Application Report

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DC Controlled Low-Pass Filter

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ABSTRACT

This application report describes a dc controlled low-pass filter circuit using LM3046. The cut off frequency can be varied by varying the capacitance of the low-pass filter.

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Trademarks

1 Introduction

In medical ultrasound systems, in the CW Doppler mode the received echoes are passed through the CW mixer of the receive AFEs to demodulate the Doppler frequencies and produce I and Q signals. Output of all the AFEs are summed, filtered and amplified before digitizing. The filter requires variable cut off based on the analog signal bandwidth. The filter cut off frequencies can be selected by using a DC controlled variable capacitance circuit. By using this method continuously variable cut off frequencies can be achieved over a large range of frequency and this circuit has large signal handling capability. This can also be used as front end for precision ADCs as anti-aliasing filter and any general purpose low-pass filter.

2 Basic Theory

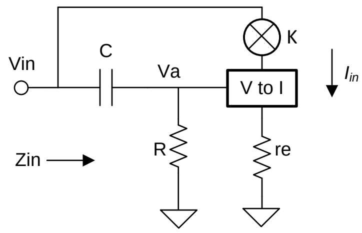

Figure 1. DC Controlled Low-Pass Filter

In a differentiator, output voltage leads the input voltage by 90° , so V_a leads V_{IN} by 90°. Therefore, I_{IN} leads V_{IN} by 90° that is the known property of a capacitor. By varying the phase shifted current, it is possible to vary the capacitance of the circuit. Current can be controlled by a DC control voltage (multiplier K).

As shown in Figure 1, V_a is the output voltage of the differentiator. The equation for V_a is shown in Equation 1.

$$V_a = V_{IN} \times R \,/ \left(R + \frac{1}{SC} \right) \tag{1}$$

For a high-pass filter, X_c >> R, R can be neglected in the denominator and then Equation 1 becomes the following:

$$V_a = V_{IN} \times S \times C \times R \tag{2}$$

In Figure 1, the current I_{in} is shown as follows:

$$I_{IN} = K \times V_a \,/\, re \tag{3}$$

By substituting V_a from Equation 2 into Equation 3,Equation 3 then becomes as follows:

$$I_{IN} = V_{IN} \times SC \times R \times \frac{K}{re} \tag{4}$$

In Figure 1, the impedence Z_{in} is shown as follows:

$Z_{IN} = V_{IN} / I_{IN}$

where (5)

By substituting Z_{IN} in Equation 4 becomes the following:

$$Z_{IN} = 1/s\left(\left(C \times R \times K \right) / re \right) \tag{6}$$

Therefore, Z_{IN} is a capacitor of the value C × R × K/re:

$$C_{eff} = C \times R \times \frac{K}{re} \tag{7}$$

and the circuit is capacitive.

By substituting the information from Equation 7 in the equation of the cut off frequency (fc = 1/(2*3.14*R*C)), the equation becomes Equation 8.

$$f_c = \frac{1}{2} * 3.14 * R1 * C_{eff} \tag{8}$$

For C_{eff}, re, C, R, R1, see Figure 2. By substituting Equation 7 into Equation 8, Equation 8 becomes as follows:

$$f_c = 1/\left(2 \times \pi \times R1 \times C \times R \times \frac{K}{re} \right) \tag{9}$$

Hence, because of the differences in the value of ‘K’, the cut off frequencies of the filter can be varied.

3 Schematic Diagram

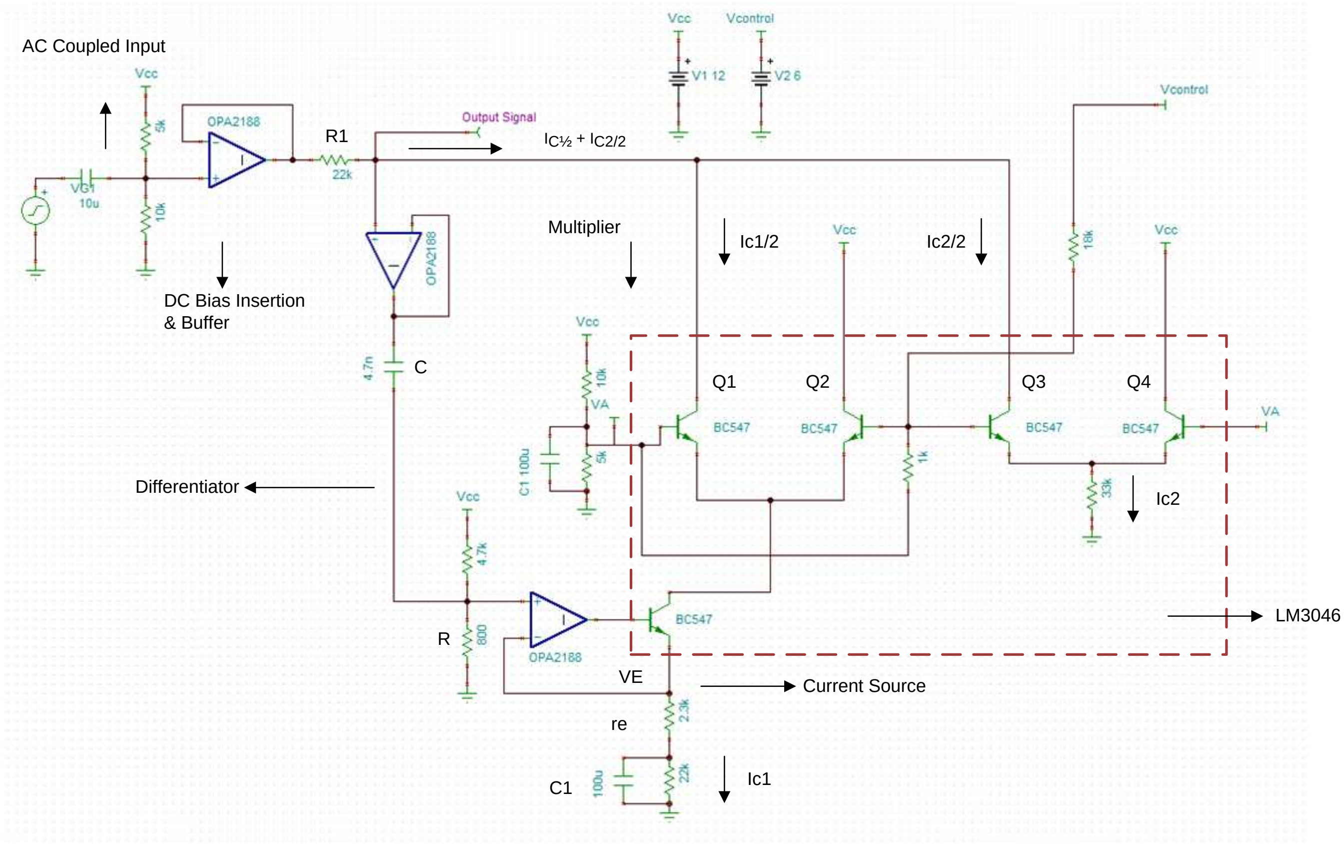

Figure 2. DC Controlled Low-Pass Filter Schematic

4 Schematic Description

The variable capacitance circuit is implemented using an analog multiplier that uses four transistors, which are used to make the dc conditions stable. This circuit can be integrated into a single LM3046 IC as shown in Figure 2. Differentiator output drives the current source and the multiplier factor, K is varied by the dc control voltage.

4.1 DC Conditions

$$I_{c1} = \frac{V_a}{33k} = \frac{3\,V}{33K} = 0.1\,mA \tag{10}$$

For dc, C1 is open, therefore,

$$I_{c2} = \frac{V_e}{24.3K} = \frac{1.74\,V}{24.3K} = 0.07\,mA \tag{11}$$

$$V_{22K} = 22K \times \left(I_{C1}/2 + I_{C2}/2\right) \tag{12}$$

By substituting I_{C1} and I_{C2} in Equation 10 and Equation 11 into Equation 12, the equation becomes Equation 13.

$$V_{22K} = 22K \times \left(\frac{0.1}{2} + \frac{0.07}{2}\right) mA = 1.87\,V \tag{13}$$

So, the dc operating voltage, V_{dc} = 8 V – 1.87 V = 6.13 V, 8 V is set by the DC bias insertion, see Figure 2.

As $V_{control}$ increases, the current through Q2 increases, therefore, the current through Q1 is reduced. As current through Q1 is reduced, the current through Q3 increases. which in turn makes the dc operating voltage constant at 6.13 V. By the four transistor configuration dc, the bias point is kept stable.

4.2 AC Conditions

For AC conditions, C1 is short and the emitter resistor is r_e . In ac conditions, Q3 and Q2 do not come into play. As $V_{control}$ increases, Q2 becomes more conductive and the current through Q1 is reduced. This reduces the C_{eff} value; finally, Q1 stops conducting and the capacitance value becomes zero. For more information, see Figure 2 for Q_1. Q_1. Q_2. Q_3. Q_4. I_{c1}, I_{C2}.

4.3 Example

R = 800 Ω

C = 4. 7 nF, for K = 1

C_{eff} = (4.7 nF × 800 Ω ×1)/2.3K

= 1.63 nF

Provided f ≪ $f_{cutoff\_differentiator}$

And, R1 = 22K

$$f_C = \frac{1}{2} \times 3.14 \times R1 \times C_{eff} \tag{14}$$

By substituting C_{eff} and R1 in Equation 14 becomes f_c = 4.46 KHz for K = 1.

$F_{cutoff\ \_differentiator}$ = 1/2 × π × R × C = 1/2 × 3.14 × 800 × 4.7 nF = 42.5 KHz

The cut off frequency is higher than the range of the filter suggested. Therefore, by varying the dc control voltage in this example from 1 V to 6 V, the f_c can be varied from 4.4 KHz to 21 KHz.

5 Test Results

The circuit is tested using 1 Vpp sine wave source and the results are as shown in Figure 3.

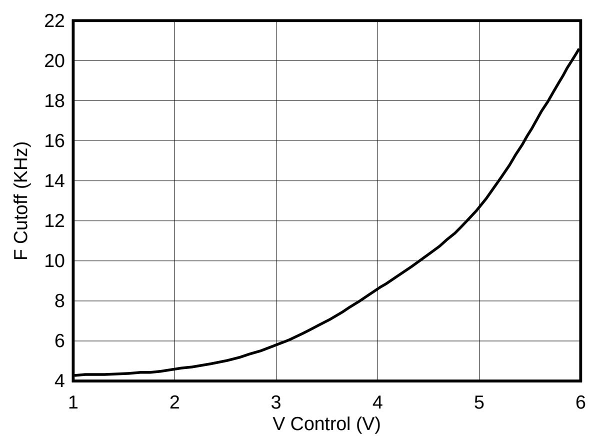

Figure 3. Plot of Cut Off Frequencies vs Control Voltage

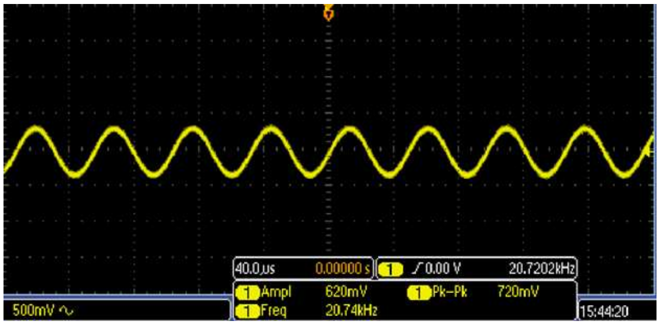

Figure 4. With $V_{control}$ = 6 V, F_c = 20.7 KHz

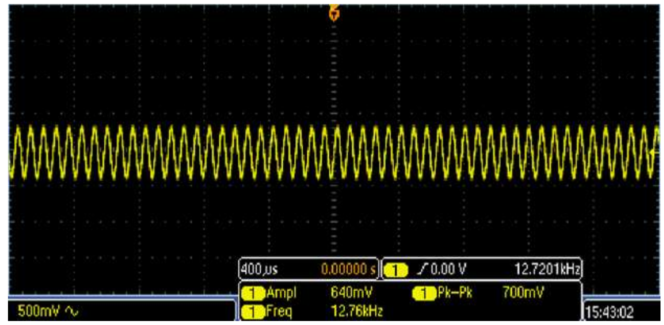

Figure 5. With $V_{control}$ = 5 V, F_c = 12.7 KHz

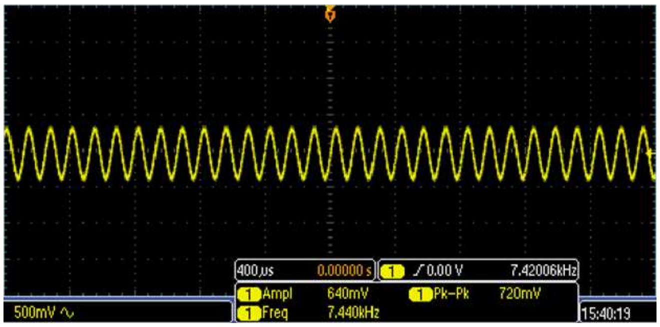

Figure 6. With $V_{control}$ = 4 V, F_c = 7.42 KHz

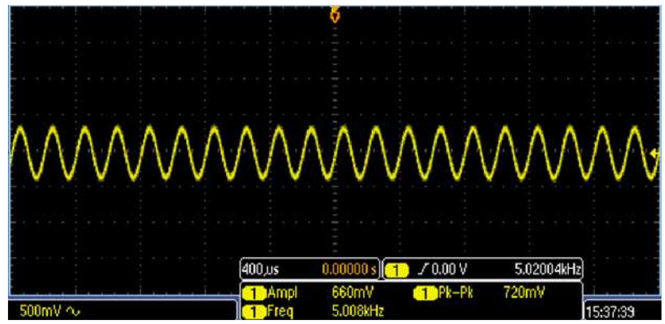

Figure 7. With $V_{control}$ = 3 V, F_c = 5.88 KHz

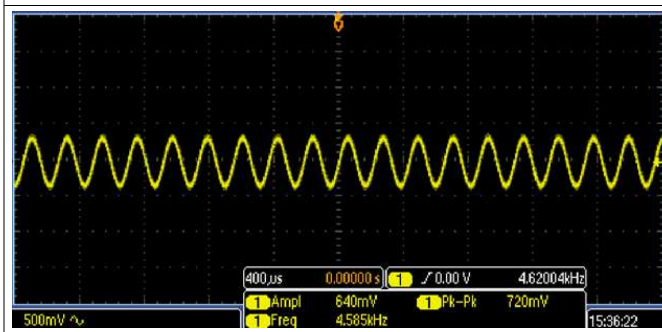

Figure 8. With $V_{control}$ = 2 V, F_c = 4.6 KHz

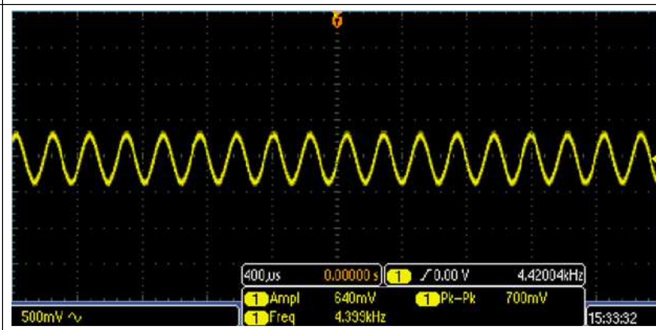

Figure 9. With $V_{control}$ = 1 V, F_c = 4.39 KHz

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