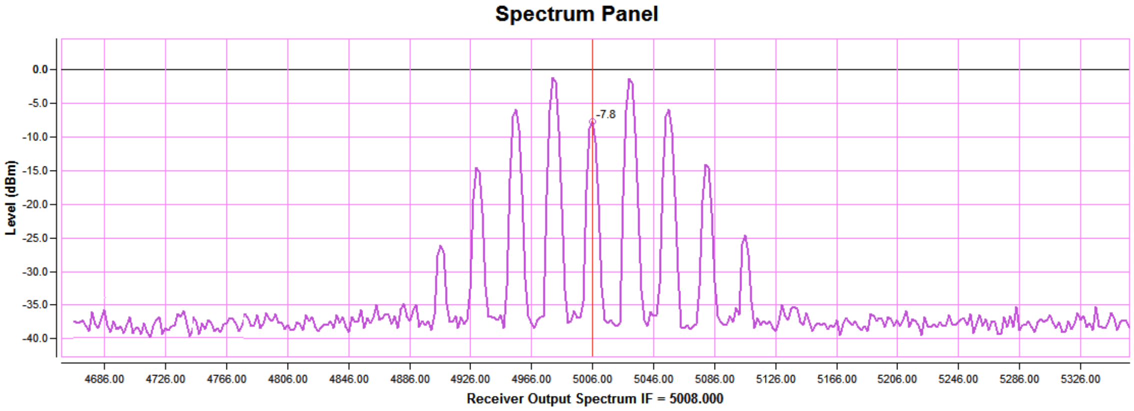

Fig. 6. The value of the original carrier is about -8dB for β = 1.697.

Tables 1 and 2 show the values obtained from this method for the two frequencies 5GHz and 6GHz. In these two tables, V_{mod} is the same voltage that is set in the signal generator.

Then this experiment was performed for several different frequencies and finally the values obtained for FM bandwidth are shown in Fig. 7.

Table 1. Values measured at 5GHz.

$f_{mod}(MHz)$	$V_{mod}(mV)$	$P_{carrier}(dBm)$
5	10.714	-50
10	21.428	-25
15	32.142	-17
20	42.856	-12.3
25	53.57	-9
30	64.284	-7

Table 2. Values measured at 6GHz.

$f_{mod}(MHz)$	$V_{mod}(mV)$	$P_{carrier}(dBm)$
5	9.14	-35
10	18.28	-26
15	27.42	-21
20	36.56	-18
25	45.7	-14
30	54.84	-12
35	63.98	-10
40	73.12	-9.5
45	82.26	-8.5
50	91.4	-7.5

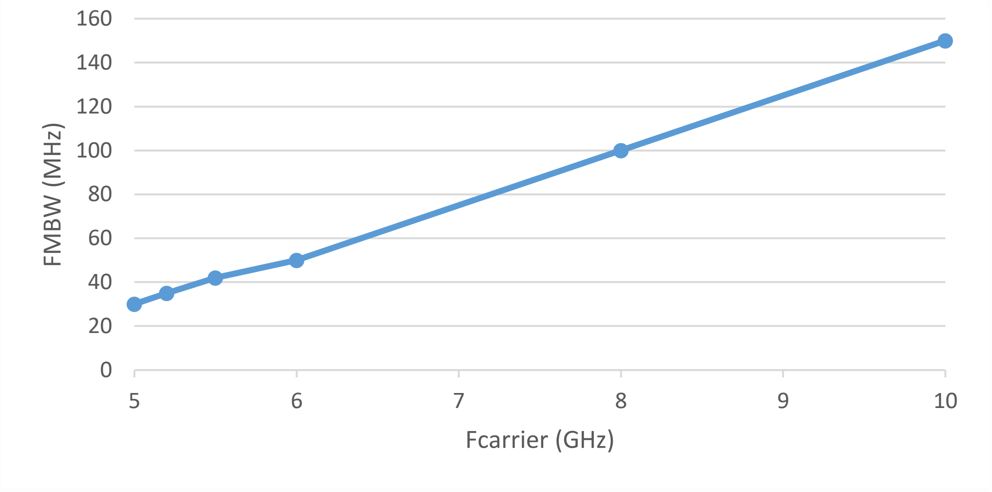

Fig. 7. FM bandwidth chart in terms of main carrier frequency.

5. CONCLUSION

In this paper, a practical method for measurement of FM bandwidth of voltage controlled oscillators was introduced. Then, by using this method and available equipment in a telecommunication circuit laboratory for a sample VCO, this method was described step by step and this parameter was measured accurately.

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